MnDOT RESEARCH PROGRAM

STRATEGIC PLAN 2017-2022

Final Report 2017-12

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16. Abstract (Limit: 250 words)

In response to the top transportation trends in Minnesota, and opportunities and challenges facing its transportation system, MnDOT has developed this five-year Research Program Strategic Plan (2017 – 2022) to take stock of its research portfolio, refine its research strategy to support its overall vision and mission, and communicate the value of its research to a variety of stakeholders and audiences. The Plan was developed using extensive stakeholder engagement; a review of the guidance and best practices for transportation research programs; a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of MnDOT's approach to research; and in-depth analysis of MnDOT's approach to topic prioritization, funding, project and performance tracking, and partner relationships. These efforts were documented in detail in three working papers, and the main findings and recommendations that emerged are discussed in this Plan.

This Research Program Strategic Plan makes six strategic recommendations on how MnDOT can improve both its research activities and research implementation. The Plan is a conceptual and agenda-setting guide; the strategies must be translated into internal actions and changes over the next five years by MnDOT to extract value from this strategic planning process.

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MnDOT Research Program Strategic Plan (2017-2022)

FINAL REPORT

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Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AASHTO SCOR/RAC	AASHTO Standing Committee on Research and its Research Advisory Committee
ARTS	Automated Research Tracking System
CTS / UMN CTS	University of Minnesota – Center for Transportation Studies
DOT	Department of Transportation
FHWA	Federal Highway Administration
FHWA STP	FHWA Surface Transportation Program
GI	Guiding Indicators
ITS	Intelligent Transportation Systems
LRRB	Local Road Research Board
MOR	Maintenance Operation Research
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NRRA	National Road Research Alliance
RS	MnDOT Research Services section
SMTP	Statewide Multimodal Transporation Plan
SRP	State Research Program
SP&R-II	State Planning & Research – Part II
TPF	Transportation Pooled Funds
TRB	Transportation Research Board
UMA	University Master Agreements

Executive Summary

In response to the top transportation trends in Minnesota, and opportunities and challenges facing its transportation system, MnDOT has developed this five-year Research Program Strategic Plan 2017 – 2022 (Plan) to take stock of its research portfolio, refine its research strategy to support its overall vision and mission, and communicate the value of its research to a variety of stakeholders and audiences.

The Plan was developed using extensive stakeholder engagement; a review of the guidance and best practices for transportation research programs; a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of MnDOT's approach to research; and in-depth analysis of MnDOT's approach to topic prioritization, funding, project and performance tracking, and partner relationships. These efforts were documented in detail in three working papers, and the main findings and recommendations that emerged are discussed in this Plan.

This Research Program Strategic Plan makes six strategic recommendations on how MnDOT can improve both its research activities and research implementation. The recommendations are addressed to MnDOT leadership, the Research Services section, office directors, Transportation Research and Innovation Group (TRIG) panel members, district engineers, and other research champions within MnDOT. The Plan is a conceptual and agenda-setting guide; the strategies must be translated into internal actions and changes over the next five years by MnDOT to extract value from this strategic planning process.

Strategic Recommendation #1 - Visioning Exercise: MnDOT should conduct an internal priority-setting exercise to refine topic priorities and specify high value research needs for the next five years. As a starting point, MnDOT can use the framework shown in Figure ES-1, which links high-level priority topics (blue boxes) with Top Five Trends (vertical) and Guiding Indicators (across) from the Statewide Multimodal Transportation Plan. Two steps are suggested: the circulation of a strategic memorandum from MnDOT leaders outlining strategic priorities, and a visioning exercise to help refine topic priorities and make them more specific.

Strategic Recommendation #2 - Tracking Research Investments: MnDOT should develop a comprehensive understanding and tracking system for its research investments. As part of implementing the Research Program Strategic Plan 2017-2022, MnDOT should examine past accounts to develop at least an order of magnitude estimate of its overall research expenditures over the last five to six fiscal year funding cycles. MnDOT should also streamline its research tracking and accounting process so that MnDOT leadership, Research Services, office directors, districts, and the proposed MnDOT Research Champion (see Strategic Recommendation #4 below) can quickly obtain customizable research funding and expenditure reports through an enterprise-wide tracking system.

Strategic Recommendation #3 - Investment Levels: MnDOT should mark overall research spending to revenues in future years, based on the best practice in R&D heavy industries. To establish a baseline, MnDOT should first develop a comprehensive understanding of its research spending in relation to revenues for the last five to six fiscal cycles. Meanwhile, MnDOT could at a minimum maintain its aggregate research spending level in real terms for the next one to two years to preserve the value of its research program.

Figure ES-1. Recommended framework for fine-tuning MnDOT's strategic research priorities
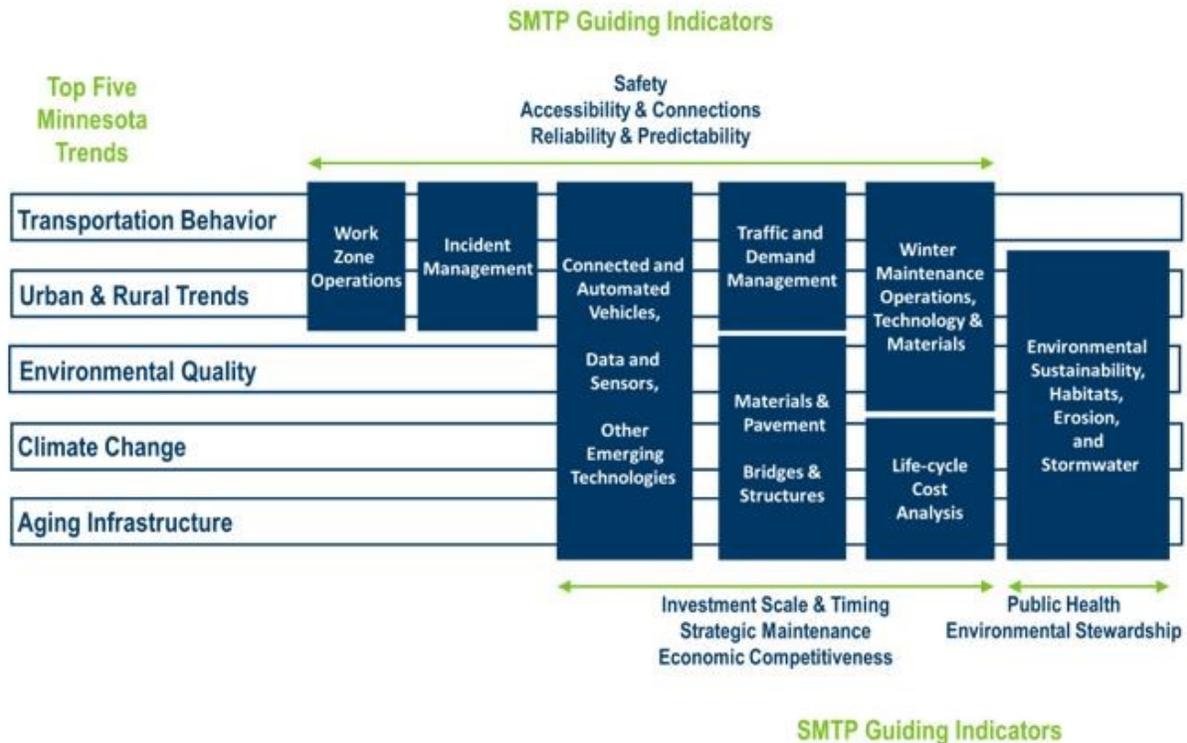
Strategic Recommendation #4 - Streamlined Governance: MnDOT should refine its governance structure to better reflect its decision-making principles and clearly establish roles and responsibilities. The proposed governance structure reflects five principles: integration over separation, accountability, specialist expert committees, value capture, and strategic responsibility and feedback. A research champion at the assistant commissioner level, and a high-level Research Advisory Committee will help with integration, accountability, and a strategic feedback loop. Technical decision-making best resides in offices and expert committees.

Strategic Recommendation #5 - Life-cycle Project Tracking: MnDOT should track research projects throughout their life-cycle and until at least five years after project results have been implemented. This includes tracking both centrally coordinated projects governed by the Transportation Research and Innovation Group (TRIG) as well as the independent projects governed and executed within MnDOT's offices. Research Services should be a clearinghouse for a comprehensive view of MnDOT's research portfolio.

Strategic Recommendation #6 - Portfolio Approach: MnDOT should identify the value and impact of its research at a program-level. MnDOT should think of its research program as a portfolio of investments and work to enhance value across the portfolio as a whole. Further, MnDOT should report the benefits of all its research at both the topic-level and the program-level because not all project outcomes are quantifiable.

1. Introduction

Transportation agencies rely on research activities to inform daily and long-term decision making. The Minnesota Department of Transportation (MnDOT) has one of the leading applied transportation research portfolios in the country. Research helps MnDOT direct scarce resources to more effectively maintain, preserve, and operate the transportation system.

As demands on the system evolve, MnDOT must adapt the role and type of research activities it conducts to those changes to provide a high-performing, safe, reliable, and sustainable system. Technical research that is both high-value and implementable can be an integral part of this adaptation. Further, transportation system policies set the course for how the system will adapt to the future. Policy-focused research can be valuable to MnDOT to inform effective decision-making and facilitate cohesive communication. Further, harnessing new knowledge and emerging technologies may require changes in how MnDOT governs itself and undertakes research.

Given current and future challenges related to changing technology, system maintenance, safety, reliability, and sustainability, MnDOT has decided to **take stock of its research portfolio, refine its research strategy to support its overall vision and mission, and communicate the value of its research to a variety of stakeholders and audiences.** MnDOT is developing a five-year Research Program Strategic Plan 2017 – 2022 (Plan) to accomplish these objectives.

1.1 Key Questions

The project to develop the Plan addressed the following key questions:

Nature of Research and Role: What is the nature of MnDOT research, i.e., basic, applied or otherwise? What are the roles and responsibilities of MnDOT and its offices in developing and deploying research?

Stakeholder Connections: What are the connections between MnDOT's internal and external research stakeholders, including public and private organizations?

Key Products and Services: What are the key products and services that support MnDOT's vision and objectives? How should MnDOT's different research topic areas map to its key products and services?

Investment Levels: How much does MnDOT invest in research today, and what is the appropriate level going forward?

Research Governance: What governance model and decision-making processes should MnDOT adopt to accomplish its objectives?

Performance Assessment: What is an estimate of the value and impact of MnDOT's research program? What are the specific mechanisms needed for comprehensive performance assessment and reporting, and what performance measures should MnDOT utilize in the future to track research performance and value?

Relationship to National Priorities: How will MnDOT's research program address the national research priorities as benchmarked in the Transportation Research Board (TRB) and American Association of State Highway and

Transportation Officials (AASHTO) Standing Committee on Research (SCOR)/Research Advisory Committee (RAC) plans?

1.2 Methodology and Outputs

To develop the MnDOT Research Program Strategic Plan, the CPCS team consulted with research stakeholders, reviewed national literature (including other state's approaches to research, and FHWA, TRB, National Cooperative Highway Researcn Program (NCHRP) and AASHTO guidance), analyzed MnDOT's existing research program, and benchmarked the program against other DOTs' practices in strategic research planning, performance assessment, and strategic marketing. The team also worked closely with MnDOT's Research Services staff to understand the complex nature of MnDOT's research enterprise, and supplemented this with a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. The team published its intermediate findings in a series of three working papers and sought feedback from MnDOT leaders and from members of the project's Technical Advisory Group, many of who direct or manage significant components of MnDOT's research portfolio. This Plan summarizes the project's findings and strategic recommendations.

This Plan makes six strategic recommendations on how MnDOT can improve both its research activities and research implementation in the next five years (2017 – 2022). These recommendations cover:

#1 Visioning Exercise

#2 Tracking Investments

#3 Investment Levels

#4 Streamlined Governance

#5 Life-cycle Project Tracking

#6 Portfolio Approach to Assessment

1.3 Audience

This document and its recommendations are addressed to MnDOT leadership, the Research Services section, office directors, TRIG panel members, district engineers, and other research champions within MnDOT. Our understanding is that these stakeholders will consider these recommendations and establish a process for implementing the Research Program Strategic Plan.

2. Why Should MnDOT have a Research Program Strategic Plan?

2.1 The Goal of Research

To acquire and apply the knowledge MnDOT needs to realize its vision

MnDOT invests in and maintains a transportation system to provide Minnesotans with the products and services necessary for an excellent quality of life and a competitive economy. In a rapidly changing world, research enables MnDOT to continuously improve how it designs and delivers infrastructure, how it operates the system, and how it responds to problems and issues as they arise. Research also helps MnDOT understand what Minnesotans need and expect from their transportation system and the effects of this system on the economy and the environment. Ultimately, research enables MnDOT to accomplish its collective vision for transportation embodied in Minnesota GO.

2.2 Minnesota GO Vision for Transportation

The Minnesota Department of Transportation (MnDOT) adopted the 50-year Minnesota GO Vision in 2011. It describes a transportation system for Minnesota that **connects Minnesota's primary assets**—the people, natural resources and businesses within the state—to each other and to markets and resources outside the state and country. The multimodal system **provides safe, convenient, efficient and effective movement of people and goods**. The system is flexible and nimble enough to adapt to changes in society, technology, the environment and the economy. This vision guides all planning and investment work for the department.

2.3 Research Definition and Process

The purpose of applied research is to answer a question or solve a problem to meet a recognized need.

In other words, applied research is need-inspired. Researchers design their investigations so that they can systematically identify the means to solve the problem.[1] For example, research helps MnDOT:

- Safeguard assets by understanding which kind of asphalt is most resilient to the snow removal and salt.
- Save lives by designing effective center line rumble strips for two-lane rural highways.
- Reduce congestion and pollution and increase safety by improving ramp metering algorithms and better design and management of MnPass lanes.
- Safeguard the structural health of bridges by safely and efficiently inspecting them with drones.
- Make Minnesota a more equitable place to live by studying how transportation options can enable all Minnesotans to access jobs, education, and services.

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[1] The US government also defines applied research in this manner, in Title 23 of the Code of Federal Regulations (CFR)

To answer these important questions, MnDOT's research follows an intentional and well-structured process. Investigators first begin with a problem that they or someone else has identified (**need identification**), and uncover what is already known or understood about the problem (**literature review**). The literature review step is very important as it helps save valuable time and resources when others may have already developed solutions. Looking at how others have described the problem sometimes also helps investigators improve their own description of the identified need. Investigators can also pick from a number of available approaches to solve the problem—the literature review helps them develop hypotheses and the methods to test them. All of this background work is written into a more formal proposal or research plan (**proposal development**). After sufficient feedback and review on these descriptions and approach, investigators begin their hypothesis testing and solution development process (**data collection and analysis**). When the analysis of data has revealed enough evidence so that the results point to a solution, or to an area of further investigation (**results**), researchers must carefully document what they posited and what they found. This documentation is not only important for dissemination, i.e. others to use in future literature reviews for example, but also for the researchers themselves so that they can replicate and implement the solutions (**implementation**) when the same need arises again.

2.4 Important Attributes of Research

Research is time-intensive. For some types of projects, this process is covered in a short duration of time, maybe a few months to a year. For other topics requiring materials, facilities and equipment, the same process takes years. It is often the case that the final outcome of a research project is an identification of another related need. In these cases, it may be many years before there is an implementable solution to the problem. MnDOT has deep experience with both short- and long-term research projects, as described in the Research Services' At-A-Glance series, and project technical summaries.

Research requires expertise and capacity. Conducting and managing sound and valuable research requires technical experts and project managers who are steeped in the research process. This expertise cannot be developed overnight; it takes organizations decades to develop the internal knowledge, systems, and processes to manage and execute research. MnDOT's technical experts and staff have cultivated their research execution and management skills over time. MnDOT thinks of research as an investment that must be tended and cultivated, so that the seeds planted can eventually bear fruit in accomplishing its vision. The corollary is that erosion in research capacity will harm the agency and it will take MnDOT many years to redevelop its research program.

Research must be carefully scoped. Since MnDOT must dedicate resources – time, effort, funds, and people – to research, it is and should continue to be careful to limit what it considers research. Research is NOT the process of making work routines more efficient through automation from installing computerized systems, or digitizing records. However, research could involve a structured and systematic evaluation of new products, or controlled testing of equipment to improve engineering processes for more efficiency. To fulfill the definition of research, there must be a clear guiding question to which the community or industry does not already know the answer. The accessible body of knowledge extends far beyond MnDOT, and the research process should leverage existing knowledge where available.

Research has real value and benefits. A Return on Investment (ROI) study of eleven of MnDOT's recent research projects showed enough cost savings to pay for the entire research program for seven years. The value of the

Department's full research portfolio is much larger, even though some benefits such as saving lives, and lessons learned, are not directly monetizable (because monetizing requires assumptions). These valuable projects also help MnDOT to invest in research areas where direct monetary payoffs are expected further down the line, or benefits are intangible in nature.

Research delivers important lessons. By its nature, research may result in an apparent "failure", i.e. unexpected or unintended outcomes. Such an outcome is valuable because it helped determine that a certain approach does not work as initially expected. Only a certain portion of the research performed across an entire program will result in successful implementable solutions. The research enterprise must therefore allow for some individual projects to have no positive net benefit, while the program as a whole does yields benefits across the research portfolio.

These attributes of research shape the discussion that follows in the rest of this document. The recommendations that follow later are cognizant of these unique attributes of research.

2.5 Purpose of a Research Program Strategic Plan

To direct MnDOT's research priorities toward the most valuable activities and then implement their results

A Research Program Strategic Plan is the set of research ideas, topics and priorities that MnDOT must execute to pursue its overall vision and direction. All of MnDOT's research topics are important, but strategic research priorities are key enablers of the Minnesota GO Vision. They address knowledge areas in which MnDOT must continue to be proficient and exemplary to fulfill its business objectives. Strategic research priorities are clearly linked to MnDOT's other planning activities such as the Statewide Multimodal Transportation Plan, and informed by transportation trends and guiding principles for investments. These priorities do not substitute the need for or eliminate other research topics, or preclude unforeseen needs that arise. Strategic priorities do however elevate and make some topics more visible than others.

A Research Program Strategic Plan identifies strategic research priorities to guide MnDOT's research investments and implementation decisions. The Plan is a framework for MnDOT's decision-makers, project managers and technical experts on how to identify critical needs, screen project ideas, and select high quality proposals. It is a helpful aide in deciding not only what research to pursue, but also how much of MnDOT's limited resources to allocate to different topics. The Research Program Strategic Plan is much like a blueprint, providing a single reference to MnDOT's internal research stakeholders to assist in governance and decision-making.

The process of developing the Research Program Strategic Plan is just as important as the Plan itself. A number of technical experts and management leaders have shared their views and helped to craft MnDOT's research vision, to identify strategic research priorities, and to enhance the execution of research. In the planning process, MnDOT should take stock of its current research investments, identify new opportunities, and also flag projects that should be completed prior to phasing out some topic areas.

The Plan serves as a valuable communication tool. It provides insight to stakeholders outside MnDOT on the topics the agency believes to be the most important. Sponsors, research investigators, and users of MnDOT research can have a clear and consistent sense of why it invests in certain projects. The Plan elevates the

findings of research. MnDOT can use the Research Program Strategic Plan as a platform to seek the most qualified sponsors and partners for its research program.

3. What Research Should MnDOT Prioritize?

3.1 MnDOT'S Research Vision

MnDOT conducts need-inspired applied transportation research to maximize the health of people, the environment, and the economy.

As above, MnDOT should define need-inspired applied transportation research as developing new knowledge and techniques to address current or anticipated problems. MnDOT's policy-based and technical research is performed to meet the needs of customers and stakeholders and has a clear link to maximizing the health of people, the environment, and the economy. This definition is based on a synthesis of survey responses from MnDOT's research stakeholders and office directors, in which they described their research activities and highlight elements of their research projects and programs.

3.2 Minnesota is Changing: Top Five Transportation Trends

A strategic approach to research will help MnDOT meet Minnesota's changing transportation needs

New trends and future changes will create new demands on the transportation system. In some case, current needs will be intensified or exacerbated. Strategically pursuing research is important for not only learning what changes could come about, but also so that MnDOT can account for them in the other parts of its business such as planning, investments, design, operations and maintenance.

MnDOT's vision is a transportation system that can accommodate current needs as well as adapt to the future. The extensive stakeholder engagement and research for the Minnesota GO Vision, and Statewide Multimodal Transportation Plan (SMTP) identified a number of trends affecting Minnesota. The trends are broken into five categories: population, economy, environment, transportation behavior and technology.[2] Stakeholders prioritized the top five trends affecting the state, as shown in Figure 1.

The discussion below provides a summary discussion of each prioritized trend. Some potential research questions for each prioritized trend are also proposed, shown in the inset boxes. These questions are illustrative of the types of strategic questions that MnDOT could formulate while implementing this Strategic Plan. They are intentionally broader than very carefully scoped research needs statements so that they can link a variety of specific research needs that may arise, to the language and ideas of the Statewide Multimodal Transportation Plan. These broad questions are included here to provide a starting point for discussion during the implementation phase of this Plan.

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[2] Minnesota GO SMTP Trend Library http://minnesotago.org/what-others-are-saying/whats-changing-minnesota

Figure 1. Top Five Trends affecting Transportation in Minnesota

Top five Minnesota trends

1 Aging Infrastructure

The priority should be on maintaining existing assets rather than expansion of assets.

2 Urban & Rural Population Trends

Recognize different contexts and have different goals / objectives for each.

3 Climate Change

Be aware of climate change and plan ahead for impacts, specifically where impacts may disrupt transportation.

4 Environmental Quality

Build an environmentally friendly transportation system – less pollution, improved health.

5 Transportation Behavior

Make sure to understand how transportation behaviors are going to change in the future. Develop system priorities accordingly.

Source: MnDOT Statewide Multimodal Transportation Plan (SMTP) trends library

Trend 1 -- Aging Infrastructure

Minnesota faces a wave of aging roads and bridges that are in need of upkeep. To illustrate the trend, Figure 2 shows the age of pavements on the state highway system in Minnesota. MnDOT typically reconstructs roads when they are between 70 and 80 years old. Bridge replacement typically occurs at 50 to 100 years. Additional needs for maintenance are observed on city and county roads as well as Minnesota's airports, railroads, ports and waterways. These needs add to an ever-growing list of investments to maintain the quality of the state's public systems.

Figure 2. Age of pavement on Minnesota's state highway system as of 2014
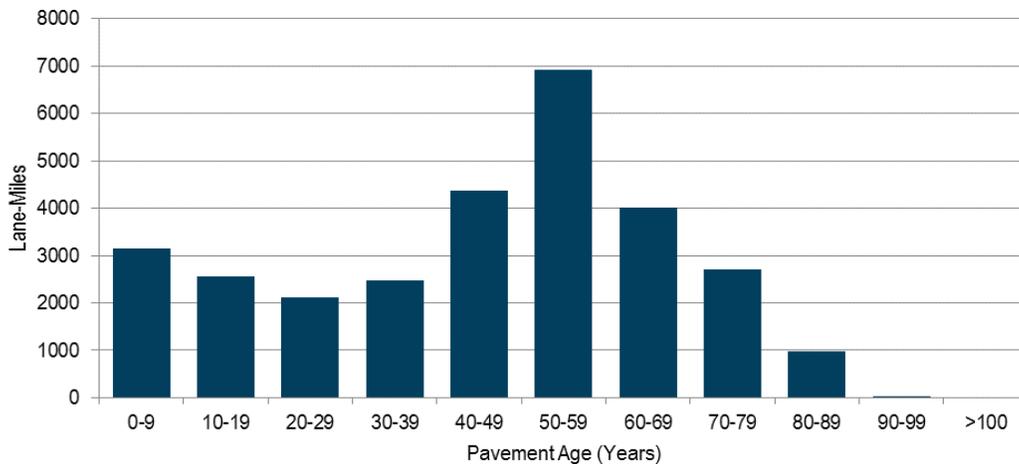
Source: MnDOT Transportation Asset Management Plan, 2014

The illustrative research questions shown in the inset box below are provided as a starting point for discussion during the implementation phase of this Research Program Strategic Plan, to identify how specific research needs statements address this trend.

Potential research questions to address the 'Aging Infrastructure' priority

- What design and maintenance techniques can maximize the useful life of roads and bridges?
- What is the life-cycle cost impact of new materials and construction techniques?
- How does right-sizing and performance-based design affect the maintenance and replacement schedule of assets?
- What is the relationship between asset condition, value and available funding from an asset management perspective?
- How can we develop and refine asset management strategies for specific asset classes?
- How do asset-related decisions affect the financial health of the agency?
- What are the implications of Connected and Automated Vehicles for the design, construction, and management of assets?
- What sensors and data across multiple modes could provide the visibility necessary to improve asset management and overall asset lifecycles?

