

Cross-Asset Resource Allocation and Multi-Objective Decision Analysis Literature Review

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13. ABSTRACT (Maximum 200 words) This report documents the results of a literature review on the topics of Cross-Asset Resource Allocation (CARA) and Multi-Objective Decision Analysis (MODA). This literature review is intended to be used as an educational resource for transportation agencies and practitioners, providing a general/fundamental understanding of CARA and MODA. This report also suggests additional research areas for further study, makes references to ongoing CARA and MODA efforts, and highlights tools and resources that are available to advance the state of the practice. The literature review does not document the universe of research on these topics; instead, this report aims to summarize a selection of relevant, noteworthy resources in order to provide an overview of CARA and MODA, and how they may be used by transportation agencies as part of their performance-driven programming processes.				
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Acronyms

Acronym	Term
AASHTO	American Association of State Highway and Transportation Officials
BCA	Benefit Cost Analysis
Caltrans	California Department of Transportation
CARA	Cross-Asset Resource Allocation
CARATS	Cross-Asset Resource Allocation Spreadsheet Tool
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DOT	Department of Transportation
DVRPC	Delaware Valley Regional Planning Commission
FHWA	Federal Highway Administration
FHWA HEPP	Federal Highway Administration Office of Planning
MCDM	Multi-Criteria Decision Making
MODA	Multi-Objective Decision Analysis
MODAT	Multiple Objective Decision Analysis Tool
MPO	Metropolitan Planning Organization
NASEM	National Academies of Sciences, Engineering, and Medicine
NHPP	National Highway Performance Program
NHS	National Highway System
PBPP	Performance-Based Planning and Programming
SHOPP	State Highway Operation and Protection Program
SPOT	Strategic Transportation Prioritization
STIP	Statewide Transportation Improvement Program
TAM	Transportation Asset Management
TIP	Transportation Improvement Program
TPCB	Transportation Planning Capacity Building
TPM	Transportation Performance Management

Executive Summary

Purpose

The U.S. DOT Volpe Center prepared this literature review on Cross-Asset Resource Allocation (CARA) and Multi-Objective Decision Analysis (MODA) approaches for the Federal Highway Administration (FHWA) Office of Planning (HEPP) to summarize relevant CARA and MODA resources, with a focus on implementation of CARA and MODA by State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) in the context of performance-driven programming.

Overview of CARA and MODA

CARA is the decisionmaking process by which resources to multiple programs or asset classes are distributed based on the simultaneous quantified prioritization of utility (American Association of State Highway and Transportation Officials (AASHTO), 2015). MODA is an approach used for implementing CARA and is defined as a structured prioritization process incorporating consideration of multiple objectives (AASHTO, 2021b). The use of CARA methods, including MODA, is a component within both Transportation Performance Management (TPM) and Transportation Asset Management (TAM) as it supports programming across performance areas. Performance-driven programming, which is the activity within which CARA is performed, can bridge the gap between TPM and TAM, since it involves the use of performance measures, metrics, targets, and/or data to help make investment decisions across transportation assets, modes, and performance areas.

Tools for Implementing MODA

Some transportation agencies have implemented standard software systems (e.g., Decision Lens) or developed specific in-house tools for implementing MODA. Some examples include the Virginia DOT's System Management and Allocation of Resources for Transportation: Safety, Congestion, Accessibility, Land Use, Economic Development and Environment (SMART SCALE) project prioritization process, the North Carolina DOT's Strategic Transportation Prioritization (SPOT) On!ine project evaluation system, and the Oregon DOT's Mosaic transportation planning tool. AASHTO has also produced a tool, the Multiple Objective Decision Analysis Tool (MODAT), as well as a training course, Performance-Based Prioritization Using MODA, both of which are further described in the sub-sections below.

Examples of CARA and MODA Implementation

Much of the literature and research was based on case studies of States and/or MPOs developing their own approaches to resource allocation. CARA examples include: the Florida DOT; Idaho DOT; Maryland DOT; Massachusetts DOT; and the Oregon DOT. MODA examples include: the California Department of Transportation (Caltrans); North Carolina DOT; Virginia DOT; Delaware Valley Regional Planning Commission; and the Genesee Transportation Council.

Conclusions

As transportation agencies' performance-driven programming processes continue to mature, CARA and MODA will be critical to understand and apply. There are many opportunities to advance the state of the practice through additional research to better understand how agencies are using these approaches today, and how lessons learned may be transferred across the transportation sector.

1. Introduction

1.1. Background and Purpose

Cross-Asset Resource Allocation (CARA) and Multi-Objective Decision Analysis (MODA) approaches have the potential to support program-level trade-off analyses and project prioritization and selection processes within the statewide and metropolitan transportation planning processes. Specifically, these methods have the potential to serve as important tools for State DOTs and MPOs to successfully implement Performance-Based Planning and Programming (PBPP) and Transportation Performance Management (TPM) approaches. This literature review, prepared by the U.S. DOT Volpe Center for the Federal Highway Administration (FHWA) Office of Planning (HEPP), summarizes relevant CARA and MODA resources, with a focus on implementation of CARA and MODA by State DOTs and MPOs in the context of performance-driven programming.

