Guidance for Applying the State of Good Repair Prioritization Framework and Tools: Research Report

Draft Final Report

Prepared for
TCRP Project E-09A
by

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1. Introduction

BACKGROUND

Transit agencies have a wide variety of physical assets to maintain, including, but not limited to, rail cars, buses, stations, fixed guideway, facilities, and various supporting systems. Absent adequate funds many transit agencies could suffer significant reductions in system reliability, which may eventually result in restricted transit service. In recent years transit ridership has increased, but funds for keeping transit assets in a state of good repair (SGR) remain tightly constrained. The Federal Transit Administration (FTA) State of Good Repair Assessment *(1)* calculated a backlog of over $78 billion for state-of-good-repair investment needs for the U.S. transit system, well above the annual level of spending. The FTA assessment highlights the fact that U.S. public transportation agencies face an enormous set of challenges as they seek to preserve their existing capital assets. Asset preservation is an important concern for transit agencies throughout the U.S. regardless of their age, location, ridership, or the size of their asset inventory.

Many transit agencies are working to better assess, predict and prioritize their SGR needs. However, this area received increased emphasis with the passage of the U.S. transportation reauthorization legislation, Moving Ahead for Progress in the 21st Century (MAP-21). This legislation includes requirements for FTA to develop "establish and implement a national transit asset management system" that includes:

- A definition of SGR with objective standards for measuring the conditions of capital assets;
- A requirement that funding recipients and sub-recipients develop a transit asset management plan;
- A requirement that funding recipients report on asset conditions;
- An analytical process for assessing and prioritizing SGR needs; and
- Technical assistance to funding recipients.

As of this writing, the rules for implementation of MAP-21 were still under development. Nonetheless, it is clear that in the future many transit agencies will require assistance as they analyze their SGR needs and develop their transit asset management plans, both to determine how to make the best use of available capital funding, and comply with federal requirements.

PROJECT SCOPE

Transit Cooperative Research Program (TCRP) Project E-09A was initiated to help transit agencies apply the approaches being developed previously through TCRP Project E-09 to evaluate state-of-good-repair (SGR) investments. The results of the previous effort were published in TCRP Report 157 *State of Good Repair: Prioritizing the Rehabilitation and Replacement of Existing Capital Assets and Evaluating the Implications for Transit (2).* As noted in the research problem statement, additional research is needed to:

- Better establish data requirements for supporting application of the framework and tools;

- Develop procedures for performing analysis of capital asset rehabilitation and replacement investments; and
- Integrate evaluation of state-of-good-repair investments with development of a transit agency's capital program.

The objective of TCRP Project E-09A is to develop guidance for applying the framework and tools from TCRP Report 157 to evaluate and prioritize capital investments in transit assets for achieving a state of good repair. The research enhanced the existing framework and tools, created spreadsheet-based prioritization tool, demonstrated application of the framework and tool through a set of pilots and a transit agency workshop, and developed guidance for transit agencies in developing transit asset management plans.

This research report documents the work completed to conduct TCRP Project E-09A. It is supplements the transit asset management plan guidance and documentation of the Transit Asset Prioritization Tool (TAPT) published as a separate guidance document.

REPORT ORGANIZATION

The remainder of this document is organized into the following sections:

- **Section 2 – Literature Review Findings** discusses the results of a supplemental literature review performed to update the review documented in TCRP Report 157 to incorporate recent references and address approaches for incorporating sustainability measures.
- **Section 3 – Transit Agency Pilots** summarizes the result of the transit agency pilots performed to test the TCRP Report 157 SGR framework and tools.
- **Section 4 – Tool Development** details a set of enhancements made to improve the SGR tools develop previously and integrate these into a single tool, TAPT.
- **Section 5 – Workshop Overview** provides an overview of the workshop conducted to review draft versions of the project deliverables and transit agency pilots.
- **Section 6 – Recommendations for Future Research** discusses additional research that could enhance or support the work completed for this project.
- **Appendix A** provides an annotated bibliography of the materials reviewed as part of the research.
- **Appendix B** provides the detailed results memoranda for each transit agency pilot.
- **Appendix C** provides the presentation presented at the workshop.