Trend 2 – Urban and Rural Population Trends

Minnesota is becoming more urban in all parts of the state. Figure 3 shows these population and urbanization trends between 1900 and 2040.Just over 70 percent of people live in cities and towns with populations over 2,500 people, which the US Census defines as urban regions. The number of people living in rural areas has stayed fairly level since 1900. Minnesota's urban population has grown significantly during the same time. The State Demographer's Office estimates that most counties will grow in population during the next 30 years. The largest population growth is projected to occur in the Twin Cities region. A smaller rate of growth is expected in Greater Minnesota's urban communities. A growing urban population will use transportation in different ways than people do today. It will be important to provide a variety of options for people to travel within and between urban areas.

Figure 3. Minnesota's historic and projected urban/rural population split
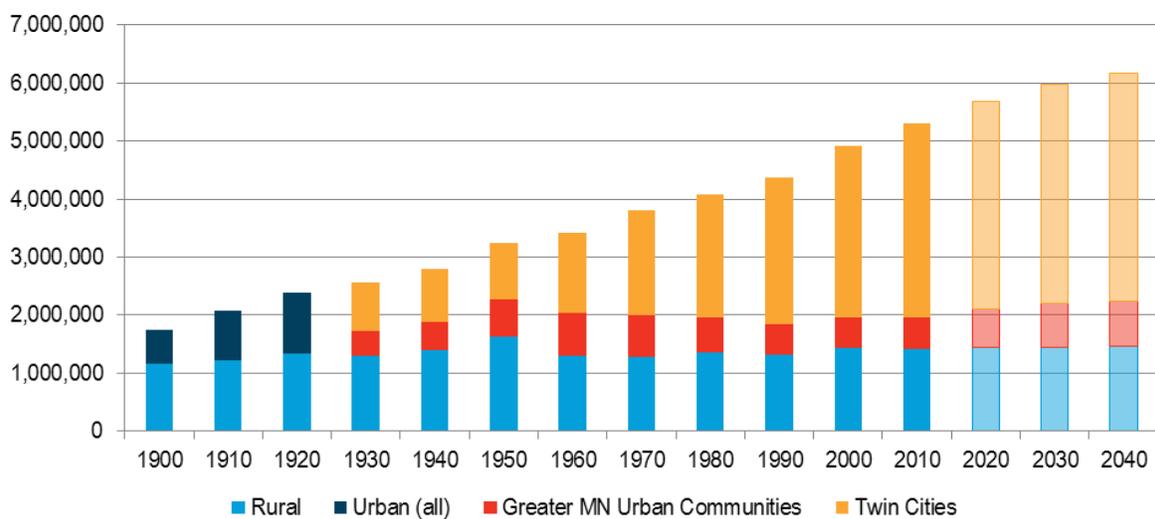
Source: SMTP Trends Library, Urbanization Trends white paper, based on US census and Minnesota state demographer data

As above, potential research questions on the topic for Trend 2 are included below. MnDOT could use these to evaluate the strategic importance and relevance of specific research needs statements to the Urbanization priority.

Potential research questions to address the 'Urbanization' priority

- How reliable, accessible, and affordable are urban services to rural populations?
- How do urbanized areas, especially the Twin Cities, improve their understanding of the movement of people and goods, especially in the "last mile", to enhance mobility?
- How does the availability and distribution of services affect travel demand and economic competitiveness?
- What are the strategies to optimize the movement of people and goods through important corridors?
- What transportation system elements and modes can better align the demand for travel with the value of services?

Trend 3 – Climate Change

Climate change is already having major impacts in Minnesota and will continue to have impacts into the future. What these future impacts will be is not always clear. Greater variation in temperatures, precipitation levels, and frequency of extreme weather events will stress the transportation system. It is possible that these changes could increase maintenance costs and impact the way that Minnesotans travel. Figure 4 outlines some of the most likely climate impacts as determined by the Minnesota State Climatology Office.

Figure 4. Impact of Climate Change on Minnesota's Transportation System

Climate Impact	Confidence in change for MN during next 20 years	Potential Negative Effects to Transportation System
Heavy Precipitation / Flooding	Very High	• Damage to highway, rail infrastructure, hydraulics infrastructure, airport runways • Overtopping roads will slow operations and performance.
Warmer Winters	Very High	• More ice build-up and freezing precipitation • Reduced pavement conditions and life cycles • Downed power lines with ice storms • Reduced ice cover on water bodies leading to greater rates of evaporation
New species ranges	High	• Changes in roadside vegetation mixes • Soil erosion • Increase in invasive species populations • Increased exposure of construction and maintenance crews to vector-borne diseases
Drought	Medium	• Reduced river navigability for barges. • Stress roadside vegetation, which may reduce rainwater storage and increase soil erosion in the long-term.
High Heat	Low	• Pavement and rail buckling • Vehicles overheating • Electrical system malfunctions • Limitations on construction hours
Wildfires	Unknown	• Road closures • Immediate and significant threat to human safety • Damage to roadside infrastructure

Source: SMTP Trends Library

Some corresponding potential research questions to address the impacts of climate change on Minnesota's transportation system are listed below. These can help develop a link between strategic ideas to actionable research and implementation.

Potential research questions to address the 'Climate Change' priority

- How will multi-modal assets deteriorate under different climate change scenarios? What are the maintenance and investment implications?
- What are the impacts of extreme events such as storms, flooding, etc. on transportation system operations and management?
- What design and standards changes are needed for road and bridge construction under extreme events?
- How will transportation system design and operations need to change to support other critical infrastructure links such as power and water system maintenance?

Trend 4 – Environmental Quality

Transportation impacts the air, water, plant and animal resources in the state. As the population grows, so too does the demand on natural resources. Studying transportation's effects on environmental quality today shows where changes are needed. Ideally, transportation investments and strategies may even be able to help improve the environment in some areas.

Reducing greenhouse gas emissions from burning fossil fuels is key to limiting environmental and climate change impacts. Figure 5 shows past and future emissions from transportation in the state. While emissions are going down, the state is not on track to meet the 2007 Next Generation Energy Act targets. Reducing emissions will require shifting away from gasoline-powered vehicles and promoting cleaner transportation options.

Figure 5. Historical and projected transportation sector greenhouse gas emissions in Minnesota
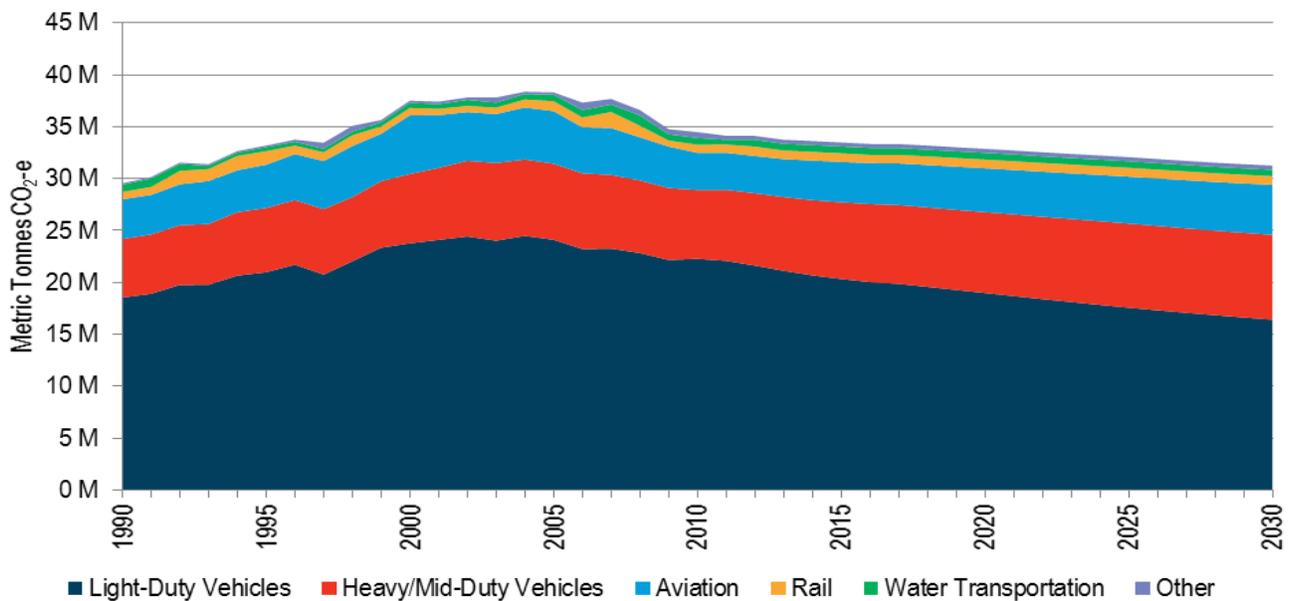
Source: SMTP Trends Library; Emissions data from MPCA; does not include emissions from natural gas pipeline transmissions

On-road vehicles are the greatest source of air pollution in Minnesota. Yet, despite growth in vehicle miles traveled, emissions from highway vehicles dropped by more than 50 percent over the last 25 years. This drop is largely due to changes in federal vehicle and fuel standards. Further reductions in emissions could also help to limit public health impacts from air pollution.

The transportation system also impacts Minnesota's water quality. Run-off from roads can carry pollutants into bodies of water and wetlands. Chloride (i.e. salt) is one pollutant of concern because of its effects on wildlife and drinking water supplies. Chloride is very difficult to remove once present in a body of water.[3]

Many of the state's ecosystems are now home to invasive species. In some cases the transportation system may facilitate the spread of invasive species. While the impacts of some invasive species are only a nuisance, while others can potentially be devastating in terms of imposing maintenance requirements or asset deterioration. Examples of invasive species include zebra mussels, emerald ash borer, silver carp and buckthorn. In some cases, the effects include the extinction of native plants and animals.[4]

Supporting pollinator habitats is an example of how the transportation system can protect and enhance the environment. MnDOT recently announced an agreement with five other states to use rights-of-way in the I-35 corridor to protect pollinators such as the Monarch butterfly. MnDOT is conducting further research on more opportunities to use rights-of-way in this manner.

As above, potential research questions on the topic for Trend 4 are included below. MnDOT could use these to evaluate the strategic importance and relevance of specific research needs statements to the Environmental Quality priority.

Potential research questions to address the 'Environmental Quality' priority

- What are the rural and urban health impacts of emissions in the Minnesota region?
- How do invasive species and altering habitats interact with the transportation system?
- How do transportation system design, operations, and maintenance affect habitats, air quality, water quality, soil condition, and noise?
- How can the transportation system be better integrated with the environment to not only safeguard it but also provide access to high environmental quality zones for the urban population?

Trend 5 – Transportation Behavior

Anticipating trends in transportation behavior can help MnDOT and other transportation partners meet the needs of all users. Twin Cities residents are increasingly using options other than cars to travel. Per-capita vehicle miles traveled remains below the peak set in 2004. Transit ridership and the percentage of people who

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[3] MN EQB Water Policy Report, 2016
[4] Minnesota Department of Natural Resources

bicycle and walk have grown in recent years.[5] Data suggests that more investment in transit, bicycling and walking infrastructure would encourage people to use these modes more often.

Telecommunication systems also play a part in how people travel. As access to high speed internet grows, more people will have the option to shop, see a doctor, or work online. The implications of this shift on transportation are uncertain at this time, but warrant careful attention going forward.

New companies and technologies have made people re-think how they travel, especially in urban areas. Mobility as a service - the ability to travel in exchange for a fee without utilizing one's own vehicles or assets - offers new ways to use the system through the "sharing economy." One example of mobility as a service is car sharing, available through companies like Zipcar in the Twin Cities, Mankato and Winona. Other ride matching services like Uber and Lyft have seen rapid growth in recent years.

Many questions remain about how mobility services will evolve in the future. For example, the advent of self-driving cars has the potential to reshape entire systems as we know them today. Self-driving cars, combined with mobility-as-a-service platforms such as Uber, Lyft, and Via could also reduce overall car ownership levels, producing profound impacts on transportation system management and land use.

Potential research questions to address the 'Transportation Behavior' priority

- How do people currently access transportation system services across multiple modes and move between modes on trip?
- What factors influence mobility-as-a-service trends in Minnesota, and in particular the Twin Cities region?
- What policies and regulations either detract from or support the alternative modes of travel?
- How do goods movement practices influence system performance outcomes in terms of congestions, reliability, or environmental impacts?
- What policies, regulations, and investments can influence the demand for transportation services (for both people and goods movement) for improved system performance?

The summary discussion of the top five trends identified as part of the Strategic Multimodal Transportation Plan development process shows that Minnesota is changing and that its transportation system will need to evolve accordingly. Research can help MnDOT with this evolution, and this section has identified examples of important high-level research questions that can be used as a starting point to show clear links between the trends and specific research needs statements that MnDOT will eventually develop.

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[5] Metropolitan Council Travel Behavior Inventory

3.3 Guiding Principles and Indicators for Research Priorities

MnDOT also needs a way to evaluate the outcomes of research efforts (and later, implementation) and to assess the impacts of new approaches on the transportation system. The Guiding Principles component of the SMTP can also be useful in this regard, as they provide a framework to help evaluate and report on the outcomes of the research program. MnDOT's research activities must reflect the overall direction of the SMTP to ensure that the whole organization is working towards the same vision.

MnDOT's Statewide Multimodal Transportation Plan outlines eight guiding principles for MnDOT's overall organization strategy. These principles are to be used collectively for all of MnDOT's business activities as a whole, including research planning and investments. These Guiding Principles have therefore been converted to reflective questions so that MnDOT can evaluate the outcomes of its research portfolio.

Each principle also provides Guiding Indicators (GIs), which are high-level Key Performance Indicators. Key Performance Indicators aggregate and summarize the information in more specific performance measures. For example, 'Safety' is a high-level Guiding Indicator and it includes specific performance measures such as fatalities, crashes, spills, etc. Taken together, these measures could be aggregated and described to make a higher-level statement on how research helps MnDOT improve 'Safety'. While reporting on the outcomes of the research program, MnDOT could aggregate performance results and tie them back to the SMTP Guiding Principles in this way.

The leading questions below each refer to an SMTP Guiding Principle, and the underlined ideas are the suggested Guiding Indicators:

How does research inform the multiple purposes of public investments? The transportation system should support other public purposes, such as environmental stewardship, economic competitiveness, public health and energy independence. Our research should help identify these relationships and pathways.

How does research improve system accessibility? The transportation system must be accessible and safe for users of all abilities and incomes. The system must provide access to key resources and amenities throughout communities. Research should help identify both the barriers to access and solutions for overcoming them.

How does research influence the scale and timing of investments? The scale of the system should reflect and respect the surrounding physical and social context of the facility. The transportation system should affordably contribute to the overall quality of life and prosperity of the state, while minimizing long-term obligations and not overbuilding. We should conduct research that helps us understand the life-cycle of the assets we build and how investments should be timed.

How does research inform decisions to improve regional connections? Key regional centers need to be connected to each other through multiple modes of transportation. We must investigate how people and goods flow through the system.

How does research improve the integration of safety in to design, operations and management? We must systematically and holistically improve safety for all forms of transportation. Research can help us be proactive, innovative and strategic in creating safe options.

How does research enable the transportation system to become more reliable and predictable? The <u>reliability</u> of the system and <u>predictability of travel time</u> are frequently as important as or more important than speed. We should study choke points, failure modes, and how to be responsive to them.

How can research point out which parts of the system must be strategically fixed and maintained? Some parts of the system may need to be reduced while other parts are to be <u>strategically enhanced</u> or expanded to meet changing demand. Research should help us look at assets in light of the long-term opportunities and risks they face.

How can research partnerships improve products and services? <u>Coordinate</u> across sectors and jurisdictions to make transportation products and services more efficient. We must engage with <u>partners</u> who share our objectives and complement our abilities, expertise, and resources.

The set of guiding principles thus offer a number of Guiding Indicators as key outcome dimensions that can be used to assess the impacts and benefits of research in different priority areas. Distilling the language of the principles gives the following list of indicators:

- Accessibility & Connections
- Safety
- Investment Scale & Timing
- Strategic Maintenance
- Environmental Stewardship
- Reliability & Predictability
- Economic Competitiveness
- Public Health
- Energy Independence

These GIs should be discussed during the implementation phase of this Research Program Strategic Plan to help select suitable specific performance measures. Then those can be aggregated back at this level to describe overall benefits, and progress towards meeting SMTP goals.

3.4 Setting a Research Direction

As discussed above, MnDOT has two important sources of information from its recent planning efforts on which to base its agency-wide agenda setting policy guidance on the strategic direction for research: (1) the SMTP Top Five Minnesota Trends, and (2) the Guiding Indicators. Additionally, as part of the research and stakeholder engagement process for developing this Research Program Strategic Plan, a third high-level source of information was (3) survey responses from TRIG members and office directors describing their top research priorities for the next five years. These three sources of information were synthesized into a single framework, which connects the aspirational priorities to the top five Trends as well as Guiding Indicators (see Figure 6 below).

The vertical axis shows the Top 5 Trends as cross-cutting themes across a number of research topics. The Trends provide information about the drivers or need for research. The Guiding Indicators on the horizontal axis provide the key performance indicators or measurable outcomes for system performance, as a result of research. The

topics in the blue boxes refers to high-level research priorities established by stakeholders in the survey responses. The framework shown in Figure 6 is thus a way to relate priority topics with the SMTP Trends and Guiding Indicators.

Figure 1. Recommended strategic framework for fine-tuning MnDOT's strategic priorities
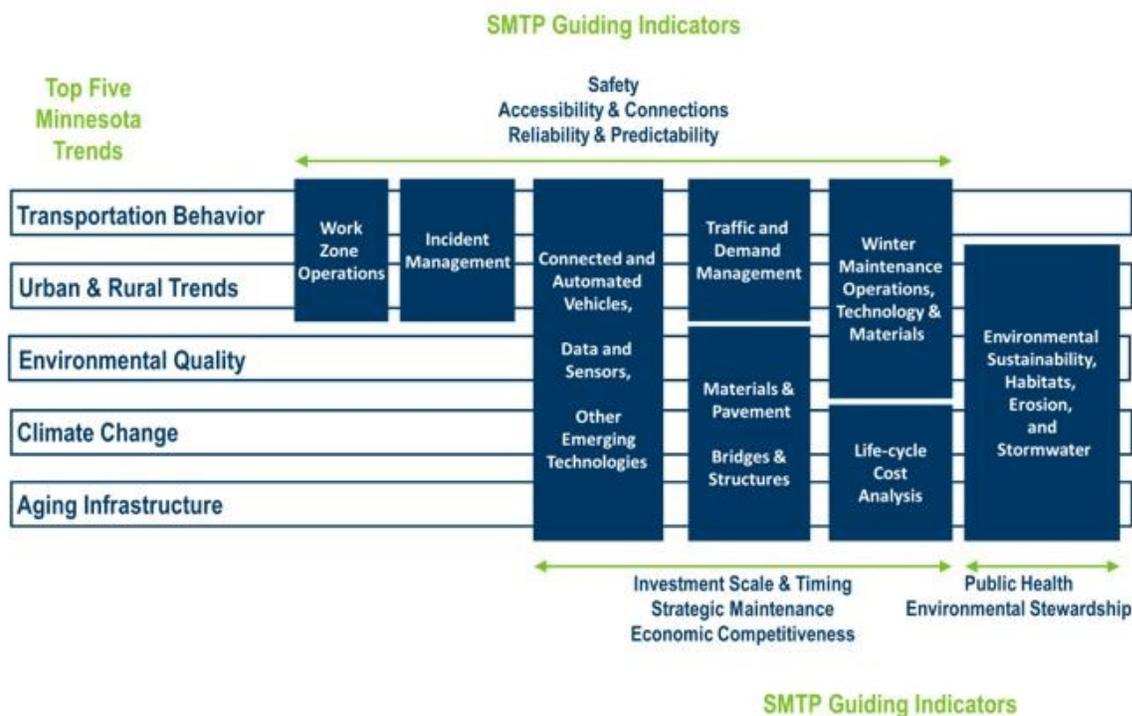
Source: CPCS analysis of SMTP Trends Library and survey responses from Specialty Office directors and TRIG members

This strategic framework is proposed as a starting point for further discussions during the implementation phase of this Research Program Strategic Plan. However, some additional steps are required to fine-tune these priorities into an implementable research agenda.

3.5 Strategic Recommendation #1: Visioning Exercise

MnDOT should conduct an internal priority setting exercise

MnDOT will need to further refine and specify topic priorities and high value research needs for the next five years (planning period of this Strategic Plan). Offices and technical work groups will meet to discuss how the elements of Figure 6, i.e. Trends, GIs, and topic areas should be converted to research needs statements along with the corresponding performance measures. This recommendation is broken down into a two suggested steps: the circulation of a strategic memorandum from MnDOT leaders outlining strategic priorities, and a Visioning Exercise to help refine topic priorities and make them more specific.

As a first step, MnDOT leaders should use the GIs in conjunction with the SMTP top five trends to first develop an agency-wide research strategy memo. This memo would summarize some of the information above (for ex. using Figure 6) and solicit specific information to establish at a Department-level the relationships between the trends, the GIs and different elements of MnDOT's research program (TRIG, offices, districts etc.). As a high-level internal communique, the note should urge program area and office directors, district engineers and other research champions to reflect on and answer the following questions:

- How have your recent projects addressed the top five trends, and how will your program / Office do so in the next five years (2017 – 2022)?
- How does your program / office measure realized system impacts (or potential system impacts) as a result of research and how will you accomplish this in future? Which of the Guiding Indicators (and performance measures) does your research inform?
- Which obsolete or less important topic areas should MnDOT disinvest from?
- What is your program's current level of annual research spending in each of the top five trends areas? How much would you like to spend every year going forward, and why? In other words, what is the aspirational funding gap?[6]

As a second step, MnDOT leaders should convene a stakeholder visioning session – a Visioning Exercise - to discuss responses, develop further clarity and consensus across the group of participants, and further narrow objectives and priorities.

MnDOT has experience with such a session in the past – it conducted a similar visioning exercise in 2007. The proceedings of that session can be used as a starting point. In fact, it is recommended that MnDOT conduct such an exercise every three to four years as part of the Research Program Strategic Plan update process.

Conducting a visioning session in the absence of prior reflection as suggested above in Step 1 will be unproductive. In other words, MnDOT leaders should request and receive responses to the questions above (Step 1) before convening a Visioning Exercise round-table discussion (Step 2) to make this effort valuable.

To close out Step 2, MnDOT leaders should circulate among research stakeholders, a policy brief documenting the conclusions of the Visioning Exercise, the priorities established, and the process and framework for ultimately monitoring and reporting progress towards the SMTP goals and Minnesota Go Vision.

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[6] This addresses the need for comprehensive tracking of both current and desired (or aspirational) level of research investments in each of the priority areas. This is also encapsulated below in Strategic Recommendation 2: Tracking Research Investments.

4. How Should MnDOT Govern Research?

4.1 Institutional Context

Two key entities drive and collaborate on transportation research in Minnesota: MnDOT and the Local Road Research Board (LRRB). As state transportation research programs, they rely on entities such as the Center for Transportation Studies (CTS) at the University of Minnesota, other Minnesota state colleges and universities, out-of-state universities, vendors and consultants to conduct the majority of MnDOT's research activities. Of these, the University of Minnesota performs the largest share of research sponsored by MnDOT.

As Minnesota's principal state transportation research programs, MnDOT and LRRB and their main external executor – CTS - are intertwined as a result of their histories and governing statutes. These entities work together frequently to administer and perform research that benefits MnDOT and other transportation agencies. MnDOT has closer ties with UMN CTS than with its other external contractors through a partnership agreement and some technical and administrative working groups. It is essential that MnDOT continue to coordinate closely with both LRRB and UMN, and also its other university partners and contractors to accomplish the Minnesota Go Vision. Section 4.8 below further discusses the need to streamline these relationships.

4.2 Research Funding

MnDOT has sponsored an average of $6.7 million per year in strategic research administered through Research Services in the last six years, from FY2010 to FY2015

MnDOT receives research funds from a number of sources. The funds administered by Research Services are summarized on the left in Figure 7. From FY2010 to 2015, MnDOT received approximately $69 million in total from federal and state sources. In inflation-adjusted terms (i.e. converting to 2016 $), this translates to annual average of $12 million per year over the last six fiscal years.

State funds accounted for 64% (State Research and LRRB funds) of total funds received for research. Of these, the State Research Program Funds (34%) were largely for MnDOT's discretionary spending on research, whereas the Local Road Research Board funds (29%) were a set-aside and pass through. In other words, MnDOT receives and administers funds on behalf of LRRB, which are allocated by Minnesota statute. The remaining 37% of research funds came from federal sources. The Federal Highway Administration's (FHWA) State Planning & Research Funds – Part II amounted to $3 million per year (27%) of the total research inflows. Finally, MnDOT received around 10% from other federal and agency sources. MnDOT's Research Services administers and tracks these funds.

