Wyoming Transportation Asset Management Plan (TAMP)

By

Marwan Hafez, Ph.D. P.E.
Postdoctoral Research Associate, Wyoming Technology Transfer Center, University of Wyoming, Laramie, WY 82071, mhafez@uwyo.edu

Omar Albatayneh, Ph.D.
Postdoctoral Research Associate, Wyoming Technology Transfer Center, University of Wyoming, Laramie, WY 82071, oalbatay@uwyo.edu

Muhammad Tahmidul Haq, Ph.D., P.E.
Postdoctoral Research Associate, Wyoming Technology Transfer Center, University of Wyoming, Laramie, WY 82071, mhaq@uwyo.edu

Khaled Ksaibati, Ph.D., P.E.
Director, Wyoming Technology Transfer Center, University of Wyoming, WY 82071, Tel: (307) 766-6230; khaled@uwyo.edu

Cosponsored by:

Greg Milburn, P.E.
State Materials Engineer
Wyoming DOT
Greg.milburn@wyo.gov

Michael Menghini, P.E.
State Bridge Engineer
Wyoming DOT
michael.menghini@wyo.gov

Mark Wingate, P.E.
State Planning Engineer
Wyoming DOT
mark.wingate@wyo.gov

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1 INTRODUCTION

Transportation Asset Management Plan (TAMP) has become a focal point in providing useful information about the assets, including asset performance, management strategies, long-term expenditure forecasts, and best investment scenarios. Functional transportation assets, including highways, tunnels, and bridges, keep the nation's economy moving, and therefore, top-of-the-line transportation networks are vital to attain in order to transport people, goods, and services across the U.S. safely and efficiently. States' Department of Transportation (DOTs) and local transportation agencies are seeking to manage the maintenance plans of transportation assets cost-effectively so that the maximum return is achieved. In the state of Wyoming, the state funding of transportation asset management has decreased while the federal funding has stayed the same. However, all in all, the purchasing power of funding has been recently reduced as a result of inflation. Consequently, state DOTs need to use their budgets more wisely in order to optimize the services on these assets and enhance the perception from the public users. To do that, a proactive approach is needed that requires transportation agencies to (1) preserve the serviceability of current assets, and (2) manage and plan for the long-term investment so that transportation systems and networks will meet the needs of future generations. To address these goals, asset management programs are needed. The asset management system is a strategic and systematic approach to manage transportation assets, and consider risk and investment needs over the entire life of a transportation asset (Amadi-Echendu et al., 2010). Therefore, it will ensure that the available funding will be used for the assets with the highest priorities.

The heartland location of Wyoming makes its transportation systems a crossroad of the nation's economy, helping the United States maintaining global leadership. Hence, the interstate systems in the state are characterized with excessive accommodations of through out-of-state vehicular traffic. In addition, many of Wyoming's industries, such as oil, gas, and agriculture, depend on the transportation network to deliver the goods and services to the global marketplace. In terms of Wyoming's tourism industry, Wyoming is featured with numerous national parks and recreation areas, including Yellowstone and Grand Teton national parks, which attract more than 4 million visitors annually. These competitive advantages of Wyoming encourage the Wyoming Department of Transportation (WYDOT) to make the right decisions on how to manage the transportation assets within the state. Other needs are also considered by WYDOT, such as mobility, capacity, safety, wildlife, active transportation, roadside features, and Information Technology Services (ITS). Statistically, WYDOT is responsible for managing over 6,530 centerline miles of the state-owned highway network (approximately 1,700 pavement management sections) (WYDOT Transportation Asset Management Plan, 2018). This large road network includes approximately 5,923 bridges/structures, 42,200 culverts, 800 signs, and 12,000 miles of fence. For WYDOT, the objective of the asset management program is to maintain, preserve, and modernize the overall transportation network's condition in the state at the highest possible level given the available funding and resources.

Since the transportation infrastructure is considered the lifeblood of the sustainable economic growth, congress passed several federal infrastructure bills to invest in the nation's roads and bridges. In 2012, the Moving Ahead for Progress in the 21st Century Act (MAP-21) consisted of a $105 billion two-year bill that controls the spending on the federal transportation network in the U.S (Weisman, 2012; Montopoli, 2012). The MAP-21 was estimated to consolidate or eliminate the federal budget deficit over the 2012–2022 period by $16.3 billion (Congressional Budget Office, 2012). In 2015, congress allocated additional funding bills on the national highway systems through the five-year Fixing America's Surface Transportation Act (FAST Act; P.L. 114-94) (Robert, 2020). Recently, congress passed the Bipartisan Infrastructure Deal (Infrastructure Investment and Jobs Act) which will deliver $110 billion of new federal investment to repair roads and bridges and support major transformational projects (The White House, 2021). The Bipartisan Infrastructure Deal makes the single largest investment in repairing and reconstructing the nation's bridges since the construction of the interstate highway system. It will rebuild the most economically significant bridges in the country as well as thousands of smaller bridges. As a result, public agencies will have more flexibility to direct funding and resources to high-priority transportation network assets.