2. Literature Review Findings

This section details findings of the literature review performed for this project. The review was conducted to review SGR-related references published since completion of the review detailed in TCRP Report 157, and to address the issue of potential performance measures for use in SGR analyses not considered in the previous review. Appendix A is an annotated bibliography detailing the materials that were reviewed. The following subsections summarize the review and its findings with respect to each of these areas.

TRANSIT STATE OF GOOD REPAIR

The review of SGR-related references focused on selected materials published since the completion of the 2011 review detailed in TCRP Report 157. Specifically, the review examined 28 presentations from the third and fourth FTA SGR Roundtables (in 2011 and 2012, respectively), 20 presentations from the 2012 Transportation Research Board (TRB) Asset Management Conference, and eight other papers and presentations.

Since completion of the previous review, a number of transit agencies have performed further work to implement asset management systems, and apply analytical approaches for SGR analysis such as those described in TCRP Report 157. Table 1 summarizes the examples described in recent literature of transit asset management implementation efforts and/or SGR analysis approaches being implemented by U.S. transit agencies. Most of the examples in the literature describe efforts to implement condition assessment approaches and/or asset management systems. In particular, a number of transit agencies describe efforts to implement Enterprise Asset Management (EAM) systems used to store detailed asset inventory data, work orders, cost data and other information needed both for day-to-day maintenance and operation of an asset inventory. Condition assessments and asset management systems are important for supporting an asset management approach and for supporting analysis of SGR needs and priorities. Thus the continuing trend towards their implementation indicates transit agencies are increasingly collecting the data needed to support SGR analysis.

Table 1. Transit Asset Management and SGR Analysis Case Studies in the Recent Literature

Transit Agency	Description	Source
Bay Area Rapid Transit (BART)	Asset management system implementation, use of TERM Lite for SGR analysis	*(3), (4)*
Chicago Transit Authority (CTA)	Asset management system implementation	*(4), (5), (6),*
Dallas Area Rapid Transit (DART)	Asset condition assessment approach	*(7)*
King County Metro Transit	Asset management system implementation and communication	*(4)*

London Underground	Asset management system implementation using performance measurement	*(4)*
Long Beach Transit(LBT)	Comprehensive Facility Master Plan (CFMP) development, development of key performance indicators (KPI)	*(8), (9)*
Maryland Transit Administration	Asset management system implementation	*(10)*
Massachusetts Bay Transportation Authority (MBTA)	SGR Database, project prioritization approach	*(4), (11), (12)*
Metropolitan Atlanta Rapid Transit Authority (MARTA)	Asset management system implementation, project prioritization approach	*(4), (13), (14), (15)*
Metropolitan Transit Authority of Harris County (Houston METRO)	Planning for asset management implementation	*(16)*
Metropolitan Transportation Authority (MTA)	Capital planning approach, benefits of focusing on SGR	*(17)*
MTA Long Island Railroad (LIRR)	Asset management system implementation	*(18)*
MTA New York City Transit (NYCT)	Asset condition assessment approach	*(19)*
Metropolitan Transportation Commission (MTC)	Use of TERM to support the Regional Transit Capital Inventory (RTCI)	*(20)*
National Railroad Passenger Corporation (Amtrak)	Asset management system implementation	*(21), (22)*
Regional Transportation Authority (RTA)	Asset condition assessment	*(4), (23), (24), (25)*
Santa Clara Valley Transportation Authority (VTA)	Use of the MBTA SGR Database for SGR analysis and DecisionLens for project prioritization	*(4), (26)*
San Diego Metropolitan Transit System (MTS)	System renewal efforts	*(27)*
San Francisco Municipal Transportation Authority (SFMTA)	Asset management system implementation, use of DecisionLens for project prioritization, condition	*(28), (29)*

	assessment approach	
Southeastern Pennsylvania Transportation Authority (SEPTA)	Asset management system implementation, development of an asset inventory	*(30), (31), (32)*
St. Louis Metro	Asset management system implementation, fleet management strategy	*(33), (34)*
Utah Transit Authority (UTA)	Asset management system implementation	*(35), (36)*
Valley Regional Transit (VRT)	Regional partnerships among smaller transit agencies to improve transit asset management	*(4)*
Victoria Department of Transport	Asset management cost and performance consideration during competitive bidding process	*(4)*
Virginia Department of Rail and Public Transportation (DRPT)	Implementation of PROGGRES (now Trans-AM) for SGR analysis	*(37), (38)*
Washington Metropolitan Area Transit Authority (WMATA)	Life cycle cost tracking, shifting focus to SGR, escalator maintenance efforts	*(39), (40), (41)*