Not all of the $12 million per year is available to MnDOT to spend on research – about 43% is passed through. The Local Road Research Board is a governing organization that sets priorities for research benefiting Minnesota's county roads and city streets. Over the last six years, it had spending authority over about $20 million in these pass through funds (or 29% of the total research funds), as directed by law. When there is opportunity for overlap between MnDOT and LRRB research priorities, the two organizations jointly select and share costs for projects meeting these priorities. The other pass through of funds is the operating budget for the

Center for Transportation Studies and the University of Minnesota, and the Local Transportation Assistance Program (LTAP).

Figure 7. MnDOT's Research Funding Flows
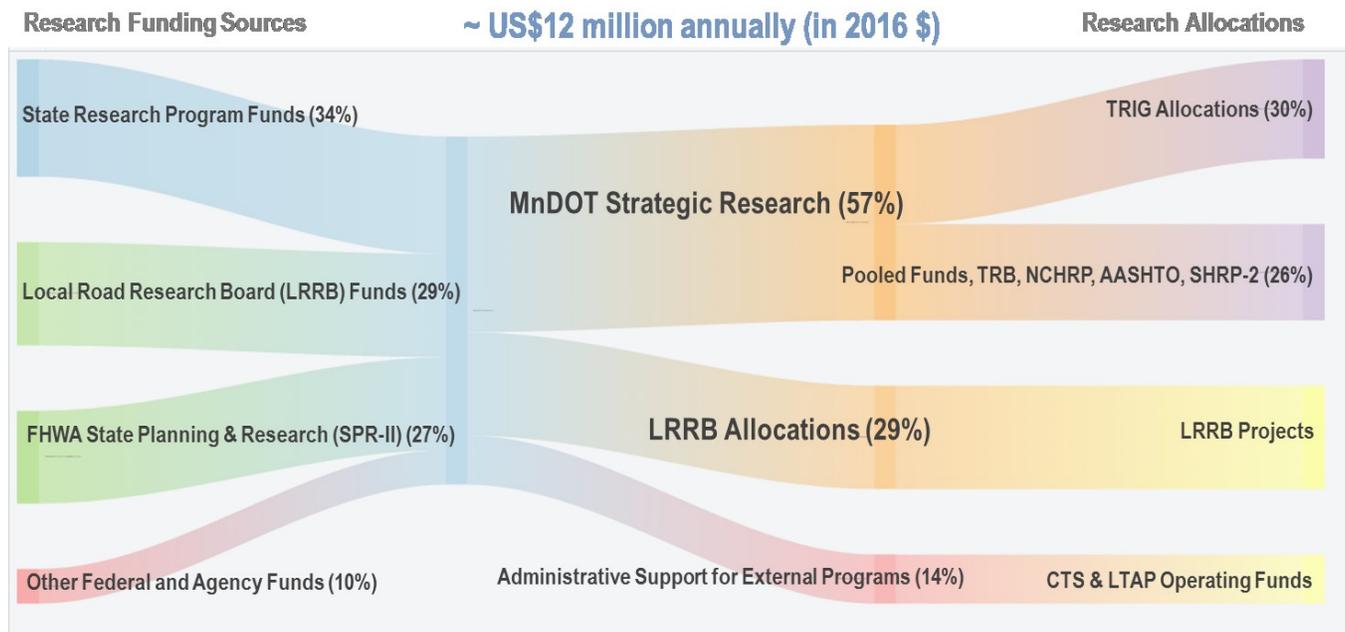
MnDOT spent on average $6.7 million per year on strategic, centrally coordinated research during this time period – on topics that met MnDOT's strategic needs, as well as topics that fulfilled multi-state and federal priorities. MnDOT's own priorities over this time have included materials, structures, traffic, safety, bridges, multimodal, and environment. Multi-state and federal priorities also include these topic areas, but the projects are conducted as single- and multi-state pooled-fund studies, or National Cooperative Highway Research Program projects. In addition to the above, MnDOT allocates some funds in the form of membership contributions to other TRB, AASHTO, and SHRP-2 programs, allowing MnDOT to access and participate in those programs.

NOTE: These amounts do not provide a complete picture of MnDOT spending on research. The statistics above are based on an analysis of data provided by Research Services, for the portfolio of funds that this office administers. MnDOT's current accounting approach to tracking research funds expended elsewhere in the agency does not permit a full bottom-line or otherwise comprehensive understanding of research investments.

Many of MnDOT's offices (mainly Materials and Road Research; Maintenance and Operations; Traffic, Safety, and Technology) also conduct independent discretionary research, in addition to projects funded through the mechanisms summarized in Figure 7. The funding sources and breakdowns for office independent research are NOT included in Figure 7 above.

4.3 Strategic Recommendation #2: Tracking Research Investments

MnDOT must develop a comprehensive understanding and tracking system for its research investments

As part of implementing the Research Program Strategic Plan (2017-2022), MnDOT should examine past accounts to develop at least an order of magnitude estimate of its overall research expenditures over the last five to six fiscal year funding cycles. One of the suggested questions in Strategic Recommendation #1 – Visioning Exercise is to request information from research leaders about their research expenditures in certain topic areas, to help triangulate on the amounts both from a bottom up and top down point of view.

In addition, MnDOT should streamline its research tracking and accounting process so that MnDOT leadership, Research Services, office directors, and the proposed MnDOT Research Champion (see Section 4.6 below) can quickly obtain customizable research funding and expenditure reports through an enterprise wide tracking system. This would involve developing specific budgeting and accounting codes, and detailed guidance on how to label certain types of research expenditures.

4.4 Setting Investment Levels

There is no formula that governs how much a state transportation agency should spend on research to generate a certain level of system performance improvement or overall benefits. Over the last six fiscal years, MnDOT's centrally coordinated research portfolio (administered by Research Services) has been growing at an average annual growth rate of about 6.5% (inclusive of pass through funds comprising 43% of the funding). This rate accounts for the effect of inflation. The question going forward is how much should MnDOT spend on research in future years? Should it maintain this level of investment, spend less, or spend more?[7]

The analysis attempted to shed light on this set of questions in a number of ways. The first was to try to establish an empirical relationship between MnDOT's own research investments, and its reported benefits. As noted above in the discussion for Strategic Recommendations #1 and #2, our understanding of both sides of this equation – spending and benefits – is severely limited by the available data. This is partly because of what MnDOT does (and does not) track on the spending side, and also because of how difficult it is to measure returns or value, on the benefits side.

The second approach was to benchmark research spending against the programs of other DOTs. The analysis asked the question how much do other state DOTs spend on research in relation to their asset base (Research $ / Asset $ ratio), compared to overall agency revenues (Research $ / Revenue $ ratio), and other such metrics that might shed light on research investment levels. Only a small handful of DOT's (CA, TX, UT) publish research program information, and it is partial. The available data do not allow for a suitable and large enough comparator base to draw any substantial conclusions. The many differences in how agencies report (or do not

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[7] Section 161.53 of MN statutes allows the MnDOT Commissioner to spend up to 2% of all funds appropriated to the Commissioner other than county state-aid and municipal state-aid highway funds for transportation research. It is unlikely that MnDOT's current or planned research investments will run up against this ceiling.

report) research spending, asset base values, and overall revenues made this benchmarking process near impossible.

A third approach was to look at private industry in North America across a variety of sectors to identify investment levels in R&D. Figure 8 summarizes this analysis. The trend lines show the level of R&D spending in US$ billions between 2005 and 2014. The first adjoining column show the spending as an average % of annual revenue, and the second column shows the correlation of spending with annual revenues.

Figure 8. R&D Investments (US $ billions) by Industry in North America (2005 – 2014), with columns showing spending as an average % of annual revenue and correlation with revenues.

	Annual Average % of Revenue	Correlation with Annual Revenue
Computing & Electronics	8 %	0.92
Healthcare	11%	0.88
Software & Internet	14%	0.99
Industrials	3%	-0.12
Automotive	4%	0.95
Energy & Chemicals	1%	0.45
Aerospace & Defense	3%	0.76
Consumer	2%	0.96
Telecom	1%	0.91
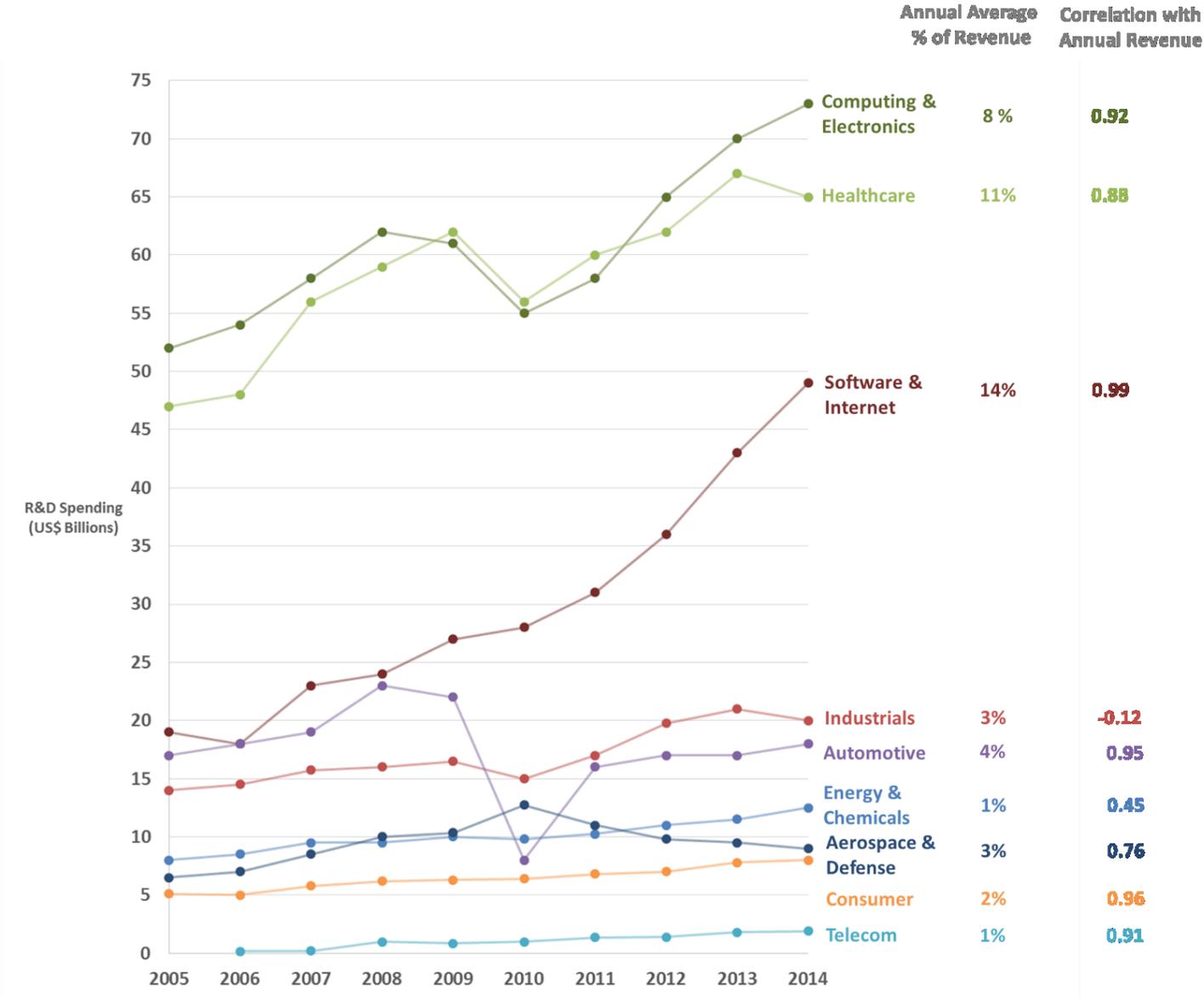
Source: CPCS analysis of publicly available data, PwC consulting reports, and SEC filings

The main takeaways are as follows:

- **All industry sectors invest in R&D, although to different levels**. The "High Tech" group (Computing & Electronics, Healthcare, and Software & Internet) are the big spenders, both in absolute terms as well as a % of annual revenues. Heavy Industry (Industrials, Automotive, Energy & Chemicals, Aerospace & Defense) and the Consumer sector are in the middle of the pack, still spending many billions on R$D but a smaller fraction of revenues. Telecom spending is minimal in comparison.
- **R&D spending tends to track revenues**. For most industry sectors analyzed here, R&D spending is highly positively correlated (0.7 as a rule of thumb for strong positive correlation). In other words, when revenues are high, research spending also tends to be high, and vice versa. Energy & Chemicals shows positive correlation, although not as pronounced. The Industrials sector is an exception.

The analysis concludes that a broad cross-section of private industry maintains high levels of aggregate research investments and that they are usually marked to revenues in that industry. Correlation of research spending and overall revenues can thus inform future investment levels.

4.5 Strategic Recommendation #3: Investment Levels

MnDOT should at minimum maintain its aggregate research spending level in real terms, and mark overall spending to revenues in future years

MnDOT should mark its future research spending to its revenue. This has emerged as a best practice in R&D heavy industries, as discussed above. However, a number of preceding steps are required before MnDOT can consistently adopt this procedure.

As discussed above, Strategic Recommendation #2 highlights the need for MnDOT to comprehensively track research investments. Without a reasonable understanding of total research spending, it is difficult for MnDOT to understand either the denominator in the Benefit/Cost ratio for research spending, or the numerator in the Research $ / Revenue $ ratio.

After developing a comprehensive understanding of research spending for the last five to six fiscal cycles, MnDOT can mark spending to revenue over the same duration, i.e. all appropriations to the Commissioner other than county state-aid or municipal state-aid highway funds as is defined in MN statute. This exercise would generate the historical correlation between research spending and revenue, and the desired spending ratio going forward.

Until such a process is established however, MnDOT can maintain its aggregate research spending at current levels to preserve the value of its research portfolio.

4.6 Research Governance

Research governance at MnDOT is distributed across disparate functional levels, divisions, and offices. Each entity must have a clear role to play in the governance of MnDOT research, but these should come together cohesively. Based on extensive stakeholder involvement and a study of national best practices (extensively documented in Working Paper 2: Strategic Framework and Principles), MnDOT should base the governance and decision-making framework for its research program on the following principles:

Governance Principles

1. **Integration over separation**: close coordination between stakeholders and activities involved in Minnesota transportation research.
2. **Accountability**: a comprehensive view of MnDOT's entire research and implementation portfolio, coupled with a Research Champion role vested in a single leadership position or office, with feedback and advocacy provided by an external Research Advisory Group.
3. **Specialist Expert Committees**: Deep technical experts provide advice, and evaluate project proposals and results, and help make project funding decision, along with implementation recommendations for research results.
4. **Value Capture**: funded implementation / deployment and benefits tracking, all consolidated within an enterprise-wide research tracking system.
5. **Strategic Responsibility and Feedback**: a feedback loop to from the research program to MnDOT leaders so that research can eventually influence MnDOT's organizational strategy, in turn advised by a mix of public and private stakeholders.

4.7 Strategic Recommendation #4: Streamlined Governance

MnDOT must refine its governance structure to better reflect its decision-making principles and clearly establish roles and responsibilities

Figure 9. G shows the recommended governance structure for MnDOT's research organization. This governance structure incorporates the five governance principles. The roles of different offices in this model are further discussed below.

Research Champion

MnDOT should establish a Research Champion at the highest level of its research organization. Research could be championed by the Assistant Commissioner for Modal Planning and Program Management, as this division oversees a number of critical business areas, including long-range planning activities, data management, asset management, performance metrics, research services, and multimodal operations. The Assistant Commissioner of this Division is therefore well-positioned to convene and support the Strategic Research Program.

Research Advisory Committee

MnDOT should add a Research Advisory Committee, whose members can provide feedback to MnDOT leaders – the Commissioner, the Deputy Commissioners and the Assistant Commissioners, and the Research Champion. In addition to some internal technical experts and transportation and business industry leaders, a number of individuals from local, state and federal groups such as the LRRB, AASHTO, TRB and FHWA could advise on broader trends facing transportation, help advocate for research sponsorship, and communicate the value and impact of research to a broad range of external stakeholders. The members would be selected during the implementation phase of this Plan.

Figure 9. Governance Structure for MnDOT's Research Organization
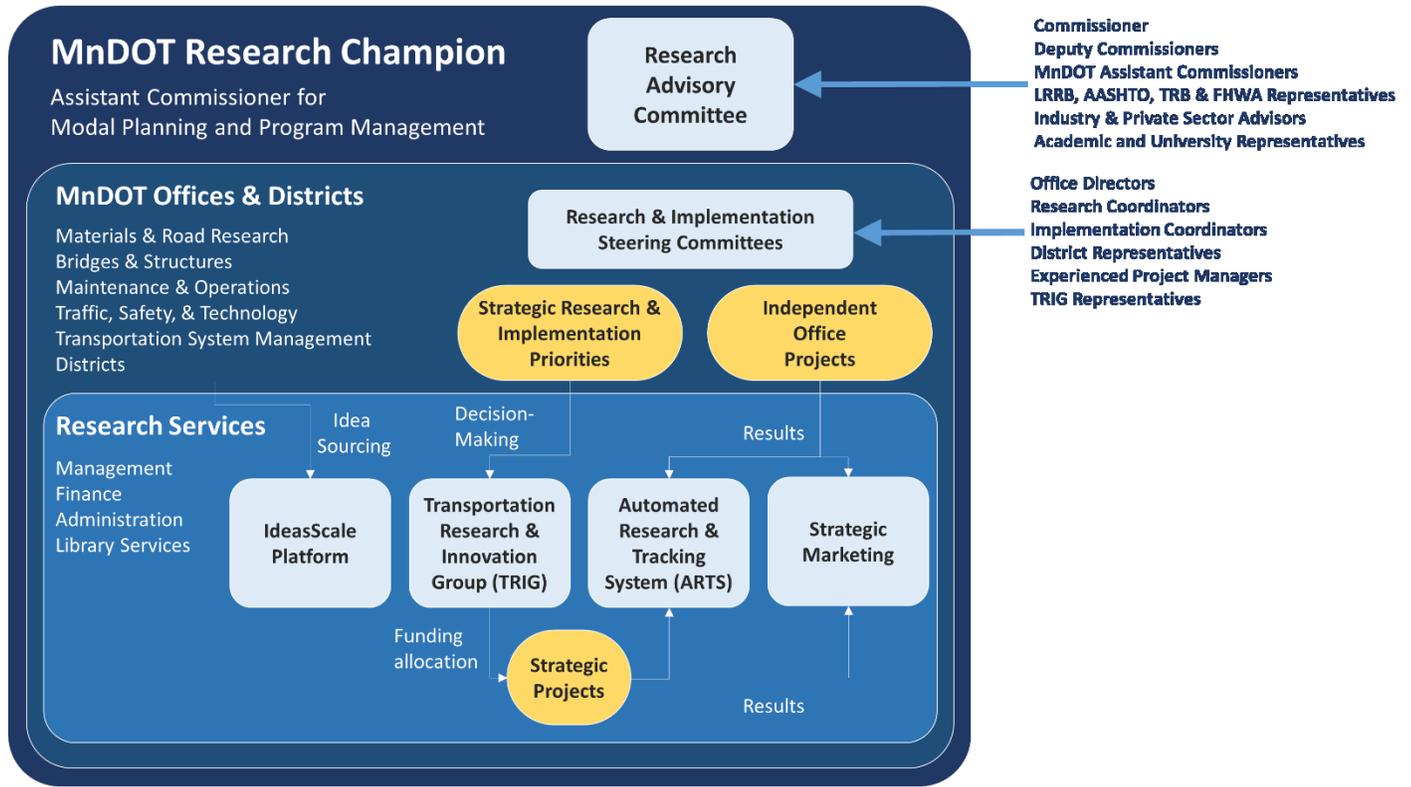
Source: CPCS analysis of MnDOT's current organizational chart, stakeholder interviews, and best practices

Offices & Districts

MnDOT's offices often sponsor research using internal budgets, which are not administered by Research Services. MnDOT Districts also conduct their own research, as and when frontline staff identify a need. Figure 10 illustrates which offices sponsor independent research and examples of their activities. This grassroots flexibility allows MnDOT's experts to be responsive to technical challenges. However, a consequence is that no one at MnDOT is able to comprehensively track and maintain visibility on research being conducted across the enterprise.

To improve tracking and visibility of research activities, offices and districts should use ARTS – a research management database run by Research Services (see below) – to enter in the results of their research and implementation projects. Research Services should further pick up the strategic marketing effort once (independent and centrally coordinated) project results are known, or once new findings have been implemented and benefits have been captured (see discussion of ARTS below).

Offices could also convene their own Research & Implementation Steering Committees comprising technical experts in the respective Office's technical focus areas. Internal experts from MnDOT, and external experts from other DOTs and universities on these Committees would advise office directors about how to better select projects, evaluate results, and pursue implementation. The respective office directors would assemble these committees based on expertise and fit, cognizant of potential conflicts of interest with external organizations.

Figure 10. Independent research conducted by Offices[8]

Office	Research Activities
Office of Maintenance The Office of Maintenance provides expertise, leadership, direction and statewide coordination services to the eight MnDOT districts/regions for the maintenance and preservation of Minnesota state highways.	The **Maintenance Operation Research (MOR)** program encourages and funds applied research to assist in developing innovations. It promotes operational or "hands on" research, encourages the development of ideas and methods that improve transportation, and furthers implementation. The Program strives to maintain an active and visible applied research effort that involves all MnDOT maintenance areas, including snow and ice control technology/winter maintenance (Road Weather Technology), road and bridge maintenance, roadside maintenance, work zone safety and traffic control, advanced technologies and technology transfer. The goal is to identify, develop and implement the most effective maintenance procedures, materials and equipment throughout the state. MOR is funded primarily through state funding from the trunk highway fund. The Office of Maintenance has previously received a few project-specific federal grants, unrelated to the MOR research program. The six-year annual funding average for the MOR program is about is $330,000. Some notable examples of MOR projects are: - The Portable Emulsion Storage Tank was a NTREC funded project costing $86,000. The portable roll-off storage tank is self-contained and insulated which allows for year-round material transfer. - The Blending Station was a NTREC funded project costing $140,000. The Blending Station is a trailer mounted, self-contained mobile unit that blends liquid and granular deicing materials for uniform coat and consistency. - The RoadQuake Rumble Strips was a MOR funded project costing $3,600. The project aimed to reduce near misses and personal injury by both MnDOT and private contractors in a work zone. - Road Guard Plus 8 was a MOR funded project costing $5,000. Road Guard Plus 8 is a corrosion-inhibited liquid form of calcium chloride and magnesium chloride brine developed for anti-icing and pre-wetting at extremely low temperatures down to -45 C.
Office of Traffic, Safety and Technology	The MnDOT Office of Traffic, Safety and Technology (OTST) contracts with numerous public, private and academic partners to conduct

[8] The Bridge Office is different from MnDOT's other offices in that the Bridge Office does not conduct independent research. It leverages national projects through programs such NCHRP, or utilizes Pooled Fund studies or funding from TRIG in key areas of interest to the region or state.

The Office of Traffic, Safety and Technology establishes guidelines and procedures - striving for uniformity in traffic engineering - throughout the state of Minnesota, and builds relationships between state, county and city engineering staff to resolve questions about engineering and roadway safety.	Intelligent Transportation Systems (ITS) research, operational tests and deployment projects. MnDOT's ITS Program uses three different funding sources to fund three types of projects. The funding sources primarily used are 1) OTST ITS funds consisting of $1.3 million/year from MN trunk highway funds; 2) $1.5 million/year from the FHWA Surface Transportation Program (STP); and 3) US Department of Transportation (USDOT) grants. The ITS projects are of three types: 1) Development projects that are conducted primarily by consultants and are focused in moving previously developed products into field operations testing (average annual spending is about $1.9 million); 2) Deployment projects that are conducted by consultants and contractors, and are focused on deploying tested technologies and systems for mainstream MnDOT operations. Average annual spending is opportunity based and dependent on successful grant application funding. Grants have ranged up to $1.5 million in some years. 3) Capital Improvement Projects where contractors are used to build proven ITS infrastructure statewide. These projects are funded by the $1.5 million per year from the FHWA STP.
Office of Materials and Road Research The Office of Materials and Road Research provides timely specialized expertise, testing, leadership, guidance and direction in geotechnical, materials, pavement and research engineering to improve performance and cost effectiveness. We also provide tools to practice the most efficient pavement designs, maintenance and construction procedures, and provide technical training to our transportation partners.	The goal of the research program of this Office is to improve pavement and road performance and optimize the use of funding for road and pavement investments. This Office leads the National Road Research Alliance, a pooled fund project developed to provide guidance for Phase 3 of the MnROAD research program. MnROAD is a state-of-the-art outdoor pavement research facility consisting of over 50 instrumented test cells comprising various combinations of road building materials and designs, which has been in operation since 1994. MnDOT has invested $2.5 million to aid in the development of new test sections at MnROAD in Phase 3. Led by an Executive Committee of state DOT members, NRRA plans and oversees the entire lifecycle of MnROAD research, from the selection of research topics to communication and implementation of results. NRRA consists of five project teams: Flexible, Rigid, Geotechnical, Preventive Maintenance and Technology Transfer. MnROAD has also partnered with the National Center for Asphalt Technologies (NCAT) Partnership to advance pavement engineering focusing on two important national issues that impact each agency. Two research efforts were started in the fall of 2015 which include:

	- Development of a National Pavement Preservation research effort to determine the life extending benefit curves of a number of different pavement preservation techniques constructed in both Alabama and Minnesota.
	- Development and implementation of asphalt performance tests to predict cracking for common distress found in North America. Both MnROAD and NCAT will develop test sections to support this effort in 2015 and 2016.
	The total budget of this program is about $2.5 million annually, of which about $570,000 is sponsored research by LRRB. The NCAT and NRRA vary from $200,000 to $600,000 per year. The rest of the budget comes from MnDOT operating funds.

