Value of VTrans Research: Qualitative and Quantitative Analysis

Dr. Gregory Rowangould

Mitchell Robinson

University of Vermont Transportation Research Center

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Gregory Rowangould (ORCID 0000-0003-3315-5028) Mitchell Robinson (ORCID 0000-0002-3709-638X)	

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16. Abstract

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Abstract

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1 Introduction

The Vermont Agency of Transportation (VTrans) contracted with the University of Vermont Transportation Research Center (TRC) to develop a method for assessing the value of external research projects sponsored by the Agency. Information about the value of its External Research program is used to support continued program funding, enhance accountability, track program performance, help ensure strategic needs are being addressed and communicate the value of the agency's sponsored research to management, policy makers and the public. While it is well established that there is great value in and need for publicly funded research, including in the transportation sector, assessing the value of benefits linked to a research program or project is extremely challenging. The benefits of some research outcomes are intangible such as new ideas and knowledge produced by fundamental or "basic" research or impacts on workforce development from the involvement of students in university led research. The benefits of more applied research outcomes are indeed tangible, but are also often difficult to quantify. Many benefits are only realized after research findings have been implemented or applied in some way which may take years. The size of benefits will also depend on how widely and for how long the findings are implemented, factors that are often very uncertain. Furthermore, the value of many social and environmental benefits can be extremely challenging to estimate. With these challenges in mind, VTrans was particularly interested in the development of qualitative methods for assessing the value of its external research projects.

When we set out to begin our study, we planned on completing four main tasks:

1) A brief literature review of prior transportation research evaluation projects sponsored by state departments of transportation,
2) A survey of VTrans project champions (agency staff who have advocated for and then oversee specific research projects) to collect information on the outcomes and benefits of projects completed between 2016 and 2020,
3) Demonstrate the use of an existing quantitative benefits estimation tool using data collected from the survey in task 2, and
4) Develop a qualitative benefit assessment tool and demonstrate how it works.

We re-evaluated and eventually changed the course of the study after completing the literature review and survey of VTrans project champions. Our review of the literature identified numerous, unresolved, challenges to the practical implementation of most quantitative research valuation tools – including those that were considered for demonstration in task 3. Furthermore, our survey of VTrans project champions yielded a very low response rate and the few responses we did receive were generally lacking useful information. Based on these interim outcomes, the project scope was revised to replace tasks 3 and 4 with two new tasks:

a) Identify information gaps that currently limit the assessment of quantitative and qualitative research project value, and
b) Create a quantitative and qualitative research project assessment framework or tool that VTrans could implement.

This report describes our findings from the original Tasks 1 and 2 and the added Tasks A and B. Despite our study's mid-course change in direction, we were able to develop a practical and useful framework for assessing the value of individual VTrans sponsored research projects the overall VTrans research program. Our recommendations and proposed assessment framework are grounded in the literature pertaining to the assessment of research value but diverge from most prior studies that have set out with similar objectives as ours. There is a broad consensus in prior research that the value of many

transportation research outcomes are difficult or impossible to accurately quantify, and therefore some type of qualitative assessment is required. There are also a number of outcomes that can be measured and quantitatively evaluated; however, we find that most of the approaches previously described in the literature would be very difficult and costly to implement and introduce uncertainties that are largely unaccounted for. Therefore, we provide an assessment framework that works for any type of transportation research project and any type of benefit. Our recommended assessment framework is simple, flexible, can be implemented with limited resources and should provide VTrans with new and useful information to assess the value of its research program and communicate this information to management, policy makers and the public at large.

2 Literature Review

There is a vast collection of literature on the valuation of research and development activities, including entire academic journals devoted to this topic[1]. For this project we were only asked to perform a scan of several recent research valuation studies conducted by or for state DOTs. A technical memo with the results of the scan were provided to VTrans in January 2022. Unsatisfied with what we learned from reviewing this limited set of studies, we also performed a brief review of academic literature published in peer reviewed journals and other reports focused on valuing state DOT sponsored transportation research. We excluded a review of the broader research valuation literature, which may yield additional useful insights but was beyond the scope of work and resources available for this project.

Overall, we find that recommendations for assessing the value of state DOT research programs and the challenges in implementing them have changed little over the past four decades. In 1979, a paper published in the Transportation Research Record argues for the importance of measuring research benefits to justify continued support for state DOT research programs and calls for a quantitative assessment of outcomes that improve state DOT operations (Peterson, 1979). Peterson's recommendations focus on valuing results stemming from the implementation of research findings and is biased towards applied research that can achieve benefits in the near term. For example, Peterson suggests selecting research projects based on the probability of finding a solution and the expected benefit cost ratio that would result from implementing the solution. Subsequent research has grown to embrace a more expansive view of the research that can benefit state DOTs, including riskier, longer term and more basic research (Concas et al., 2002; Deakin & Yip, 2018; du Plessis & Krüger, 2018; Love, 1981); however, most published studies still recommend performing a quantitative economic assessment, (e.g., estimating cost benefit ratios or the rate of return on investment) of implementable findings that can be quantified (Concas et al., 2002; National Cooperative Highway Research Program et al., 2008; Sabol, 2001; Saha et al., 2019; Shackleton & Young, 2010; Yoon & Dai, 2018).

A significant factor affecting formal economic analysis or other quantitative analysis of the benefits stemming from implementation or application of transportation research findings is that the data to support them is often lacking, difficult to acquire or highly uncertain (Concas et al., 2002). Additionally, it is often difficult to disentangle the contribution of a specific research project's findings to the eventual implementation of a new product, process or policy that may have been influenced from the findings of a combination of studies and other forms of knowledge generation (du Plessis & Krüger, 2018; Sabol, 2001). Furthermore, the timing of a potentially lengthy stream of future benefits further complicates many economic appraisals (Concas et al., 2002). Different assumptions about when benefits will begin accruing, for how long they will accrue and the discount rate that should be used to compare future benefits to present research investment costs can have a large impact on estimates.

While the vast majority of studies support a quantitative, typically financial, assessment of benefits for projects that result in implementation of research findings, there is little evidence that this is a practical, cost effective and useful approach to evaluating routine state DOT sponsored research projects. Many studies have created worksheets and simplified forms to collect quantitative information to support a cost benefit or similar economic appraisal; however, the mechanics of performing a cost benefit analysis are not where the main challenges lay. Acquiring necessary input data is the main barrier. In most cases, worksheets and similar tools that have been used in prior studies provide little guidance on how to collect the required information or evaluate its quality. For example, some studies rely on project managers and principal investigators to simply estimate costs and the value of implementation benefits

[1] For example, the journal Research Evaluation, https://academic.oup.com/rev

through a survey conducted sometime after a study has been completed (Anderson, 2016a; Saha et al., 2019). At best, these estimation methods result in poor survey response rates that prevent the quantification of benefits or they create estimates of questionable validity. More robust assessments that quantify some benefits and project outcomes are possible and have been completed (see FHWA's website on Research and Technology Evaluation Program Publications)[2], but they often require significant resources, are conducted after extensive implementation or pilot testing, and are essentially a research project unto themselves.

What to do about outcomes that do not lend themselves to quantification is more varied. While it is appropriate for state DOTs to place significant emphasis on applied research projects that are likely to produce findings that can be readily implemented to address current operational challenges, riskier, more fundamental or "basic" research, and longer-term projects can also provide substantial benefits (Deakin & Yip, 2018; Love, 1981). As one moves away from low risk applied research projects, findings are less likely to be immediately implementable and may be increasingly intangible or difficult to quantify. For example, student involvement in academic research and its trickle down of ideas and new methods into the classroom is one of, if not the largest, source of state DOT workforce development even though it is rarely emphasized in the evaluation of DOT research programs (Deakin & Yip, 2018; Sabol, 2001). Findings from more basic research are also less likely to be implementable because they are intangible. For example, basic research can lead to new research directions or ways of thinking about a problem that could eventually lead to substantial benefits to agency operations and society (Deakin & Yip, 2018; Love, 1981). Indeed, a comprehensive review of the benefits of basic research finds that while difficult to measure the return on investment appears to be very large (Salter & Martin, 2001). Less applied research also faces a greater risk of failure, which comes with its own albeit difficult to measure benefits (i.e., the value of learning by doing). Even applied research projects are likely to produce a wide range of non-implementable and difficult to quantify benefits, particularly those focused on social benefits rather than direct benefits to agency operations.