In several cases, the literature focuses on efforts undertaken to supplement implementation of an asset management system or condition assessment with analysis of SGR investment needs. Generally these example describe the use of analytical approaches that are still under development (e.g., in the case of CTA, RTA and SEPTA) or that are based on approaches described previously in TCRP Report 157. For instance, BART and MTC describe the use of the FTA Transit Economic Requirements Model (TERM). MBTA and VTA describe their use of the MBTA SGR Database. DRPT describes its tool, PROGRESS (now renamed Trans-AM). MTA details its own SGR assessment approach. Two transit agencies, VTA and SFMTA, describe the use of DecisionLens for project prioritization.

Two transit agencies describe implementation of analytical approaches that were not previously detailed in the literature and that are relevant to the research effort. Springstead *(14)* describes MARTA's effort to implement the FA Suite EAM, and integrate this system with the Commercial Off- the-Shelf (COTS) system Expert Choice for supporting analysis and project prioritization. However, the presentation describing the use of Expert Choice lacks details on the analytical approach.

Also notable is LBT's development of performance measures for characterizing effectiveness of facility maintenance, described by Cruz *(9)*. Table 2 below lists the proposed measures developed by Cruz, with the category, measure and target set by LBT. This provides an example of a comprehensive set of facility maintenance measures which may be relevant to other transit agencies establishing measures for evaluating the implications of different investment levels for facility maintenance. Also, this provides an example of the use of sustainability-related measures in evaluating SGR, as discussed further in the next section.

Table 2. Long Beach Transit Proposed Facility Maintenance Measures

Category	Measure	Target
Facility Condition Index	Deficiency cost divided by replacement value	TBD
	Maintenance cost divided by replacement value	TBD
Equipment Condition Assessment	Percentage of assessments performed annually	100%
	Percentage of critical assets with an average condition of 2.5 or greater (on a 5-point scale)	100%
Equipment Replacement	Percent of critical equipment replaced within its useful life as dictated by plan	100%
	Percent of projects completed on time and on budget	100%
Maintenance Performance	hours of ready work divided by weekly hours of crew capacity	< 2
	% of work that is planned/proactive	>70%
	Ratio of actual number of work orders completed to the number on weekly schedule	
	Work order aging - % of worker orders over 30 days old	<10%
Customer Satisfaction	Customer rate divided by response rate standard	100%
	Customer survey results – percent of responses scored good or excellent	85%
Resource Use	Annual electricity consumption(kwh)	2% reduction
	Annual natural gas consumption	3% reduction
	Annual water consumption	4% reduction
	Annual recycled waste volume	10% increase
Energy Plan	Completion of equipment replacement evaluation upon equipment replacement	100%
	Completion of energy project as proposed by the Employee Green Team	100%

Source: (9)

In June 2013 the Federal Transit Administration released the finalized *Asset Management Guide (4)*. The guide provides an overview of transit asset management, presents a framework that can be used as "best practice" guidance, and offers details on major asset class and other practical guidance for transit agencies interested in improving the performance and effectiveness of their asset management practices. This report refers to, and describes, an "asset management plan." However, the plan described in the FTA document is a process improvement plan that describes how a transit agency conducts asset management, and what improvements are planned to its business process. The asset management plan described in TCRP Report 157 and in MAP-21 is focused on asset performance, and prioritizing investments. Regardless, the FTA Guide complements the work completed for this project by providing a reference for topics not covered by the research, such as data collection.

Several other references detail research efforts which were identified as being active during development of TCRP Report 157 (see Table A-2 of the report), but which have since been completed. Boudart and Figliozzi detail an optimization model for determining the age at which to replace a bus to minimize bus life cycle costs *(42)*. Like the TCRP Report 157 model their model includes costs from maintenance, fuel, and passenger delay, and assumes that maintenance costs increase as a bus ages. Unlike the Report 157 model, however, their model does not consider increases in delay or fuel costs, but does add costs from emissions and vehicle salvage. The model is applied to King County Metro, yielding a result that the optimal replacement age is 21.5 years.