The purpose of this literature review is to help build FHWA's knowledgebase of CARA methods, including MODA, and respond to the following questions:

1. What is CARA, what is MODA, and how are these two ideas related?
2. How do CARA and MODA address transportation decisions across assets, modes, and performance areas?
3. How are State DOTs and MPOs using CARA and MODA tools and approaches in their transportation planning and decision-making processes?
4. Are there opportunities for State DOTs, MPOs, and other practitioners to implement or advance CARA and MODA?

The results of this research are intended to be used as an educational resource for transportation agencies and practitioners, providing a fundamental understanding of CARA and MODA. In addition, this effort provides additional research areas for further study, makes references to ongoing CARA and MODA efforts, and highlights tools and resources that are available to advance the state of the practice.

1.2. Key Concepts

The following table highlights important concepts identified during the literature review, ranging from CARA and MODA to TPM, TAM, and PBPP.

Table 1. Key concepts from the literature review

Concept	Description
Cross-Asset Resource Allocation (CARA)	The decisionmaking process by which resources to multiple programs or asset classes are distributed based on the simultaneous quantified prioritization of utility (AASHTO, 2015). ¹
Cross-Asset Optimization	The use of recursive (repeatedly applied) mathematical computations to determine the maximum utility for a given set of investments constrained by defined performance parameters (AASHTO, 2015).

¹ Note that AASHTO, 2015 defines "Cross Asset Allocation," which is considered synonymous with "Cross-Asset Resource Allocation" in this paper.

Concept	Description
Cross-Asset Tradeoffs	The decisionmaking process by which resources from one asset class are transferred to another in order to maximize perceived utility (AASHTO, 2015).
Data Envelopment Analysis (DEA)	An analytical approach that identifies the most productive “decision making unit” (“DMU”) where each DMU may require a range of inputs and produce a range of different outputs that cannot be easily compared (NASEM, 2019).
Monetized Benefit Value	Expressing the value of an asset or societal benefit in monetary terms so that “apples-to-apples” comparisons can be made.
Multi-Objective Decision Analysis (MODA)	A structured prioritization process incorporating consideration of multiple objectives (AASHTO, 2021b).
Performance-Based Planning	The use of goals and performance trends to drive the development of strategies and priorities in the long-range transportation plan and other performance-based plans and processes (FHWA, 2021).
Performance-Based Programming	The use of strategies and priorities to guide the allocation of resources to projects that are selected to achieve goals, objectives, and targets. Performance-based programming establishes clear linkages between investments made and expected performance outputs and outcomes (FHWA, 2021).
Performance-Driven Programming	The use of performance measures, metrics, targets, and/or data to help inform or guide the development of a programming document (FHWA, 2022).
Project Prioritization Process	How a transportation agency evaluates and ranks potential projects or investment strategies considering specific evaluation criteria, weightings, and scoring systems (FHWA, 2022).
Project Selection Process	How a transportation agency decides which projects or investment strategies to include in a programming document considering the results of the project prioritization process and funding availability in a given fiscal year (FHWA, 2022).
Scaling	A leveling technique used to convert metrics with different units of measurement into a normalized unit for comparison (NASEM, 2017).
Tradeoff Analysis	A method for comparing the performance impacts of alternative investment scenarios considering budget constraints and agency priorities related to goals, performance measures, and outcomes (FHWA, 2021).

Concept	Description
Transportation Asset Management (TAM)²	The strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle. TAM focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined objectives (AASHTO, 2021b).
Transportation Performance Management (TPM)	A strategic data-driven approach that uses system information to make investment and policy decisions to achieve performance goals. TPM principles guide agencies to select projects to produce desired performance outcomes (FHWA, 2021).
Weighted Scoring	A quantitative and qualitative model used to measure preferences of investment decisions by assigning a numerical value based on pre-determined value criteria, such as costs advantages, time savings, or environmental impacts.

1.3. Literature Review Approach

The research team reviewed literature seeking to define and explain CARA methods, including MODA, and identify examples of State DOTs and MPOs utilizing related tools and processes for transportation investment decisionmaking. Subject matter experts from the FHWA HEPP provided initial documentation, reports, and workshop briefings for review, which were supplemented by additional resources identified by the research team.

This report does not establish a standard, regulation, or agency guidance, and the inclusion of an example practice does not constitute a regulatory compliance determination. Except for the statutes and regulations cited, the contents of this report do not have the force and effect of law and are not meant to bind the public in any way. This report is intended only to provide information regarding existing requirements under the law or agency policies.

1.4. Document Organization

The intended audience for this report includes transportation agencies and practitioners whose activities intersect with performance-driven programming, especially planning and programming staff from FHWA's Headquarters and Division Offices, State DOTs, MPOs, and other relevant planning partners. The remainder of this report includes the following sections:

- Section 2 provides an overview of CARA and MODA, including associated roles in performance-driven programming and TPM, and each method's framework and purpose.

² FHWA defines asset management in [23 CFR 515.5](#) as "a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at minimum practicable cost."

- Section 3 documents tools for implementing CARA and MODA.
- Section 4 highlights example practices from State DOTs and MPOs.
- Section 5 summarizes opportunities to advance the state of the practice and support State DOTs, MPOs, and other practitioners with CARA and MODA, as well as areas for further research.
- Section 6 summarizes the references used for this literature review.