Realizing that not every project or research finding lends itself to quantification or valuation, most studies recommend supplementing what can be quantified in terms of monetary value or concrete operational improvements (e.g., number of crashes avoided) with alternative evaluation methods or data. Three general approaches are often recommended: (1) scoring and rating schemes, (2) enumeration of various outcomes that are not directly tied to implementation, and (3) peer review.

Scoring and rating schemes often depend on agency project managers and sometimes principal investigators to score or rate various project outcomes using a numeric or A – F grading scale. External experts or peer reviewers may also be asked to do the same. For example, in addition to performing a cost benefit analysis, the Utah DOT grades projects using an A (major impact) to F (tasks not completed) scale based on the judgment of project managers (Anderson, 2016a). One strength of this approach is that it's possible to evaluate outcomes that are difficult to quantify either because they are intangible or because of a lack of data or resources to perform a more in-depth analysis. A significant weakness in this approach is that judgements used to score difficult to quantify outcomes are necessarily subjective and dependent on the specific reviewer and highly uncertain (Nadafianshahamabadi et al., 2017; Peterson, 1979). For example, what counts as a "major" impact to one person (earning an A on Utah's scale) may be considered a "significant" impact by another (earning a B score on Utah's scale). Simply describing how research findings impacted a decision, process or technology would be far more informative than an A or B rating.

[2] https://www.fhwa.dot.gov/publications/lists/008.cfm

A more common recommendation and one widely used by federal research sponsors is the enumeration of various project outcomes that go beyond implementation benefits, including items such as the number of students supported by the research project, number of publications created, and the number of patents filed (Deakin & Yip, 2018). These and other outcomes are indicators of workforce development and knowledge generation that occur independent of implementation and are considered important outcomes of publicly funded research.

Another very common and flexible approach to evaluate individual research projects is a peer review or exchange (Sabol, 2001). A peer review relies on experts, typically external to the sponsor and researchers, to provide an independent evaluation of research findings. Peer reviews can be confidential, like those that occur in the evaluation of research proposals and journal publishing decisions or as open peer exchanges. In either case, peer reviewers are typically provided criteria to guide their evaluation such as the validity of the research methods and findings and the study's contribution to knowledge. The outcome of a peer review is typically a narrative description of a study's strengths, weaknesses, and contributions with supporting evidence to back up each finding. There are several key differences between peer review and expert grading. The use of experts who did not participate in the project and who do not have any potential conflicts of interest with the research sponsor or the research team increases objectivity. Narrative responses provide more information than numeric or letter scores that may have different meanings to different evaluators. Furthermore, peer review findings, both critical and positive, are generally expected to cite supporting evidence to back up claims which may reduce subjectivity.

Our overall impression from this brief review of the transportation related research assessment literature is that simpler is generally better. For projects where implementation is expected or indeed occurs, many benefits can be quantified but its unclear that the costs of carrying out a robust economic appraisal are justified for most projects. It may be necessary to evaluate the economic impact of implementing research findings, but that is a different task than evaluating the value of funding research projects. For the many projects where benefits are intangible or too difficult to quantify, scoring and rating schemes appear to cloud the picture of a project's value rather than elucidate it. Simply understanding if and how research findings have made an impact appears may be more valuable.

3 Survey of Project Participants and Use of Quantitative Assessment Tools

We developed a survey in Qualtrics and distributed it to VTrans project champions and TAC committee members (Appendix I: Project Champions/Participant Survey). The objectives of the survey were to attempt to collect data to demonstrate the use of a quantitative project assessment tool developed by the New England Transportation Consortium (NETC) and to evaluate what types of qualitative benefits a project might generate.

The NETC benefit assessment tool was adapted from the Minnesota Department of Transportation's quantitative benefits tool to fit the specific needs of the NETC. The tool provides a spreadsheet-based entry format for evaluating the quantitative benefits stemming from transportation projects that apply new methods, processes or technology. The tool has nine cost categories including, Engineering and Administrative, Construction, Operation and Maintenance, Lifecycle, Road User, Safety, Environmental, Risk Management, and Other. The user begins the assessment by entering general information describing the project location, analysis time period and discount rate to use. Additional information is then entered on separate worksheets corresponding to each cost category. These worksheets ask for values that correspond to current practice and those that correspond to implementing new methods, processes or technologies. The information entered into each sheet is used to calculate an overall cost benefit ratio for implementing a project with new methods, processes or technologies.

Our survey had a very poor response rate with 22 total interactions, but only 2 respondents completed most of the survey (Table 1). The two respondents who completed most of the survey provided some qualitative information about potential implementation benefits but did not provide any quantifiable information. The low response rate and lack of quantitative information precluded the use of the survey data for evaluating and demonstrating the use of the NETC tool. The two responses received did provide some useful qualitative information.

Table 1 Stated benefits from survey of project champions and participants.

Project	Stated Benefits	Challenges or Further Needs
18-3:HSM Calibration	1. Not fully implemented, but used for a few safety evaluations as part of traffic impact studies.	Need for a spreadsheet tool or safety management software package to fully implement.
	2. Potential for monetary benefit due to better understanding of project costs and safety benefits. Safety project selection mainly governed by B/C ratio, so calibration may lead to lower cost projects or improved safety benefits.	
20-2: Snow/ Ice Correlations	1. The standard was changed, increasing confidence in predicted cost variability.	None Stated
	2. Consider in future budgeting.	

3.1 Demonstrating NETC Tool Using Existing Data

Since we were unable to collect any quantitative information through our survey, we then decided to evaluate documents describing the outcomes of five recently completed projects with the aim of identifying information required for applying the NETC tool and identifying data gaps. We selected five

projects that spanned a range of topics and had different expectations regarding implementation and the type of benefits they would produce. The five projects were:

- 18-1: Radio Frequency Identification (RFID) Technology for Transportation Signage Inventory Management
- 18-3: HSM Calibration Rural Two-Lane Roads
- 19-2 Quantifying Nutrient Pollution Reductions Achieved by Erosion Remediation Projects on Vermont's Roads
- 19-3: HIVE 2.0: Updated Culvert Inspection Vehicle
- 20-2: Snow and Ice Correlation

None of the projects we reviewed contained information that we could use in the NETC tool. The NETC tool requires quantities such as hours and type of labor, amount of construction materials, the number of vehicle crashes and mass of environmental pollutants along with associated costs. While each project appears to have accomplished its stated objectives, estimating and reporting the data required by the NETC tool was not a research objective.

For example, Project 18-1 tested and developed a process for inventorying roadway signs with RFID tags. This could save VTrans time in managing signs and reduce the agency's operational costs; however, the research objectives were focused on testing and developing the technology rather than studying how much VTrans could save by deploying RFID technology. While the final report for Project 18-1 contains unit cost estimates for some of the equipment required and some estimates for the amount of labor required to set up the equipment, total cost estimates for deploying the technology statewide or in more limited scenarios are not provided (e.g., how many signs would need to be replaced and how long might this take? What are the maintenance and operation costs involved?). Furthermore, there is no cost information about current sign management practices for comparison.

Similarly, the other four projects appear to have produced useful and implementable findings but estimating implementation costs and the savings compared to current practices were not study objectives and therefore relevant quantitative data needed for the NETC tool was not produced. Project 19-2 demonstrates a method for more accurately estimating phosphorous pollution from erosion along culverts and gullies using lidar, allowing VTrans to better understand the scope of this environmental concern. The project was not intended to identify mitigation measures or estimate cost of phosphorous pollution damages. Project 20-2 developed a tool that VTrans can use to better predict winter snow and ice control costs and optimize winter maintenance investments overtime. The cost savings from the ability to more accurately estimate winter maintenance budgets or the potential savings that could be achieved from optimization of winter maintenance investments was not a study objective and no relevant data were produced that could be used in the NETC tool to estimate these. Project 18-3 calibrated crash modification factors for Vermont roads, which provides VTrans with a more accurate method of evaluating crash risks and the effectiveness of applying various safety countermeasures. The study did not focus on the number of crashes that could be avoided by better understanding risks and the efficacy of countermeasures – the information required for using the NETC tool to evaluate safety projects. Finally, Project 19-3 developed an improved robot for inspecting culverts. The robot increases VTrans' inspection capacity by reducing inspection time which means more culverts can be inspected and potentially replaced or repaired before they fail resulting in cost savings from reduced construction costs, property damage and injuries. Estimating the number of culvert failures and associated costs that could be avoided through increased inspection capacity was not a study objective and therefore no relevant data were produced that could be used with the NETC tool.