McCollom describes the results of TCRP Synthesis J-07/Topic SG-11 on transit asset condition reporting *(43)*. The conclusions of this synthesis are largely consistent with TCRP Report 157 regarding the current state-of-the-practice. Several of the presentations included in the review describe FTA research, most notably, FTA's work to develop a transit asset management guide and on a set of asset management pilot projects, but these efforts are still underway.

Regarding the review of transit asset management literature, the major conclusion of the review is that the results from TCRP Report 157 remain valid regarding the state-of-the-practice and available tools for SGR analysis. The review mainly serves to document the extent of activity to implement asset management and condition assessment systems, which in turn enable analysis of the implications of different investment levels on SGR. To the extent that transit agencies are implementing analytical approaches for analyzing their SGR needs and/or prioritizing SGR investments, they are largely relying on approaches documented previously in TCRP Report 157, such as TERM and the MBTA SGR Database. Notable developments relevant to the research effort include MARTA's effort to implement Expert Choice, LBT's development of performance measures for facilities, and the work described by Boudart and Fogliozzi to develop a bus replacement model *(42)*.

SUSTAINABILITY PERFORMANCE MEASURES

In addition to reviewing SGR-related materials, the research team reviewed literature related to performance measures for sustainability. Nine papers and reports reviewed had information useful for establishing sustainability performance measures to support SGR decisions. Several of the reports reviewed were compilations of reviews and surveys, so together the materials review reflect a broad range of experience in establishing sustainability performance measures.

The word, "sustainability," can be used and defined in many ways, especially in the transportation sector. Commonly it is used specifically to refer to the impact of transportation on areas of environmental concern. However, it can also be used more holistically. For example, NCHRP Report 708: *A Guidebook for Sustainability Performance Measurement for Transportation Agencies*, uses the following principles to define sustainability: "Sustainability entails meeting human needs for the present and future while:

- Preserving and restoring environmental and ecological systems;
- Fostering community health and vitality;
- Promoting economic development and prosperity; and
- Ensuring equity between and among population groups and over generations." *(44)*

This broader definition of sustainability is arguably closely related to or intertwined with the concepts of SGR for transit agencies. Keeping a transit system operating safely and efficiently for the foreseeable future can have a positive impact on the environment, help to promote vital communities, support economic activity, and ensure that populations without access to private vehicles have sufficient mobility. Viewed through this lens, we could argue that a system is not sustainable *unless* it is in a state of good repair. Applied to performance measures, this means that all SGR performance measures are measuring an element of sustainability. The American Public Transportation Association (APTA) provides additional direction and guidance on sustainability for transit agencies. The APTA website describes sustainability as being:

> "…about practices that make good business sense and good environmental sense. It is balancing the economic, social and environmental needs of a community. For the public transportation industry this means:
>
> - Employing practices in design and capital construction, such as using sustainable building materials, recycled materials, and solar and other renewable energy sources to make facilities as 'green' as possible.
> - Employing practices in operations and maintenance such as reducing hazardous waste, increasing fuel efficiency, creating more efficient lighting and using energy-efficient propulsion systems.
> - Employing community-based strategies to encourage land use and transit-oriented development designed to increase public transit ridership." *(45)*

APTA sponsors a program for transit agencies interested in being recognized for their sustainability commitment *(45)*. The program requires that signatories commit to a set of core principles and processes that demonstrate their consideration of sustainability. The fourth one, undertaking a sustainability inventory of your organization, relates directly to SGR. The sustainability inventory is conducted and tracked using the following indicators:

- Water usage
- Criteria air pollutant emissions
- GHG emissions and savings
- Energy use (electricity, fuel)
- Recycling levels/waste
- Operating expense
- Unlinked passenger trips per capita in service area of operation
- VMT per capita in service area of operation

With respect to SGR, some of the above measures are directly related to areas that transit agencies are already tracking as they manage their assets (e.g. energy use and operating expense), and others have a secondary relationship to a well maintained system (e.g. passenger trips or VMT per capita in service area of operation). These measures could all be included in models utilized to prioritize and select projects to be included in a transit agency's Transit Asset Management Plan.