2. Overview of CARA and MODA

2.1. CARA and MODA: Components of Performance-Driven Programming and TPM

Applying a performance-driven programming process across different program areas and making resource allocation decisions across assets are complex challenges for transportation agencies (AASHTO, 2021a). As summarized in the “key concepts” table above in Section 1.2, CARA is the decisionmaking process by which resources to multiple programs or asset classes are distributed based on the simultaneous quantified prioritization of utility (AASHTO, 2015). CARA is an important aspect of performance-driven programming and is described further in Section 2.2.

FHWA’s TPM Guidebook provides a standard set of implementation steps for programming across performance areas (FHWA, 2021):

1. Identify and assign internal roles and responsibilities;
2. Clarify purpose of cross performance area prioritization;
3. Develop a methodology that reflects agency priorities and external stakeholder interests; and
4. Document the process.

Under these implementation steps, Multi-Objective Decision Analysis (MODA), also referred to as Multi-Criteria Decision Making (MCDM), falls under Step 3, Develop a methodology that reflects agency priorities and external stakeholder interests (FHWA, 2021). As summarized in the “key concepts” table above in Section 1.2, MODA is a structured prioritization process incorporating consideration of multiple objectives (AASHTO, 2021b). In the literature, MODA has been widely recommended to address CARA problems (NASEM, 2015). MODA is further described in Section 2.3.

MODA is considered one of the three primary approaches that may be used for implementing CARA (NASEM, 2015). The other two approaches are benefit/cost analysis (BCA) and risk/reward-based allocation. BCA is likely the most familiar approach to transportation agencies. Agencies use it to rank order similar projects, such as safety projects or pavement treatments. Drawbacks to BCA at the program level are that broad assumptions may be needed to estimate benefits from an entire class of projects, such as the benefits aggregated from multiple pavement projects. It is also difficult to monetize intangible benefits and estimate project costs early in the planning process when scopes are undefined. MODA is distinct from BCA in that the common denominator is not money but points or other numeric values.

The risk/reward-based allocation approach is not commonly used by transportation agencies. AASHTO defines risk/reward-based allocation as “an investment strategy that seeks to apportion investment in different assets to maximize the overall utility while not exceeding acceptable levels of risk” (AASHTO, 2015). This allocation strategy is more likely to be used in the private investment sector where the benefits of one investment decision are weighed against the risks of another. AASHTO provides an example of risk/reward-based allocation in the 2015 discussion paper, *Defining Cross-Asset Decision Making*, on prioritizing pavement investments. The report describes the investment decision of a department to reduce its overall pavement budget so that the miles of “fair” pavements increase, and the number of “good” pavements decline while also calculating the additional risk of roads falling into

“poor” condition because of the investment decision. The cost savings from the decision are then re-invested into areas that are already in poor condition.

The use of CARA methods, including MODA, is a component within both TPM and TAM as it supports programming across performance areas. As summarized in the “key concepts” table in Section 1.2, TPM is an *approach* to managing transportation system performance outcomes, and TAM is the *application of this approach* to manage the condition of the infrastructure assets that are needed to provide for mobility and safety on the nation's transportation system (FHWA, 2019). Performance-driven programming, which is the activity within which CARA is performed, can bridge the gap between TPM and TAM, since it involves the use of performance measures, metrics, targets, and/or data to help make investment decisions across transportation assets, modes, and performance areas.