Under the infrastructure bills requirements, any state DOT that accepts federal funds is required to develop and implement a risk-based Transportation Asset Management Plan (TAMP) that establishes asset groups and performance targets for each group. Wyoming's TAMP classifies assets within the state into three main types; pavement, bridge, and safety (WYDOT Transportation Asset Management Plan, 2018). These assets are compiled into different management programs, including materials, bridge, maintenance, and planning. Figure 1 shows the organizational structure of the WYDOT's TAMP process. Generally speaking, the chief engineer is responsible for coordinating the TAMP working groups to study the investment plans and the corresponding performance and strategic targets. The state materials engineer compiles section IV for statewide pavement condition and programs, while the state bridge engineer compiles section V for statewide bridge condition and programs. The state planning engineer serves as executive of the TAMP working group. The planning office compiles and prioritizes transportation needs for the state transportation system by collecting and interpreting different forms of traffic, transportation, and socio-economic data. The performance-based management system tools of the different assets use these needs and guidelines to develop the Statewide transportation improvement plan (STIP). Basically, the FHWA requires that the STIP is developed along a four-year planning period. However, WYDOT carries out a 6-year STIP for the TAMP projects. The STIP includes the funding splits and lists of project candidates. The STIP is then presented to the transportation commission for approval. The planning office keeps compiling the asset management data to update the transportation needs and the federal highway administration requirements. This information is used for the long-range transportation planning and other city, county, and urban plans.

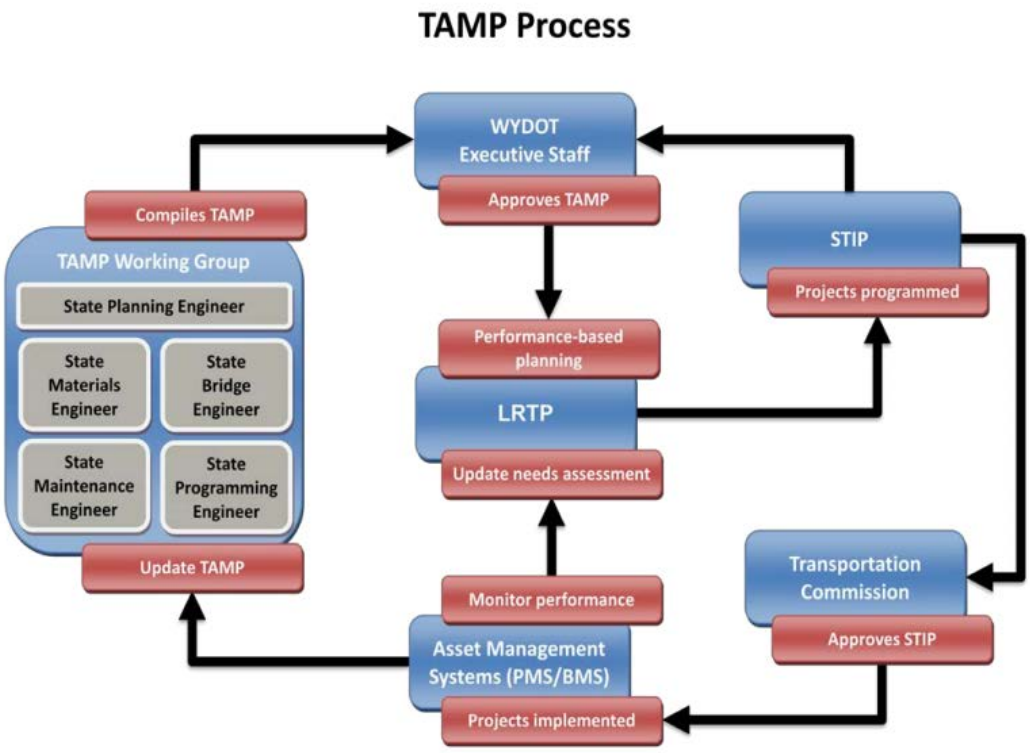

Figure 1. The WYDOT's Transportation Asset Management Process (WYDOT Transportation Asset Management Plan, 2018).

Since the funding is always limited to consider all the treatment projects into the STIP, the management systems produce a list of candidate projects to assist the district engineers in project selection. The district engineers use the treatment type requirements, budget, and candidate lists to construct their fiscally constrained STIP. They also perform kinds of tradeoff among the projects for the different assets considering local and administrative factors, along with guidance on mileage, square footage, and treatment types needed. While the district-level decision making is considered mainly through the asset management programs, district engineers make some trade-off decisions relying more on public information programs, annual meetings with local governments, input from program managers, and end-user recommendations (WYDOT Transportation Asset Management Plan, 2018). Therefore, district engineers are held responsible for ensuring the expected condition of bridges, pavements, and safety assets within their districts are met while working within pre-determined funding constraints.

2 PROBLEM STATEMENT

Although WYDOT operates comprehensive asset management programs at the network level, independent planning and separate analysis are implemented for each asset. Pavement, bridge, and safety performances are evaluated separately considering federal and state policies, such as

the minimum MAP-21 requirements, without addressing the overall return of investments in the state asset management plan. As a consequence, each asset management program provides its specific list of maintenance needs and potential projects. For example, the WYDOT's pavement management system (PMS) identifies road segments requiring minor/major rehabilitation candidate projects. For bridge assets, the Bridge Management System (BMS) can determine the bridge candidates for reconstruction. However, such separate programs and practices currently do not recommend transferring funding among the different assets to enhance the overall performance. Although the district-level decision making is considered locally by the executive staff to transfer the budgets among assets, WYDOT central funding can enhance the effectiveness of tradeoff considering the central budget transferring among the different assets, especially when additional funding is available to allocate by the central planning program. Congress is expected to allocate additional funding bills on the national highway systems through the five-year Fixing America's Surface Transportation Act (FAST Act; P.L. 114-94) (Robert, 2020). These additional funds provide a golden opportunity to be addressed by state DOTs to prioritize and tradeoff spending decisions among the different assets as well as the various roadway categories, including interstates, NHS, and non-NHS roadways. However, the standard tradeoff analysis is limited during the WYDOT's central funding allocation. No specific methodologies of tradeoff analysis were defined to select the best combination of treatment projects among the different roadway categories or the optimum split of total funding among the different assets.