As described in the previous section, transit agency practices documented for the literature review included performance measures that relate directly to the environmental aspect of sustainability. For example, LBT has established proposed measures for evaluating resource use *(9)*. Further VTA reports considering environmental sustainability in prioritizing its SGR projects *(26)*. Additional environmental sustainability measures common in the literature that can be incorporated in an SGR analysis tool include measures of:

- Consumption, such as gallons of fuel or energy use (which can be applied to fleet vehicles only, or can include all transit agency facilities);
- Emissions, such as tons of CO2 and/or other pollutants; and
- Fleet characteristics, such as the percentage of a fleet upgraded to zero or low-emissions vehicles.

Elements of these findings, including potential enhancements to the SGR analyis approach, and potential measures of sustainability for incorporation to the analysis tools, have been incorporated into the tool development task described subsequently in this report.

3. Transit Agency Pilots

This section discusses the three transit agency pilots performed to test the SGR framework and tools developed previously and documented in TCRP Report 157. The following subsections discuss: the approach to selecting the pilot transit agencies and performing the pilots; summary results by pilot; and the lessons learned from the pilot relevant for improvement of the tools and guidance being prepared as part of the current effort. Detailed descriptions and slides presented at the project workshop of each pilot are included in the pilot memoranda in Appendix B.

PILOT APPROACH

Plans for the transit agency pilots were presented along with the results of the TCRP E-09 project at various technical, meetings, and forums in 2012. Three transit agencies volunteered to participate in the pilots: Denver Regional Transportation District (RTD); King County Metro; and the Southeastern Pennsylvania Transportation Authority (SEPTA). The TCRP Project Panel approved the selection of the three agencies, based on their meeting the following criteria established for pilot selection:

- Transit agencies recommended for the pilots should have indicated a willingness to participate.
- Pilot participants should be willing to have examples drawn from the pilot used for project publications, including workshop materials, the project report and interactive how-to guide.
- Pilot participants should have some form of asset inventory for any assets to be analyzed in the pilot, including data on asset age and/or condition or level of use.
- There should be a mix of transit agencies included in the pilots, with different types and modes of assets represented.
- Ideally the transit agencies included in the pilots should be geographically distributed so that any relevant regional differences are addressed in the pilots.
- One or more of the pilots should have indicated an interest in evaluating sustainability-related issues as part of the pilot, such as potential replacement of diesel buses with low emissions vehicles.

For each pilot the basic goal was to test the SGR framework and supporting tools from TCRP Report 157. The framework and tools are intended to help agencies quantify the impacts of investing in rehabilitation and replacement of existing transit capital assets, and to help prioritize SGR investments. These tools help support the following tasks:

- Quantifying a transit agency's asset inventory.
- Developing models for each individual asset type. These models predict the life cycle costs of the asset, compute a variety of performance measures, and recommend when to rehabilitate or replace the asset.
- Prioritizing asset rehabilitation/replacement given details on the asset inventory, the asset type models, and an assumed budget.

- Predicting the conditions and performance that will result from a given set of asset replacement projects.

For each of the pilots the research team conducted the following activities:

- Met with the transit agency to discuss the goals of the research effort, establish the scope of the pilot and discuss available data.
- Prepared a memorandum summarizing the initial discussions.
- Developed asset rehabilitation/replacement models for the set of assets agreed upon with the transit agency, with the exact set of assets addressed based on available data.
- Determined how SGR investments should be prioritized based on the models, and compared this to any data or insights on how each transit agency currently prioritizes.
- Defined investment scenarios to illustrate the impacts over time of alternative investment levels.
- Detailed the draft pilot results in a memorandum.
- Met with the transit agency to review the draft results and identify issues.
- Revised the draft results based on the review.
- Migrated the data and models to the revised version of the SGR tools, TAPT, described in the next section.
- Where requested by the transit agency, supplemented the analysis with a needs analysis performed using the FTA's TERM Lite.
- Detailed the revised results in a memorandum. The memoranda for each pilot are provided in Appendix B.
- Discussed the pilot results with the pilot agency to compare and contrast the results with actual transit agency practice and priorities.
- Worked with the pilot agency to prepare a presentation on the pilot at the project workshop. Materials from the presentations are included in Appendix C.
- Updated the analysis with the completed version of TAPT.