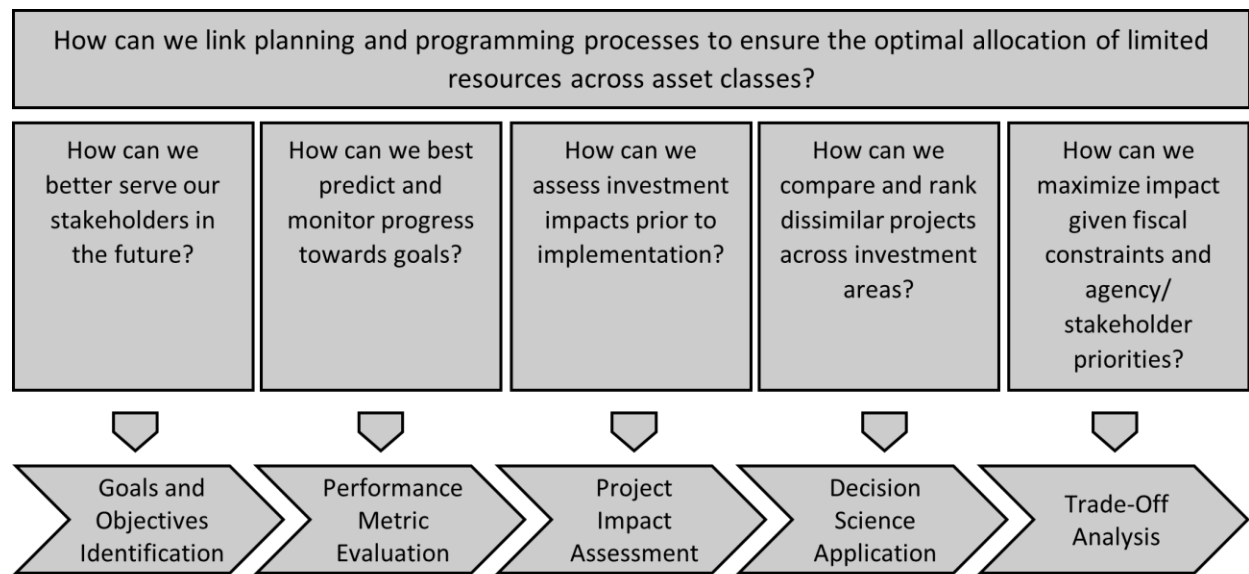
2.2. CARA Purpose and Framework

As with TPM and TAM, CARA is a fairly recent transportation decisionmaking concept entering the public sphere from the corporate world. There are other cross-asset decisionmaking processes that have migrated from the corporate sector to the transportation sector as well, such as “cross-asset tradeoffs” and “cross-asset optimization”. Although all three of these “cross-asset” processes relate to improved, fact-based decisionmaking, they have several key differences. This literature review focuses on CARA, though cross-asset tradeoffs (the simplest and most common of the three processes) and cross-asset optimization (a further refinement of CARA) are defined in the “key concepts” table in Section 1.2 (AASHTO, 2015). The 2015 AASHTO discussion paper, *Defining Cross-Asset Decision Making*, which is highlighted in Section 6, Annotated References, provides a detailed summary and examples of each of these three processes.

CARA can be applied to help decisionmakers develop the optimal combination of performance outcomes that can be achieved under various funding levels. The unique feature of CARA is the ability to compare physical assets and operational performance. CARA also allows for the flexibility to test different combinations of priorities and performance measures across different investment categories (AASHTO, 2015).

The *Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance*, developed under National Cooperative Highway Research Program (NCHRP) Project 08-91 proposes a framework and tool prototype for CARA (Figure 1). The framework and tool prototype reflect both technical practices and transportation agencies’ organizational and institutional needs. The framework allows for flexibility in agency goals, objectives, and performance measures, where any measure from the planning process can be selected given agency needs and regional, state, and federal requirements. Its application can facilitate an inclusive goal development process and better planning/programming linkages by bringing various stakeholders to the table (NASEM, 2015). The framework and tool prototype have been tested and refined under the 2019 *NCHRP Research Report 921: Case Studies in Implementing Cross-Asset, Multi-Objective Resource Allocation*. The refined framework and tool are further discussed below in Section 3, Tools for Supporting CARA and MODA.

Figure 1. CARA framework (adapted from NASEM, 2015)



2.3. MODA Purpose and Framework

As described in Section 2.1 above, MODA is one of the most widely used approaches for implementing CARA (NASEM, 2015). The purpose of MODA is to overcome complex cross-asset resource problems using a formal decision-making process and quantitative scoring system. There are several benefits to using a formal decision-making process, such as that used for MODA. Two important benefits are that (1) it can help agencies make investments that best accomplish their objectives with the funding available, and (2) it standardizes a repeatable approach that is transparent to the public, enhancing agency credibility (NASEM, 2017). In addition, MODA provides a replicable structure for prioritizing transportation investments without being dependent on any one management system. MODA also provides a means to compare asset management investments with other investments to improve mobility and achieve other objectives outside the scope of a typical asset management system (AASHTO, 2021b).

It is important for investment decisionmakers to recognize that MODA is more data intensive than conventional resource allocation methods. MODA may also result in simplification of the asset-specific modeling performed in a pavement or bridge management system, which typically use complex empirical models to predict deterioration that may not be reflected in MODA calculations without specific customization. MODA tools and approaches are also typically intended for application in analyzing specific candidate projects and used for prioritizing investments for a single common decision period chosen by the user, such as a specific budget year or planning horizon (AASHTO, 2021b).

NCHRP Report 921, *Case Studies in Implementing Cross-Asset, Multi-Objective Resource Allocation*, provides eight steps through which MODA is implemented (NASEM, 2019):

1. Establish the scope;
2. Define goals and objectives;

3. Select performance measures and evaluation criteria;
4. Assess data and analytical capabilities;
5. Prototype the approach;
6. Set weights on goals and objectives;
7. Apply the model; and
8. Communicate the results.

These steps are also used in AASHTO's recent training course, *Performance-Based Prioritization Using Multi-Objective Decision Analysis*, and in FHWA's TPM Guidebook (AASHTO, 2021a; FHWA, 2021). The FHWA TPM Guidebook provides additional details on each step, as well as agency implementation examples (FHWA, 2021).

3. Tools for Implementing MODA

Based on survey results from 35 State DOTs in 2017, Sperling et al. concludes that overall, States lack evaluation tools for mode-neutral project assessments (Sperling et al., 2020). Kittelson and Associates highlight in their 2020 research report that some transportation agencies have started to implement standard software systems (e.g., Decision Lens) or have developed specific in-house tools for implementing MODA. Some agency-specific tools include the Virginia DOT's System Management and Allocation of Resources for Transportation: Safety, Congestion, Accessibility, Land Use, Economic Development and Environment (SMART SCALE) project prioritization process, the North Carolina DOT's Strategic Transportation Prioritization (SPOT) OnLine project evaluation system, and the Oregon DOT's Mosaic transportation planning tool. Regardless of the tool used, agencies cite that it takes significant resources, stakeholder input, and continual re-evaluation for successful implementation (Kittelson and Associates, 2020).