In Wyoming, the interstate systems accommodate mainly trucks for the purpose of national freight and food transportation across the nation. On the other hand, the non-interstate national highway systems (NHS) and non-NHS are frequently used by Wyoming residents serving different traffic populations. Hence, the benefits of allocating funds among interstates, NHS, and non-NHS should be weighted considering the average daily traffic, as well as the truck traffic volume, so that maintenance plans will be developed to serve more public users of the mentioned infrastructure. However, the utility of the maintenance investments on the different roadway categories, including interstate, NHS, and non-NHS, is not defined within the WYDOT central funding process. This utility should define the priorities in the decision making when considering additional funds.

In addition, a decentralized program is currently followed among the different districts in Wyoming to choose maintenance projects from the recommended list of projects. For example, the WYDOT's bridge program employs a project-level optimization approach to maximizing WYDOT's bridge performance by providing lists of projects to the districts to maximize the performance of the bridge network in the state level. However, due to the limited funding, district engineers can carry out a selected subset of candidate projects. The practices of selecting projects within the constrained STIP among districts are not standardized. Therefore, it is important to have a strong integration between headquarters and districts. In light of this, some districts may follow more effective practices of selecting projects; however, the effectiveness of

the district-level decision making is not evaluated nor documented. Although several factors and local considerations are involved when district engineers tradeoff among the candidate projects, some districts may provide better effectiveness when selecting treatment projects. Other districts may have also been constrained with limited funding during a specific period. Even though district engineers may have a mechanism to validate district-level decision making practices, asset performance, and funding allocation, the consequences at the district-level are not documented from the historical point of view. WYDOT's TAMP keeps track of the statewide performance of the different assets over time. However, the historical evaluation of the individual districts can be further analyzed and is expected to link between the decisions made the their consequences on the performance of assets.

Moreover, most public transportation agencies employ commercial software packages that consider single asset types to manage (i.e., pavement or bridges asset management software), and limited planning tools were developed for cross-asset management techniques. According to an investigation conducted by Caltrans Division of Research and Innovation (DRI) (Guenther, 2014), North Carolina DOT and Utah DOT started to perform cross-asset management using powerful software packages, such as AgileAssets, to manage the maintenance and repair (M&R) activities of multiple assets. WYDOT can integrate the existing software used for managing Wyoming assets to tradeoff the funding distribution among the assets. This can be done by applying a multi-objective optimization to maximize the global performance of assets while considering the federal requirements of each individual asset as analysis constraints. The results of optimization analysis can provide multiple optimum strategies on the Pareto front in multiple objective spaces. Then, the tradeoff of diverting funding can be investigated using effective trade-off analysis methodologies. To successfully implement cross-asset management, preliminarily analysis and simplified techniques are recommended to evaluate the integrated techniques of tradeoff analysis on case studies before the full implementation at the statewide level. This study intends to help WYDOT identify the methodologies and techniques to tradeoff the strategic investments of multiple assets and different roadway categories at the central management level.

3 OBJECTIVES

Although WYDOT is responsible for managing numerous assets, this study will consider only pavement and bridge assets to investigate the supportive techniques of central funding allocation and district practices at the network level. To achieve this, the study is aimed to fulfill the following objectives:

- Investigate the current experiences of TAMP among state DOTs in terms of best practices, strategies, goals, and decision making.

- Propose supportive techniques to WYDOT's asset management programs to identify the best project portfolios of pavement and bridge assets considering the overall economic and social impacts in addition to the federal requirements.
- Define the utility of investing in both pavement and bridge assets to optimize the funding plans.
- Evaluate the historical funding distributions among pavement and bridge assets.
- Establish the tradeoff methodologies of funding allocation and funding transfer among the pavement and bridge assets when additional funding is available to invest.
- Investigate the trade-off practices of pavement funding scenarios among the different roadway categories, including interstates, NHS, and non-NHS, to benefit both resident and out-of-state vehicular traffic.
- Provide beneficial guidelines to Wyoming asset management systems considering best practices of district decision making.
- Study how current practices can be enhanced to increase the value of spending decisions on the transportation assets.

4 EXPECTED BENEFITS

The findings of this study will provide WYDOT with the tools and documented guidelines to enhance both central and district-level funding allocation processes while considering the tradeoff practices for decision making. The primary benefits include:

- Support WYDOT with techniques that would allow effective selection of maintenance, rehabilitation, and reconstruction projects and funding allocation.
- Transfer the management plan from section improvement programs to asset management programs.
- Form a powerful justification for additional or alternative investment.
- Maximize the values of all assets in each district.
- Obtain more cost-effective maintenance, rehabilitation, and reconstructions plans for pavement and bridge assets.
- Obtain more cost-effective maintenance, rehabilitation, and reconstruction plans for interstates, non-interstate NHS, and non-NHS in Wyoming.
- Achieve higher performance of pavement and bridge assets.
- Increase safety, mobility, and efficiency of transportation assets.
- Enhance the public impression of transportation users.

5 BACKGROUND

Cross-asset allocation and trade-off analysis tools describe the project benefits using dollar values. These determined benefits help prioritize candidate projects by benefit/cost ratio. Each

project has a set of forecast effects on agency objectives, such as safety, mobility, condition, and life-cycle cost. Decision makers can adjust the relative weight given to different objectives to achieve the desired performance outcomes in each District or statewide. According to the FHWA's TAMP Expert Task Group (ETG), cross-asset allocation is a gap limiting the ability of most DOTs to fully utilize comprehensive asset management. Many states are only beginning to address this gap so best practices are yet to be established. The ETG included cross-asset allocation as a focus area over the next five years to close this gap. Below are examples of cross-asset and trade-off analysis tools currently employed.

a. Colorado DOT

The Colorado DOT is evaluating the expansion of trade-off capabilities. About four years ago, the Colorado DOT worked with a consultant to develop an Excel-based trade-off analysis tool for three areas: bridge, surface treatment, and maintenance service level (CDOT, 2019). The tool relied on data from the agency's SAP® software system. The results of this effort were not as effective as the Colorado DOT had hoped, so they looked into an alternative that would utilize both SAP (which supports financial planning systems) and a system from Deighton Associates.