The three transit agencies participating in the pilot together manage a wide variety of assets of different ages and conditions, and each transit agency faces a different set of challenges in managing its assets. Table 3 summarizes the extent of the systems managed by each pilot participant, particular challenges identified in prioritizing asset rehabilitation and replacement, the assets modeled in the pilot, and specialized analyses performed for each pilot.

Table 3. Transit Agency Pilot Overview

Description	Pilot Participant		
	Denver RTD	**King County Metro**	**SEPTA**
Extent of Asset Inventory	• Over 900 buses • 172 light rail vehicles • 36 stations • 74 park & ride lots • 35 miles of track • 6 operation and maintenance facilities • 5 support facilities	• Over 1,300 vehicles • 130 park & ride lots • 13 transit centers • 71 miles of trolley overhead wire • 1 transit tunnel with 5 stations • 7 operations and maintenance facilities • 6 support facilities	• Over 1,400 buses and trackless trolleys • 905 light rail, heavy rail and commuter rail vehicles • 342 stations • 487 miles of track • 23 operation and maintenance facilities • numerous additional support facilities
Challenges in Prioritizing SGR Needs	Wide variety of asset types, a number of assets are now reaching their first rehabilitation/ replacement point	Balancing needs for fleet replacement with facility rehabilitation/ replacement	Extensive asset inventory with a number of assets at or near the end of their economic useful life
Assets Included in the Pilot	• Buses (transit, articulated, intercity and mall shuttle) • Light Rail Vehicles (2 types) • Guideway (4 types) • Track (12 types) • Facilities (administrative, maintenance and stations)	• Buses (transit, bus rapid transit, electric trolley) • Fire Detection • Fuel Management Systems (FMS) • Heating Ventilation and Cooling Systems (HVAC) • Roofs	• Buses (diesel, hybrid, electric trolley) • Light Rail Vehicles (3 types) • Commuter Rail Vehicles
Specialized Analyses	Compared the pilot results to a needs analysis performed in TERM Lite using data provided by FTA	Approximated decay curves for facility assets, developed a condition-based model for roofs	Compared life cycle costs of diesel and hybrid to a hypothetical compressed natural gas (CNG) bus

SUMMARY RESULTS BY PILOT

Below is a brief summary of the results by pilot, with emphasis on issues encountered and any specialized analyses the research team performed. Appendix B has detailed data on each pilot, including data sources used, the asset inventory models, asset-level models developed, and network-level and project-level results for alternative funding scenarios.

Denver RTD

For Denver RTD, the pilot addressed a wide a range of assets, including bus, light rail vehicles, guideway, track and facilities. RTD had detailed data available on its vehicles to support the pilot, and summary data on its guideway, track and facilities.

For buses the research team used National Transit Database (NTD) data for the models. However, it was necessary to disaggregate the NTD data to model four different types of buses: transit buses, articulated buses, intercity buses and mall shuttles. The model for mall shuttles required the greatest amount of revision and review. RTD's mall shuttles are specialized buses that make frequent stops. The research team found that estimating the number of vehicle failures for these buses through the NTD data understated the amount of delay experienced by RTD passengers. Thus, the research team used data from RTD's enterprise asset management (EAM) system to estimate the number of failures for these buses.

For light rail vehicles (LRVs) the research team modeled two different types of LRVs used by RTD. Development of the LRV models resulted in a number of enhancements, including addition of mean distance between failures (MDBF) as a performance measure, allowing the user to specify that the future mileage of the fleet will vary from the previously-reported value (which is the case for RTD as it has recently opened new lines), and specification of mileage thresholds for mid-life renewal.

Table 4 shows example asset-level results for RTD vehicles. The table shows, for each vehicle type modeled, the optimal (cost-minimizing) replacement mileage, the optimal replacement age, and average annual cost, including transit agency costs, user delay costs, and emissions cost. In the table SD100 and SD160 indicate different LRV model numbers. The table shows that RTD's cost minimizing strategy is to replace its buses when they reach an age of 15 to 18 years, depending on bus type, and replace their LRVs when the have accumulated approximately 2.1 to 2.3 million miles (at an age of 31 to 45 years).