AASHTO has also produced a tool, the Multiple Objective Decision Analysis Tool (MODAT), as well as a training course, Performance-Based Prioritization Using MODA, both of which are further described in the sub-sections below.

3.1. The Multiple Objective Decision Analysis Tool (MODAT)

MODAT is a tool for applying MODA methodology to a set of projects to support project prioritization across assets, modes, and performance areas. The tool, available at <https://www.multiobjective.org/>, allows for performance measures to be weighted and scaled. Once measurements are input, the system calculates objective scores for each project. The user can then prioritize projects to determine how to best allocate resources given a specified budget.

To use the tool the user first defines a set of investment objectives and measures for describing progress towards meeting those objectives. Each measure is scaled to produce a score proportional to the value produced by the project. Measures are scaled as a percentage so that the scaled measure value is proportional to utility or benefit. The scaled values range between 0% (least utility) and 100% (most utility). Then based on relative importance, the user assigns specific weights for each measure to calculate performance scores which will inform the overall score.

After configuring the system, projects may be analyzed by inserting the cost and measure values for each project. The tool will calculate the new scaled measure values and objective scores for each project using the configuration data. With the scaled measures the user can evaluate projects across assets, modes, and performance areas, and determine which to fund given an overall budget and priorities related to goals, performance measures, and outcomes.

The MODAT tool is the successor to AASHTO's Cross-Asset Resource Allocation Tool Spreadsheet (CARATS) developed under the 2015 NCHRP Report 806: *Guide to Cross Asset Resource Allocation and the Impact on Transportation System Performance*. The MODAT web tool was developed to enable the use of Data Envelopment Analysis (DEA) in the optimization step of the implementation process and to demonstrate a web service that transportation agencies can use in their own web applications to automate DEA. DEA is an analytical approach that identifies the most productive decision making unit (DMU), where each DMU may require a range of inputs and produce a range of different outputs that cannot be easily compared without the use of an analytical model (NASEM, 2019).

NCHRP Report 806 had originally presented CARATS as a framework and prototype tool for implementing a MODA-based approach. CARATS was developed following an extensive review of theoretical and practical approaches to CARA and publicly published online; however, the tool has since evolved into MODAT after pilot testing and additional field feedback on the usability of the interface under the 2019 NCHRP Report 921: *Case Studies in Implementing Cross-Asset, Multi-Objective Resource Allocation*. The CARATS website now redirects to the MODAT tool.

NCHRP Research Report 921 describes the experiences of four States testing the implementation of a CARA process, which greatly informed the development of these tools. The case studies covered in the report include the following agencies:

- Arizona DOT;
- California Department of Transportation (Caltrans);
- Delaware Valley Regional Planning Commission (DVRPC); and
- Maryland DOT.

The MODAT tool is free and available to any agency or practitioner that creates an account and provides a brief explanation on how they will use the tool (AASHTO, 2022).

3.2. Training on Performance-Based Prioritization Using MODA

This AASHTO training course was developed to educate and introduce transportation practitioners to the basics of MODA. The course describes in detail how a transportation agency might implement MODA as an approach to help analyze complex investment decisions. The first lesson provides a basic overview of MODA, summarizing core definitions and general approaches to making programming decisions across performance areas, challenges to programming across areas, and the benefits of utilizing a MODA methodology. Lesson one also provides a real-world example of the Maryland DOT to illustrate what MODA is and how they implemented it to prioritize investments in their Consolidated Transportation Plan. The second lesson goes over the eight steps from NCHRP Report 921 for implementing MODA for investment prioritization.

4. Examples of CARA and MODA Implementation Cited in the Literature

Much of the literature and research reviewed for this report was based on case studies of States and/or MPOs developing their own approaches to resource allocation. The following tables highlight a few examples referenced throughout the literature. Several of these examples highlight effective tools and practices for project prioritization, while others identify approaches that need further development. Future research could evaluate the continued progress of these examples, as well as identify agencies not yet explored in the literature.

Table 2. Example CARA tools and approaches

Agency	CARA Tool and/or Approach	Reference
Florida DOT	Implemented a CARA strategy using their Strategic Investment Tool.	NASEM, 2017
Idaho DOT	Implemented a CARA approach using a strategic initiatives program.	NASEM, 2017
Maryland DOT	Piloted CARATS and now piloting a MODA tool to help prioritize projects for the State's Consolidated Transportation Plan.	AASHTO, 2021b; FHWA, 2021
Massachusetts DOT	Implemented a CARA strategy using their Planning for Performance tool.	NASEM, 2017; FHWA, 2021
Oregon DOT	Implemented a CARA approach called Connect Oregon.	Middleton, 2015; NASEM, 2017; Kittelson and Associates, 2020

Table 3. Example MODA tools and approaches

Agency	MODA Tool and/or Approach	Reference
Caltrans	Utilized MODA to prioritize projects in the California State Highway Operation and Protection Program (SHOPP).	AASHTO, 2021b
DVRPC	Implemented a MODA approach for evaluating and selecting projects.	FHWA, 2021
Genesee Transportation Council	Implemented a MODA approach to data-driven prioritization by combining highway/bridge condition data, annual average daily traffic, and environmental criteria.	Middleton, 2015
North Carolina DOT	Developed an in-house MODA platform called SPOT OnLine.	Kittelson and Associates, 2020; FHWA, 2021
Virginia DOT	Implemented a MODA program called SMART SCALE.	Middleton, 2015; Sperling et al., 2018; Kittelson and Associates, 2020; FHWA, 2021; Noyce et al., 2021