Each of the above projects produced valuable findings, many of which appear to be implementable or could be implemented with a limited amount of additional research and development work. It also seems likely that implementation would result in cost savings to VTrans as well as produce social benefits through improved roadway safety and pollution reduction. Based on our analysis of a small sample of recent research projects, a quantitative analysis of the potential implementation benefits of research findings and outcomes using the NETC or similar tools is limited by the absence of necessary data. These data include information about relevant baseline conditions (e.g., current snow and ice control costs or crash risks) and forecasts of implementation outcomes (e.g., the change in snow and ice control costs or crash risk). Including the collection of baseline data and forecasting of implementation outcomes as a research project objective may be an effective means to generate data for conducting a quantitative economic assessment for projects where this is desirable. However, it is also important to understand that substantial research effort may be required to produce these additional data.

Our review of the NETC tool and these VTrans projects support our conclusions from the literature review. While many state DOT research projects produce implementable findings, an economic analysis of the value created by these projects would be a complex and expensive undertaking in most cases with unclear benefits for the purpose of assessing the value of research programs and projects. It may be, and in many cases is, advisable to study the costs and benefits of implementing a new innovation or policy that may have been born from the outcome of a research project, particularly if costs are large and decisions are relatively irreversible; however, such assessments should primarily be undertaken to guide implementation or policy decision making rather than assessing the value of research program investments.

4 Qualitative Project Assessment

Based on our review of prior research, the agency's current procedures and a sample of recent research project reports, we recommend a mostly qualitative research evaluation framework that collects information in a structured way throughout a project's lifecycle. The framework can be used to evaluate individual projects as well as the agency's overall research program. The framework is designed to provide standardized information that can be used to report research program outcomes, track research program trends and identify research program gaps. The framework is also designed to minimize reporting burden in order to increase the number of projects with complete project information. The framework draws on several common findings from our literature review:

- Many state DOTs fail to routinely collect data about projects in their research programs, including the research need, original study intent and eventual outcomes and possible implementation. This information by itself is extremely valuable for assessing the performance of research programs and communicating their value.
- While many projects that are currently supported by state DOT research programs result in implementation and quantifiable outcomes, estimating the value of these outcomes is a non-trivial task that in practice often requires significant effort, time and resources.
- The time and resources allotted to conduct research program and project assessments are often limited, so assessment tools need to be simple and easy to use.
- Scoring and rating schemes are often considered subjective and they obscure otherwise useful information.
- Intangible benefits and those that are difficult to value such as knowledge creation from basic research and workforce development from student involvement in research are routinely assessed through enumeration of research products such as number of journal and conference papers and the number of students involved in the research project or through external peer review of research findings. These are relatively simple methods and common practice at the federal level.

4.1 Recommended Framework for Assessing the Value of Research Projects and Programs

We recommend a simplified, largely qualitative, framework for assessing the value of VTrans research projects and the overall research program. The assessment framework focuses on collecting information about the main objectives and benefits of sponsored research projects and the degree to which successful projects influence decision making or lead to the implementation of new methods, processes, tools and technologies. The assessment framework also collects information about indirect and intangible benefits stemming from less applied and more fundamental or "basic" research including workforce development impacts and the publication of research findings.

The flow chart in Figure 2 provides a high-level overview of the logic guiding our assessment framework. The assessment is broken into three phases. The first phase begins by evaluating information created during the generation of a research idea, including the problem statement and research proposal. The problem statement should, following current VTrans practice, define the primary objectives of the research to be undertaken and the benefits of doing so. Objectives should include research questions to be evaluated and specific products to be produced, if any. At this stage, it is also useful to identify how findings from the successful completion of each research objective are expected to be used. For example, is the objective of the research to produce a new technology that VTrans will consider implementing or new information that will inform a critical policy or planning decision? Or is the objective more intermediate in nature; for example, to better understand the cause of problem or

survey the range of possible solutions to a challenge? Likewise, the benefits expected to stem from the successful completion of the research project should be defined. For example, is the knowledge generated by the project expected to reduce construction costs, reduce the number of pedestrian-involved crashes or reduce greenhouse gas emissions? Proposals generated in response to a problem statement should be evaluated to ensure their scope of work addresses each of the identified objectives and that the methods are sufficient for generating decisive outcomes. If proposals meet these two criteria, then VTrans should expect value to be created by the research. Research projects where objectives are not well defined and associated with specific benefits and potential uses are less likely to create value and are more difficult to gauge success.

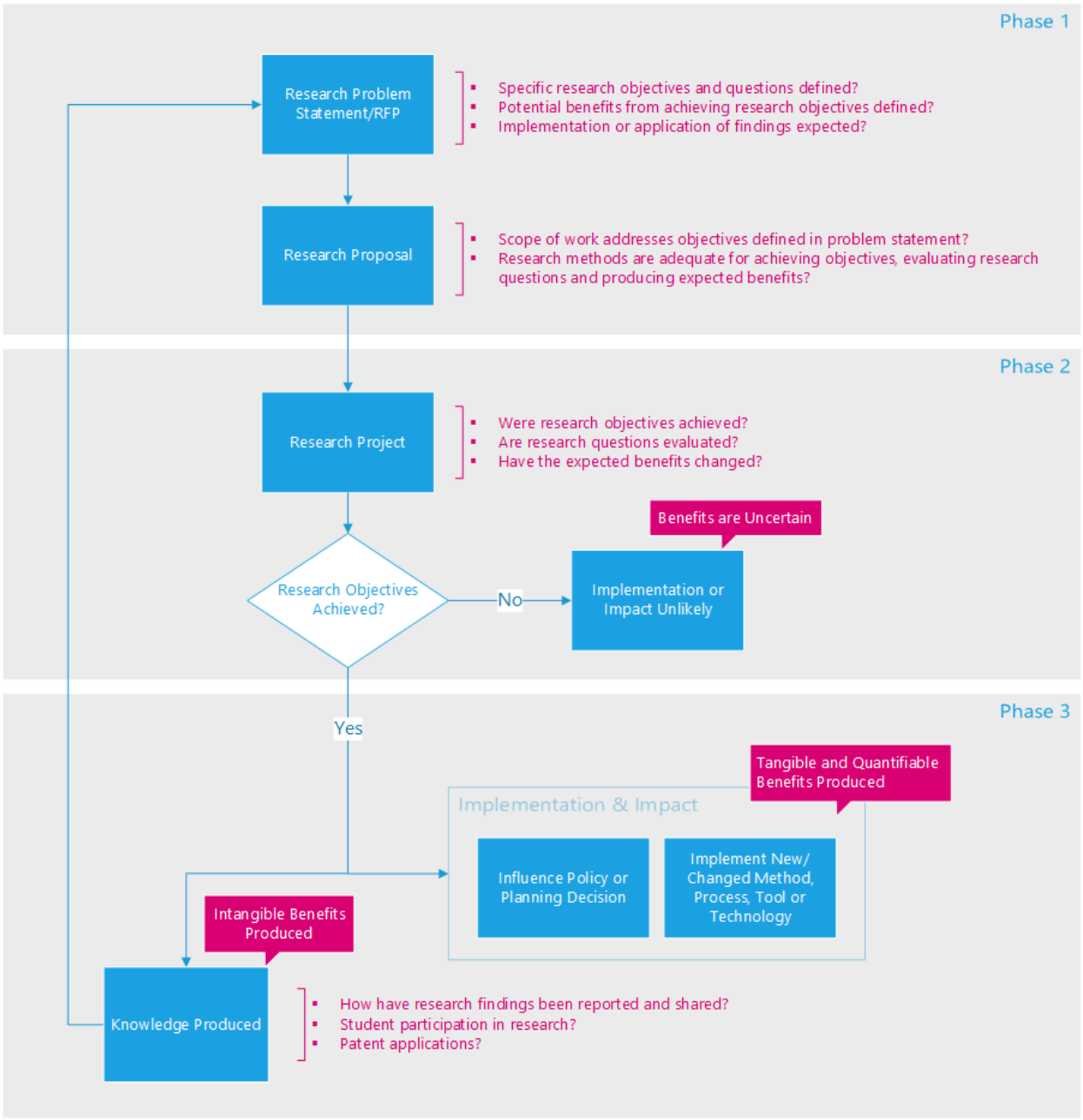

Figure 1 Overview of Research Value Assessment Framework

The second phase in the assessment framework occurs at the completion of the research project (or during interim reporting periods). In this phase, research findings and outcomes are evaluated against the project's original objectives. Here, the extent to which objectives have been met is determined.