Table 4. Example RTD Vehicle Model Results

Vehicle Type		Optimal Replacement Mileage (000)	Optimal Replacement Age (years)	Average Annual Cost (000)
Bus	Transit	665	15	142
	Articulated	569	16	191
	Intercity	1,085	18	177
	Mall	219	15	128
LRV	SD100	2,142	45	532
	SD160	2,337	31	847

For modeling guideway and track the research team used the age-based model detailed in TCRP Report 157, and distinguished between regular track and "intensive use" track used by multiple lines. Application of the model indicated that the highest priority for rehabilitation/replacement were RTD's grade crossings and embedded rail, consistent with RTD experience. The age-based was also was used for facilities. Here it was necessary to model assets at a high level (e.g., for an entire facility or building) due to lack of detailed data.

For each asset type the models yielded a recommended asset rehabilitation/replacement age, as shown in Table 4 for vehicles, and a prediction of the transit agency and user costs of the asset over time. Once the asset-level models were developed, the research team used TAPT to predict a range of performance measures and the recommended projects for three different funding scenarios: a "do nothing" scenario in which no money is spent on asset rehabilitation or replacement, a scenario with annual SGR spending of $25 million, and a scenario in which all SGR needs are funded.

The analysis showed that the highest priority SGR projects are replacement of selected types of guideway and track, including grade crossings, embedded rail, and special trackwork, followed by replacement of intercity buses and the mall shuttles which are nearing their optimal replacement mileage. Existing needs for the assets modeled total approximately $117 million, and the tool recommends spending approximately $439 million on asset rehabilitation/replacement over a 10-year period.

One important part of the analysis was to compare the results generated using TAPT to those from TERM Lite. Table 5 shows the results of this comparison, summarizing results by scenario generated using TAPT and TERM Lite. The following measures are shown for the TAPT results:

- Unmet needs: cost of performing all replacement work needed at the end of the period.
- Cumulative spent on replacement work through the end of the period.
- Mean Distance Between Failures (MDBF)for vehicles in miles
- Average TERM condition for non-vehicle assets (on the 5-point TERM scale, ranging from 1 for assets in poor condition to 5 for assets in excellent condition)
- Passenger delay from roadcalls/failures in hours
- CO_2 emissions from operations and new assets in tons. These have been specified for vehicles only.
- Other Agency Costs, including costs of maintenance, vehicle rehabilitation, energy and any unplanned work resulting for asset failures.
- Total Agency and User Costs, including the other agency costs described above (delay costs, emissions costs, and any other external costs) but not including capital expenditures.

For TERM Lite the results include unmet needs, cumulative spent, percent of assets exceeding their useful life, and percent of assets in marginal or poor condition (1 or 2 on the TERM 5-point scale).

Table 5. Denver RTD Scenarios and Comparison to TERM Lite

Scenario	Initial Value (2014)	Value in 2023		
		1-Do Nothing	2-$25M Annually	3-Unconstrained
Transit Asset Prioritization Tool Results				
Unmet Needs ($ 000)	116,803	439,419	233,004	0
Cumulative Spent ($ 000)	N/A	0	209,415	439,419
MDBF (miles)	35,649	20,407	33,033	39,791
Average TERM Condition (non-vehicle assets)	4.68	4.39	4.54	4.62
Passenger Delay (hrs)	113,682	170,399	150,781	146,801
CO_2 Emissions (tons)	248,160	294,722	278,009	271,134
Other Agency Costs ($ 000)	196,292	278,332	219,534	197,762
Total Agency and User and External Costs ($ 000)	207,750	293,654	233,504	211,374
TERM Lite Results				
Unmet Needs ($ 000)	761,500	1,513,800	1,281,900	0
Cumulative Spent ($ 000)	N/A	0	250,000	1,775,200
Percent of Assets Exceeding Useful Life	4.6%	28.4%	22.0%	0.0%
Percent of Assets in Marginal or Poor Condition	18.6%	37.2%	31.0%	22.7%