5. Conclusions

As transportation agencies' performance-driven programming processes continue to mature, CARA and MODA will be critical to understand and apply. This report introduces the concepts of CARA and MODA, reviewing existing literature and research to provide a high-level overview of each. There are many opportunities to advance the state of the practice through additional research to better understand how agencies are using these approaches today, and how lessons learned may be transferred across the transportation sector. Some opportunities for further research are summarized below.

5.1. Noteworthy Practices and Lessons Learned

The literature provides many examples of agencies implementing CARA and MODA approaches that researchers could draw upon to further investigate agency processes, tools, and outcomes. The case study research could be synthesized to highlight noteworthy practices and lessons learned, as well as identify other opportunities for further research.

5.2. Synthesis of Available Tools

The literature provides examples of tools that agencies are using to implement CARA and MODA. It would be helpful for researchers to examine the aspects of these tools that have been successful for supporting and implementing CARA and MODA and share the findings with State DOTs and MPOs.

5.3. Peer Exchanges

There is a lot of interest in CARA and MODA among State DOTs and MPOs. Peer exchanges that include agencies that have strong practices along with those that are new to CARA and MODA could help advance the state of the practice.

5.4. Data Sources Clearinghouse

As noted by Kittelson and Associates in their 2020 report on performance-based planning research for the Alaska Department of Transportation and Public Facilities, "data is vital to how DOTs plan, invest in, and evaluate transportation networks in response to increasing regulations, funding constraints, and rising demands for transparency in the decision-making process. There is also rapid growth of connected devices which provide geospatial movement data at a scale never seen before" (Kittelson and Associates, 2020). As data availability is ever-evolving, there are opportunities to advance the state of the practice by identifying existing data sources that may be available to support CARA and MODA implementation.

6. Annotated References

American Association of State Highway and Transportation Officials (AASHTO). September, 2015. *Defining Cross-Asset Decision Making: A Discussion Paper.* <https://www.tam-portal.com/document/defining-cross-asset-decision-making-a-discussion-paper-2/>

AASHTO developed this discussion paper to briefly examine some of the concepts around optimization and cross-asset allocations or tradeoffs. It is not a primer on the topic, but rather it helped start a conversation around establishing a common set of definitions so that transportation officials can communicate more precisely as they discuss these topics.

American Association of State Highway and Transportation Officials (AASHTO). December, 2021a (accessed). *Performance-Based Prioritization Using Multi-Objective Decision Analysis (MODA).* <https://store.transportation.org/Item/TrainingDetail?ID=4506>

AASHTO developed this training course to educate and introduce transportation practitioners to MODA. The course describes in detail how a transportation agency might implement MODA as an approach to help analyze complex investment decisions. The course is targeted toward transportation professionals responsible for: prioritizing investments across program areas; developing statewide transportation improvement programs (STIPs) or metropolitan transportation improvement programs (TIPs); and/or establishing performance targets. The course is organized around two lessons: (1) What is MODA? and (2) Steps in Implementing MODA.

The first lesson provides a basic overview of MODA highlighting core definitions and general approaches to making programming decisions across performance areas, challenges to programming across areas, and the benefits of utilizing a MODA methodology. Lesson one also provides a real-world example to illustrate what MODA is and how it can be implemented. In the first example, the Maryland DOT uses MODA to prioritize investments for their Consolidated Transportation Plan.

The second lesson explains the eight steps for implementing MODA for investment prioritization. Each step includes key activities needed to move on to subsequent steps along with potential challenges. Clear and informative graphics are provided to illustrate the complex nature of the methodology.

American Association of State Highway and Transportation Officials (AASHTO). December, 2021b (accessed). *Transportation Asset Management Guide, Chapter 5: Resource Allocation.* <https://www.tamguide.com/chapter/5-resource-allocation/>

The Transportation Asset Management (TAM) Guide is intended to further transportation agencies' understanding of asset management techniques and advance associated practices. Resource allocation is considered a key component of TAM and is covered in Chapter 5 of the Guide. CARA methods, including MODA, are also covered.

The guide provides a broad overview of CARA and MODA. The basic benefit of MODA is to provide a structure for prioritizing investments outside the scope of any one management system, such as projects combining pavement, bridge, and safety improvements. MODA provides a means to compare asset management investments with other investments to improve mobility and achieve other objectives outside the scope of a typical asset management system.

The guide cautions that MODA is more data intensive than conventional resource allocation methods and may result in simplification of the asset-specific modeling performed in a pavement or bridge management system. MODA tools and approaches are typically intended for application in analyzing specific candidate projects and used for prioritizing investments for a single decision period. The guide references *NCHRP Report 806: Guide to Cross Asset Resource Allocation and the Impact on Transportation System Performance* as a framework for implementing a MODA-based approach.