A successful research project achieves its objectives and produces new information that can be used to evaluate previously defined research questions or hypothesis even if the research findings are unexpected or counter to prior expectations. For example, a project may find through a series of pilot studies that a proposed new type of traffic safety countermeasure is ineffective. The research objectives are achieved because the research produced useful information for evaluating the effectiveness of the

new traffic safety countermeasure. Alternatively, if insufficient data were collected from the pilot studies to evaluate the effectiveness of the new traffic safety countermeasure due, for example, to equipment failure or a flaw in the design of the study, the research objectives would be unmet and its unlikely that the project would produce benefits or result in implementation. For objectives that are not fully met, additional information is collected to understand what went wrong, adjust the study methods or inform the design of future research projects. Expectations about the project's benefits are also re-evaluated. For example, given the research findings, are the potential benefits now greater or less than prior expectations? If objectives have been met, the research project can be expected to produce benefits although they may still depend on future implementation or application which is considered in the final phase of the assessment framework.

The final phase of the assessment evaluates the extent to which research findings and outcomes from projects that successfully accomplished their research objectives are implemented or applied. Not all research is expected to result in implementation of specific technologies or be applied to a specific purpose, but many state DOT projects are. When implementation or application of research findings occur, tangible benefits are also produced and can be more accurately described and possibly quantified. The assessment framework evaluates the extent to which benefit expectations have changed from the prior assessment phases and also collects additional information about specific benefits, including any that have been quantified. While in most cases it is possible to quantitatively estimate the magnitude of benefits created by implementation or application of research findings and use these estimates in an economic assessment of the value of the research project or its innovations, unless one of the project's research objectives is focused on producing these data they are unlikely to be available. A robust and defensible assessment of the impact and value of the implementation or application of an innovation stemming from a research project should, in most cases, be defined as an independent research project given the substantial additional research effort that is typically required. In this final phase, the assessment also collects information about the students involved, if any, in the research project which serves as an indicator of potential workforce development benefits. Additionally, information about publications, presentations, patent applications and other knowledge and technology transfer activates is collected as an indicator of the intangible knowledge generation benefits created by the project.

4.2 Assessment Tool

We created a Microsoft Excel spreadsheet tool to implement the framework described above. The tool contains fields to collect basic information about each research project such as its title, relevant programmatic area within VTrans and which overarching VTrans goal the research addresses. These fields and their options can be easily updated in the excel tool as necessary to align with changing agency goals and structures. There are then three sections that correspond to the three assessment phases discussed above: research problem statement/proposal, research findings, and implementation and application. We use a mix of pre-populated dropdown menus and text fields for narrative responses. The dropdown menus are designed to reduce reporting burden and provide some scaffolding for the information requested. Narrative text fields are included to collect additional detail and context corresponding to the responses selected in the dropdown menus. The data collection fields are laid out on a single worksheet so that how a project progresses from its original intent to its final implementation or application can be seen and evaluated in one place. A new workbook should be created for each project that is evaluated.

The spreadsheet tool is simple and its main purpose is to structure the collection of relevant information to implement our assessment recommendations. The information required to complete the assessment will come from various research participants including agency staff promoting and overseeing the

research, technical advisory committee members, researchers conducting the work, and personnel involved in the eventual implementation and application of research findings. The spreadsheet tool is designed to be the repository for the collected information rather than a tool for its collection. The tool could be further developed into an internet-based questionnaire or form designed to collect relevant information from those who are in the best position to provide it. For example, while a project's technical advisory committee may be able to evaluate if the objectives of a research project were met, the project principle investigator would likely need to provide an accounting of student involvement, publication and other outreach activities.

An evaluation of research findings and their potential benefits could also be accomplished or supplemented by an external peer review of the final research report. In most cases, the extent to which research objectives are met is along a continuum that depends on various factors including an assessment of the quality of evidence or information produced and the degree to which the scope of work remained on task. While program managers should be able to determine the extent to which tasks were completed, determining the quality (validity, reliability and accuracy) of research findings may require a review by an independent subject area expert. It may also be beneficial to collect assessment information about research outcomes (objectives met and expected benefits) from technical advisory board members and the researchers conducting the research to determine if there is consensus in the outcomes and if further external review may be necessary.

4.3 Assessment Tool Demonstration

Here we provide a brief demonstration of the assessment tool for the evaluation of a recently completed VTrans research project. Figures 3 to 6 are screen shots from the Excel workbook tool. The screenshots are provided to give the reader a sense of how the workbook is organized and the information requested. For this demonstration we evaluated the final report and other deliverables produced by Project 19-3 "Hydraulic Inspection Vehicle Explorer (HIVE) Culvert Upgrade". We did not review the original problem statement, we assumed the objectives and benefits described in the proposal match those in the request for proposals. The assessment of project outcomes is our own and only based on a scan of the final report. The technical advisory committee likely has more information to gauge the extent to which objectives were met and if benefits are as expected or not. Finally, we have no information about the current implementation status of HIVE, but we assume implementation is pending. We have also provided the Excel workbook file for the assessment tool, which provides a more complete picture of the tool and its functionality.

Project Title:	Hydraulic Inspection Vehicle Explorer (HIVE) Culvert Upgrade
Project Number:	19-3
Which AOT division does this research pertain to?	Highway
Which AOT Strategic Goal does this research most closely align with?	Grow Vermont's economy by providing a safe, reliable, and efficient transportation system in a state of good repair.
Instructions:	Complete each section at the indicated point within the research lifecycle and update as nessary if new information becomes availble. Additional rows can be added where lists of individual items are requested by right clicking on the row number and inserting a new row.

Figure 2 Basic Project Information

Assessment Category	Phase 1 - Research Proposal/Idea/RFP	
Assement Time Period	Date (month/year) of Project Solicitation/Idea Generation	
	Nov-19	
Research Objectives	List and briefly describe each research objective (e.g., research or policy questions to be evaluated; development of new analytical methods, processes, tools or technologies; data collection; literature review or scan; or other specific purposes of this research).	Implementation & Impact Expectations [select one]
1	Design, build and test prototype inspection vehicle	Intermediate Reseach Step - Informs Research Effort
2	Fabricate and deliever a functional culvert inspection vehicle	Implement New Method, Process, Tool or Technology
3	Estimate benefits and provide implementation guidelines	Implement New Method, Process, Tool or Technology
Expected Benefits	List and briefly describe each benefit expected from this project if the research objectives are achieved.	Benefit Category [select best match]
1	Reduce risk of injury and damage to property from culvert failures	Increase Traffic/Roadway Safety
2	Reduce maitenance/inspection costs	Reduce Construction, Operations and Maintenance Costs

Figure 3 Information from Phase 1

Assessment Category	Phase 2 - Completed Research Project/Report	
Assement Time Period	Date (month/year) Project Completed	
	Apr-21	
Research Objectives	Were objectives met? [select one]	If not met or partially met, briefly describe why (e.g., project tasks not completed, insufficient data or methodology, inconclusive findings, etc.).
1	Yes	
2	Yes	
3	Partially	A technical comparison of new HIVE to prior robot is provdied, but cost savings or other benefits are not quantified. A rough outline of implementation steps are provdied, but not a detailed guide to implementation and use.
Expected Benefits	Benefits as expected? [select one]	If not as expected, briefly describe why. (e.g., benefits appear greater or less than expected prior to research, different category of benefits than anticipated, benefits remain unclear, etc.)
1	As Expected	
2	As Expected	
Student Participation	Students Directly Funded/Supported by Project (e.g., gradaute research assistants)	Other Students Participating in the Project (not directly supported by the project)
Degree Program:		
Undergradaute Students	0	1
MS Students	2	0
PhD Students	0	0
Journal Publications	Full Citation for Each Published Article	DOI or URL to Article
1	Burton, J., D. Orfeo, L. Griswold, S. Stanley, M. Redmond, T. Xia, D. Huston. (2021) "Inspection Vehicle with Improved Telemetry Range". Transportation Research Record. 2675 (11), pp. 946-54.	https://doi.org/10.1177/03611981211021850
2		
Conference/Meeting Presentations	For each, provide the presentation title and the name, location and date of the conference or	
1	Burton, J., D. Orfeo, L. Griswold, S. Stanley, M. Redmond, T. Xia, D. Huston. (2021) "Inspection Vehicle with Improved Telemetry Range". Presented at the Transportation Research Board Annual Meeting, Washington, D.C.	
2		
Webinars and Other Knowledge Transfer and Outreach Activities	For each activity, provide a breif description of the activity, the location and date.	
1	Burton, J., D. Orfeo, L. Griswold, S. Stanley, M. Redmond, T. Xia, D. Huston. (2021) "HIVE 2.0: Updated Culvert Inspection Vehicle". Poster presented at Vermont Agency of Transportation Annual Research Symposium.	
2		
Patents/Patent Applications	List each and their current status	
1		
2		