Based on lessons learned while developing its TAMP, the Colorado DOT recommends the use of a holistic approach to managing assets. If a culvert fails, the pavement will fail as well. All of the data needed to support asset management should link together in a geospatial environment to support analysis and decision-making.

b. Georgia DOT

The Georgia DOT has developed a trade-off tool with an online dashboard that combines analysis from individual tools to demonstrate anticipated performance levels, given funding allocation to different project areas (GDOT, 2019). The tool extracts outputs from multiple analysis sources and presents them all in an easy-to-understand format. The outcome of these efforts is a series of program-level funding and performance targets, such as those that MAP-21 requires. These targets are also a fundamental element of a comprehensive TAMP.

The Georgia DOT's lessons learned about trade-off analysis include:

- The development of trade-off analysis tools can help DOTs evaluate where to allocate resources to meet performance needs.
- Dashboards are an effective tool to draw results from multiple source systems and display them in a way that supports trade-off decisions.

c. North Carolina DOT

The North Carolina DOT (NCDOT) has made the development of trade-off analysis capacity a key goal for asset management. The agency uses AgileAssets software that includes a Pavement Management System (PMS), Bridge Management System (BMS), and Maintenance Management System (MMS) (NCDOT, 2018). NCDOT's goal is to complete the investment

scenario analysis within each module and then combine the results. The pavement analysis is underway, and there are plans to use this approach for bridges and maintenance. They are working with the system vendor to make adjustments that, once complete, should be able to run scenarios to facilitate trade-off analysis across these different asset classes.

NCDOT's lessons learned about trade-off analysis include:

- NCDOT uses a single weighted index for pavement condition, but it may expand to include other indices (such as mobility, safety, and other assets like facilities and ports).
- NCDOT recognizes that agencies need to have buy-in from different organizational groups and will need to overcome difficulties involved in getting groups to think long range and embrace planning mentalities that are broader than their own interest areas.

d. Pennsylvania DOT

In order to conduct precise forecasting on the 25,000 state-owned structures and 40,000 linear miles of roadway, the Pennsylvania DOT (PennDOT) has deployed Infrastructure Asset Management (IAM), an Applied Research Associates shareware solution that has been customized to meet the needs and data depth of PennDOT (PennDOT, 2019). It has been fully developed and is in the initial stages of implementation at PennDOT.

IAM has been configured for bridges and pavements to produce future condition forecasting for PennDOT. As with all asset management systems, IAM generates prioritized lists of recommended preservation, rehabilitation, and replacement projects based on inputs including current condition data, deterioration models, committed projects, budgets, condition targets, and specific network and management priorities. Within those specified parameters, the software evaluates the benefit/cost ratio for feasible treatments and selects a program of treatments that meets targets and criteria most cost-effectively. The system also generates condition forecasts based on that investment scenario.

e. Vermont DOT

The following Vermont Agency of Transportation (VTrans) underway in 2018 support or relate to asset management (VTrans, 2018).

- Project Selection and Prioritization: An example of VTrans' commitment to an integrated approach is its Project Selection and Prioritization Process (VPSP2) project. The TAMP provides most of the contents described in the regulations about developing an optimized transportation program, but at the later stages it intertwines with VPSP2. Starting in 2019-2020, VPSP2 will be used to select multimodal projects. It communicates the value of projects provided to Vermonters using eight criteria: safety, asset condition, mobility/connectivity, economic access, resiliency, environment, health access, and community.

- Data Integration and Information Sharing: The Vermont Asset Management Information System (VAMIS) is a key initiative by VTrans to enhance data integration and information sharing. It also supports the analysis of different investment scenarios across multiple asset types. The VAMIS is a collection of hardware, software, data, and processes that support asset management business processes. It will gather data from various sources, process, store, and analyze it. It will be used for budget and planning to implement sound maintenance, rehabilitation, and replacement strategies, and to schedule, track, and manage projects conducted. In 2020, The VAMIS project was deployed and started with sprint developments that are available on Vermont official state website (VTrans, 2021). Statewide entities are interested in it, including Buildings and General Services, the Agency of Natural Resources, and the Agency of Human Services.
- Future of Asset Management: VTrans is committed to continually improving how it advances healthy, safe, and efficient transportation options for future generations. The action plan in Chapter 7 has important next steps that VTrans will invest in and track for completion. Asset management will continue to be used to make risk-based, performance-based, and data-driven decisions.

f. Washington DOT

To assist with the performance scenario analysis, Washington DOT (WSDOT) purchased and customized a software package called "Decision Lens." Decision Lens is a priority and resource optimization software used to aid decision-making in capital planning and budget processes (WSDOT, 2019). This software can be used for identifying, prioritizing, analyzing, and measuring which investments, projects, or resources will deliver the highest returns to an organization. WSDOT used this tool to create performance scenarios for bridge and pavement assets to see the potential impact and trade-offs of choices made between different investment options at varying funding levels. The decision models are applicable for:

- Pavements,
- Bridges,
- Unstable Slopes,
- Major Electrical Assets, and
- New Revenue Proposals during the 2019 Legislative Session.

Remarks

While several vendors advertise cross-asset allocation and trade-off analysis tools (AASHTOWare, AgileAssets, Deighton Associates, and VueWorks to name a few), implementations in state DOTs are noticed to be limited, and more time is needed to fully evaluate their effectiveness and applicability.