Research Services

Research Services (RS) administers MnDOT's current strategic research, i.e. the centrally governed share of the portfolio funded through FHWA State Planning and Research (Part II) and State Research Program (trunk highway) funds. RS includes teams dedicated to research management, finance, contract administration and marketing, who together manage and support:

- IdeaScale – the idea sourcing platform
- the Transportation Research & Innovation Group – a decision-making and funds allocation body
- Automated Research Tracking System database, and
- Strategic marketing efforts for the research program

Idea Sourcing

Idea sourcing is a hallmark of MnDOT's research program, making it responsive to grassroots and frontline employee needs. Anyone can submit research ideas through IdeaScale. The approach to generating research ideas offers strength to the program. Ideas are submitted by MnDOT staff, county and District engineers, CTS-affiliated researchers, researchers from other universities, and consultants. Thus IdeaScale provides a common pool and repository of research topics that are relevant for all the entities involved in Minnesota transportation research (see Figure 11). MnDOT should continue to encourage and support the cultural flexibility of an open idea sourcing process. However, MnDOT should also guide and advise staff on how to tailor research ideas and needs statements to match the strategic priorities that will be established going forward. Some additional guidance may have to be developed, as described in Strategic Recommendation #1, based on the outcomes of the Visioning Exercise.

Figure 11. IdeaScale landing page for MnDOT and LRRB's idea submission system
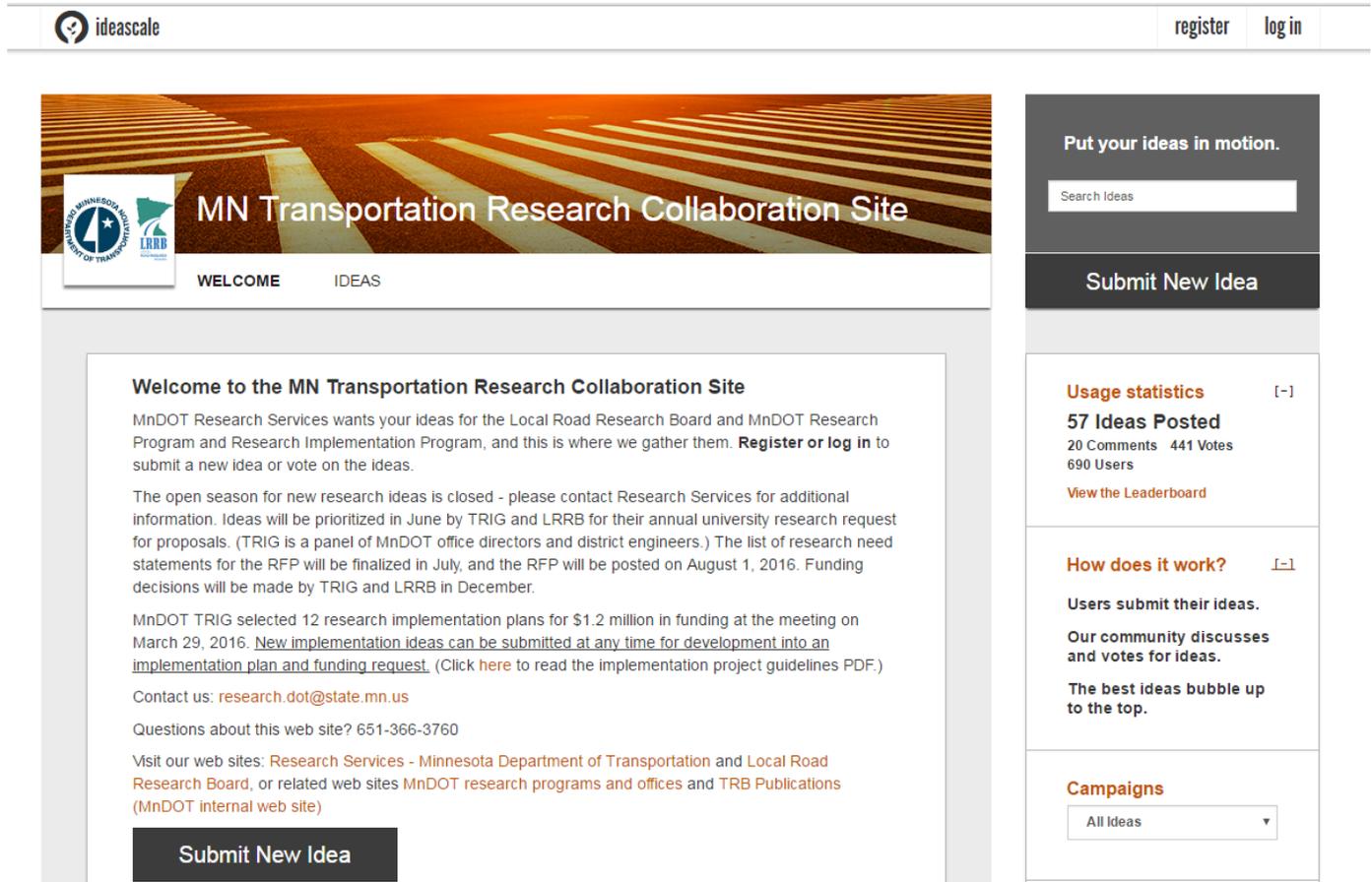
Transportation Research Innovation Group

The Transportation Research Innovation Group (TRIG) is a governance board convened by Research Services to select projects and award funds. The board is comprised of 14 voting representatives from each of MnDOT's offices and some districts. Two non-voting members and RS staff make up the rest of the board. The office representatives comprising TRIG often also oversee the internal or "grassroots" projects in their respective offices. These individual managers are responsible for the independent and discretionary research within their offices or districts. Figure 12 shows the membership of TRIG.

About 95% of the strategic research that TRIG centrally governs (and RS administers) is executed through contracts with universities and consultants. Between FY2010 – FY2016, TRIG allocated about $6.7 million per year on average in funds to strategic projects, including MnDOT's cost sharing amounts with LRRB projects. Because of the high degree of overlap in mutual interests, cost-sharing arrangements, and overlap in administration, TRIG should include a non-voting LRRB representative going forward (also see discussion below in Section 4.8 Streamlining Relationships).

Figure 12. Transportation Research Innovation Group members – voting and non-voting

Voting Members		Non-Voting Members
Directors of Offices	**District Engineer from**	**Representatives of**
Environmental Stewardship	District 3	Federal Highway Administration
Materials & Road Research	District 6	Technology Investment Management
Bridges & Structures	District 7	
Transportation System Management (3 members)	Metro District	
Maintenance		
Traffic, Safety & Technology		
Transit		
Project Management & Technical Support		

Source: MnDOT Research Services At-A-Glance 2015

Automated Research Tracking System

Over the years, MnDOT's Research Services has developed the Automated Research Tracking System (ARTS), a database for managing the administration of research, tracking proposals and project progress, and project outcomes. Figure 13 shows a dashboard view of this database.

Figure 13. A view of the ARTS dashboard for research project management, administration and tracking

Source: MnDOT Research Services, accessed December 2016

The goals and capabilities of the current generation of ARTS are to:

- Enable life-cycle tracking of research projects to understand project performance and support decision-making
- Enable project managers to enter in project information by establishing remote and online access to ARTS regardless of the physical location of the individual
- Allow the Research Services group to become more efficient at managing research contracts, developing strategic communications, and supporting research project managers

The ARTS system can therefore enable to improve life-cycle project tracking for research, and eventually the implementation of research.

4.7 Strategic Recommendation #5: Life-cycle Project Tracking

MnDOT should track research projects throughout their life-cycle, and until at least five years after project results have been implemented

MnDOT should track both strategic research (centrally governed subset administered by RS) and the independent research projects conducted by the offices and districts. To avoid additional overhead and staffing, Research Services could rely on offices to administer, manage, and report on their internal and independent discretionary projects, and enter this information into ARTS. All research managers at MnDOT should therefore consistently use ARTS for life-cycle project tracking. ARTS may need upgrades to fully deliver tracking and reporting functions, and enabling access to a larger number of users. Research Services could be the go-to clearinghouse for a comprehensive view of MnDOT's research portfolio, and MnDOT leaders may also be able to obtain comprehensive reports on MnDOT's research portfolio.

Strategic Marketing and Communication

MnDOT's Research Services helps communicate the value of MnDOT's entire research portfolio, and educates many audiences about what MnDOT is learning through research. Communications staff play an important role as they work with technical experts to translate technical information into broadly accessible narratives for policy as well as users of the transportation system. Translating how MnDOT's applied research creates benefits into simple, accessible narratives is important for enabling:

- MnDOT staff across the organization with different types of expertise to better understand research findings and help implement them.
- MnDOT leadership to clearly and quickly understand where and how to invest.
- MnDOT's external customers, i.e. transportation system users and partners, to understand how MnDOT's research makes health, the environment and the economy better.

To promote research and its benefits, MnDOT is actively on social media, maintains a research blog ("Crossroads"), and also relies on email and traditional newsletters ("Accelerator") to ensure broad accessibility to all of its stakeholders.

To even further improve knowledge of research and its application, MnDOT should develop a content management system – a central repository and electronic database of information - for its entire research portfolio. This system could link ARTS with other library or document management systems so that both MnDOT

staff and those accessing MnDOT websites could quickly find relevant research and its results. MnDOT should also continuously update and improve its websites to better share the status of projects and their results.

MnDOT's research communications team should support the Technical Advisory Panel and Principal Investigator of funded projects right from the start to ensure that the different benefits of a project are clearly identified and communicated. The research communications team could lead a number of initiatives and efforts such as producing video vignettes on breakthrough projects, presenting to MnDOT staff who would benefit from a big picture view of MnDOT's research enterprise, recording webinars for later viewing, and publicizing slideshows of presentations by MnDOT staff at meetings and conferences nationwide. MnDOT could do more to improve its IT infrastructure and telecommunications capabilities so that the agency can better communicate about research, educate others about its benefits, and advocate for continued investment in research.

In all of these roles, RS communications staff cannot replace technical research experts, rather they would work alongside technical staff throughout the research lifecycle to maximize the communications value of research.

4.8 Streamlining Relationships

MnDOT's Relationship with LRRB

LRRB sponsors research, but does not execute it, as the body is a governance board and not an agency with its own assets and resources. All of LRRB's research is executed through contracts administered by MnDOT Research Services office. In 2015, LRRB spent about $4.4 million of statutorily allocated research funds, which are initially apportioned to MnDOT and then set aside for LRRB as shown earlier in Figure 7. MnDOT has three out of ten voting member positions on LRRB. MnDOT's Research Services centralizes and also administers this program in parallel with the centralized portion of MnDOT's own portfolio.

LRRB research projects are submitted to and selected from the same pool of projects (through IdeaScale) used by MnDOT's TRIG program. Some project ideas submitted through the IdeaScale program are of higher importance to LRRB than to MnDOT. LRRB therefore prioritizes and funds these projects, whereas MnDOT funds projects matching its own priorities. Projects of shared importance are selected and funded by both TRIG (MnDOT) and LRRB through a cost sharing approach. As recommended above, MnDOT should maintain more ongoing communication and transparency (ex. project selection, cost sharing decision-making process, follow up on implementation) with LRRB because of the overlap in strategic interests, by at minimum including a LRRB representative on TRIG.

MnDOT's Relationship with the Center for Transportation Studies at the University of Minnesota

Principal Investigators and laboratories affiliated with the University of Minnesota and its Center for Transportation Studies conduct research for both MnDOT (both TRIG and office projects) and LRRB. The University Master Agreement with UMN is a procurement vehicle that allows university Principal Investigators to respond to project needs statements. About 35% of CTS's $17.5 million in revenues in 2015 came from State of Minnesota contracts, in addition to its statutorily allocated operating funds. MnDOT and LRRB are among CTS's largest research clients.

There are many formal and informal relationships between MnDOT and UMN, and governance overlaps with UMN CTS in particular. MnDOT leadership sits on CTS's Executive Committee as well as its Partnership Leadership and Management Groups. There are no CTS representatives on TRIG, yet CTS influences MnDOT's

research priorities and practices through separate topic- and function-based groups authorized under MnDOT's Partnership Agreement. A number of CTS affiliated professors and PI's also have long-standing collaborative relationships with MnDOT staff. As a result, CTS understands MnDOT's strategic priorities. CTS also has a significant private sector and University outreach component that in turn provides external advisory support to MNDOT and LRRB.

MnDOT has recently expanded its University Master Agreement (UMA) framework to include nine eligible universities who provide research expertise and can respond to research need statements. Given this context, MnDOT could streamline its broader partnership and working group arrangements with UMN and UMN CTS, so that the Department can continue to leverage available expertise and resources within the state of Minnesota, while balancing any real or perceived conflicts of interest.

5. How Should MnDOT Assess Research Program Outcomes?

By looking broadly and comprehensively at the impact of our research and implementation

MnDOT conducts research because of the value that research creates for the transportation system. A research program is an investment and must show value returns over time to justify the continued investment.

Even though the process of monetizing the benefits of research is essential, it is only a partial view of the value of a research program. MnDOT, like many other agencies, tends to focus more on the quantifiable aspects of the value of research, so that it can make an investment case for its program. Yet, some types of research results and benefits are not monetizable. In cases where it is possible to monetize results, MnDOT and other agencies commonly use the terms benefit-cost (BC) ratio, and return on investment (ROI) to indicate monetized value. In reality, research programs create value in many different ways beyond ROI, and should therefore be evaluated accordingly.

There is no single formula for estimating the value of research; the best practice that has emerged is to report program benefits holistically over time -- monetize and quantify outcomes where possible, and otherwise document them rigorously. In addition to ROI, a measure that translates savings in cost, time and other output based metrics, MnDOT should report knowledge-based outcomes at the program level to provide a feedback loop to MnDOT leaders and the Research Advisory Group. This type of report is a narrative description of the program as a whole that answers the following questions: what have we learned through research? What do we now know that we did not know some years ago? How has this improved our business? How has this changed our investments? Given an additional $1 million, what could we demonstrate / learn?

To further emphasize implementation and better track results, MnDOT should rely on the internal research management database ARTS – Automated Research Tracking System. ARTS now provides research managers the ability to enter data on both potential benefits (early in the project cycle), and the outcomes of research for refining estimates (during the project and near its completion). The same system can also track the implementation of research results, and collect data for calculating a project's realized benefits. Current and future MnDOT research and implementation projects will benefit from the new features in ARTS. The tracking of implementation and benefits of the research should be the responsibility of the area conducting and/or sponsoring the research.

Benefit quantification should be an integral part of the entire research process. At the project level, this implies estimating potential benefits during the project proposal process, refining the estimates of available benefits based on research results, and calculating benefits actually captured once research results have been implemented. To this end, MnDOT completed the design of a systematic process for quantifying the benefits of research in December 2015. It consists of the seven steps shown in Figure 14, and involves the use of a spreadsheet-based estimation tool. The tool was piloted with a number of completed MnDOT research projects to refine the template and demonstrate its use. The spreadsheet tool makes all the inputs and assumptions transparent; they are known to all who use it. It also standardizes the formulas and relationships across the templates, which can easily be updated when necessary, so that the entire organization has a consistent approach to benefit quantification. MnDOT should systematically apply the process and tool to new proposals and on-going projects, and should retroactively assess the results of some past research projects.

Figure 14. MnDOT's seven step process for estimating the potential benefits of a research project
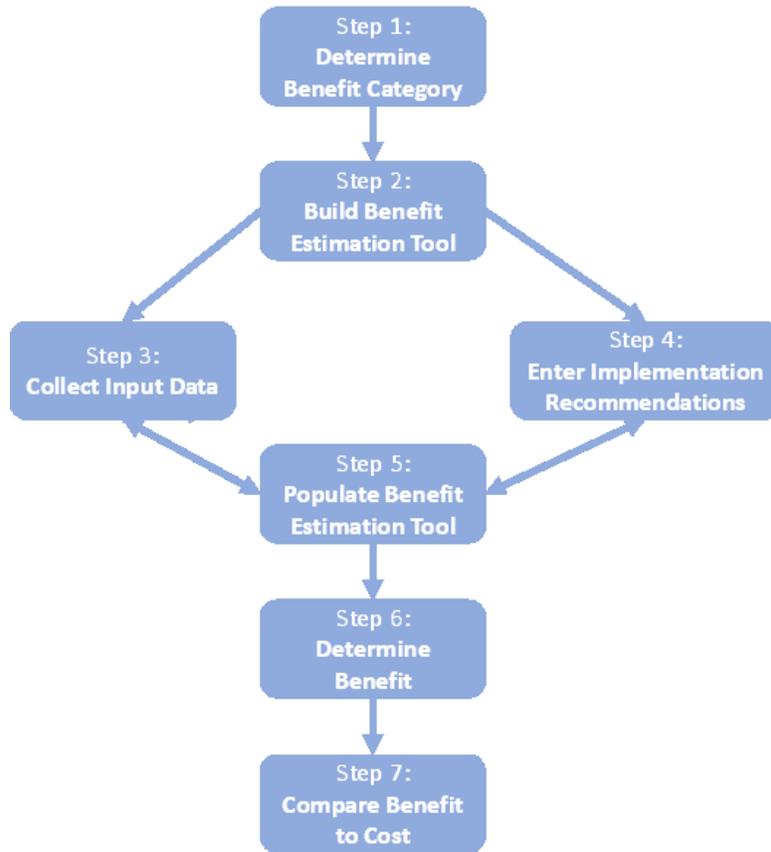
Source: Adapted from *User Guide: Process for Quantifying the Benefits of Research*, MnDOT 2015

To advance this framework, MnDOT should provide instructions to research managers and project principal investigators on how to populate and use the spreadsheet tool. MnDOT leadership and the Research Champion should also provide conceptual guidance and educational resources for staff on the following topics: the sources of value from research outcomes, why MnDOT has chosen the particular set of benefit categories, the degree of flexibility that a researcher may have in modifying the spreadsheet, and the timing of submission and the frequency with which the tool must be updated in every project. These materials should be included in the orientation guide for TRIG members and in the Requests for Proposals (RFPs), or at least easily accessible.

MnDOT should reports realized benefits, i.e. value captured through implementation, separately from potential benefits. It usually takes a few years to implement research results, and the resulting benefits can therefore only be reported three to five years after a project has been completed, allowing enough time for implementation. For example, the Office of Materials and Road Research has published estimates of costs and benefits of both Phase I (1994 – 2006) and Phase II (2007 – 2017) of the MnROAD research program. The estimated annual benefit (pre-implementation) of six selected projects from MnROAD Phase 1 was $33 million annually. In other words, these are the estimated materials and construction cost savings that are quantifiable and available if the results of these six research projects were to be implemented across the Minnesota roadway system. A similar benefits estimate for Phase II of the MnROAD program is between $10 and $18 million per year. However, MnDOT will not realize the true value and impact of these research until results are implemented and deployed across the system.

MnDOT must cultivate a cultural mindset that investigators and research managers should assess benefits throughout the research and implementation lifecycle of a project. This will help MnDOT to better link benefits assessment in the research stage to the implementation stage, so that this process can inform implementation decisions, and then also the assessment of realized benefits once projects are completed.

5.1 Strategic Recommendation #6: Portfolio Approach

MnDOT should identify the value and impact of its research at a program-level

MnDOT should think of its research program as a portfolio of investments. The objective of a portfolio is to create the most value, by balancing the risks and outcomes of its component assets (research projects in this case). To report value at the program (i.e. portfolio) level, MnDOT must first assess individual projects. The Inset Box shows the best practices that MnDOT could use for reporting program level benefits.

MnDOT should report all benefits at least at the topic-level, and if possible, at the program-level because not all topics and projects result in easily quantifiable outcomes. Many research projects have a high chance of not meeting initial expectations, but they can still be valuable in terms of lessons learned, even those that may be labelled "failures". For example, many research projects indirectly and eventually lead to improvements in quality from streamlined processes, avoiding mistakes and validating current standards and practices, and demonstrating new tools, procedures, and techniques. Evaluating and tracking non-monetizable and intangible benefits for projects can help MnDOT identify and report the lessons it has learned across projects with a range of outcomes. MnDOT could develop a systematic reporting method for both non-monetizable but quantifiable benefits, and other intangible benefits. The additional steps encourage ideas that are less suitable to monetization, and help ensure that the program invests in projects beyond "sure wins".

Recommended best practices for reporting topic- and program-level benefits of MnDOT's research portfolio

Frequency: Conduct assessments and report value estimates and outcomes annually, within 90 days of the end of a fiscal year.

Benefit Types: Clearly separate realized monetary benefits from available/potential monetary benefits, and also report qualitative or intangible benefits by topic area.

Horizon: Use a rolling average approach, lagged for realized benefits through implementation, and prospective for the available benefits based on research results.

Time Value: A dollar in the future is much less than a dollar today. Standardize the adjustment of dollar amounts to account for time value of money and inflation. The formulas and discount rates assumptions can be documented in the spreadsheet templates and reports.

Cost Treatment: Report program expenditures (costs) and monetized benefits separately and in ratios in each fiscal year. Also, separate and report both state funds (trunk highway funds), federal / SP&R-II funds, and other grants as applicable.

Assumptions: Transparently document the standard assumptions such as labor hour rates, statistical value of life estimates, discount rates, etc. in technical appendices or methodological annexes. Indicate the rationale for these assumptions, or point to the sources and bodies that have developed the relevant best practices.

Reporting: Address the reports to the Commissioner, other executive leaders, office directors and high-level managers, and members of the external advisory committee. Make the reports prominent and succinctly written in plain English to be publicly accessible. The Assistant Commissioner championing the research program and the Director of Research should be the signatories of the covering letter summarizing the value and results of research.

Case Studies: Include or provide links to case studies and media articles on selected research projects with clearly documented monetary and qualitative benefits to reinforce the message of value creation.

Communication strategy: Rely on MnDOT's previous findings and initiatives and national best practices for the media, presentation, and content of these reports.

6. Relationship with National Priorities and Programs

MnDOT participates in and influences national transportation research priorities and investments through a variety of programs. MnDOT participates most directly through Transportation Pooled Fund (TPF) studies and projects[9], which must be sponsored either by state DOTs or by the Federal Highway Administration (FHWA).

6.1 Transportation Pooled Fund projects

MnDOT both leads Pooled Fund projects and also contributes to PF projects led by other states and FHWA. Figure 15 summarizes MnDOT's contributions to TPF projects. The left half of the figure shows MnDOT's contributions to MnDOT-led Pooled Fund projects, whereas the right half shows its contributions to such projects led by others.