The guide highlights Caltrans' State Highway Operation and Protection Program (SHOPP) as a "bottom-up" MODA example. Caltrans piloted a MODA approach to prioritize projects for inclusion in SHOPP. An interesting method Caltrans used was representing each project score through a monetized benefit value, which addressed the challenge of scaling or weighting criteria differently.

American Association of State Highway and Transportation Officials (AASHTO). January, 2022 (accessed). *Multiple Objective Decision Analysis Tool (MODAT)*. <https://www.multiobjective.org/>

The Multiple Objective Decision Analysis Tool (MODAT) helps transportation agencies apply a MODA methodology to a set of projects to support project prioritization across assets, modes, and performance areas. Users define a set of investment objectives and then set performance measures for achieving project objectives. The tool allows for performance measures to be weighted and scaled. Once measurements are input, the system calculates objective scores for each project. The user can then prioritize projects and evaluate tradeoffs to determine how to best allocate resources given a specified budget.

Federal Highway Administration (FHWA). December, 2019 (last updated). *How TPM and Asset Management Work Together. FHWA Transportation Performance Management Program*. <https://www.fhwa.dot.gov/tpm/resources/working.cfm>

This online resource provided on the FHWA Transportation Performance Management (TPM) program website defines, and summarizes, the distinctions between TPM and Transportation Asset Management (TAM). For example, TPM is an approach to managing transportation system performance outcomes, and TAM is the application of this approach to manage the condition of the infrastructure assets that are needed to provide for mobility and safety on the nation's transportation system.

Federal Highway Administration (FHWA). December, 2021 (accessed). *Transportation Performance Management Guidebook: Performance-Based Programming*. Transportation Performance Management Toolbox. <https://www.tpmtools.org/guidebook/chapter-04/>

The TPM Guidebook builds upon over a decade of TPM research and agency practices to introduce a comprehensive TPM framework. The framework is comprised of six components with performance-based programming being the fourth component. The guidebook specifies that the performance-based program includes two subcomponents: programming within performance areas and programming across performance areas. CARA is described within the context of programming across performance areas. The guidebook provides an overview of CARA, how it is used for STIP and TIP development, and transportation agency implementation examples. It also presents MODA under one of the implementation steps for CARA.

Federal Highway Administration (FHWA). March, 2022 (accessed). *Example Practices for Performance-Driven Programming.*

https://www.fhwa.dot.gov/planning/performance_based_planning/resources/fhwahep22018.pdf

This report highlights how State DOTs and MPOs are implementing performance-driven programming processes and aligning transportation investment decisions with the Federal performance areas for safety, infrastructure condition, and system performance. FHWA shared these examples to help advance the state of the practice for performance-driven programming. The research included review of planning documents from four State DOTs and five MPOs, and agency discussions, to examine how agencies are using performance-driven programming processes to guide resource allocation to achieve goals, objectives, and performance targets. The report characterized the approaches and investment strategies agencies are applying in their planning and programming processes to make progress toward performance target achievement.

Kittelson & Associates, Inc. July, 2020. *Performance Based Planning Research.* Alaska Department of Transportation and Public Facilities. <https://dot.alaska.gov/stwddes/research/assets/pdf/4000-193.pdf>

The Alaska Department of Transportation and Public Facilities retained Kittelson & Associates, Inc. to research national practices related to project prioritization for STIP development so the Department could apply them to their National Highway System (NHS) project prioritization process for FHWA's National Highway Performance Program (NHPP). The research included an examination of the Department's existing project selection processes and recommendations on how national practices could be adapted to the unique Alaskan conditions and applied for a more streamlined, consistent, and transparent process. The resulting report documents example practices and tools that are used by transportation agencies for resource allocation and project prioritization, including CARA and MODA.

Middleton, S. May 1, 2015. *Cross-Modal Project Prioritization: a TPCB peer exchange.* Transportation Planning Capacity Building Program. <https://rosap.ntl.bts.gov/view/dot/12202>

This report highlights key recommendations and noteworthy practices identified at a peer exchange on cross-modal project prioritization, held in Raleigh, North Carolina in December 2014. This event was sponsored by the Transportation Planning Capacity Building (TPCB) Peer Program, which is jointly funded by FHWA and the Federal Transit Administration. The primary goal of the peer exchange was to address the concerns expressed by the North Carolina DOT regarding the challenges of implementing North Carolina's Strategic Transportation Investment legislation. The purpose of the peer exchange was to gather innovative examples, useful suggestions, and noteworthy practices from other transportation agencies that have experience prioritizing projects across different modes of transportation.

In advance of the exchange, the TPCB program identified three State DOTs and two MPOs to share their experiences, lessons learned, and recommendations for prioritizing projects across modes. The TPCB program focused on organizations with experience prioritizing or evaluating projects across modes of transportation in long-range transportation plans, STIPs, and TIPs, including the Oregon DOT, Virginia DOT, Delaware DOT, Genesee Transportation Council, and Metropolitan Transportation Commission.