6 METHODOLOGY: TRADE-OFF ANALYSIS FOR ASSET MANAGEMENT

In transportation asset management, the interest in trade-off analysis has been increased with the challenges of funding limitations, federal performance requirements, and multiple assets considerations. As shown previously, some public transportation agencies realized that the transportation infrastructure is not recommended to be evaluated on a single asset type (i.e., pavement or bridges alone) but on the system as a whole (Laumet and Bruun, 2016). Hence, asset management practitioners seek to follow a systematic approach to understand how to split available budgets among the different assets so that the overall return is maximized. To achieve this, several methodologies can be used, including the techniques in the following sections.

6.1 Benefit-Cost Analysis

The main objective of benefit cost analysis is to address the benefits expected from applying maintenance projects on the different assets. In the context of cross-asset management, the benefits are weighted on a common scale among the assets in order to make the spending decisions among the different assets comparable. This is considered by defining the “utility”, which is any perceived benefits from the investment decision. The utilities can be weighted according to different impacts, including economic, social, environmental, and healthy impacts. Then, the overall benefits are weighted in dollar values to determine the benefit-cost ratio (B/C ratio). The overall B/C ratio of the investment plans can finally be maximized using optimization techniques.

6.2 Multi-Criteria Decision Analysis

This technique considers various criteria for each asset and studies the effectiveness of the investment options on these criteria. Then, based upon professional judgement or other factors, different weights are subjectively assigned for all criteria in order to determine the overall scores. Finally, the decisions are made considering the ranking of the addressed investment scenarios. Figure 2 shows the general multi-criteria matrix developed for cross-asset funding allocation. It is expected that the subjective evaluation of investments on the different criteria will not affect the optimum strategies because the treatment candidates will be selected primarily through the optimization decision-making tools currently employed by PMS and BMS programs. The focus in this practice will be to trade off among the different scenarios to address how the budgets will be transferred among assets to maximize the overall benefits.

		Option 1	Option 2	Option 3	Option 4
Safety Criteria 1		2	1	1	3
Safety Criteria 2		4	3	4	5
Total Safety Value		6	4	5	8
Safety Weight	4				
Weighted Safety Score	(weight X value)	24	16	20	32
Pavement Criteria 1		6	5	7	5
Pavement Criteria 2		8	7	10	3
Total Pavement Value		14	12	17	8
Pavement Weight	2				
Weighted Pavement Score	(weight X value)	28	24	34	16
Bridge Criteria 1		10	9	1	1
Bridge Criteria 2		2	3	4	5
Total Bridge Value		12	12	5	6
Bridge Weight	3				
Weighted Bridge Score	(weight X value)	36	36	15	18
Mobility Criteria 1		3	3	4	5
Mobility Criteia 2		5	7	6	1
Total Mobility Value		8	10	10	6
Mobility weight	1				
Weighted Mobility Score		8	10	10	6
Weighted Ranking of the 4 Options		**96**	**86**	**79**	**72**

Figure 2. Multi-criteria analysis matrix (FHWA/AASHTO Asset Management Expert Task Group, 2015).

6.3 Risk-Reward Analysis

The risk-reward analysis is the practice of weighting the expected risks and rewards of investment scenarios. In asset management, different sources of risks entail in the multi-year maintenance planning. The risk component of the trade-off analysis can be determined from wide ranges. The highest level of risk is the agency risk, which includes the uncertainty in the funding availability to preserve and maintain the existing infrastructure, or expand the existing system to meet future needs. The lowest risk level is involved in the project risk of bringing individual projects to contract. The project risk can be formulated specifically for district engineers to tradeoff among the project candidates of the different assets. Under this methodology, the investment strategy seeks to maximize the overall utility while not exceeding acceptable levels of risks. Normally, the multi-objective optimization formula for the overall risk-reward utility of different assets will end up with different optimum investment scenarios. The trade-off of the optimum portfolio will depend on the amount of the risk tolerance considered by the decision maker. Figure 3 shows the optimum solutions using efficient frontier (Bai et al., 2012). The trade-off among these solutions will depend mainly on how the decision makers classify the amount of risk and reward for each individual portfolio.

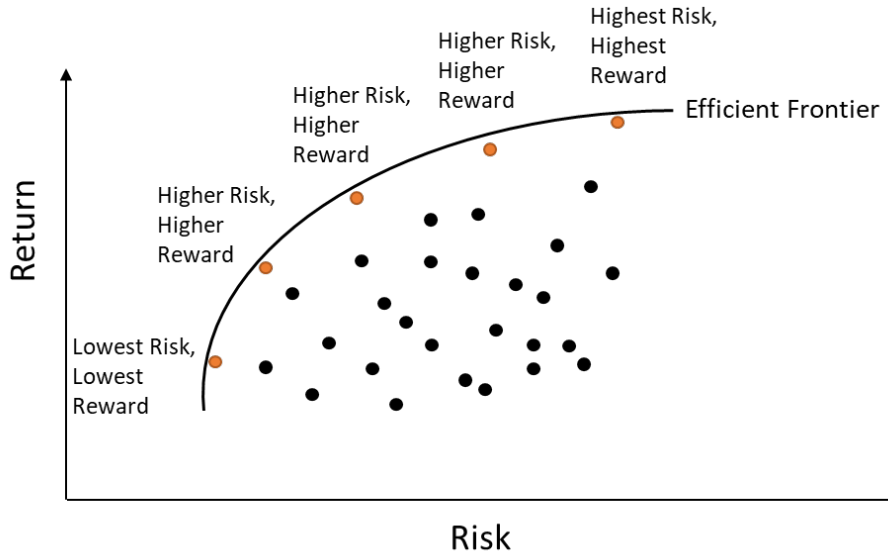

Figure 3. Risk-reward trade-off for asset management using efficient frontier (after FHWA/AASHTO Asset Management Expert Task Group, 2015).