Figure 15. Summary of MnDOT's contributions to Transportation Pooled Funds (FY2010 – FY2016). Percentages show MnDOT's share of annual totals.
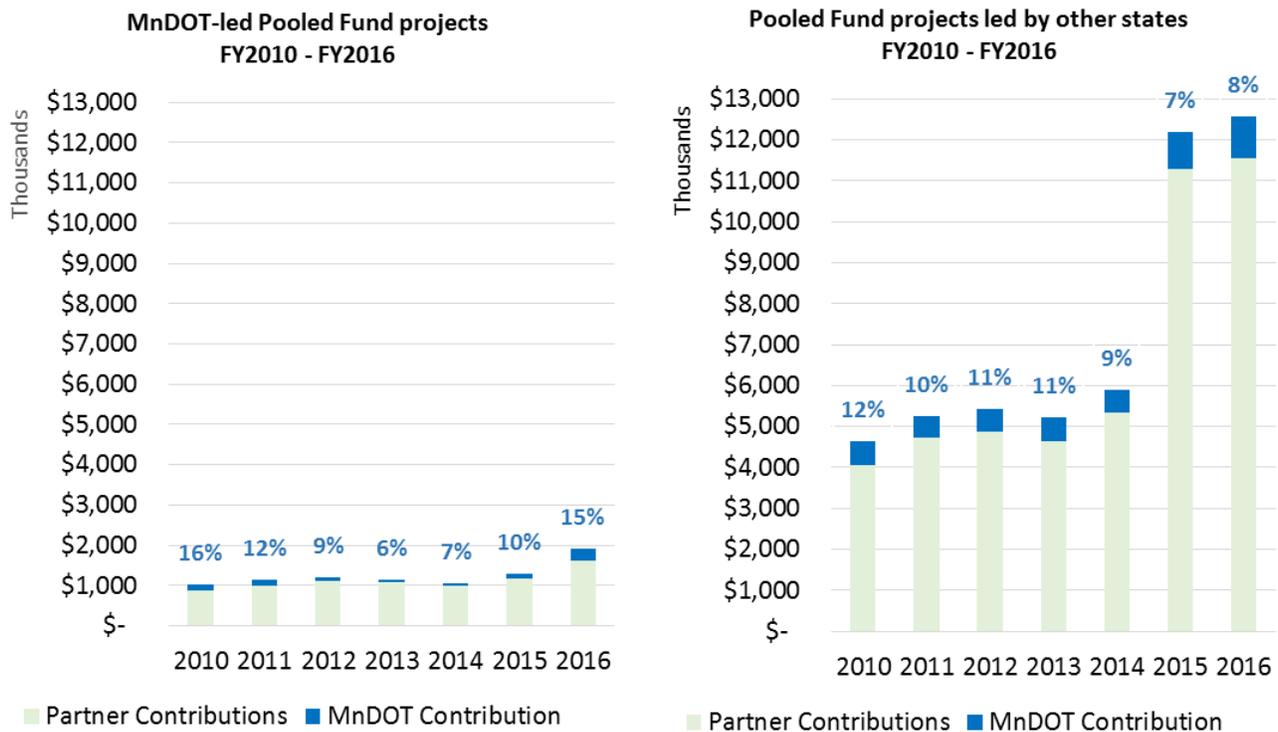
Source: CPCS analysis materials provided by MnDOT Research Services

MnDOT has led fifteen Pooled Fund projects over the duration FY2010 – FY2016. In FY2010, MnDOT contributed about $164,000 (16% of annual total) of little over $1 million in funds as part of projects that it led, and thus leveraged another $860,000 in contributions from others. Thereafter, MnDOT's absolute contributions decreased year over year until FY2015, even though the overall portfolio of MnDOT-led Pooled Fund projects remained about $1 million annually. In FY2016 however, MnDOT's contributions to MnDOT-led projects grew to

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[9] http://www.pooledfund.org/Home/About

$285,000 (15%) and leveraged another $1.6 million from partners. On average, MnDOT invested a little less than $140,000 per year (11%), and consistently leveraged about $1.1 million per year across the fifteen projects it led between FY2010 – FY2016.

MnDOT has participated in 57 Pooled Fund projects led by others between FY2010 – FY2016. Until FY2014, MnDOT's contributions were about $600,000 annually (9 – 12% of annual total), but grew to $885,000 (7%) and $1,030,000 (8%) in FY2015 and FY 2016 respectively (see Figure 15). By contributing between $600,000 and $1,000,000 every year to PF projects led by others, MnDOT has leveraged almost $50 million worth of research and research project management investments between FY2010 – FY 2016.

The choice of leading a Pooled Fund project involves the trade-off between relevance of the research for MnDOT's own system, and the project management and overhead implications. Leading a Pooled Fund project requires MnDOT to manage all of the project's supporting activities (support contracts and/or partnership agreements, research projects, travel, purchase orders, etc.). A PF project typically involves 10 to 12 partners. MnDOT leads "Clear Roads" one of the largest pool fund projects. The Clear Roads project has grown from three states at inception to 32 states now involved.

There is value to MnDOT in leading and managing projects such as Clear Roads that are relevant for and can directly benefit MnDOT's transportation system. However, MnDOT is and should continue to be selective about which PF projects it leads because of the overhead involved, as it can also leverage research through projects led by others.

6.2 Other Collaborative Activities

Transportation Research Board

MnDOT has 70 staff involved in 118 TRB activities (NCHRP panels, standing committees etc.) as either members or chairs. MnDOT staff help develop and support NCHRP problems statements. Additionally, MnDOT representatives attend TRB's Annual Meeting and other conferences. TRB participation helps MnDOT not only keep a finger on the pulse of research priorities nationwide, but also influence these priorities through helping develop problem statements, presenting research, and engaging in other knowledge-building activities. MnDOT could do more to disseminate the knowledge its representatives gather from these activities, within the agency and for local transportation practitioners.

Other Programs

MnDOT also participates in a number of other collaborative research activities as a sponsoring or contributing member. These include AASHTO programs, and USDOT and FHWA activities. MnDOT is not as actively engaged as an executor or manager of research or program activities as it is in Pooled Fund and TRB activities. However, it does participate in agenda-setting conversations and can access and consume the research and policy findings of these groups.

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Appendix A: Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis Summary

A SWOT analysis of MnDOT's research program was conducted using the information gathered during the process of developing Working Papers 1, 2 and 3 (see Appendix C). We summarize the main findings of the SWOT analysis using a typical SWOT matrix, as below:

	Positive	Negative
Internal Factors	**Strengths** • **Specialty Expertise** – depth of research expertise cultivated over time with significant investment in knowledge and human capital, ex. areas of bridges, materials, safety, operations, and maintenance • **"Grassroots" Participation** – idea nominations by frontline staff • **Robust Administrative Processes** – Research Services has refined research project administration processes over time, ex. TRIG operating structure and logistics • **Marketing** – clear messages at the project level for projects with demonstrated results • **National Collaboration** – through Pooled Funds, TRB / NCHRP, and other cross-agency projects	**Weaknesses** • **Lack of Strategic Direction** – many competing potential research directions, topics with different attributes and lifecycles, with unclear links to organizational vision and strategy • **Incomplete Coordination** – both centralized (Research Services) and discretionary (specialty offices) administration of research • **No clear Research Champion** – no organizational leader overseeing and accountable for the research portfolio • **Limited Value Capture** – insufficient implementation of results • **Incomplete Performance Assessment** – no reporting of value obtained from research at the portfolio level, either qualitative or quantitative
External Conditions	**Opportunities** • **New Technologies** – research on rapidly evolving transportation-related technologies to help improve safety, efficiency, performance • **Human Capital** – harness new and emerging skill sets in engineering, data science, web and IT technologies, stakeholder engagement through media, project management processes • **Partners** – enhance coordination with Local Road Research Board, and leverage academic (researchers, university centers), industry (specialist vendors, service providers, investors) and other stakeholders	**Threats** • **Changing Nature of Transportation in Minnesota** – aging infrastructure, urbanization trends, behavior of transportation system users, changing climate, and environmental impact are changing the needs and expectations for what the transportation system should deliver • **Risk of Diminished Resources** – lack of policy focus and public investment in research facilities, initiatives, and professionals will decrease capacity to continue leading and sponsoring applied transportation research • **Human Capital** – attrition and retirements due to broader industry and demographic trends will exacerbate the need for maintaining expertise and resources

Appendix B: Background Working Papers

Working Paper 1 - Institutional Context

Transportation agencies rely on research activities to inform daily and long-term decision making. For the Minnesota Department of Transportation (MnDOT), research helps direct the deployment of scarce resources to more effectively maintain, preserve, and operate the transportation system. As demands on the system evolve, MnDOT must adapt the role and type of research activities it conducts to those changes to provide a high performing, safe, reliable, and sustainable system [1]. Technical research that is both high-value and implementable can be an integral part of this adaptation. Further, policies set the course for how the system will adapt to the future. Policy-focused research can be valuable to MnDOT to inform effective decision-making and facilitate cohesive communication [2]. Harnessing new knowledge and emerging technologies may require changes in how MnDOT governs itself and undertakes research [3]. With an eye trained on an uncertain horizon, MnDOT is therefore reviewing and refining its approach to transportation research.

PROJECT VISION AND OBJECTIVE

The purpose of this project is to assist MnDOT in developing a 5-Year Strategic Research Plan to guide its investments in and management of its research activities.

The Plan will: 1) describe the primary purpose for MnDOT research, 2) establish research focus areas aligned with and supportive of MnDOT's Strategic Goals, 3) summarize desired research goals, 4) describe research priority areas for achieving the desired outcomes, and 5) list performance or efficiency measures to determine the impact of research. The Plan will be based on input from a broad range of research stakeholders.

The CPCS Team is charged with developing MnDOT's Strategic Research Plan. The Plan will articulate MnDOT's desired research goals in a manner consistent with its broader strategic goals, and also recommend how to assess the impact and outcomes of the chosen research priorities. MnDOT's research stakeholders will help shape its Strategic Research Plan.

THIS DOCUMENT

An effective Strategic Research Plan must recognize MnDOT's research legacy and institutions while establishing systematic forward-looking objectives. Stakeholders of MnDOT's research program provide critical input to examine both the Department's research legacy and its most important future objectives.

In the first phase of this project, we listened to many MnDOT leaders who plan, execute, implement, and extract value from research. Agency research partners and external stakeholders provided additional information on the current institutional context and needs of MnDOT's research program. This working paper distills and synthesizes over 100 person-hours of research and engagement with MnDOT stakeholders between December 2015 and February 2016. We used both interviews and published literature and reports to address the following key questions:

- What are the roles and responsibilities of MnDOT and its offices in developing and deploying research?

- Does MnDOT conduct basic or applied research?

- What are the connections between MnDOT's internal and external research stakeholders, including public and private organizations?

- How do the key products and services of MnDOT's current research activities fit within the agency's strategic objectives?

- What strengths can MnDOT enhance and what constructive opportunities can the organization seize to improve research outcomes and value?

This working paper is structured to answer these key questions and to identify gaps in existing knowledge that we will address in subsequent phases of the project.

MnDOT's RESEARCH ROLE AND RESPONSIBILITIES

MnDOT conducts a wide range of research across all disciplines and in coordination with university researchers and local engineers. While some research activities are centrally coordinated and funded, such as those governed and administered by Research Services & Library (e.g. Transportation Research and Innovation Group (TRIG) and

Local Road Research Board (LRRB) projects), individual departmental offices oversee other research, implementation, and communication functions. Thus, there is a centralized and coordinated research program within MnDOT and also self-directed "grassroots" activities governed by the needs of individual offices and districts.

Research is both centralized and "grassroots" in how it is proposed, prioritized, funded, and coordinated.

The TRIG, the governing board for MnDOT's State Research Program (SRP), for example, follows an annual cycle for its "idea to project" process, as shown in Figure 3. We refer to this as the TRIG process. Research ideas are accepted throughout the year through the IdeaScale platform, a collaboration service for collecting and processing research and implementation project proposals. Both MnDOT's internal SRP research and research conducted by the Local Road Research Board (LRRB) are processed through this service. All submitted ideas are collated and reviewed in May. Needs statements and project-specific RFPs are developed and released over the months of June and July. Proposals can be submitted between July and October. University programs and research centers are eligible to submit proposals, so the TRIG program is considered an open program, relative to some other state DOTs. All submitted proposals are reviewed over October and November and project funding awards are announced in December. Project awards are publicized through several venues including the Accelerator newsletter and the Crossroads research blog service. Implementation project proposals are accepted until

February and selected projects are awarded in May, which marks the start of the subsequent annual cycle.

MnDOT's Research Services & Library has established key roles for shepherding a research project through the TRIG process and the project's lifecycle [4]:

Technical Advisory Panel (TAP) - The Panel guides the research, and reviews and approves all deliverables. Four to six MnDOT staff members serve on each TAP. Other stakeholders may attend TAP meetings to stay informed of project progress, although they cannot influence project scope or task approvals.

Technical Liaison (TL) - The TL is a representative of the sponsoring agency, i.e. MnDOT or LRRB. The TL helps craft the need statement, RFP and project contract. This individual also helps the project's Principal Investigator create deliverables; and subsequently approves the deliverables, work plan and amendment requests.

Project Advisor (PA) - The PA is a senior Research Services & Library representative who facilitates project start up and provides a link between the TAP and other related efforts occurring within the LRRB, MnDOT and national programs. The PA may or may not be a TAP member.

Project Coordinator (PC) - The PC is the Research Services & Library team member who ensures that contract provisions are followed and that deliverables are submitted and approved on schedule and within budget. The PC works with the TL to help manage projects throughout their life

Figure 1. MnDOT's annual research Request for Proposals (RFP) process

YEAR-ROUND	MAY	JUN	JUL	AUG-SEP	OCT-NOV	DEC
1 Ideas generated — Submit your research project ideas using IdeaScale.	**2** Ideas collected — Ideas are collated and reviewed.	**3** Need statements developed — Ideas are shortlisted and developed into need statements.	**4** RFP released — Need statements are posted online.	**5** Research proposals collected	**6** Research proposals reviewed — Proposals are reviewed and shortlisted for presentation.	**7** Funding awards announced

Source: MnDOT Research At-A-Glance (2014)

cycles. The PC also coordinates the activities of project TAPs. Each PC reports to a particular PA, and PCs are

Principal Investigator (PI) - The PI is the contractor/researcher responsible for developing the project

Figure 2. MnDOT Offices and Functional groups that conduct or manage research
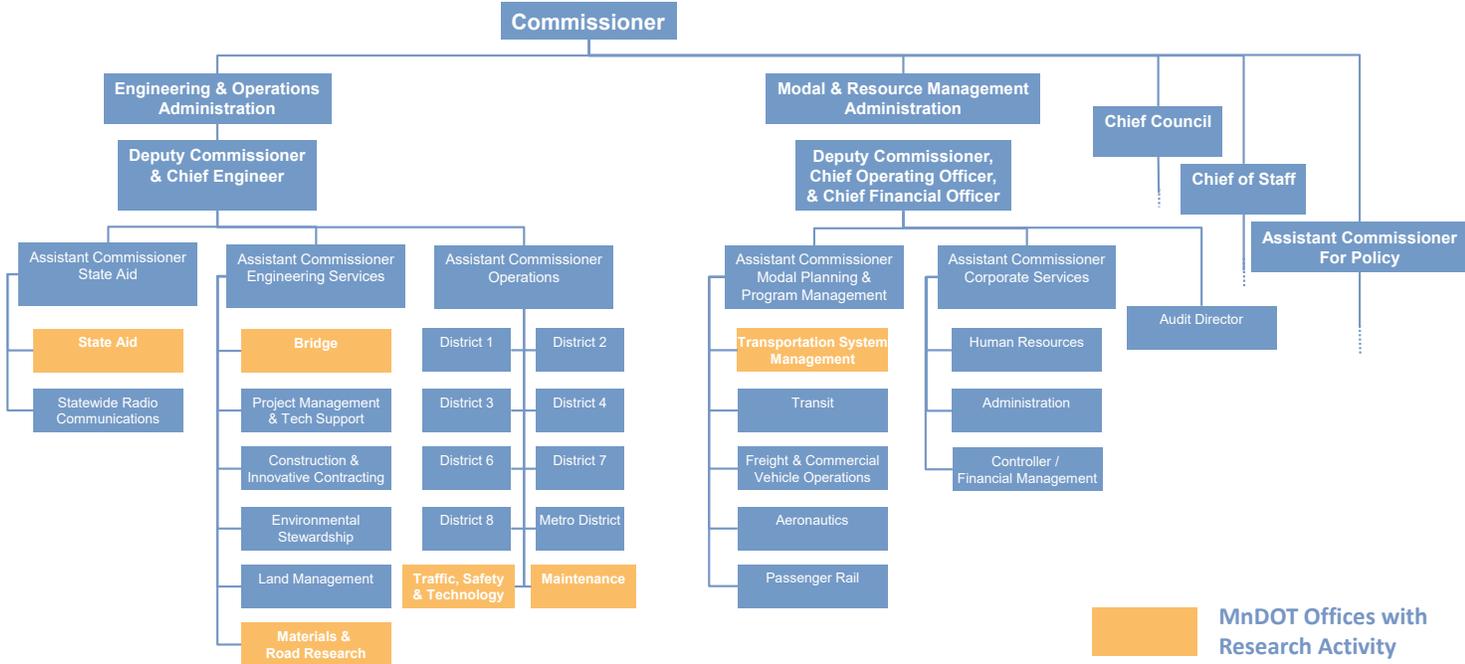
Source: CPCS analysis of MnDOT organization chart and interviews

Figure 3. Research Attributes of Select MnDOT Offices

Organization Name	Affiliation (MnDOT, University, private, etc.)	Relationship to MnDOT	Source of Funding	Source of Research Ideas	Problem-focused or policy-oriented?	Audience
Research Services and Library	MnDOT Modal Planning and Program Management	Within Office of Transportation System Management (TSM)	SRP, FHWA, LRRB	Ideas generated by submission, RFPs coordinated through TRIG	Problem-oriented, policy and planning, some long-term projects	State and national audience
Traffic, Safety and Technology	MnDOT Operations	Internal traffic engineering and safety related research	TRIG funding; and internal research budget for ITS	TRIG process, FHWA RfPs, grassroots ideas	Problem-oriented, with long-term design and cost reduction benefits	State, city and county engineers
Maintenance and Operations Research	MnDOT Operations	Internal maintenance and operations improvement program	Departmental budget, RS TRIG funding	Grassroots, discretionary; coordinated by NTREC and RS for over $15k	Maintenance-related applied research, mostly problem-oriented	State, city and county engineers
Bridge	MnDOT Engineering Services	Internal bridge research on design, inspection, and management	TRIG funding; and departmental funding	Grassroots ideas and long-term priorities, coordinated internally	Problem- and long-term design oriented research	State, city and county engineers; national audience
MnROAD	MnDOT Materials and Road Research group in MnDOT Engineering Services	Internal pavement research and testing facility; available to others	MnDOT, LRRB and FHWA (previously); now only MnDOT and NRRA pooled fund	Internally, NRRA, and NCAT	Problem-oriented, with long-term design and cost reduction benefits	State, city and county engineers
Local Road Research Board (LRRB)	Convening body for MN and local transportation practitioners	Administered by MnDOT Research Services	LRRB funds, FHWA SP&R, MN SRP	Member counties and MnDOT	Problem-oriented, policy and planning	State, city and county engineers

Source: CPCS analysis of MnDOT organization chart and interviews

typically assigned to particular topic areas to help ensure continuity over potentially related projects.

and completing contract obligations. With TAP guidance and

input, the PI designs, develops and performs tasks to carry out contract deliverables.

MnDOT has a number of function-based offices (Figure 2) across its organization that either request, conduct or manage research. The offices are Bridge; Materials and Road Research (MnROAD); Traffic, Safety & Technology; Maintenance, and Transportation System Operations. The MnDOT State Research Program is coordinated by the Research Services and Library section within the Office of Transportation System Management. The TRIG is the governing body that plays a key coordination and decision-making role for the centralized MnDOT research process described above. Each of the functional offices may further conduct their own research on a discretionary and self-directed basis. Figure 3 summarizes the key attributes of each of these research offices. It includes the internal or external affiliation, relative location in the MnDOT organization, sources of funding, sources of research ideas, nature of research – whether problem-focused (e.g. applied) or policy-oriented (e.g. basic), and audience for its research outputs.

Figure 4. MnDOT research spending (2010–2015) indexed to FY2010.
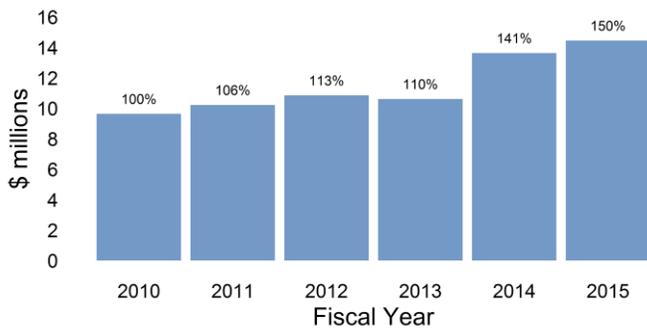
Source: CPCS analysis of MnDOT data

MnDOT dedicates significant funding to support these research activities, yet research funding comprises a small fraction of the annual budget. Since FY2011, MnDOT has invested more than $10 million in Federal and state funding in research every year. MnDOT spent $14.4 million on research in FY2015, an increase of close to 50% over its FY2010 spending (Figure 4) [4]. To put this in perspective, only one percent (~$400 million) of highway-related authorizations totaling over $40 billion in the Moving Ahead for Progress in the 21st Century Act (MAP-21) were allocated to research and education nationwide [5]. The budget

allocations for the National Cooperative Highway Research Program (NCHRP) coordinated by the Transportation Research Board have amounted to approximately $40 million over FY2012 – FY2016 [6].

MnDOT has drawn on many sources of research funds to leverage its research program over time. Between FY2010 and 2015, MnDOT accessed research funds from Minnesota's State Research Program (SRP), Local Roads Research Board (LRRB), FHWA's State Planning & Research Part-II (SP&R-II) grant program, and the Cooperative Program for Transportation Research and Studies (Figure 5). While the funding mechanisms follow pre-determined legislative requirements, MnDOT has flexibility in the selection of research partners and research topics.

Figure 5. MnDOT's sources of research funds (FY2010–FY2015)
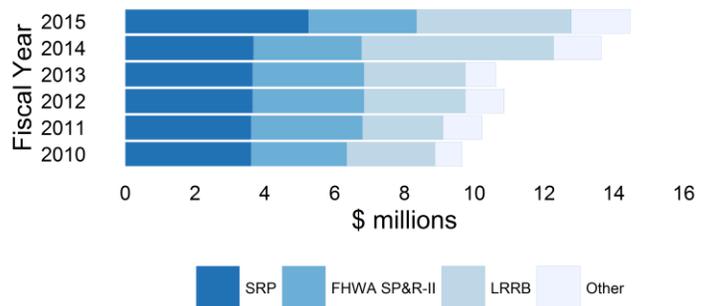
Source: CPCS analysis of MnDOT data

BASIC VERSUS APPLIED RESEARCH

MnDOT's research portfolio is primarily applied—in other words, focused on the testing and use of new technologies, studying and updating technical standards, and making available the know-how to maintain high standards of safety and reliability across the transportation system. While MnDOT primarily engages in implementable or applied research, it does conduct some basic research to improve the scientific understanding of specific issues, including for example, research on materials conducted at its MnROAD Laboratory. Such research is motivated by long-term improvements and benefits, and not constrained by immediate practical needs. The Department supplements these activities by funding basic research through universities and research centers. The overall approach of primarily focusing on applied research "in house" and

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partnering with basic research institutions such as universities is common across state DOTs and well-aligned with the respective strengths of transportation agencies and research universities.

Figure 6. Allocation of research funds to program categories (FY2010-FY2015). Bar height shows the absolute funding level in $ millions. Percentages over bars show the fraction allocated in a particular year. For example, about $2.5 million was spent on Materials & Construction in FY2010, about 29% of the budget for that fiscal year.
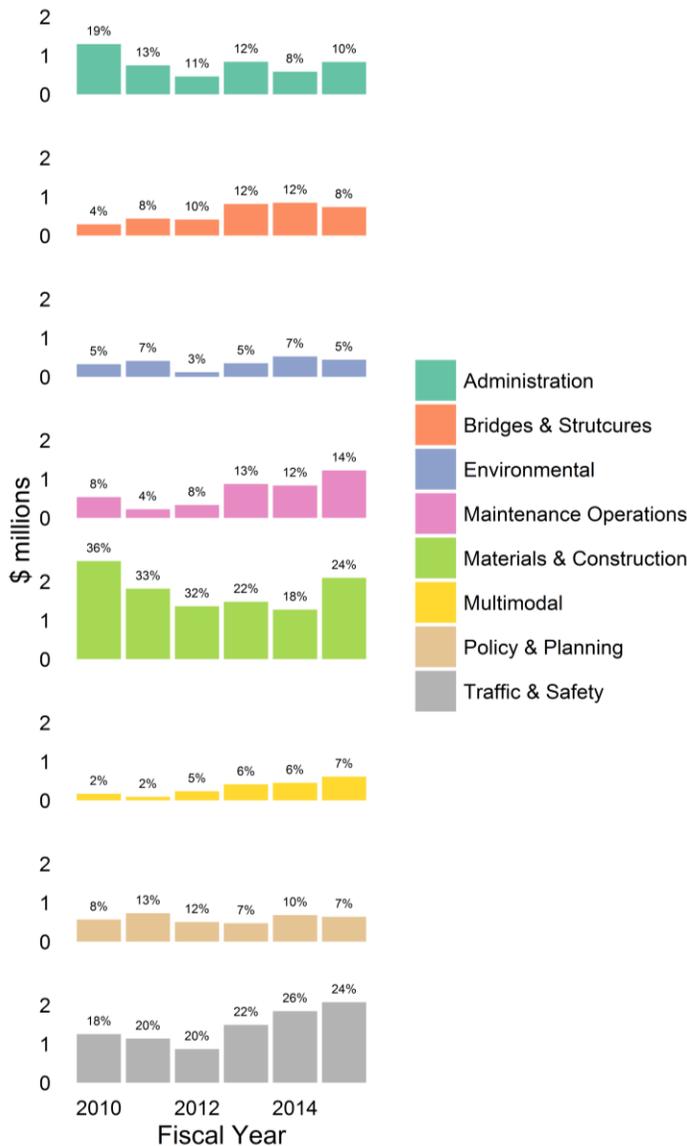
Source: CPCS analysis of MnDOT data

MnDOT's applied transportation research portfolio spans diverse topics. Figure 6 shows the eight categories (7 program areas and administration) on which MnDOT spent its State Research Program funds. Each program area contains a number of topics. The areas of Materials & Construction and Traffic & Safety cover core topics of the MnDOT research portfolio, as a share of annual research spending. Although fluctuating slightly over time, these areas each received almost a fifth of the research budget in FY2015. Administering research programs requires less than 10% of the research budget. The topic areas of Bridges & Structures, Environmental, Multimodal, and Policy & Planning consume less of the total research budget. The budget share for Maintenance & Operations has been increasing over the last five years.