National Academies of Sciences, Engineering, and Medicine (NASEM). 2015. *Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance*. Washington, DC: The National Academies Press. NCHRP 806. <https://nap.nationalacademies.org/catalog/22177/guide-to-cross-asset-resource-allocation-and-the-impact-on-transportation-system-performance>

NCHRP Report 806: *Guide to Cross-Asset Resource Allocation and the Impact on Transportation System Performance*, is a foundational source of information on CARA and is a highly referenced resource in the literature. The guide presents information for State transportation agencies on allocating limited resources among asset classes and organizational units to provide optimal system performance. The guidance includes discussion of a framework and an analytical tool to support decisionmaking and is supplemented by a spreadsheet-based prototype tool to help implement the guide's analysis framework. The spreadsheet-based prototype tool is the precursor to the web tool, the Cross-Asset Resource Allocation Spreadsheet Tool (CARATS).

The prototype tool applies Data Envelopment Analysis (DEA) techniques to create a transparent, structured, and repeatable method for project selection and communicating performance outcomes. The report describes how the prototype tool processes the weighting of all performance measures with respect to priorities by making the following actions: creating a value matrix, converting project benefits with respect to various performance metrics into dimensionless units, expressing project benefits in terms of their relative importance, and prioritizing/optimizing the project set to select the most cost-beneficial projects with respect to budget and performance constraints. The spreadsheet-based prototype tool was later field tested under NCHRP Report 921 and has since evolved to become the MODAT tool.

The principal research product is the guidance on CARA. The guidance, meant to be used by State DOT staff and others responsible for making programmatic resource allocation decisions in an agency, is designed to facilitate both strategic thinking about resource allocation and adoption of practical analysis methods.

National Academies of Sciences, Engineering, and Medicine (NASEM). 2017. *Resource Allocation of Available Funding to Programs of Work*. Washington, DC: The National Academies Press. NCHRP synthesis 510. <https://nap.nationalacademies.org/catalog/24793/resource-allocation-of-available-funding-to-programs-of-work>

The objective of this synthesis was to compile and present current knowledge and practices regarding how States approach the allocation of resources among programs in ways that are defensible and achieve reasonable balance among the competing needs in the resource allocation process. The synthesis includes a literature review of published journal articles and proceedings, and peer reviews among agencies facing issues of programmatic resource allocation. Programming across modes is a discrete section within the report. Case examples from Oregon, Florida, Massachusetts, and Idaho illustrate a diverse range of agencies developing innovative strategies for allocating their available resources. This study emphasizes the process by which funding is assigned to pools of work containing multiple projects, but does not necessarily focus on how individual projects are selected within programs.

National Academies of Sciences, Engineering, and Medicine (NASEM). 2019. *Case Studies in Cross-Asset, Multi-Objective Resource Allocation*. Washington, DC: The National Academies Press. NCHRP 921. <https://nap.nationalacademies.org/catalog/25684/case-studies-in-cross-asset-multi-objective-resource-allocation>

NCHRP Research Report 921: *Case Studies in Implementing Cross-Asset, Multi-Objective Resource Allocation* extends and implements the results of NCHRP Report 806: *Cross-Asset Resource Allocation and the Impact on System Performance*. Case studies were used to illustrate key issues in implementing a CARA approach, and the lessons learned were then used to improve the guidance and tools developed for NCHRP Report 806. In addition, a step-by-step guide for using the Cross-Asset Resource Allocation Spreadsheet Tool (CARATS) is provided. The guide includes images of the interface as it explains how to navigate features.

Noyce, D. et al. February, 2021. *Modern Project Prioritization for Transportation Investments*. Center for Transportation Equity, Decisions and Dollars. <https://trid.trb.org/view/1845434>

This study aims to fill a particular need among transportation agencies in achieving policy goals through data-driven decision-making, focusing on project prioritization within a larger decision-making structure. The study team reviewed project prioritization programs at 21 transportation agencies, including 14 State DOTs and 7 MPOs, through a combination of interviews, an online questionnaire, and publicly available written documentation. The main findings can be summarized in terms of three important opportunities in project prioritization: (1) establishing flexible funding programs (citing several State programs that provide flexible funding and leverage available revenues to advance multiple goals so that States can advance wide ranging programs when necessary), (2) evaluating key outcomes (to help ensure they represent actual goals of the agency and there is no overlap between criteria), and (3) maximizing benefits per dollar spent. The Virginia DOT's SMART SCALE process is highlighted as an example noteworthy practice.

Sperling, Elliot, and Catherine Ross. August, 2018. *Strategically aligning capital improvement prioritization to performance goals*. Transportation Research Record. <https://journals.sagepub.com/doi/10.1177/0361198118787639>

To better understand current practices, the researchers administered a survey to State DOTs to gauge their overall status in complying with FHWA's TPM rulemakings, and to measure interest in using new metrics and prioritization techniques to advance data-driven processes for decisionmaking. Furthermore, the researchers also examined evidence of cross-modal project evaluation and explored practices aligning decision criteria and analysis techniques with national performance goals and objectives. Survey results revealed a transition in practice toward performance-based approaches, but more limited use of cross-modal evaluation criteria. Case studies were also used to document decision criteria areas that help States advance alignment of their planning and programming processes. From the survey and case study analysis, recommendations are provided to underscore the need for multi-criteria decision analysis, or a similar decision analysis framework, to help States align project evaluation processes with national performance goals. As State DOTs adopt performance-based approaches, they are reviewing and refining their project selection processes to help ensure performance measures are linked to current investments, and funded projects align with agency goal areas and desired outcomes.

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