7 RESEARCH PHASES

In order to fill the gap of multi-asset management and cross-asset funding allocation, the research efforts can be divided into two phases. This proposal focuses only on the first phase, while future studies can be proposed for the second phase. The two phases are described in the following subsections.

7.1 Phase I

The first phase will focus on the historical practices of central funding allocations, as well as the district-level decision making. The literature will be reviewed in this phase to study how other state DOTs are managing their multiple assets effectively. The review will be further investigated by sending a national survey of practice as requested by the WYDOT state planning engineer. The survey will solicit the previous experiences of state DOTs to help gain more insights about the best practices of cross-asset management and trade-off analysis. Then, the techniques of cross-asset decision making will be evolved using standard trade-off methodologies. Another important objective of the first phase is to investigate how the spending decisions of WYDOT's central funding and district engineers were allocated previously and the corresponding effectiveness on the historical performance of pavement and bridge assets. This would allow the research team to evaluate the integrated techniques of multi-criteria decision making and trade-off analysis on the funding split compared to the traditional techniques followed previously. It will also support the justification of investment distribution among assets in case additional funds will be available. The trade-off analysis will be considered on two case

studies (a study for the central funding among the pavement and bridge assets, and a study for the pavement management among the different roadway categories). The case studies will consider the performance modeling of pavement and bridge assets, in addition to the treatment cost and improvement matrices. In addition, different time frames will be considered for the planning and trade off analysis. The case studies will consider several time frames ranging from 10 to 20 years to address the effectiveness of long-range planning on the optimum strategies. The results from the first phase are expected to provide informed decisions and beneficial guidelines for the full implementation of the integrated techniques on all assets managed by WYDOT in the second phase.

7.2 Phase II

In this phase, future studies will be proposed for the purpose of the full implementation of the cross-asset funding allocation at both central- and district-level management systems. In this phase, the statewide strategic goals and objectives among the different assets will be defined. Also, the trade-off policies will be identified to establish the priority of funding allocation, especially for pavement and bridge assets, considering the recommendations derived from the first phase. The performance of safety assets will be also combined into the statewide objective functions and constraints. All of the defined components will be eventually integrated into a comprehensive decision making tool that can be operated by a software package to facilitate the applications.

8 STUDY TASKS

The first phase of this research is composed of the following study tasks:

1. Literature Review.
2. State DOTs Survey of Practice for Cross-Asset Management and Trade-off Analysis.
3. Pavement and Bridge Central-Funding and Decision Making.
4. Addressing Potential Funding Increase.
5. Implementing Trade-off Analysis of Pavement Management among the Different Roadway Categories.
6. Effectiveness of District-Level Decision Making.
7. Evaluating the Historical Maintenance and Rehabilitation Records for Pavement Assets.
8. Recommendations and Guidelines.
9. Preparing the Final Report.

8.1 Literature Review

A comprehensive literature review will be conducted regarding the existing research studies, other state DOTs' guidelines, goals, and investment strategies related to transportation asset management and funding allocations.

8.2 State DOTs Survey of Practice for Cross-Asset Management and Trade-off Analysis

The literature review will be supported with more investigations about the best practices of cross-asset management through an online national survey. The survey questionnaire will comprise questions covering most related practices and techniques, currently followed by state DOTs, to cross-manage the different assets during the funding allocation process. The survey will also explore the experiences of common trade-off analysis methods and practices employed by state DOTs. The online survey will be developed and disseminated to the officials of state DOTs across the nation. Some recommendations are expected to help the researchers establish the methodologies required to integrate the trade-off analysis into Wyoming's assets management and potential strategies for cross-asset management implementations. Also, a review of available tools adopted by other state DOTs and their effectiveness will be studied to identify impacts of the project candidates from different assets on a common scale "Utility" so that comparison and selection are made possible.

8.3 Pavement and Bridge Central-Funding and Decision Making

In this task, the research team will first study the historical central funding allocation and the associated historical pavement and bridge performance for the state of Wyoming. Then, all the trade-off and multi-criteria decision making will be set for the central funding split among pavement and bridge assets. Figure 4 provides a general flowchart showing the funding allocation process. The overall performance of pavement and bridge asset is presented by the Present Serviceability Index (PSI) and National Bridge Index (NBI). These indices will be combined into a dimensionless global performance index in order to compare both assets on a common scale. Afterwards, the research team will analyze the objective function of central funding allocation by considering maximum traffic volumes served, the federal performance requirements, minimum investments needed by the district, risks integration, and environmental impacts. The analysis of decision making will be considered along different time frames, including 10, 15, and 20 years to address the effectiveness of long-range planning on the trade-off results and optimum strategies.