STAKEHOLDER CONNECTIONS

MnDOT's research organization is one node in a network of local, state, and national research endeavors. MnDOT coordinates not only its own extensive research program, but also administers the Local Roads Research Board (LRRB) program. Key research connections include those with the University of Minnesota's Center for Transportation Studies (CTS), as well as state pooled-fund programs led either by MnDOT or by other states. MnDOT also participates in research funded by the Transportation Research Board (TRB) through staff involvement in panels and through the development of research problem statements.

MnDOT serves as a coordination partner and a conduit for state funding for other organizations, including the Center for Transportation Studies (CTS) at the University of Minnesota and the Local Technical Assistance Program (LTAP)[1]. Figure 7 shows the extent of funds transferred to these programs for their operations and research activities.

Figure 7. Statutorily allocated funds transferred to federal and local programs (FY2010–FY2015)

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[1] These organizations also receive federal and other local funding.
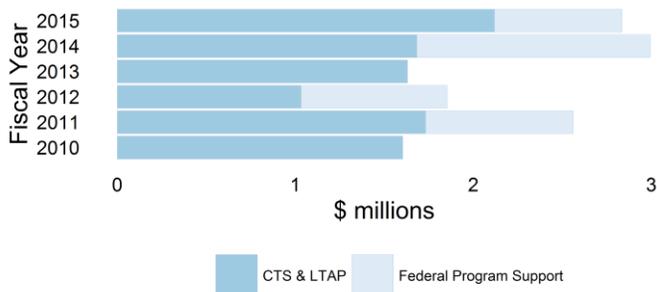
About a tenth of MnDOT's research budget supports federal research and NCHRP efforts, also shown in Figure 7[2]. MnDOT does not govern, administer or execute research through any of the CTS, LTAP or federal programs.

A significant share of research that MnDOT supports and coordinates is conducted by other organizations. Many of the FY2017 research projects receiving funding through the MnDOT Research Program's TRIG process will be executed by university researchers, some outside of Minnesota.

STRATEGIC FIT OF KEY PRODUCTS AND SERVICES

While MnDOT's research activities provide significant internal and external value, the research program appears internally decoupled from MnDOT's organizational vision and strategy. In other words, while MnDOT's research activities largely advance its Vision, Mission, and Core values, an explicit linkage between the research and these guiding principles is missing. It is difficult to find an intermediate-level articulation of goals or functional needs that can connect the broader organizational strategy to the research strategy. This makes it difficult for research stakeholders, the legislature, or others to understand the way in which research and planning decisions are made and funding allocated. The Strategic Research Plan can help close this gap.

The amount of funds allocated to a program area is one way to look at the extent of support for strategic needs, though this perspective has its limitations. For example, MnDOT's vision states that "Minnesota's multimodal transportation system maximizes the health of people, the environment and our economy" – yet, Multimodal and Environment have

received at most 5% of the allocated research budget in the last six years, and Policy & Planning has remained below 10% over the same time frame. An important caveat is that these topic areas could fall into more than one program category. Further, these areas certainly require less resources than the other equipment- and materials-intensive research topics. However, this further substantiates the need to map the relationship between specific topics, program areas, and broader organizational needs. Stakeholders directly involved with the TRIG process, such as governing board members, or those involved in grassroots activities, district engineers for example, often *internally* articulate the need for or champion some topics. Yet, there seems to be a missing feedback loop and communications channel to elevate the potential high-value of these topic areas and link them to MnDOT's strategic initiatives so that they are also *externally* visible.

STRENGTHS AND OPPORTUNITIES

The transportation research community continues to grapple with how to develop robust DOT research programs. These efforts include how to establish strategic research needs; manage and execute research; implement research findings; and communicate both the results and the value of research. MnDOT's Strategic Research Plan development process (this project) therefore includes a program evaluation component to focus MnDOT's future efforts. We report on MnDOT's strengths and opportunities, based on stakeholders' reported perceptions.

To structure our preliminary insights from interviews with internal and external stakeholders, we have adapted one of several available published frameworks, *the seven keys of robust DOT research programs*, as outlined in the NCHRP Synthesis 280 study [2]. The seven keys cover the dimensions of *trust, marketing, economics, strategic partnerships, accountability, policy engagement*, and *staff empowerment*. The structure of this NCHRP strengths and weaknesses framework is intended to help DOTs asses the efficacy of their research programs and to design program improvements.

How does MnDOT fare on each of the seven keys, as reported by its stakeholders? What are the specific

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[2] This is funded using the voluntary 5.5% contribution of the 2% set-aside for research from SP&R

strengths and opportunities? We summarize these perspectives in Figure 8. Since our research to date has made use of stakeholder interviews and published materials, we describe the state of MnDOT's program in terms of its qualitative *strengths* and *opportunities*. While subjective, these findings are substantiated by stakeholders' experiences and views. Quantitative metrics could be developed for some of these dimensions, such as *Economics,* and should indeed be applied when they can

Figure 8. MnDOT's perceived performance on the NCHRP 280 Keys

Key	Perceived Strengths	Perceived Opportunities
1. Trust: is there a feeling of connectedness, credibility, and assurance of shared goals between the research unit and parent organization?	TRIG structure and logistics	TRIG voting process; "grassroots" topic prioritization; leadership input
2. Marketing: does the research program market all aspects of the research process, from idea inception to results implementation?	Project-specific marketing	Demonstrating a pattern of value across the research portfolio
3. Economics: is there sound economic reasoning for funds allocation and program design?	Substantiating project-specific quantifiable and potential benefits	Substantiating benefits actually captured; portfolio-wide value analysis
4. Strategic Partnerships: has management established and nurtured partnerships to complement internal research expertise and resources?	Statutory and funding-based partnerships	Research public-private partnerships
5. Accountability: does the research program track projects and resources and assess efficiency over the research life cycle?	TRIG-governed project tracking	Project life-cycle tracking; topic obsolescence; efficiently leveraging previous research
6. Policy Engagement: does the research program conduct policy research in addition to technical research, and communicate findings to inform policy decisions?	Both independent and pooled policy research	Articulating policy impacts; relationship with Minnesota GO and coordination across the family of plans
7. Staff Empowerment: are staff empowered to be creative, take ownership, and effectively execute research?	Grassroots involvement, capable experts	Expanding the roles of technical experts, workforce concerns for capacity to conduct research

help strengthen the evaluation process. We identify dimensions where there is a need for more quantitative analysis and suggest the type of data needed to further evaluate MnDOT's program along these dimensions. We discuss in further detail below to highlight important observations. We discuss the preliminary findings below. Where more data is made available in future phases of work, we will re-evaluate and update these findings.

Trust: MnDOT staff engaged in research unanimously stated that they are familiar with the TRIG-governed process and believe that Research Services has effective mechanisms in place for soliciting problem statements and funding projects. MnDOT staff are enthusiastic about the process because research needs are first vetted at the divison- or office-level and then systematically championed through the "idea to project" process described earlier. Governing board members who represent different divisions identified one possible area of friction in the final stage of project selection: when they are asked to evaluate and vote on topics outside of their area of subject expertise. Voting members said that they did not feel comfortable excluding some research topics that had been vetted by the discipline offices since those topics were beyond their subject matter expertise. TRIG voting members also seek further affirmation from leadership that they are in fact allocating funds to research topics of strategic interest.

Outside the TRIG process, MnDOT research stakeholders describe an organic process wherein "MnDOT makes random good decisions" with respect to research project

prioritization, especially grassroots research. In the case of all MnDOT research, there is a sense that research decisions and coordination could be improved with a long-term or strategic research program in place.

Marketing: Centrally coordinated TRIG projects are typically more visible than function office-level projects as the TRIG process markets research projects and their outcomes effectively through several high-visibility channels. Formats follow the recommendations in the Research Services Strategic Plan [7]. We found evidence of clear, concise and well-presented project summaries communicating the value of specific projects in the LTAP newsletters, the Crossroads research blog series, the Research Service & Library's At-A-Glance reports, MnDOT and LRRB Youtube channels, and AASHTO's High Value Research series [8]. The Office of Maintenance also showcases research outcomes in its Monthly Research Bulletins.

Since the marketing communication is most often project-specific, the pattern of value across the entire MnDOT research portfolio is difficult to recognize.

The outcomes and impact of MnDOT research may not be easily available to other stakeholders until a conscious effort is made to "push out" or communicate this research. More importantly, a number of discretionary research projects that are not selected and funded through the centralized TRIG process may not receive broader visibility.

Data and statistics on research marketing would help MnDOT understand the effectiveness of its outreach. Such data include: the number of hits on different websites, video views, number of publication downloads, and information on organization type and affiliation of the audience consuming research products.

Economics: For many of its successful research projects, MnDOT has published statistics on potential increases in asset life and cost reduction available if the projects' outputs were to be implemented [9]. Other types of cost and time savings have also been documented upon project completion [4] [8], however MnDOT recognizes that value cannot be assessed in terms of cost and time saving alone. For example, some projects are valuable because they

validate best practices while other research may lead to "lessons learned" of what *not* to do.

Identifying the potential value of projects at the idea stage continues to remain a challenge because the outcomes of the research are uncertain and difficult to quantify.

Managing the risk of the entire portfolio of research is therefore a work in progress. Calculating benefits captured through completed projects also continues to remain a daunting task for Research Services staff. MnDOT has made strides by examining the ways in which state DOTs identify return on investment and value of research activities. It previously commissioned a study on best practices in this area [10], and also convened peer exchanges on the benefits of research and its implementation [9] [11]. MnDOT is also internally developing a performance calculator and research portfolio risk management tools along these lines. Information on these tools and efforts is currently not publicly available. Subsequent working papers will report on the current and potential MnDOT applications of this effort.

Strategic Partnerships MnDOT has long-standing partnerships with the Center for Transportation studies at UMN and the Local Roads Research Board. It has participated in pooled fund studies with many organizations around the country, including more recently the National Road Research Alliance (NRRA) and the National Center for Asphalt and Technology (NCAT). These partnerships have been forged based on statutory and funding relationships. In some of these cases, MnDOT clearly dominates the value flow, i.e. it brings resources, expertise, and the ability to coordinate whereas the other groups are consumers of MnDOT's research.

We did not uncover any discretionary research-focused partnerships with industry or private sector organizations where the reverse is true; MnDOT does not currently tap the capabilities of private sector research organizations or technology transfer and commercialization mechanisms. This area presents an opportunity for MnDOT to be creative and innovative in how it both accesses expertise and resources. MnDOT can then better disseminate the outcomes and better implement the outputs of research than it can through current partnerships.

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Accountability: Three possible indicators (among many) for understanding program accountability are project tracking, program obsolescence, and efficiency. The first is the degree to which project progress and outcomes are tracked over their life and beyond into the implementation stage. While the TRIG program tracks all projects in its pipeline, we did not get a good sense of what happens with project outcomes post-completion. We would also like to learn more about the life-cycle of grassroots research that is not coordinated by the TRIG process. MnDOT does diligently market the potential value of implementing selected projects, but is research systematically implemented? We are continuing to collect data in this area and will report on this topic in future deliverables.

The second indicator of accountability is the declaration that a particular stream of research or program area is obsolete and should be discontinued. We are investigating whether MnDOT has arrived at this conclusion on a topic area in the past, and MnDOT's evaluation process.

Finally, the efficiency of research (at the very least in terms of redundancy) could also indicate accountability. How well is MnDOT leveraging NCHRP, AASHTO, state DOT, and university research? How well can it contribute the findings of its own research program to these other efforts? These aspects of our study are also works in progress.

Policy Engagement: MnDOT could do more policy research, and also better articulate the impact of its efforts in this area. From FY2010 – FY 2015, Policy & Planning research comprised 7% of MnDOT's research budget on average. MnDOT allocated funds to topics such as traffic data quality verification, local agency capacity building, industry clusters, the link between transportation and economic development, and technology change [4]. Many pooled fund studies and AASHTO projects to which MnDOT contributed fall into the Policy & Planning category. While this type of research is not material- or equipment-intensive, it requires capable internal experts and close links to the organization's strategic management and direction. For instance, we did not find an articulation of the relationship between Minnesota GO (the 50-year vision based on Environment, Economy, and Quality of Life), the family of Modal and System plans (ex. Transit, SHIP, Freight System) under it [12], and MnDOT's own Policy & Planning research portfolio. How are the outcomes of MnDOT's Policy &

Planning research informing the broader planning efforts, and vice versa? This link is vital especially since the next Statewide Multimodal Transportation Plan will be finalized at the end of 2016 and adopted in early 2017. More coordination may be needed between policy-focused research within MnDOT's Research Services, policy efforts elsewhere within MnDOT, and also external programs including federal grants and pooled-fund programs.

Staff Empowerment: MnDOT research is conducted by highly capable and motivated staff. The researchers and managers we interviewed convinced us that they deeply understood not only the objectives for research, but also MnDOT's functional imperatives in maintaining a reliable and sustainable transportation system. Many MnDOT staff who do not directly conduct research have often requested research through the TRIG process. They have also served in one or more key roles (TAP, TL, PC, etc. as discussed above). Long-serving engineers and research managers who have helped institutionalize both the research process and implementation have retired or are approaching retirement. This has given rise to workforce concerns, especially in the near- to mid-term future about the capacity to conduct research. Another concern is the ability to expand the roles of MnDOT's technical research experts so that they can also market the value and impacts of research to stakeholders.

NEXT STEPS

Stakeholder engagement – both internal and external – has been a priority for this study. We include below a list of the staff with whom we have spoken. Many of their perspectives have been included in this working paper. Additional insights will emerge through subsequent interaction with city and county engineers, consultants, universities, and districts and their observations may shape this discussion further. Some outstanding questions we have highlighted here and will address include:

- How is MnDOT's policy research influenced by, and how does it feed back to its broader planning efforts?

- How does MnDOT keep its research program accountable and efficient?

- How can MnDOT be creative in its partnership opportunities?

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■ What are the potential applications for the performance calculators MnDOT is developing?

In Phase 2: Strategic Framework and Principles, we will continue to examine the strategic fit between MnDOT's current and proposed research priorities and its broader vision and relationships with the Minnesota GO family of plans. The strategic plans and research plans of other organizations will also be informative in crafting a strategic framework for MnDOT research.

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LIST OF INTERVIEWEES

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Working Paper 2 - Strategic Framework and Principles

PREFACE

The purpose of this project is to assist MnDOT in developing a 5-Year Strategic Research Plan (Plan). The Strategic Research Plan will guide MnDOT's investments in research and shape how MnDOT governs and makes decisions about research. The Plan will connect MnDOT's research aspirations to its broader strategic goals, and also recommend how to assess the impact and outcomes of the chosen research priorities. MnDOT's research stakeholders will help shape its Strategic Research Plan.

PURPOSE OF THIS DOCUMENT

In this phase of the project (Phase 2: Strategic Framework and Principles) we examined how MnDOT governs research decision-making and the focus of its research programs. We also studied the strategic plans and governance structures of other state DOT research programs, TRB, AASHTO, and FHWA. Some key questions shaped our analysis:

- How does MnDOT govern and structure its research portfolio?

- How does MnDOT prioritize research topics, select projects, and implement the results of research?

- What are the key products and services that support MnDOT's vision and objectives?

- How should MnDOT's different research topic areas map to its key products and services?

- How will MnDOT's Strategic Research Plan address the national research priorities as benchmarked in the TRB, and AASHTO SCOR/RAC plans?

- What governance model and decision-making processes should MnDOT adopt to accomplish its objectives?

Phase 2 of this project for developing MnDOT's Strategic Research Plan is based on four primary inputs:

1) Interviews and focus groups with internal and external research stakeholders
2) Research on strategic research plans nationwide
3) Team experience with state DOT research programs
4) Feedback on Working Paper 1 – Institutional Context and follow-on conversations

This document distills our findings in the area of research governance and decision-making. Our findings and recommendations fall into two broad categories – Research Governance and Research Direction and Focus.

RESEARCH GOVERNANCE

Research governance and activity at MnDOT are distributed across functional levels, divisions, and offices. This decentralized approach poses executive leadership, focus, governance, decision-making, assessment, and funding challenges. Given its distributed nature, MnDOT's research program faces risks of (a) project duplication – because no one has a comprehensive view of the portfolio, (b) limited accountability – in the absence of a singular leader for research at the executive level, and (c) low value capture – through sub-optimal use of research funding and inadequate and unclear implementation of research results.

Two key entities drive and collaborate on transportation research in Minnesota: MnDOT and the Local Road Research Board (LRRB). These state transportation research programs rely on entities such as the Center for Transportation Studies (CTS) at the University of Minnesota,

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other Minnesota state colleges and universities, out-of-state universities, vendors and consultants to conduct the majority of MnDOT's research activities. Of these, the University of Minnesota performs the largest share of MnDOT-sponsored research. Figure 1 depicts the governance and decision-making relationships among the two key programs and the set of external researchers.

Minnesota's principal state transportation research programs – MnDOT and LRRB - and a main external executor – CTS - are intertwined as result of their history and laws.

This is both a strength and weakness of transportation research in Minnesota as a whole. The three

entities work together frequently to administer and perform research that benefits MnDOT and other transportation agencies. Yet, the activities of the key research entities are not currently aligned at a strategic level, leading to disconnects in program focus, risk of project duplication, and missed opportunities to leverage each other's skills and resources. We discovered that the efforts to coordinate between the programs rely heavily on advisory committees and liaisons. MnDOT has closer ties with UMN CTS than with its other external contractors through a partnership agreement and some technical and administrative working groups [1, 2]. And while there is some tactical and operational coordination, there seems to be a missing feedback loop to influence the executive leadership and strategic alignment of MnDOT, LRRB and their principal research contractors.

Figure 1. Current governance structure and decision-making framework for MnDOT and LRRB research. This figure shows the relationships between the two state transportation research programs and the external entities that conduct research for MnDOT and LRRB.
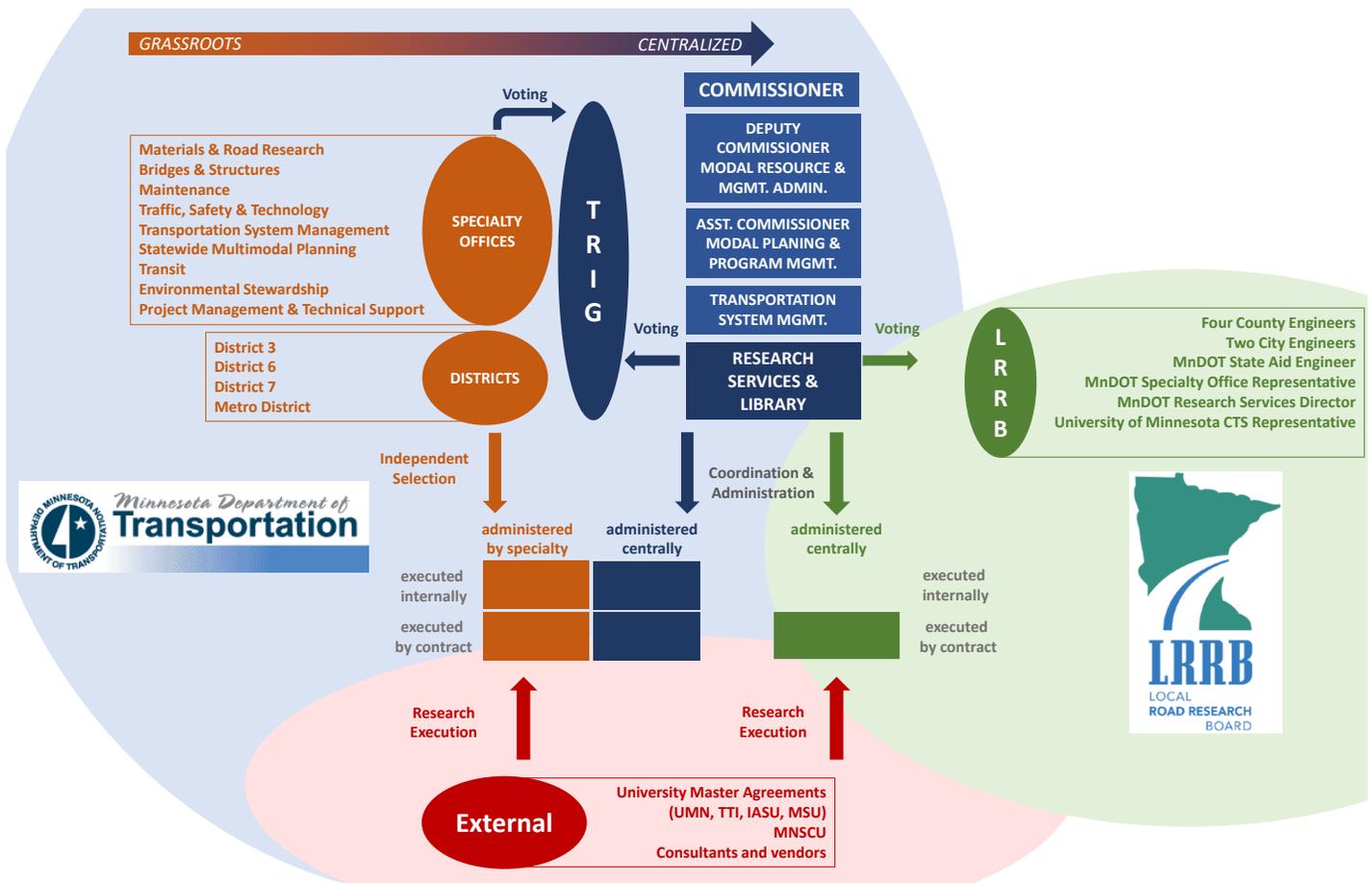
Source: CPCS analysis of MnDOT, LRRB, and UMN materials, reports and interviews

MnDOT's own governance and decision-making cannot be completely separated from LRRB and UMN CTS. And yet, neither does MnDOT have executive authority over the other programs, nor is it structured to effectively manage or fully coordinate with those programs.

While improved coordination and strategic alignment of the three entities would improve overall research outcomes, given MnDOT's limited ability to affect the other programs, this study is focused on ideas to improve the way MnDOT leads, governs, and makes decisions about research to better align with Department's strategic goals.

Idea Sourcing

The approach to generating research ideas offers strength to the program. Anyone can submit research ideas through the IdeaScale collaboration website. Idea sourcing is a hallmark of MnDOT's research program, making it responsive to grassroots and frontline employee needs.

MnDOT wants to preserve the cultural flexibility of an open idea sourcing process.

Ideas are submitted by MnDOT staff, county and District engineers, CTS-affiliated researchers, researchers from other universities, and consultants. Thus IdeaScale provides a common pool and repository of research topics that are relevant for all three entities involved in Minnesota transportation research.

The concept of research is often confused with immediate, short-term problem solving or "technical assistance". Research questions tend to be more open-ended, have uncertain outcomes, and often involve follow-ups and further study before implementable results are obtained. On the other hand, "technical assistance" activities are intended to improve the efficiency of MnDOT's day-to-day operations by implementing innovative work procedures and tools—but these changes do not always entail research. They do not have the high degree of uncertainty or the risks as multi-year research projects, and are very specific to the immediate problem at hand. Research is thus one means to the end of efficiency improvement. The testing of new pavement materials, technologies and sensors, and new construction techniques are clear examples of research. Retrofits to specialized equipment and one-off solutions improve

efficiency but research may not be a prerequisite for capturing these efficiency improvements. It is important for MnDOT to be diligent in what it labels as research given its finite research budget and to be able to carefully track research results, implementation, and value.