Figure 4 Information from Phase 2

Assessment Category	Phase 3 - Implementation & Impact		
Assement Time Period	Date (month/year) Implementation Status Last Reviewed		
	Aug-22		
Research Objectives	Implementation & Impact Status [select one]	Date (month/year) first implemented/impacted decision making	Briefly describe how research findings related to each objective were implemented or informed deicsion making (if applicable) or describe why implementation or the ability to inform decisions has not occurred or is no longer expected to occure.
1	Not Applicable to this Objective		
2	Implementation Pending Other Contingencies		Research developed and provided VTrans with a new HIVE vehicle. Unclear if it has been used?
3	Implementation Pending Additional R&D		Guidelines for producing additional HIVE vehicles provdied. Unclear if VTrans has attemepted to build additional HIVE vehicles.
Expected Benefits	Benefits from Implementation & Impact [select one]	Describe benefits of implementation or impact on decision making, including quantitative information if available (e.g., cost savings, number of crashes avioded, reduction in air pollutant emissions, etc.)	
1	N/A Implementation/Impact Pending		
2	N/A Implementation/Impact Pending		

Figure 5 Information from Phase 3

In the example shown above, the HIVE project was expected to result in the implementation of a new and improved culvert inspection vehicle that would reduce the cost of culvert inspections, increase safety and further reduce maintenance costs by allowing for more frequent and higher quality inspections. The project also aligns with the agency's goal of "Grow(ing) Vermont's economy by providing a safe, reliable, and efficient transportation system in a state of good repair." The final report indicates the objectives were largely met, although the implementation guidelines and benefit estimation may be less than what was expected. The benefits are expected to be unchanged from the original expectations given that the inspection vehicle that was created achieved the expected performance benchmarks. If, and when, the HIVE is deployed by VTrans the magnitude of the benefits should become clearer and it may be possible to estimate the amount of time saved during inspections or the additional number of inspections that are completed annually. Estimating the impact of time savings and the additional inspection capacity on maintenance cost savings and improved safety would likely be possible, but much more challenging. The project also funded two graduate research assistants and one undergraduate student was also involved and therefore may have a positive impact on transportation workforce development in Vermont. Furthermore, the results of the research were published in an academic journal and presented at two venues, facilitating knowledge transfer which may inform additional research and implementation activities that result in further benefits.

5 Conclusions

A review of prior research and valuation studies and a sample of recent VTrans research project reports indicate that state DOT sponsored research projects are likely to produce a range of benefits, most of which are difficult to quantitatively evaluate. Benefits from research stem from the production of knowledge that may not have an immediate implementable application which makes value assessment difficult. Knowledge generation is often evaluated through the activities related to sharing and transferring it, including the publication of technical reports and peer reviewed journal articles and professional and scientific presentations. The impact of these knowledge transfer activities may also be considered, such as the number of references to published reports and papers or the attendance at presentations. Research projects often involve student research assistants who gain valuable knowledge and training during the project and faculty who pass on knowledge gained into classroom instruction. In these ways, research projects also contribute to transportation workforce development but measuring the value in terms of dollars would be extremely challenging. Research projects may also produce findings that can be implemented at the end of the project or with a modest amount of additional research and development. There is potential to conduct economic appraisals of the benefits stemming from the application research findings, but numerous factors often make this a challenging and costly task. Implementation can take years from when a research project is completed. How widely and quickly an innovation is implemented will also have a significant impact on the size of the benefits produced relative to research costs. Many innovations that are applied can be traced back to the findings of multiple research projects and other sources of innovation, complicating the accounting of the value produced by a specific project or program. Furthermore, most research is focused on producing knowledge or innovation. Tangible and quantifiable benefits are created when knowledge and innovations are applied through implementation of a new process, method, tool or technology or their impact on decision making. Evaluating the benefits from applying research findings therefore requires studying implementation activities (e.g., collecting before and after data to compare changes in costs and benefits), generally as a sperate research project that occurs sometime after the research that generated implementable findings.

Considering the above challenges and the need to evaluate research programs, we developed a simple and mostly qualitative research project assessment framework and associated spreadsheet tool. The logic of our framework is that research proposals and problem statements should contain clearly defined objectives and associated benefits. Problem statements and proposals should also describe the potential use and application of expected research findings, if any. We assume that VTrans and other state DOTs only funding research projects that are expected to solve important problems the agency faces, answer important questions or provide useful information. Projects are therefore beneficial and valuable largely to the extent that objectives are successfully accomplished. The framework collects information about these initial research expectations and how they materialize or change as the research progresses towards eventual implementation or application. Rather than seeking to enumerate the size of benefits stemming from implementing research findings, our framework aims to document the extent to which research projects meet their original objectives and how benefit expectations may be modified as the research progresses (e.g., due to the generation of new data and knowledge).

Our framework results in a qualitative data set that summarizes the purpose, potential uses and expected benefits of each research project and how successful each project was in meeting its objectives and moving towards implementation. These data can be used to report and track investments made towards research addressing various challenges and producing different types of benefits. Overtime, as research findings are implemented, the dataset will track how research findings are implemented and the benefits that are produced. The three-phase design of the framework also allows

for a systematic analysis of how expected research benefits and uses change from research problem statements to eventual implementation as well as issues that impact project success and implementation. This information can help VTrans discuss the value of its research program and identify opportunities to improve its design and management.

We do not recommend using scoring and rating schemes to translate qualitative data into quantitative indices. These methods, although commonly applied, are highly subjective and reduce otherwise useful information into unreliable indices. It is unclear how indices help communicate the value of research. Summarizing in a narrative form and collecting in one place the purpose, expected benefits and success of research projects seems far more valuable and much less subjective. We also do not recommend using the NETC or similar cost benefit tools for evaluating the value of research projects and programs (the NETC tool may be useful for evaluating specific implementation projects). These tools are focused on evaluating the benefits of implementing innovative or new projects rather than the benefits of research investments. While research may have created the innovation being implemented, the NETC and other cost-benefit analysis tools are designed for project level assessments and therefore require relatively detailed project level data. Research projects do not generally produce the required input data. Lastly, we recommend that VTrans consider obtaining arm's length external peer review of completed research projects. External reviews could add additional credibility and reliability to the qualitative assessment or research project value. External reviews can be difficult to obtain and therefore may only be considered for projects on topics where VTrans or the project technical advisory committee has less expertise or where the technical advisory committee and researchers dispute certain outcomes.

6 Appendix I: Results of Prior DOT Research Evaluation Studies Provided to VTrans in January 2022

TECHNICAL MEMO

To: Emily Parkany, Policy and Planning & Research Bureau

From: Jonathan Dowds, UVM TRC
Gregory Rowangould, UVM TRC

Date: December 21, 2021

Re: Value of VTrans Research: Qualitative and Quantitative Analysis: Task 1 Summary Tech Memo

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Introduction

The capacity to assess the value of research provides considerable internal and external benefits for transportation agencies. Quantifying the benefits resulting from research enhances transparency and accountability to the public and state government. Demonstrating monetary research benefits is also useful for securing federal research funding and incentivizes technology transfer and research implementation. While many research outcomes can be quantified and monetized to evaluate the relative cost and benefits of the research, some important benefits cannot. Nonetheless, all research projects should be able to be assessed in a meaningful fashion. The purpose of the project is to improve the VTrans' ability to assess the value of external research projects with a specific focus on developing and demonstrating a qualitative assessment strategy that can be applied to all research projects.

For Task 1 of this project, the research team conducted a review of seven research evaluation projects, focusing on identifying the benefit categories used in each project and, especially, benefits identified as difficult to evaluate quantitatively. Three of these research valuation projects resulted in publicly available Excel tools that can be used to calculate the monetary value of a specific research project over a user-defined time scale (Gross & Le, 2019; Preston & Bennett, 2017; TxDOT, 2013). Concrete, though relatively rudimentary, processes for grading projects that include qualitative benefits are described in three projects (Anderson, 2016; Stokes et al., 2004) while a recent NCHRP report provides a more generalized description of how to conduct qualitative evaluations (Zmud et al., 2021). Research evaluation projects by the Southeast Transportation Consortium and NCHRP are also valuable for the extensive benefit categorization that they undertake (Yoon et al., 2016; Zmud et al., 2021).