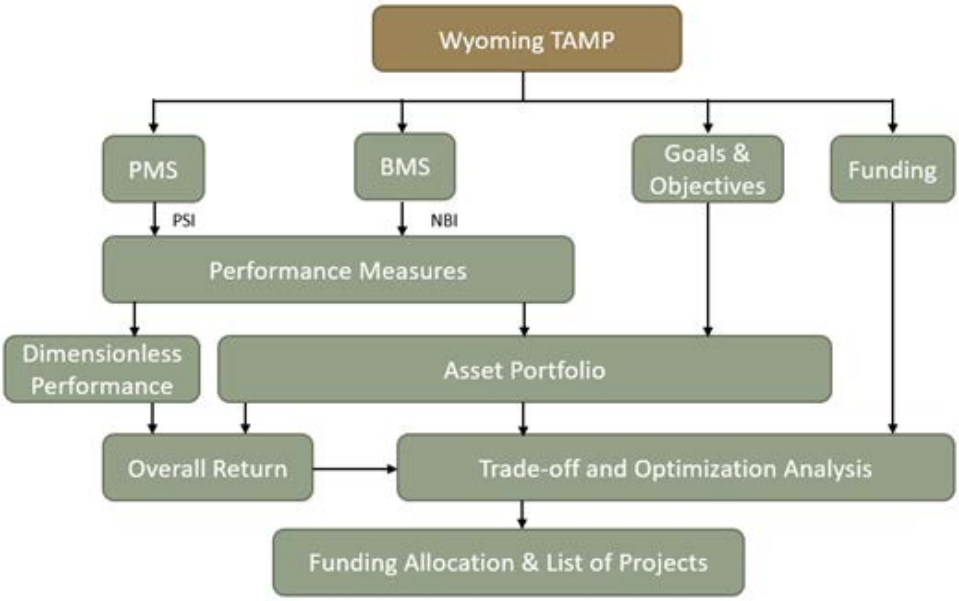

Figure 4. Central Funding Allocation Process.

8.4 Addressing Potential Funding Increase

Based on the historical funding allocation and the corresponding asset performance, the research team will identify the impact of potential funding increments on asset management. For example, in case of securing a funding raise by federal and congress legislations, the central funding allocation of WYDOT on the different assets will be accordingly increased. In this task, the research team will demonstrate the trade-off practices of distributing the funding increase among the pavement and bridge assets to maximize the benefits. Several funding increase scenarios will be studied, including a funding raise of $50, $100, $150, and $200 million.

8.5 Implementing Trade-off Analysis of Pavement Management among the Different Roadway Categories

WYDOT divides the state road networks into three roadway categories as described below (WYDOT Transportation Asset Management Plan, 2018):

- **Interstate**: High speed, typically four-lane, divided and controlled access roadways that carry the highest traffic volumes and the most freight load.
- **Non-Interstate National Highway System (NHS)**: Federally designated roadways that are functionally classified as principal arterials and expressways but not as interstates.
- **Non-NHS**: The remaining roadways that the state manages.

In this task, the historical funding allocation will be investigated specifically for pavement assets for the three roadway categories: interstate, non-Interstate NHS, and non-NHS. From the historical evaluation process, a preliminary understanding will be gained on how the annual pavement maintenance budgets were assigned for each category. This will help the research team

define the state considerations of funding split, especially when funding is limited. In addition, a systematic analysis of decision making will be incorporated to maximize the overall return of investing in the pavement asset of the three systems. In terms of funding sources, some highway projects are funded 90/10 (Federal/State) while other projects are funded 80/20. Evaluating the historical spending on the roadway categories is expected to define the points of merits and limitations of the funding sources. It will also provide the understanding to establish the utility to benefit both resident and out-of-state vehicular traffic served by the different roadway categories. The optimum trade-off will be determined in case additional dollar amounts are available for cross-funding allocation among the three systems. The objective functions will be established considering major criteria. The most important criteria will be the average daily traffic, as well as the truck traffic volume, so that maintenance plans will be developed to serve more public users of the mentioned infrastructure. A sensitivity analysis will be conducted to explore how the different weighting factors of the objective functions affected the optimum strategies in terms of budgets and expected performances. Also, the federal matches and the overall budget constraints will be formulated in the optimization process of funding allocation at the network level. The potential funding increase will also be investigated to tradeoff the cross-system funding allocation so that the best overall performance of the public stakeholders is obtained.

Real data examples of the interstate, non-interstate NHS, and non-NHS will be considered as a case study to demonstrate the application of the predefined techniques and evaluate the effectiveness of the funding scenarios on the future performance. This will allow the research team and WYDOT to compare the developed techniques with the traditional and the historical funding allocation; hence, useful guidelines can be recommended. Similar to the central funding task, the analysis will be performed along different time frames, including 10, 15, and 20 years to address the long-range planning and its effectiveness on the optimum strategies.

8.6 Effectiveness of District-Level Decision Making

There is a need for a clear policy formulation to support district engineers with tools on how to effectively allocate the limited funding among the different assets. These policies should include key functional requirements that secure the quality of the existing road network from deteriorating, especially when limited funding is available. Similarly, there is a need to identify several requirements at the management and operational levels to perform the necessary maintenance. Therefore, the objective of this task in the district-level decision-making process is to investigate how district engineers made decisions about the maintenance of the road network in their districts. The goal is to better understand district engineers' reasoning and processes for selecting and deploying maintenance activities and practices, including any potential data considered to support the district-level decision-making. These historical decisions of the district engineers will be linked with the network-level performance to define the effectiveness of each practice used by district engineers on the district-level performance. Ultimately, this task will attempt to document the best districts having optimum performance of assets, and the related

decision making and funding so that general recommendations can be developed for the other districts.

8.7 Evaluating the Historical Maintenance and Rehabilitation Records for Pavement Assets

The feedback received from WYDOT's planning program emphasizes on the importance of studying the maintenance records to learn from the past and improve the future of treatment decision making. In this task, the historical maintenance and rehabilitation practices on Wyoming's pavement assets will be assessed using the as-built history and project records. WYDOT employs a centralized mechanism to govern the as-built files related to pavement projects. The data set provides information of previous maintenance activities, including the work code, treatment types, mile posts, layer thicknesses, among other related information. The historical records will be analyzed to assess the volume of implemented treatment projects applied on the different systems considering the volume of road inventory and pavement performance. This would help gain more insights about the level of treatments normally considered on maintenance sections in a repeatable manner. The findings from this task will provide basic programming information to determine the frequency of maintenance activities required by each maintenance section to keep the overall pavement performance in acceptable conditions. This can be determined using the network coverage ratio (NCR) which represents the time needed to cover the entire road network with treatments (Wang et al., 2021). With this, useful recommendations will guide the long-range pavement investments with more representative plans that can quantify treatment types, budgets, and maintenance section candidates annually. The output from this task will be linked with the previous tasks of funding allocation as part of the trade off practices for pavement assets.