Project Selection, Execution and Administration

A number of different decision-making processes determine which research ideas advance to the evaluation and selection stage.

Even within MnDOT, many individuals and offices overlap in how they make decisions about research, with no single individual or entity accountable for the entire portfolio.

For example, some research ideas are advanced and centrally monitored by Research Services (RS) while independent discretionary research is conducted by technical offices, sometimes referred to as "specialty offices". There is no single individual, leader, or office who supervises, promotes and is accountable for all of MnDOT's research activities.

Research Services (RS) administers the centrally governed share of the portfolio funded through FHWA State Planning and Research (Part II) and State Research Program (trunk highway) funds. RS includes teams dedicated to research management, contract administration and marketing. These teams within RS track the centrally governed subset of projects through to completion (and beyond only if a funded implementation decision is made). This process is shown in the center of Figure 1, under "Centralized" in dark blue.

MnDOT's specialty offices have the discretion to conduct research using internal budgets. Some MnDOT Districts also conduct their own research. The Traffic, Safety, and Technology office's Guidestar program [3, 4], and some of the office of Materials & Road Research's projects are notable examples. These projects are selected, managed and administered within the specialty offices, and not tracked by Research Services. The left side of Figure 1 shows the governance for the "grassroots" and otherwise independent share of the portfolio in orange.

The Transportation Research Innovation Group (TRIG) is a governance board convened by Research Services to select projects and award funds. The board is comprised of 14 voting representatives from each of MnDOT's specialty offices and some Districts [5]. Two non-voting members and RS staff make up the rest of the board. The office representatives comprising TRIG often also oversee the internal or "grassroots" projects in their respective offices. These individual managers are responsible for their functional offices and Districts (and the research within those offices). But TRIG operates as a committee and there is no clear executive leadership guiding it. Instead, TRIG selects projects which are administered by RS, and the individual offices who send representatives to TRIG also select and administer projects independently.

The current governance model divides MnDOT's research portfolio into four separate quadrants, based on who executes and who administers research.

The 2 x 2 matrix embedded in Figure 1 shows the four quadrants. The first dividing factor is whether research is administered by a specialty office, or centrally by Research Services through TRIG's governance process. The second line of division arises because research is either conducted in-house by MnDOT employees or contracted out to universities (such as UMN CTS), consultants, or vendors.
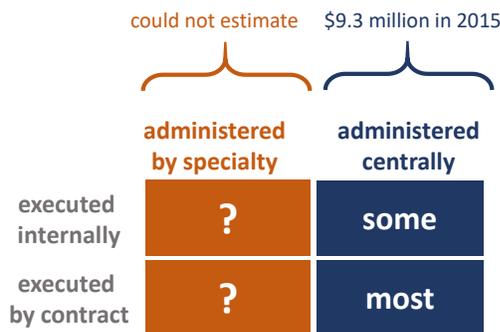
reports. The research in these two quadrants amounted to $9.3 million in 2015 [5].

In comparison, the orange boxes show the research administered by the specialty offices, which can also be conducted internally or with contracts through the University Master Agreement vehicle (UMA), for example. We did not find a comprehensive or office-level listing of specialty office research projects or their research expenditures. One estimate for these activities is that MnDOT offices *excluding* RS spent about $12.9 million through the University of Minnesota UMA alone in the last five years [6].The term "MnDOT research" therefore obscures the execution aspect; there is research and innovation sharing that MnDOT conducts *itself* using internal staff and resources, and the research it funds but executes through contracts.

A consequence of this distributed research model is that MnDOT's research efforts are not readily visible across quadrants. While research managers in MnDOT's Research Services are responsible for observing and tracking "centralized" research that is selected through the TRIG process, information on research administered by specialty offices is not readily accessible. Unless other offices share or publicize their research findings and implementation activities, the research may not be implemented by internal or external stakeholders.

MnDOT offices cannot safeguard against duplication of projects or improve coordination if there is no comprehensive view of the portfolio. This points to a major need for improved information sharing and coordination.

While the logistical and administrative role of Research Services is clear, this office lacks governance authority to coordinate or report research activities of the specialty offices. RS is embedded in the Transportation System Management Office, one of the specialty offices, and its Director sits on TRIG.

LRRB Relationship
The right side of Figure 1 shows the LRRB - MnDOT governance relationship. MnDOT has three out of ten voting member positions on LRRB [1]. MnDOT's Research

could not estimate $9.3 million in 2015

|	administered by specialty	administered centrally
executed internally	?	some
executed by contract	?	most

Figure 2 below enlarges the same matrix. The blue boxes show that most of the research that TRIG centrally governs (and RS administers) is executed through contracts. Some of this research is in-house (notably Maintenance and Materials), based on the published lists in the At-A-Glance

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Services centralizes and also administers this program in parallel with the centralized portion of MnDOT's own portfolio. The governance relationship between MnDOT and LRRB is asymmetric, since there are no county or city engineers (and also no UMN CTS representatives) on TRIG.

LRRB does not execute research as it is a governance board, and not an agency with its own assets and resources.

All of LRRB's research is executed through contracts administered by MnDOT Research Services office. In 2015, LRRB spent about $4.4 million of statutorily allocated research funds, which are initially apportioned to MnDOT and then set aside for LRRB [7].

LRRB research projects are submitted to and selected from the same pool of projects (IdeaScale) used by MnDOT's TRIG program. Some project ideas submitted through the IdeaScale program are of higher importance to LRRB than to MnDOT. LRRB therefore prioritizes and funds these projects, whereas MnDOT funds projects matching its own priorities. Projects of shared importance are selected and funded by both TRIG (MnDOT) and LRRB. The cost sharing process is ad-hoc and cost shares are negotiated between voting members of TRIG and LRRB, with the RS acting as a liaison [6].

CTS Relationship
Principal Investigators and laboratories affiliated with the University of Minnesota's Center for Transportation Studies conduct research for both MnDOT (both TRIG and specialty office projects) and LRRB. The University Master Agreement with UMN is a procurement vehicle that allows university Principal Investigators to respond to project needs statements. About 35% of CTS's $17.5 million in revenues in 2015 came from State of Minnesota contracts, in addition to its statutorily allocated operating funds [8]. MnDOT and LRRB are CTS's largest research clients.

MnDOT leadership sit on CTS's Executive Committee as well as its Partnership Leadership and Management Groups. There are no CTS representatives on TRIG, yet CTS influences MnDOT's research priorities and practices through separate topic- and function-based groups authorized under MnDOT's Partnership Agreement. A number of CTS affiliated professors and PI's also have long-standing collaborative relationships with MnDOT staff. As a result, CTS understands MnDOT's research procurement processes and positions itself to succeed in these competitive processes. CTS also has a significant private sector and University outreach component that is not present in MNDOT or LRRB.

External Advisory Group
In spite of the scale, volume, and relevance of MnDOT's research for Minnesota's and the nation's transportation needs, the agency has little to no external advisory guidance or support.

The lack of a single management-level individual or office that ultimately oversees MnDOT's entire research portfolio, and no industry or academic advisory guidance impinges the agency's ability to strategically conduct transportation research.

For example, there is no vehicle by which private firms, universities, or other government agencies can advise MnDOT's leadership on the evolution of research priorities. Without this type of oversight, the credibility of MnDOT's research program is reduced.

Governance Recommendations
Based on the interviews conducted for the study and national best practices, the governance and decision-making framework for MnDOT's research activities should be founded on the following principles:

1. Integration over separation: close coordination between stakeholders and activities involved in Minnesota transportation research.

2. Accountability: a comprehensive view of MnDOT's entire research and implementation portfolio, coupled with decision-making authority vested in a single leadership position or office, with oversight provided by an external Research Advisory Group.

3. Executive authority: a single executive authority for the components of the research program that is aided by specialist technical committees who provide advice, and evaluate project proposals and results.

4. Value Capture: funded implementation / deployment and benefits tracking.

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5. Strategic Responsibility: a feedback loop to influence MnDOT's organizational strategy through research, which in turn is advised by a mix of public and private stakeholders.

Ultimately MnDOT will need to determine the best governance model to address these five principles and the current gaps they represent. The most comprehensive solution would establish a clear and accountable executive authority structure to comprehensively develop, govern, track, and assess performance of both MnDOT's research and implementation project portfolios. However, we recognize that MnDOT may not currently be in a position to develop a new executive structure. As such, we have developed three possible governance and decision-making options for MnDOT to consider based on study observations and national best practices. Option 1 is an enhanced

structure between MnDOT, LRRB, and CTS potentially named the Minnesota Transportation Research Institute (MnTRI) intended to significantly enhance coordination and comprehensive management of the entire Minnesota state transportation research portfolio.

Option 1 – Comprehensive Tracking of Research and Implementation by an Enhanced Research Services. This option would require little internal restructuring, but would significantly expand the scope and coordinating authority of RS (see Figure 3). Its new mandate would include working with specialty offices to track discretionary research and communicate its results and value to the rest of MnDOT's organization. This option would require changes in reporting requirements and also increased scrutiny over both project selection and results

Figure 3. The governance option (Option 1) for an enhanced Research Services & Library with increased coordination responsibility
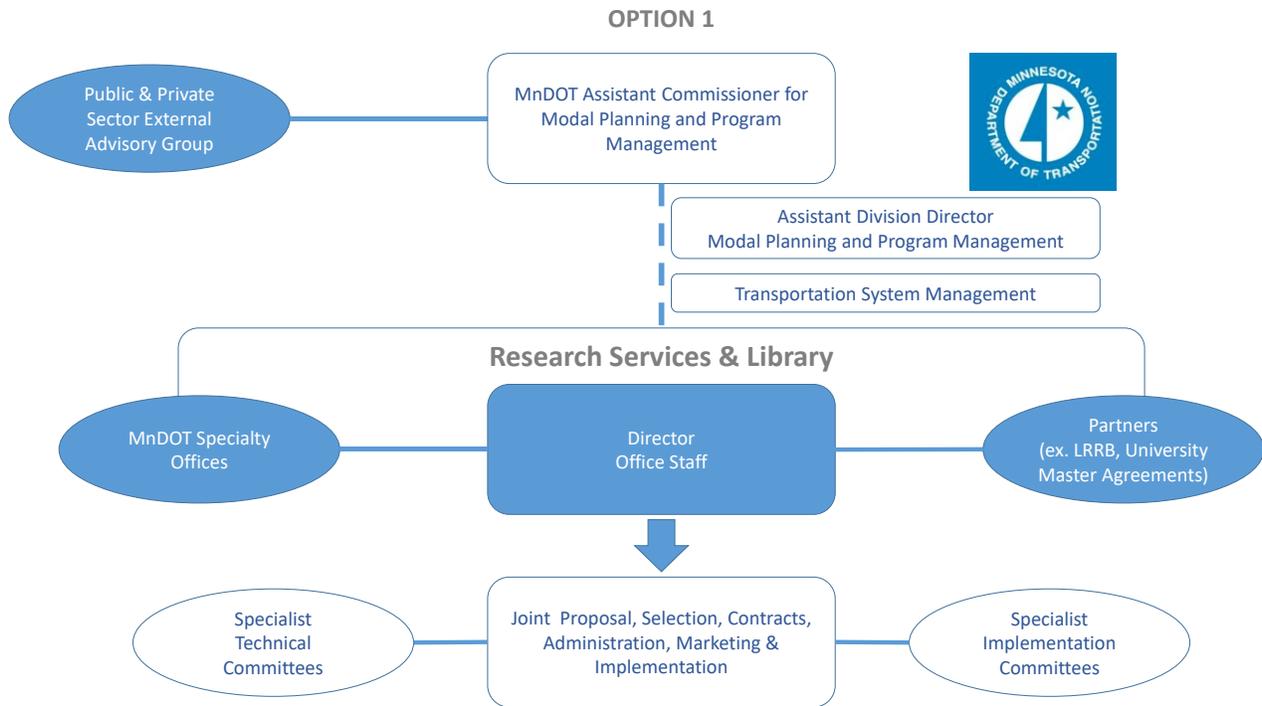
Source: CPCS analysis

Research Services & Library with increased coordination responsibility. Option 2 envisions a new structure internal to MnDOT: an Office of Research, Innovation, Technology, and Education (RITE) with a Director reporting directly to the Assistant Commissioner for Modal Planning and Program Management. Finally, Option 3 is a new partnership

implementation decisions -- for example, by modifying TRIG's operating structure to include specialist technical

Figure 4. The two options that envision new structures for MnDOT's research program. Option 2 is a new internal Office of Research, Innovation, Technology, and Education. Option 3 is a hybrid organization – Minnesota Transportation Research Institute (MnTRI) that integrates MnDOT's research, LRRB, and elements of UMN CTS's program.

OPTION 2

MnDOT Assistant Commissioner for Modal Planning and Program Management

Office of Research, Innovation, Technology, and Education (RITE)

Public & Private Sector External Advisory Group

Director Office Staff

Partners (ex. LRRB, University Master Agreements)

Specialist Technical Committees

Joint Proposal, Selection, Contracts, Administration, Marketing & Implementation

Specialist Implementation Committees

OPTION 3

MN Transportation Research Institute (MnTRI)

Public & Private Sector External Advisory Group

Executive Director Staff Internal Steering Committee

Partners (ex. LRRB, University Master Agreements)

Specialist Technical Committees

Joint Proposal, Selection, Contracts, Administration, Marketing

Specialist Implementation Committees

MnDOT Implementation & Technical Assistance

CTS Education & Technical Assistance

LRRB Implementation & Technical Assistance

Source: CPCS analysis

and implementation committees. The current RS would need additional resources of two types to better coordinate, administer and market research. The first is information technology resources such as more flexible websites, content management systems, and collaboration technologies so that specialty offices and RS staff can work more closely together and altogether operate efficiently. The second type is additional staff resources to help this office administer a larger portfolio of ongoing research. A strong champion for research would be needed at the Assistant Commissioner level (presumably that of Modal Planning and Program Management). The research champion would also be advised by an external advisory group of public, academic, and private sector experts.

Benefits of Option 1: a comprehensive view of MnDOT's research portfolio achieved primarily by increasing the scope and coordination authority of Research Services for better tracking of research and implementation.

Option 2 - Elevated and Empowered Research Office This option would internally restructure MnDOT's research process and portfolio, see Figure 4. It would move the research office up in MnDOT's hierarchy, from its current position (within the Office of Transportation System Management) so that the Director of this office would report directly to the Assistant Commissioner of Modal Planning and Program Management. MnDOT's entire portfolio of research and implementation would be consolidated under the purview of this office. Specialist technical committees would help identify project needs, evaluate proposals, assess results, and make implementation recommendations. The Director of this new office, potentially called RITE, to reflect its broadened scope of "Research, Innovation, Technology, and Education" has more legitimate convening and coordination authority across MnDOT's organization. The "Education" function of RITE would be responsible for better outreach, marketing and communication about the importance, results and value of research and innovation in transportation. Currently only UMN CTS is well positioned to accomplish this "education" function. An advisory group of public and private sector experts would advise the Director of RITE. Partnerships may be established with facilities (ex.

MnROAD lab) and research programs (ex. through University Master Agreements).

Benefits of Option 2: A clear delineation of the roles of research decision-making, administration, and governance, consolidated in one office so that MnDOT can systematically govern, track and implement research.

Option 3 - Establishes a Research Partnership Between MnDOT, LRRB, and CTS. This option is a broader restructuring than envisioned in Option 2 and would require organizational changes outside MnDOT purview. It would create a new organization potentially called the joint Minnesota Transportation Research Institute (MnTRI), see Figure 4. Since MnDOT already passes through statutorily allocated funds to both LRRB and CTS, administers LRRB's program, and both formally and informally partners with CTS, a formal restructuring could significantly streamline and strengthen transportation research in Minnesota. The Executive Director of this new organization could be appointed as an Assistant Commissioner or similar. Specialist technical committees would help identify project needs, evaluate proposals, assess results, and make implementation recommendations. MnDOT staff, District engineers, and county engineers can serve on these committees to ensure that both MnDOT's and LRRB's research priorities are maintained. This new organization would also have a diverse advisory group of public and private sector experts. It would further have the flexibility of CTS in establishing partnerships with other universities and private organizations.

Benefits of Option 3: An integrated approach that streamlines governance, decision-making and financial management of Minnesota's three main research programs, and provides flexibility for private sector and university partnerships.

All three options should be explored further to assess whether they can meet MnDOT's long-term needs and to identify the best fit. Once the governance structure is in

place, MnDOT should revisit the substantive portion of the research program: the direction and focus of its research activities.

RESEARCH DIRECTION AND FOCUS

MnDOT's vision and goals for research should, in principle, both shape its broader organizational strategy and also inform its key function areas, i.e. its key products and services. The LRRB and some leading state DOTs have developed strategic visions for research topics and priorities through periodic workshops, focus groups and visioning exercises [1, 9]. One approach is therefore to bring together internal and external stakeholders to develop a strategic blueprint that can guide research and implementation topic prioritization.

Strategic Visioning

MnDOT last conducted a strategic visioning exercise in 2007. The objective of this day-long workshop was to design a research program "to address larger, complex, cross-organizational problems or opportunities" and also to address the tendency to focus on "the immediate research project, not on what implementation would look like or how it might be supported." MnDOT leadership and the managers of its specialty offices participated in the 2007 strategic visioning exercise, after which the outcomes were broadly circulated. The exercise prompted an Innovation Roadmap and led to significant structural changes in the research program. The current roles and responsibilities of the Research Services & Library office and the current incarnation of the TRIG evolved out of this workshop. The roadmaps themselves may now be out of date. Almost a decade later, MnDOT should take stock of its research program and refine its research strategy by engaging both internal and external stakeholders. Ideally MnDOT would initiate strategic visioning once governance recommendations from this study are implemented to reflect resulting changes to the research decision-making process and leadership. If MnDOT does not choose to advance governance recommendations at this time, the strategic visioning should still be advanced, using the Strategic Research Plan as a starting point for discussions. Specifically, the strategic principles (above), matrix of key products and services aligned against MnDOT's strategic vision (below); and the program performance assessment framework (Working Paper 3) would guide the visioning exercise.

Research Focus Areas

Another challenge facing MnDOT is the breadth of the research activities. We observe that MnDOT's research portfolio is spread over many topics and program areas, diminishing its ability to conduct research in an efficient and focused manner. There are at least ten topic categories used in MnDOT's annual Research At-A-Glance series to classify research. Further, many of these topics can be cross-classified in more than one area.

Maintaining excellence in a large number of topic areas requires significant coordination and resources, whereas a focused set of four to five topics can reinforce organizational priorities.

MnDOT's Key Products and Services

Another approach to strategic topic alignment is to use MnDOT's list of key products and services (Figure 5). This list was developed using a survey of MnDOT leaders and reflects their current views. This exercise is the closest resemblance to a prioritization effort recently conducted by MnDOT.

In August 2014, MnDOT developed a three-tiered ranking of its key products and services. Figure 5 summarizes the relative priorities among MnDOT's key products and services, as reported by MnDOT in its internal source materials.

The list of Key Products and Services does not immediately inform MnDOT's research topic prioritization. The list was intended for broader investment decision-making, and not for allocating research funds among topics. In fact, research must inform MnDOT's broader investment decision-making. Research is an integral part of each of MnDOT's functions, and therefore contributes to each of its key products and services. In other words, since MnDOT conducts research that is applicable to most if not all of its key products and services, a framework that recognizes these but goes beyond is needed.

To prioritize among research topics, MnDOT must ask: "what further research is needed on each of our key products and services?" and "which specific research topics can inform the need for future investments?" This is also a point at which MnDOT could incorporate three key cross-cutting considerations: performance measurement, asset management, and risk management. For example, "What risks might prevent us from optimizing our investment within the Key Products and Services Tiers?" "How can research manage these risks?" "What assets drive the largest allocations of funds, and how can we optimize the life cycle of these asset to reduce or optimize investment needs?" "What performance data do we have or do we need to be able to increase the life or our asset in these categories?"

Figure 5. MnDOT's Key Products and Services, ranked in three tiers in 2014.

Tier A

Snow and Ice Operations

Roadway System Activities: Paving, Shoulder Repair; Surfacing

Bridges and Structures: Inspection, Reactive Maintenance; Preventive Maintenance

Traffic Management: Traffic Operations; Traffic Management System Maintenance and Support

Traffic Devices Operations and Maintenance: Signals, Signs, Striping, Message Painting

Highway System and Project Planning

Tier B

Highway Projects: Project Development, Construction Management and Oversight

Roadway System Activities: Drainage Systems

Bridges and Structures: Overhead Sign Structures Inspection and Maintenance, Tower Lighting Inspection and Maintenance, Signal System Structural Inspection and Maintenance

Rail Crossing Safety

Traffic Devices Operations and Maintenance – Guardrail, Cable Median Barriers, Attenuators, Roadway Lighting, other applied research

Tier C

System Planning: Freight, Bicycle and Pedestrian

Roadway System Activities: Clear Obstructions

Bridges and Structures: Earth Retaining System Inspection and Maintenance, Noise Wall Inspection and Maintenance

Commercial Truck and Bus Safety

Research and Development

Roadside and Auxiliary Infrastructure: Issue Road Permits, Rest Area Maintenance, Property Management, Vegetation Management

Source: CPCS analysis of materials shared by MnDOT

"Which research will help to answer these questions." An example of the tradeoff facing MnDOT is "should we spend more of our research funds on bridges and structures research versus vegetation management research?" Addressing these questions requires further discussion of the strategic role and value of research and the relevant decision-making processes, which is tied to the Research Governance issues described above. However, we also believe that it would help to use a matrix approach since the nature of MnDOT's research topics varies both by topic as well as its business areas. We outline such an approach below.

Matrix Approach

As a means of illustrating MnDOT's research focus in a more holistic manner, we have developed a conceptual matrix in Figure 6. The intent of the matrix is to prompt discussion on the way in which MnDOT's research topics are organized and prioritized. This is meant to be a starting point for future discussions and would benefit from a strategic visioning process.

This is how the matrix works. On the horizontal axis are three broad "Research Focus Areas", which represent the desired outcomes of the things that MnDOT wants to achieve to fulfill its Strategic Vision [10]. That Vision aspires for a transportation system that "maximizes the health of people, the environment and our economy" (represented by safety, mobility and goods movement, and environment). On the vertical axis are the "Business Focus Areas", which are the activities at the core of MnDOT's mission reflecting the things that MnDOT does to achieve its Strategic Vision to: "plan, build, operate and maintain a safe, accessible, efficient and reliable multimodal transportation system that connects people to destinations and markets throughout the state, regionally and around the world." MnDOT's key products and services are sorted into the different cells of the matrix, with the 2014 rankings in parentheses. The sorting shows where MnDOT has emphasized its investments and business operations. The distribution of the key products and services across cells shows how key products and services are cross-cutting. MnDOT can further integrate a three-pronged approach of asset management, performance management, and risk-management as these three cut across all rows and columns of the matrix.

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research and matrix of research and business focus areas

Figure 6. A conceptual matrix approach to aligning research focus areas and business focus areas. The matrix includes MnDOT's key products and services to show relative priority within the matrix.

2014 Rankings of Key Products & Services **Tier A** **Tier B** **Tier C**	**BUSINESS**				
RESEARCH	**Plan**	**Design**	**Build**	**Maintain**	**Operate**
Safety	• System Planning: Bicycle, & Pedestrian **(C)**	• Drainage Systems **(B)**		• Inspection **(A)** • Preventive and Reactive Maintenance **(A)** • Overhead sign structures, tower lighting, signal systems **(B)** • Traffic Devices Maintenance: Signals, Signs, Striping, Message Painting **(A)**	• Traffic Operations **(A)** • Rail Crossing Safety **(B)** • Commercial Truck and Bus Safety **(C)**
Mobility & Goods	• Highway System & Project Planning **(A)** • System Planning: Bicycle, & Pedestrian **(C)** • System Planning: Freight **(C)**	• Paving, Surfacing **(A)** • Traffic Devices: Guardrail, Cable Median Barriers, Attenuators, Roadway Lighting **(B)**	• Construction Management & Oversight **(B)** • Project Development **(B)**	• Shoulder Repair, Snow and Ice Operations **(A)** • Clear obstructions **(C)** • Traffic Devices Maintenance: Signals, Signs, Striping, Message Painting **(A)**	• Traffic Operations **(A)** • Traffic Management System Maintenance & Support **(A)**
Environment				• Vegetation Management **(C)** • Earth retaining systems, noise wall systems **(C)**	
CROSS CUTTING CONSIDERATIONS **Performance Measurement	Asset Management	Risk Management**					

Source: CPCS analysis

A matrix view could improve the level of coordination and integration of research activities and aligning those activities with MnDOT's strategic vision.