Table 1 provides an overview of benefit categories identified across these studies. Shaded cells indicate benefits that are frequently evaluated qualitatively.

Generally speaking, the efforts to quantify the value of research described here seek to monetize the benefits of the research projects evaluated to produce benefit-cost ratios or other similar measures. While it is tempting to see these evaluations as objective and authoritative, both the quantification and monetization processes can include considerable uncertainty and subjective assumptions. Monetized estimates of both the social cost of GHG emissions and the value of human life, for example, can vary widely depending on the methodology and assumption used. Conversely, it is frequently assumed that subjective benefits cannot be evaluated quantitatively but many subjective matters, such as asset condition or customer satisfaction can be rated quantitatively.

Table 2. Benefits Categories

Benefit Categories	MnDOT	NETC	KDOT	UDOT	TxDOT	STC
Engineering & Admin	X	X	X	X	Engineering Design Improvement Reduced Administrative Costs	
Construction & Installation Costs	X	X	X	X	X	
Operation & Maintenance Costs	X	X	X	X	X	
Lifecycle & Lifecycle Costs	X	X	X		X	X
Road users benefits/Improved Mobility	X	X		X	Reduced User Cost Traffic and Congestion Reduction System Reliability Freight movement and Economic Vitality	Reduced Congestion Improved Travel Speed/Time/Reliability Travel Cost Accessibility to Facilities and Services
Safety	X	X	X	X	X	X
Environmental	X	X	X	X	X	Reduced Vehicle Emissions Air Quality Water Quality, Farmlands Energy Impacts Noise Impacts
Risk Management	X	X				
Technology/Innovation			X			X
Expedited Project Delivery					X	X
Infrastructure Condition					X	Capacity and Availability Asset Condition Remaining Life/Structural Capacity
Improved Productivity and Work Efficiency					X	
Materials and Pavements					X	
Intelligent Transportation Systems					X	
Others		X				
Level of Knowledge				X	X	X
Management and Policy			X		X	
Quality of Life					X	X
Customer Satisfaction					X	X
Workforce Development						X

MnDOT and NETC

Two recent projects sponsored by Minnesota DOT (Preston & Bennett, 2017) and the NETC (Gross & Le, 2019) aimed to develop implementation-ready Excel tools to quantify the monetary benefits of transportation research. The MnDOT tool was completed in 2017 and applied to a sample of 11 projects which showed a cost savings of approximately $69 million over three years. The NETC tool was completed in 2019 and applied to two sample projects with estimated benefits of close to $30 million over a five to seven-year horizon.

The basic approach used by the MnDOT tool is to document changes in the utilization of specific resources, the cost of utilizing these resources, and the frequency with which they are used in order to calculate the change in total cost in each of the nine benefit categories shown in Table 2. For example, if a project reduced the number of labors hours required to conduct a bridge inspection, the user would specify the labor hours required for the inspection before and after implementing the research findings, the cost of labor, and the number of bridge inspections conducted each year. With these inputs, the tool would calculate the annual labor savings, the total labors savings over a specified evaluation window, and the net present value of the total labor savings. Similarly, to evaluate a project that reduced crash fatalities at a particular facility type, the user would specify the historical crash rate, reduction in this rate (or reduction in the severity of the crashes), the number of facilities of the type, and crash costs and the tool would calculate the expected savings. Finally, the Excel tool calculates the ratio of benefits to the cost of the research project. Collecting inputs for the tool involved reviewing project final reports, and meeting with researchers and DOT staff and involved a significant and unexpected level of effort and relied on information with varying degrees of reliability.

The NETC project was intended to build off of the results on the MnDOT project and modify the tool for use by NETC member DOTs. Reviewing the MnDOT tool, the research team identified several opportunities to improve the usability of the tool by altering the organization of the spreadsheet tool so that each benefit category is captured fully on a single sheet and automatically calculating the total benefit and overall B/C ratio. In addition, the NETC revised the naming convention for some of the benefit categories to acknowledge that not all changes in DOT practice produce cost savings. The overall benefit categories are essentially the same between the two projects, as shown in Table 1, and the calculation methodology is substantially the same as well. Thus, the NECT tool can be considered to be an improved implementation of the MnDOT tool.

While these two projects provide highly structured and implementation-ready tools for evaluating the benefit-cost ratio for research projects, both projects acknowledge that research can provide numerous benefits that are not easily quantified and monetized but exclude these benefits from their evaluations processes.

Table 3. MnDOT and NETC Benefit Categories

Benefit Categories	MnDOT	NETC
Engineering & Admin		X
Construction Saving/Construction & Installation	X	X
Operation and Maintenance Saving/Operation & Maintenance	X	X
Lifecycle		X
User Benefits/Road users	X	X
Safety	X	X
Environmental Aspects/Environmental	X	X
Decrease Engineering/Administrative Costs	X	
Decrease Lifecycle Costs	X	
Increase Lifecycle	X	
Risk Management	X	X
Others		X

NCHRP No. 20-44(9)

A draft final report for NCHRP No. 20-44(9), "Quantitative and Qualitative Methods for Capturing The Impacts and Value of NCHRP Research" was completed in October of this year (Zmud et al., 2021). The goal of the project was to provide guidance on how NCHRP could systematically gather evidence that research results are being implemented and are providing lasting value for implement agencies. The report emphasizes the importance of capturing qualitative benefits stating:

Excluding qualitative research impacts—focusing solely on easy-to-measure, quantitative impacts (e.g., saving lives or costs)—risks excluding important policy and management benefits coming from some research, particularly answers to questions coming from agency leadership and their community constituencies. Systematic description and scoring of qualitative research impacts will bring them into the evaluation process.

And

[M]onetary evaluation should be reserved for those project impacts where such valuation makes sense and provides a comprehensive picture of value. Where it does not, other dimensions of value should be used.

The project team conducted a literature review, stakeholder interviews, and developed a "Research Impact Assessment" (RIA) framework. The recommended RIA consists of five steps:

1. Select studies to evaluate
2. Find implementations of the selected study and assess its feasibility for evaluation
3. Identify relevant research impacts
4. Data collection and analysis on those impacts

5. Comunicating the value of the research in a multidimensional manner that captures both quantifiable and qualitative impacts, often in narrative form.

The research team recommends that projects that do not have a knowledgeable agency champion, that have not had sufficient time for their results to be implemented, or that otherwise are particularly difficult or costly to evaluate should be excluded from the evaluation process.

Benefit-cost analysis and cost-effectiveness analysis are both suggested as viable methods for analyzing quantitative measures. Unlike benefit-cost analysis (which is used in the MnDOT and NETC tools) cost-effectiveness analysis does not require that research benefits are monetized. Instead, the results of cost-effectiveness analysis are provided as a cost per unit of impact (e.g. cost per life saved), which can be useful when selecting among different potential solutions.

For qualitative evaluations, the report recommends interviews or focus groups with the practitioners that were involved in the implementation of a research project. Including both the project champion and other agency personal can help to provide a broader, unbiased perspective on the success of a research project. Rating projects on a simple 1-5 scale is also recommended. The research benefit categories identified by the report are shown in Figure I.