8.8 Preparing the Final Report

Once all the data has been collected and analyzed, and the optimization models and trade off practices are developed, the WYT2/LTAP center will prepare a final report describing all the findings of the study.

8.9 Present Findings, Recommendations, and Guidelines

The Wyoming T2/LTAP center will present the findings of the study at local, regional, and national meetings and conferences. The recommendations and guidelines will be presented to the WYDOT Research Center to facilitate the full implementation of the recommendation of this study.

9 TIMELINE

The first phase, proposed in this report, is anticipated to be completed in 33 months, after receiving the notice to proceed from WYDOT. Progress reports will be provided to WYDOT quarterly. The proposed timeline of the study is presented in Figure 5. This will be the main timelines, however, some of the tasks will be conducted throughout the entire study (such as literature review with new information, newly available methodology to improve the proposed system, and progress reports).

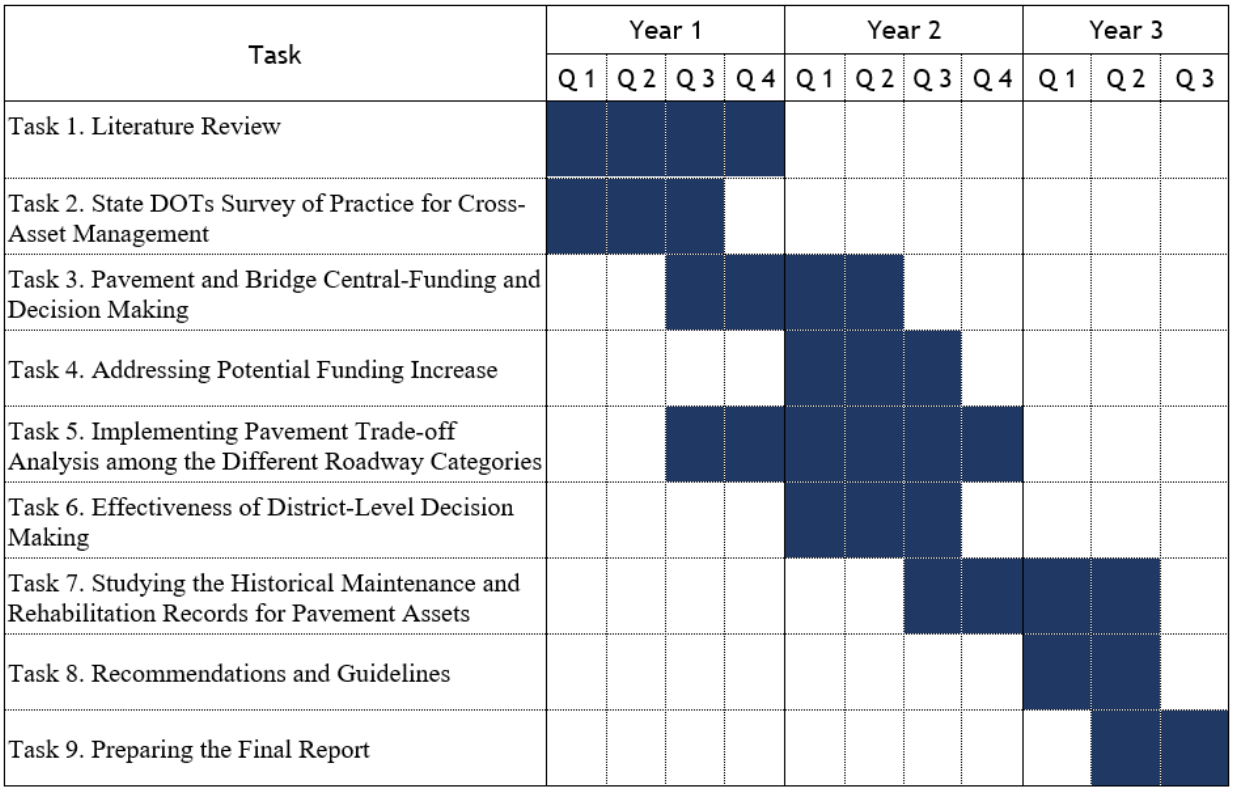

Figure 5: Proposed Study Timeline.

10 BUDGET

The total budget for this Phase I study will be $179,877. The breakdown of the study cost is shown in Table 1.

Table 1: Proposed Study Budget.

Categories	WYDOT
Faculty Salaries	$28,100
Post Doc	$29,400
Faculty/Post doc Fringe Benefits (42.1%)	$24,208
Student Salaries	$42,500
Student Fringe Benefits (2.8%)	$1,190
Total Personnel Salaries	$100,000
Total Fringe Benefits	$25,398
TOTAL Salaries & Fringe Benefits	**$125,398**
Travel	$4,000
Equipment/software	$2,500
Supplies	$4,000
Contractual	
Construction	
Other Direct Costs (Specify)*	$14,000
TOTAL Direct Costs	**$149,898**
F&A (Indirect) Costs	$29,980
TOTAL COSTS	**$179,877**

*OTHER DIRECT COST INCLUDES GRADUATE STUDENT TUITION, FEES AND INSURANCE

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