The matrix view has a number of additional benefits. It eliminates the need for the labels of "basic" and "applied" research. The matrix also provides a basis for making trade-offs among research areas, ex. bridge inspection research versus bridge design research. The matrix allows for flexibility without having to alter the broader strategic framework. In other words, as the relative priority of topics or key products and services changes in the future, emphasis can be moved from some areas of the matrix to others. Finally, the matrix approach allows for more specific benchmarks with broader transportation trends and the strategic efforts of other transportation research organizations.

Research Focus Recommendation
Once the appropriate governance option is implemented, we recommend that MnDOT update its strategic vision for

every five years, as part of the process to develop and update its Strategic Research Plan. A visioning exercise would help identify objectives, set performance goals, and better emphasize value capture through research implementation. MnDOT leaders, managers and stakeholders should participate in the update process. MnDOT's research program will struggle to find cohesiveness without their participation and ownership.

Strategic Research Plan Outline
During the course of preparing WP2, the research team has developed a draft outline for the final deliverable of the study. The outline is based on stakeholder engagement in Phases 1 and 2, research on other DOT strategic plans, and a review of TRB, FHWA, and AASHTO SCOR/RAC strategic plans, we propose the outline shown in Figure 7 for MnDOT's Strategic Research Plan (2017 – 2022).

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[2] Minnesota Department of Transportation, "Partnership Agreement between MnDOT and University of Minnesota Center for Transportation Studies," April 2014.

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[4] R. Starr, "ITS at MnDOT Presentation," April 2015.

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[7] LRRB, "Recent budgets," 2016.

[8] Center for Transportation Studies, "Annual Reports (2012 - 2015)".

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[10] Minnesota Department of Transportation, "MnDOT's Strategic Vision," [Online]. Available: http://www.dot.state.mn.us/vision/.

Figure 7. Proposed outline of MnDOT's Strategic Research Plan (2017 – 2022).

- Transportation Sector Context and Change Drivers
- Institutional Context for MnDOT's Research Program
  - Funding
  - Topics
  - Governance
- Program Focus (2017 – 2022)
  - Relationship with MinnesotaGO and Family of Plans
  - Matrix of Focus and Function Alignments
- Performance Assessment
  - Strategy for systematic Program Assessment
  - Best practices for quantitative and qualitative assessment
- Results Implementation and Tracking
- Governance and Accountability
- Local, National, and Cross-sectoral Partnerships
- Forward Action Plan

Source: CPCS analysis

NEXT STEPS

The project team has been working in parallel on Phase 3: Performance and Efficiency Measures and Targets to better coordinate our analysis with the Phase 2: Strategic Framework and Principles discussion summarized in this document. The associated deliverable for Phase 3 is Working Paper 3: Performance and Efficiency Assessment for Research, will be submitted for MnDOT review at the end of June.

We look forward to receiving feedback on both Working Papers 2 (this one) and 3 (forthcoming) in our meeting with the project Technical Advisory Group planned for July 20. Based on the discussion and outcomes of the TAG meeting, we will move to further develop the Draft Strategic Research Framework and Plan.

REFERENCES

[1] Local Road Research Board, "Strategic Plan and Operating Procedures," 2012.

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Working Paper 3 - Assessing Program Performance

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Preface

The purpose of this project is to assist MnDOT in developing a 5-Year Strategic Research Plan (Plan). The Strategic Research Plan will guide MnDOT's investments in research and shape how MnDOT governs and makes decisions about research. The Plan will connect MnDOT's research aspirations to its broader strategic goals, and also recommend how to assess the impact and outcomes of the chosen research priorities. MnDOT's research stakeholders will help shape its Strategic Research Plan.

Purpose of This Document

In this phase of the project (Phase 3: Performance Measures and Targets) we examined how MnDOT and other state DOTs assess the performance of their research programs. The following key questions shaped our analysis:

■ What is MnDOT's current approach to assessing the performance of its research program?
■ What is an estimate of the value and impact of MnDOT's research program?
■ What performance measures and targets should MnDOT utilize in future to track research performance and value?
■ What are the specific mechanisms needed for comprehensive performance assessment and reporting?

Phase 3 of this project for developing MnDOT's Strategic Research Plan is based on three primary inputs: 1) Interviews with MnDOT staff (internal stakeholders) 2) Research on strategic research plans nationwide 3) Team experience with state DOT research programs.

This document summarizes our findings in the area of research program performance assessment. We recommend a portfolio approach for MnDOT's performance assessment, and also outline specific ways in which MnDOT could implement such an approach.

Assessing the Value of MnDOT's Research

The primary purpose and premise for MnDOT's research program is the value that research creates for the transportation system. A research program is an investment and must show value returns over time to justify the continued investment.

We note at the outset that although monetization of outcomes is an essential exercise, it is only a partial view of the value of a research program. MnDOT, like many other agencies, tends to focus more on the quantifiable aspects of the value of research, so that it can make an investment case for its program. MnDOT and other agencies therefore commonly use the terms benefit-cost (BC) ratio, and return on investment (ROI) to indicate monetized value. In reality, research programs create value in many different ways, and should therefore be evaluated accordingly.

The value of research is multi-dimensional; monetizable in some cases, tangible in others, and otherwise intangible and intuitive.

Since there is no single formula for estimating the value of research, the best practice that has emerged is to report program benefits holistically over time -- monetize and quantify outcomes where possible, and otherwise document them rigorously. In addition to ROI, a measure that translates savings in cost, time and other output based metrics, research programs also report knowledge-based outcomes at the program level to provide a feedback loop to executives and to governance stakeholders (an external advisory group, for example). This is a narrative description of the program as a whole that answers the following questions: what have we *learned* through research? What do we now *know* that we did not know some years ago? How has this improved our business? How has this changed our

investments? We looked at these best practices in the areas of measurement and reporting in assessing how MnDOT evaluates the performance of its research program.

MnDOT's Current Approach

MnDOT's approach to evaluating the benefits of its research has evolved over time. In 2013, MnDOT reviewed how other state DOTs quantify research benefits so that it could update its own approach [1]. The study looked at the practices of four state DOTs in detail (Utah, Missouri, Florida and Louisiana) and a sample of practices from thirteen other DOTs. The study recommended some one-time actions to update systems and processes and develop estimates of the value of MnDOT's past research. It also suggested aspirational long-term changes in how MnDOT manages research, implementation, and performance assessment.

MnDOT's Research Services & Library (RS&L) has since adopted some recommendations of that study and has made important changes in its internal processes. These changes will affect ongoing and future projects. For example, RS&L has updated ARTS – Automated Research Tracking System, its internal research management database. ARTS now provides research managers the ability to enter data on both potential benefits (early in the project cycle), and the outcomes of research for refining estimates (during the project and near its completion). The same system can also track the implementation of research results, and collect data for calculating a project's realized benefits. Current and future research and implementation projects will benefit from the new features in ARTS.

MnDOT recognizes that benefit quantification should be an integral part of the entire research process. At the project level, this implies estimating potential benefits during the project proposal process, refining the estimates of available benefits based on research results, and calculating benefits *actually* captured once research results have been implemented.

To this end, MnDOT completed the design of a systematic process for quantifying the benefits of research in December 2015 [2]. It consists of the seven steps shown in Figure 1, and involves the use of a spreadsheet-based estimation tool. The tool was piloted with a number of completed MnDOT research projects to refine the template and demonstrate its use.

Figure 1. MnDOT's new seven step process for quantifying the benefits of ongoing and future research projects
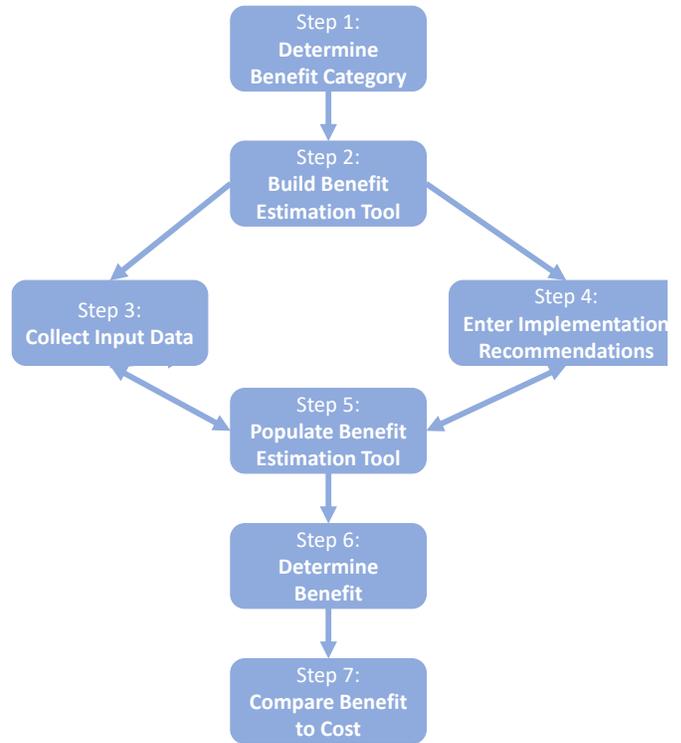
Source: Adapted from [2]

MnDOT's new process is for monetizing the *potential* benefits of individual projects.

The new process is a significant improvement over MnDOT's previous approaches, which were "black boxed" and relied primarily on reported benefits estimates from proposals and principal investigators through survey forms and interviews. The spreadsheet tool is transparent because the inputs and assumptions can be understood and discussed. It also standardizes the formulas and relationships across the templates, which can easily be updated when necessary. MnDOT is currently applying the process and tool to new proposals and on-going projects. It will also retroactively assess the results of some past research projects.

In addition to the clear instructions for the mechanics of how to populate and use the spreadsheet tool [3], MnDOT could

provide more conceptual guidance and educational resources for its research and technical staff on the following topics: the sources of value from research outcomes, why MnDOT has chosen the particular set of benefit categories, the degree of flexibility that a researcher may have in modifying the spreadsheet, and the timing of submission and the frequency with which the tool must be updated in every project. The conceptual guidance could also be reflected in the orientation guide for TRIG members [4] and in the Requests for Proposals (RFPs).

Improved guidance will help with cultivating a mindset of integrating benefits assessment throughout the research and implementation lifecycle of a project. Within the new benefit quantification approach, MnDOT could better link the research stage to the implementation stage, so that this process can inform implementation decisions, and then the assessment of *realized* benefits post-implementation. MnDOT will extract the most value from these new tools and processes by educating its internal staff who propose or supervise research, as well as external investigators on the conceptual issues, and also the expectations for collecting data and periodically reporting updates right from the proposal stage through to implementation.

MnDOT could supplement the benefit quantification process it has developed with a comparable systematic reporting method for non-monetizable but quantifiable benefits, or other intangible benefits. The additional steps will encourage ideas that are less suitable to monetization, and help ensure that the program invests in projects beyond "sure wins". Many research projects have a high chance of not meeting initial expectations, but they can still be valuable in terms of lessons learned, even those that may be labelled "failures". Evaluating and tracking non-monetizable and intangible benefits for projects can help MnDOT identify and report the lessons it has learned across projects with a range of outcomes.

Value Estimates of MnDOT's Research Impact
We did not find, and cannot easily estimate based on the limited data we have, the value of MnDOT's portfolio of research. MnDOT does not currently publish a composite estimate of research value (or monetized benefits, or a list of intangible benefits captured) at the program level, either annually or for a multi-year period. The ARTS system contains limited information on the benefits captured from MnDOT's past research projects. The quality of data on

implementation and on the realized benefits is most consistent for those projects chosen for funded implementation through TRIG's central governance process. For other research projects, the understanding of outcomes is highly variable for a number of reasons. Research managers rely on principal investigators and others most familiar and directly involved with the project to enter data on project outcomes. Some investigators are better than others at recording project findings and their plans for implementation. In other cases, the process for updating benefits estimates was not consistently enforced or tracked after project completion. Specialty offices are the most aware of the outcomes of their internal discretionary projects, and unless they are reported out systematically and consistently, RS&L may not be able to track them. As a consequence, implementation or adoption outside the Specialty offices is unknown or limited.

MnDOT's research program would benefit from identifying the value and impact of its past research at a program-level.

Some MnDOT offices report value estimates for their subset of the research portfolio. For example, the Office of Materials and Road Research has published estimates of costs and benefits of both Phase I (1994 – 2006) and Phase II (2007 – 2017) of the MnROAD research program. The estimated annual benefit (pre-implementation) of six selected projects from MnROAD Phase 1 was $33 million annually [5]. In other words, these are the estimated materials and construction cost savings that are quantifiable and available if the results of these six research projects were to be implemented across the Minnesota roadway system. A similar benefits estimate for Phase II of the MnROAD program is between $10 and $18 million per year [6].

The authors of these reports note that quantified benefits are not life-cycle estimates because they assume a limited implementation window of ten to twelve years. These estimates do not account for the time value of money. The authors also identified indirect value outcomes that were not easy to monetize, such as improvements to quality from streamlined processes, avoiding mistakes and validating current standards and practices, and demonstrating new tools, procedures, and techniques (see the examples in [6]).As part of the design of MnDOT's new benefit quantification process (December 2015), MnDOT quantified

the benefits of eleven completed research projects [2]. The chosen projects covered topics such as road materials and traffic operations that typically produce quantifiable results. Even within the handful of projects, the data for some projects were more reliable or plentiful than others. The study found that the *potential* three-year cost savings of $70 million for all eleven projects would fund the entire research program for over seven years, and that the research program pays for itself. This study provides an incomplete picture of the overall value of the research program.

The value of MnDOT's entire research program is likely much larger and its benefits more diverse, than the small handful of projects recently assessed.

An important reason for this is that selecting a small number of projects whose outcomes are easy to quantify obscures the value of the other projects in the portfolio. Based on these results alone, some might argue that only those projects with quantifiable and large expected benefits should be selected in the first place. This common approach shows project level benefit-cost ratios far in excess of one. If this is the case, it is hard to think of these as research projects, whose outcomes by definition should be uncertain. There is a tendency to report these "no brainer" investments as research projects. In reality, research outcomes are uncertain and as we discuss above, MnDOT can identify many successful research projects with non-monetizable benefits. MnDOT should systematically report the value of its whole program, including all projects (with their associated costs) and all types of benefits.

MnDOT should report all benefits at the program level because not all not all project outcomes are quantifiable.

Reporting the value of the program using pre-implementation estimates conflates *potential* benefits with *realized* benefits. The results of a research project help improve the estimates of the potential value of implementation. However, this value is only captured after implementation. Otherwise, these benefits are a hypothetical – available but not captured. So justifying the program based on *potential project* benefits is problematic.

The economically quantifiable benefits of research accrue to the program only if the results of research are implemented.

The solution is to implement projects and assess the value of that implementation. The *realized* value of research can therefore only be reported three to five years after a project has been completed, allowing enough time for implementation. MnDOT should therefore report *realized* benefits based on implementation separately from the *available* benefits whose estimates are based on as yet unimplemented research.

Performance and Efficiency Measures
The choice of metrics depends on the nature of research and expected benefits. Previous surveys of DOT best practices have identified several categories of metrics, listed in Figure 2. The study published by the Southeast Transportation Consortium in particular provides a systematic overview of both quantitative as well as qualitative uses of these metrics [7]. Ultimately these metrics can be further consolidated into a small set of categories such as safety, reduced time, labor, materials, environment, and economic opportunity cost. MnDOT has identified many

Figure 2. A comprehensive set of performance categories for DOT research projects and programs, identified in [7, 1]

Enhance Safety
Increase Environmental sustainability
Improve Productivity and Work Efficiency
Reduce Traffic and Congestion
Reduce Construction Costs and Impacts
Reduce Operations and Maintenance Costs
Improve Management and Policy Impacts
Increase Customer Satisfaction
Enhance System Reliability
Expedite Project Delivery
Improve Engineering Design
Increase Asset Service Life
Reduce User Cost
Reduce Administrative Costs

Source: CPCS analysis of literature and best practices

of these in its benefit categories in [2]. However, MnDOT should specify the metrics for project and program

assessment and any goals or targets after evaluating broader strategic changes and the program assessment approaches discussed below.

Assessment and Reporting Recommendations

We recommend the portfolio principle for assessing the value of research. MnDOT should think of its research program as a portfolio of investments (see Figure 3). The objective of a portfolio is to create the most value, by balancing the risks and outcomes of its component assets (research projects in this case). To report value at the program (i.e. portfolio) level, MnDOT must necessarily assess individual projects. The new process for monetizing benefits can easily support this approach. However, MnDOT should also assess the qualitative benefits of each project and elevate these to a program level report. Based on our analysis of DOT practices, previous research by MnDOT and others [1, 2, 8, 9, 7], and our own experience with research programs, we also recommend the following specific mechanisms for MnDOT's performance assessment approach:

- **Frequency**: Conduct assessments and report value estimates and outcomes annually, within 90 days of the end of a fiscal year.
- **Benefit Types**: Clearly separate *realized* monetary benefits from *available* monetary benefits, and also report qualitative or intangible benefits (Figure 2 is an example of the categories) by topic area.
- **Horizon**: Use a rolling average approach, *lagged* for realized benefits through implementation, and prospective for the *available* benefits based on research results (see the example in Figure 3)
- **Time Value**: A dollar in the future is much less than a dollar today. Standardize the adjustment of dollar amounts to account for time value of money and inflation. The formulas and discount rates assumptions can be documented in the spreadsheet templates.
- **Cost Treatment**: Report program expenditures (costs) and monetized benefits separately and in ratios in each fiscal year. Also separate and report both state funds (trunk highway funds), federal / SP&R-II funds, and other grants as applicable.
- **Assumptions**: Transparently document the standard assumptions such as labor hour rates, statistical value of life estimates, discount rates, etc. in technical appendices or methodological annexes. Indicate the rationale for these assumptions, or point to the sources

and bodies that have developed the relevant best practices.

- **Reporting**: Address the reports to the Commissioner, other executive leaders, specialty office directors and high-level managers, and members of the external advisory committee. Make the reports prominent and succinctly written in plain English to be publicly accessible. The Assistant Commissioner supervising the research program and the Director of Research should be the signatories.
- **Case Studies**: Include or provide links to case studies and media articles on selected research projects with clearly documented monetary and qualitative benefits to reinforce the message of value creation.
- **Communication strategy**: Rely on MnDOT's previous findings and initiatives [10, 11, 12] and national best practices [13, 14] for the media, presentation, and content of these reports.

Figure 3 shows a hypothetical example for a portfolio approach to systematically evaluating *both* research projects and the research program. The upper part of the figure shows an example assessment horizon, with a lag of five years for calculating the realized benefits of implementation, and a prospective period of three years for the potential benefits of projects that will be implemented. Annual programs costs are from all sources, including state and federal funds.

The bottom half of the figure shows a hypothetical research program portfolio of three projects. The project level assessment is as follows. Project A has been completed and implemented, with realized monetized benefits as well as some intangible benefits. Project B is a recently completed project that will be implemented, and so it only has potential (monetized) benefits in the current year, and uncertain intangible outcomes (to be determined after this project's results are implemented). Finally, Project C has been completed and implemented, but it only has intangible benefits (ex. validated standards, avoided mistakes).

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Figure 3. An example of how to assess and report research value at the program level. The calculations would make use of adjustments to reflect the time value of money and rolling averages for annual calculations.

Annual Program Costs =
Nominal State & Federal Research Expenditures
in FY10

Annual Realized Benefit =
Time-adjusted rolling five-year average
of implementation benefits

Annual Potential Benefit =
Time-adjusted Rolling three-year average
of potential benefits

FY05   FY06   FY07   FY08   FY09   FY11   FY12   FY13

FY10
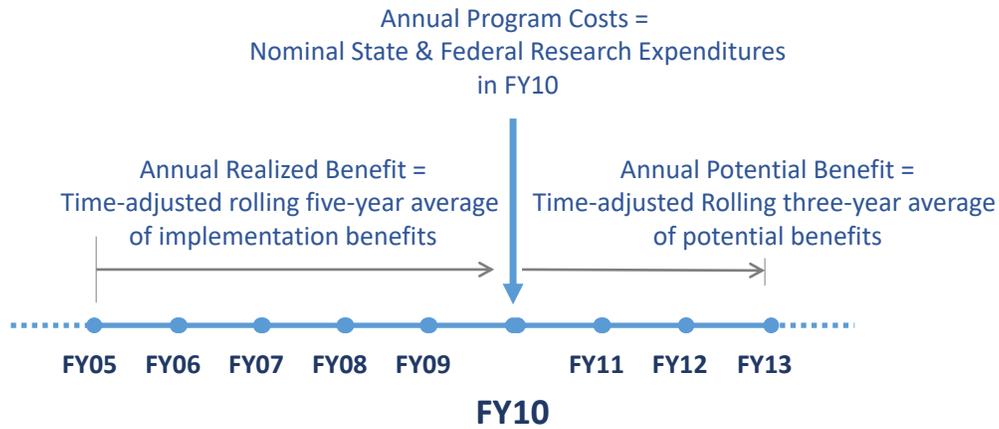
Project	Project Execution/ Implementation Cost in Current Year ($)	Potential Monetized Benefits ($)	Project Status	Results Implemented?	Present Value of Five-Year Realized Monetized Benefits ($)	Present Value of Three-Year Prospective Monetized Benefits ($)	Other Documented Benefits
A	$10,000	$50,000 / year	Completed five years ago	Y	$30,000 over five years at 5% = $165,000	$0	- Better system awareness - Improved accountability
B	$10,000	$5,000 / year	Completed one year ago	N	$0	$5,000 over three years at 5% = $14,000	- Still uncertain
C	$10,000	$0	Completed	Y	$0	$0	- Validated standards - - Mistakes avoided
Program	**$30,000**				**$165,000**	**$14,000**	

The performance of the program made up of the hypothetical portfolio of projects A, B, and C in the current year is given by the following:

→ Current year program cost (research and implementation) = $30,000

→ Present Value of Realized Implementation Benefits = $165,000

→ Realized Program BC Ratio = 4.5

→ Prospective monetized benefits of future implementation= $14,000

→ Prospective Program BC Ratio = 0.47

→ Other program benefits: better system awareness, improved accountability, validated standards, mistakes avoided

Source: CPCS Analysis

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At a program level, the current annual cost of the program is $30,000 (the sum of project-related costs or implementation efforts in that year). The present value of realized benefits over the last five years is $165,000. This gives a realized program BC ratio of 4.5 in the current year.

The present value of prospective implementation is $14,000, giving a potential BC ratio of 0.5 (note that a program level potential BC ratio could be less than one and still justified). Finally, the portfolio has intangible benefits in terms of better system awareness, validated standards and mistakes avoided.

The portfolio approach thus shows how MnDOT can assess projects to develop a program level assessment. If MnDOT chooses to move in this direction for its program assessment, this type of approach can be specified in more detail.

NEXT STEPS

Our project team has been working in parallel on Phase 2: Strategic Framework and Principles to better coordinate our analysis with the Phase 3: Performance and Efficiency Measures and Targets discussion summarized in this document. The associated deliverable for Phase 2 is Working Paper 2: Strategic Framework and Principles. The submission of Working Paper 3 (this document) marks the submission of deliverables for both these work phases. We look forward to receiving feedback on both Working Papers 2 (accompanying) and 3 (this one) in our meeting with the project Technical Advisory Group planned for July 20. Based on the discussion and outcomes of the TAG meeting, we will move to further develop the Draft Strategic Research Framework and Plan.

EXAMPLES

Our recommendations above for program assessment are based on a synthesis of best practices nationwide. We include several examples that are publicly available, and have also requested internal documents from a number of sources.

Guidance
Ohio DOT makes its guidance, forms, and templates publicly available.

Detailed Guidance on Implementation and Technology Transfer for Ohio DOT research projects, as published in the RD&T's Manual of Procedures:
http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/researchmanual/Chapters/ResearchManual.pdf

Multiple formats for tracking project progress and presenting the results and benefits for various types of research projects:
http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/researchmanual/Pages/ODOT%20Research%20Forms.aspx

Protocol for Research Value Determination at Indiana DOT. See appendices in
http://www.dot.state.mn.us/research/documents/Best_Pract_Guide_ResearchBenefits_Final_06_27_13.pdf

Program Assessment

Detailed program accounting information:
http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/Annual%20Report/Fiscal%20Year%202013%20Annual%20Report.pdf

Detailed Examples of Assessments for Quantitative and Qualitative Project Benefits
https://www.ltrc.lsu.edu/pdf/2014/FR_512.pdf

Utah DOT Program Assessment Report
https://www.udot.utah.gov/main/uconowner.gf?n=1339002847990478

Louisiana Transportation Research Center's Implementation Program Impacts:
http://www.ltrc.lsu.edu/pubs_implement_impact.html

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