Internal Impact	Type of Measure	Potential Metric
Knowledge increase	Qualitative	Perceived benefit of new knowledge gained
Engineering/administration savings (planning/design costs and paperwork)	Quantitative/ qualitative	Perceived or quantified cost/time savings due to process or practice improvement; perceived quality or accuracy improvement
New design technical standard	Quantitative	Extension in life cycle or decreased life-cycle costs
Construction savings	Quantitative	Δ $ agency savings (labor, equipment, and time)
Agency operation/maintenance savings	Quantitative	Δ $ agency savings (per worker or per week/month or per assignment, task, or project)
Better decision support	Qualitative	Perceived improvement in efficiency; effectiveness of data and analytical tools for supporting agency decisions
Worker safety	Quantitative	Δ rate of agency worker injury (per worker or per week/month); number of workers affected
Worker productivity	Quantitative	Δ agency performance per worker; number of workers affected
Workforce development	Qualitative	Extent to which agency staff perceive improvements attributable to training/education
Workforce diversity	Quantitative	Δ ratio of participation by minority or disadvantaged population groups; number affected

External Impact	Type of Measure	How Measured
System performance	Quantitative	Δ (change) in transport level of service, reliability, speed, delay, number served, and connectivity
System cost	Quantitative	Δ $ user savings (per capita, trip, vehicle-mile, or passenger-mile)
System revenue	Quantitative	Δ $ generated (per capita, trip, vehicle-mile, or passenger-mile)
System safety	Quantitative	Δ rate of collision, injury, or death (per vehicle-mile or passenger-mile)
System productivity	Quantitative	Δ $ outcome/$ invested (cost-effectiveness)
Environment	Quantitative	Δ emissions rate (for air or water), noise, or regional quality index
Quality of life	Quantitative/ qualitative	Δ index or rating for traveler comfort or broader quality of life; assessment by community leaders and stakeholders
Equity	Qualitative/ quantitative	Δ availability and quality of service for under-served groups (relative to well-served groups)
User satisfaction	Quantitative	Δ satisfaction rate from surveys

Figure VI. NCHRP Benefit Categories

Southeast Transportation Consortium

In 2018, the Southeast Transportation Consortium produced a guidebook designed to facilitate a consistent methodology for evaluating the value of research projects (Yoon et al., 2016). The research team conducted a literature review and survey of DOTs to identify research benefit categories and a "mapping table" identifying the data types that can be used to evaluate each specific benefit category. This mapping table is provided as Appendix A to this memo and summarized in Table 1. This project is most notable for the breadth the of categories examined but the final project evaluation methods are of questionable value.

The research team presents a benefit quantification method that can be used with these categories but did not develop and an implementation-ready tool for using their methodology as was done by MnDOT and NETC. Instead, they provide an equation that can be used to calculate a DOT's "Progress towards a Target" (PtT). The PtT is simply the ratio of the current outcomes in a specific category relative to the DOT target in that category. The report provides several approaches to addressing missing historical data, outcome data, or a lack of a target value but given the questionable utility of the measurement method

Kansas DOT

In 2004, Kansas DOT issued guidelines for estimating the benefits of K-Tran research projects (Stokes et al., 2004). The guidelines presented multiple methodologies for assessing research benefits, including an analysis of a subjective assessment of benefits that cannot readily be monetized. This assessment of qualitative benefits, which the guidelines describe as a "multi-objective analysis," consists of the project PI and DOT champion to rate the potential significance of the research on a 1-10 scale for 10 different assessment categories shown in Figure I.

Assessment Category	Subjective Rating	Triennial Benefits ($)	Comments
Construction Savings (materials, labor, equipment, time, quality)			
Operation and Maintenance Savings (materials, labor, equipment, time)			
Increase Lifecycle			
Decrease Lifecycle Costs			
Safety (Reduction of crash frequency. Reduction of crash severity)			
Decrease Engr./Admin. Costs (planning/design costs, paperwork)			
Environmental Aspects (pollution, hazardous waste reduction, recycling)			
Technology (technology transfer, new materials, new methods)			
User benefits (time, dollars)			
Impact On KDOT Policy			

Figure VII. KDOT Research Evaluation Template from (Stokes et al., 2004)

The guidelines state that the results of the "subjective multi-objective assessment can be assumed to represent the best assessment possible at that point in time" and that projects that receive a rating of 5 or above in one or more categories should be considered successful. It provides the following guidance for the rating each category:

- NA = factor does not apply to this project;
- 0 = absolutely no benefit;
- 1 = intuitive feeling that the project has some slight benefit;
- 5 = no clear evidence but strong subjective feeling that the project has a significant positive benefit;
- 10 = clear evidence or strong feeling the project has an excellent to outstanding, positive benefit.

Texas DOT

Texas DOT has both a handbook with instructions for how to evaluate research projects (TxDOT, 2019) and an Excel-based tool for calculating the value of quantitative benefits (TxDOT, 2013). The spreadsheet calculates the cumulative value for economic benefit variables, shown in Figure II, but this tool has considerably less structure than either the MnDOT or NETC tools. For each of the select variables, the user provides a single estimate of the economic benefit rather than specifying per unit savings and units used. The tool template also includes several setup errors that prevent it from completing its intended calculations accurately.

TxDOT also identifies 6 benefit categories that are partially or entirely qualitative in nature (Figure II) but the handbook provides relatively little guidance for how these benefit areas should be evaluated, simply stating "each of the selected qualitative and economic benefit areas should be defined and discussed in association with the project and the findings of the research" (TxDOT, 2019).

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in context to the Project Statement
Level of Knowledge	X			X			
Management and Policy	X			X			
Quality of Life	X			X			
Customer Satisfaction	X			X			
Environmental Sustainability	X				X		
System Reliability		X		X			
Increased Service Life		X		X			
Improved Productivity and Work Efficiency		X		X			
Expedited Project Delivery		X		X			
Reduced Administrative Costs		X		X			
Traffic and Congestion Reduction		X			X		
Reduced User Cost		X			X		
Reduced Construction, Operations, and Maintenance Cost		X			X		
Materials and Pavements		X			X		
Infrastructure Condition		X				X	
Freight movement and Economic Vitality		X				X	
Intelligent Transportation Systems		X				X	
Engineering Design Improvement			X			X	
Safety			X			X	

Figure VIII. TxDOT Research Benefit Categories

Utah DOT

Utah DOT sponsored a study completed in 2016 to evaluate the benefits of their research program over a four-year period (Anderson, 2016a). The monetary evaluation of 66 projects returned a 14-1 benefit-cost ratio using methods similar to those in the MnDOT and NETC tools. The tool used in the calculation of these benefits is not publicly accessible, but the benefits calculation used for the project is summarized in Figure III.

Benefit Calculations:

- **Benefits = Number x Value x Percentage**
  - Number of items increased, saved, avoided, etc
    - Facility life in years
    - Crash number/severity prevented
    - Person-hours saved
  - Value of item
    - Annual cost of facility, crash costs, wages, etc
  - Percent attributed to research project
    - Portion of initiative enhanced by the research project

Figure IX. UDOT Benefits Calculation Methodology from (Anderson, 2016a)

In addition to the estimated benefit-cost ratio, the evaluation team worked to assign a letter grade for each project. The grading process was based on the evaluation of the project champion using the rubric shown in Figure III.

Table 1
Grade Definitions

Grade	Definition
A	Major impact: New or revised specifications, policy, methods, etc.
B	Significant impact: Improved operations, procedures or policies.
C	Contributed to state-of-the-practice or institutional knowledge
D	Unclear or contradicting findings: More study needed
E	Major tasks not completed: Objectives not met

Figure X. Utah DOT Project Grading Scheme

Conclusions

Across the studies reviewed here, there is a general consensus on the benefit categories that can be quantified and monetized and a relatively consistent approach to the process of calculating benefit-cost ratios. The challenge for this process lies in collecting reliable estimates of the changes in practice brought about by a specific research project. The NETC tool is a straightforward implementation of this methodology and is recommended for use in this evaluation. The survey of Project Champions will be used to identify one or more VTrans external research projects to be evaluated using the NETC tool.

For the assessment of qualitative benefits, the state of practice is less mature. Several states use scoring systems that rely on the judgment of the PI, project champion, or both to rate qualitative benefits but the categories used are more variable than for the quantitative analyses. NCHRP recommends and combination of focus groups and subjective ratings but groups of 4-5 people involved with the research implementation.

Appendix A – STC 2018 Benefit Categories and Measures

Table 9. Benefit measures corresponding to benefit categories/subcategories

Benefit Category	Benefit Subcategory	Measures
Improved Safety and Security		- Number of crashes by type, location type, and so forth - # lives saved - Dollar savings due to reduction in crashes - Number (or rate per capita or number of travelers) of crimes at rest areas, bus stops, highways, and so forth by type or severity - Value of losses from theft per capita, person-trip, shipment value, ton - Reduction in number of incidents in construction sites
Improved Mobility and Accessibility	Reduced Congestion	- Level of service (LOS)—measure of congestion from A–F based on volume-to capacity ratio (facility-specific measure) - Number of intersections congested (e.g., with LOS E or F) during peak hours - Travel time under congested conditions - Lane-mile duration index (number of congested lane-miles times the duration of congestion)
	Improved Speed	- Average speed for given roadway segment or origin-destination pair
	Improved Travel Time	- Average travel time (by mode or cross modes) for a given origin-destination pair or trip type - Travel time from freight intermodal facilities to highway facilities
	Travel Time Reliability	- Percent on-time shipments (by commodity or mode)
	Travel Cost	- Trip cost by mode for origin-destination pairs - Dollar losses due to freight delays - Dollar savings
	Accessibility to Facilities and Services	- Percent of urban population with convenient access to public transit (e.g., living within a quarter mile of a transit stop with a non-rush-hour service frequency of 15 minutes or less) - Access time to passenger or intermodal facilities
Improved Infrastructure	Capacity and Availability	- Intermodal terminal capacity
	Asset Condition	- Average health index (0–100 scale) - Percent structurally deficient (SD) - Number of steel bridges with section loss in a member
	Remaining Life/Structural Capacity	- Percent asset quantity out of service due to deteriorated condition - Reduction in distance (or time) between failures for transit vehicles - Age of fleet by vehicle type or remaining useful life for vehicles
	Increased Lifecycle	- Dollar savings due to use of durable materials
Improved Environmental	Reduced Vehicle Emissions	- Vehicular emissions by type—NOx, VOC, CO_2, CO, ozone, fine particulate matter (PM2.5) —can be limited to nonattainment areas and identified by source (e.g., passenger versus freight)

Benefit Category	Benefit Subcategory	Measures
	Length or Extent of Air Quality Problem	- Number of days that pollution standard index is in the unhealthful range
Improved Environmental	Water Quality, Wetlands, Aquatic Life, Farmlands	- Acres of wetlands replaced or protected for every acre affected by highway projects - Level of fish habitat reduction as a result of new construction - The amount of water leaving or discharging from the system - Changes in open space, gardens, parks, farmlands and wildlife habitat (#acres)
	Energy Impacts	- Percent of vehicles using alternative fuels - Average fuel consumption
	Noise Impacts	- Dollar savings - Number of residences or percent of population exposed to highway noise exceeding established standards (or greater than X decibels) - Number of noise receptor sites above threshold
New Technology/ Innovation		- Percent of contracts (or contract value) completed on-time - Percent of contracts (or contract value) completed on-budget - Reduction in emission
Workforce Development		- Rating the effectiveness of the workforce training program
Expedited Project Delivery		- Percent of contracts (or contract value) completed on-time - Percent of contracts (or contract value) completed on-budget - Number of contractor partnerships - Reduced installation time (# days, #hrs., etc.)
Increased Knowledge		- Rating the project based on the following criteria: a. This project expands the DOT knowledge base. b. This project expands the State knowledge base. c. This project expands the National knowledge base. d. This project lays the foundation for future research. - Number of research projects/products improving the body of knowledge in a specific area(s)) or decision-making processes. - Number of sponsored students
Improved Quality of Life		- Rating the project based on the following criteria: a. This project will increase the psychological comfort of users. b. This project will produce an aesthetic improvement. c. This project will improve transportation accessibility d. This project will improve the environment. - Number of research projects/products improving or protecting the natural environment
Customer Satisfaction		- Dollar savings by offering free services to customers - Customer satisfaction rating

7 Appendix II: Project Champions/Participant Survey

Solicitation Email

"VTrans has partnered with the UVM Transportation Research Center to develop a method for evaluating the benefits of VTrans-sponsored research projects. As part of this research, we are asking VTrans project managers to complete a brief 10-minute survey that will ask you about the quantitative and qualitative benefits of research projects you have recently managed. Please complete the survey by March 31, 2022 using the link below.

https://qualtrics.uvm.edu/jfe/form/SV_6fDiQMDgJk1TWpo

Since the survey will ask you about research projects you have worked on or championed, it may be helpful to have copies of research reports and other relevant information available when taking the survey.

If you have any questions about this research or the survey questions please let me know and I can communicate them to the UVM research team if needed."

Survey Questions

Start of Block: Introduction Questions

Q1.1

The purpose of this research and survey is to improve the ability of VTrans to assess the value of external research projects with a specific focus on developing and demonstrating a qualitative assessment strategy that can be applied to all research projects. The study was requested and is funded by VTrans, and is being conducted by the UVM Transportation Research Center.

Survey Instructions

Please fill out the survey as completely as possible. If you were involved with or championed multiple projects, you may take the survey more than once - one time for each project.

Q1.2

Please enter your name and job title.

- Name (1) _____
- Job Title (2) _____

Q1.3

Please select the VTrans external research project that you have been involved with or championed from the list below.

***You may take the survey one time for each project you were involved with or championed.*

- ○ 20-2: Snow and Ice Correlations (1)
- ○ 19-1: Reclaimed Stabilized Base Explorations (2)
- ○ 19-2: Erosion Analysis (3)
- ○ 19-3: HIVE2 (4)
- ○ 18-1: RFID (5)
- ○ 18-2: LVRT Floodplain Analyses (6)
- ○ 18-3: HSM Calibration Rural Two-Lane Roads (7)
- ○ 17-1: Snow and Ice Grip Analysis (8)
- ○ 17-2: Intelligent Compaction Field Study (9)
- ○ Other project not listed but you wish to include (10) _____

Start of Block: Benefits Block

Q2.1 Have the findings from "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}" been implemented by VTrans? Please select all that apply.

- ☐ Yes - We've changed the process (1)
- ☐ Yes - We've changed the standard (2)
- ☐ Yes - We've had field demonstrations (3)
- ☐ Yes - Other (Please describe in the text box) (4)

_____

- ☐ Not yet, but currently planning for implementation in the future. (5)
- ☐ No - Our needs changed (6)
- ☐ No - We disagree with the results (7)
- ☐ No - The research does not suggest implementation (8)
- ☐ No - Management doesn't support it (9)
- ☐ No - Other (Please describe in the text box) (10)

_____

Q2.2
Did "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}" produce quantifiable benefits?
*** For example: reduced man hours, reduced material costs, contaminant reduction, etc.*

- ○ Yes (1)
- ○ No (2)

Display This Question:

If Q2.2 = Yes

Q2.3

Please describe the ***quantifiable*** benefits for "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}". Include the actual quantified metric where possible.

_____

_____

_____

Display This Question:

If Q2.2 = Yes

Q2.4 How easy or difficult would you say it was to evaluate the quantifiable benefit/s?

- ○ Extremely easy (1)
- ○ Somewhat easy (2)
- ○ Somewhat difficult (3)
- ○ Extremely difficult (4)

Display This Question:

If Q2.2 = Yes

Q2.5 Are there any additional *anticipated* quantifiable benefits from "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}" not yet put into practice?

- ○ Yes - Please describe (1) _____
- ○ No (2)

Display This Question:

If Q2.5 = Yes - Please describe

Q2.6 How easy or difficult would you say it was to evaluate the *anticipated* quantifiable benefit/s?

- ○ Extremely easy (1)
- ○ Somewhat easy (2)
- ○ Somewhat difficult (3)
- ○ Extremely difficult (4)

Q2.7
Did "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}" produce **qualitative or subjective** benefits?
For example: level of knowledge, quality of life, customer satisfaction, workforce development, etc.

- ○ Yes (1)
- ○ No (2)

Display This Question:

If Q2.7 = Yes

Q2.8 Please describe each **qualitative/subjective** benefit that resulted from "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}".
***Include any benefits which are not captured by a quantifiable metric.*

_____

_____

_____

Display This Question:

If Q2.2 = Yes

Q2.9 How easy or difficult would you say it was to evaluate the qualitative or subjective benefit/s?

- ○ Extremely easy (1)
- ○ Somewhat easy (2)
- ○ Somewhat difficult (3)
- ○ Extremely difficult (4)

Display This Question:

If Q2.7 = Yes

Q2.10 Are there any additional *anticipated* qualitative benefits that resulted from "${Q1.3/ChoiceGroup/SelectedChoicesTextEntry}" not yet put into practice?

- ○ Yes - Please describe (1) _____
- ○ No (2)

Display This Question:

If Q2.10 = Yes - Please describe

Q2.11 How easy or difficult would you say it was to evaluate the *anticipated* qualitative or subjective benefit/s?

- ○ Extremely easy (1)
- ○ Somewhat easy (2)
- ○ Somewhat difficult (3)
- ○ Extremely difficult (4)

Start of Block: Final Question

Q3.1 Describe any possible barriers to evaluating the benefits of this project. (For example: management support, new materials needed, lack of before/during/after data, etc.)

_____

_____

_____

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