Note that TERM Lite models all of Denver RTD's assets, not just those included in the pilot, and models rehabilitation as a capital cost. Thus, one would expect TERM Lite to predict somewhat higher needs than TAPT. Specifically, the replacement value of the assets in TERM Lite is $3.7 billion, versus $2.9 in TAPT. As indicated in the table, TERM Lite predicts an initial backlog for RTD of approximately $762 million. This backlog is projected to double if work is deferred for 10 years, or increase 68% to $1.28 billion if the annual budget is $25 million. By comparison, TAPT predicts a much lower initial backlog ($117 million) and greater percentage increases in the backlog over time. Further analysis of the TERM Lite results indicated that relative to TAPT the system predicts much greater needs over time for facilities and stations, in particular, and similar needs for guideway and track.

Following completion of the pilot the research team met with RTD to discuss the pilot results. RTD staff indicated the following regarding the pilot:

- The priorities identified in the pilot matched well with actually agency priorities. In particular, the pilot identified replacement of embedded guideway/track as a high priority. Following completion of the pilot RTD began work to replace sections of embedded rail, and found that it was badly corroded, confirming that this work was, indeed a high priority.

- RTD is interested in using a modeling approach similar to TAPT to analyze its SGR needs, and is developing an SGR score to assist in prioritization.
- One issue RTD would like to address is how to use visual inspection results of vehicles in the asset models. One approach to accomplishing this in TAPT is to adjust the accumulated mileage for a vehicle based on its condition, though this is a workaround approach.

King County Metro

For King County Metro, the pilot addressed buses and four types of fixed assets: fire protection; fuel management systems (FMS); heating, ventilation and cooling (HVAC) systems, and roofs. For buses the research team used NTD data to model transit buses, bus rapid transit (BRT) and electric trolley buses, which are listed as separate modes in the NTD.

For fixed assets the research team utilized the detailed data King County Metro has collected on its facilities, and incorporated in its Facilities Condition Report (FCR). The FCR includes data on the asset inventory, conditions, recommended work, and descriptions of the motivation for addressing SGR needs (e.g., avoiding the negative consequences of allowing assets to deteriorate). The research team used data on recommended replacements to approximate decay curves for fire protection, FMS and HVAC, and modeled these using the age-based model detailed in TCRP Report 157. For roofs King County Metro conducts inspections using the TERM 5-point condition scale. Thus, in this case the research team was able to use the condition-based model to determine the optimal rehabilitation/replacement point and annual cost for this asset. Table 6 summarizes the model inputs and results. Note the units of measure are square feet of area for fire protection, HVAC and roofs, and gallons of storage capacity for FMS. For each asset the table shows the replacement cost, failure cost as a percent of the replacement cost, key assumptions regarding asset deterioration, and the resulting optimal replacement point and average annual cost. For fire protection, FMS and HVAC the optimal replacement point is specified as an age, while for roofs it is specified as a condition.

Table 6. King County Metro Facility Model Inputs and Results

Parameter	Value by Asset Type			
	Fire Protection	FMS	HVAC	Roof
Inputs				
Unit replacement cost	2.44	10.00	200.00	20.75
Failure cost (as a % of the replacement cost)	200%	650%	200%	200%
Decay curve assumptions	50% likely to fail by 20 yrs, 75% likely to fail by 30 yrs	25% likely to fail by 20 years, 75% likely to fail by 30 years		Likelihood of decay in 1 year by condition – 5: 88.1% 4: 79.7% 3: 68.5% 2: 52.3%
Results				
Optimal replacement point	27	15	20	Condition=2
Average annual cost per unit	0.40	1.24	20.50	1.19

In developing the age-based models, the research team found it valuable to change how deterioration rates are specified in TAPT. Previously one entered parameters for a Weibull curve that describes the likelihood of failure, with default curves developed using TERM defaults. However, the model parameters are in practice difficult to interpret. Thus, TAPT was revised to use the TERM curves directly, and allow the user to override the TERM defaults through entering survival ages rather than Weibull curve parameters. Further, the tool was enhanced to predict conditions for non-vehicle assets using the TERM 5-point scale. Figure 1 shows an example of the predicted average condition for the three King County scenarios.

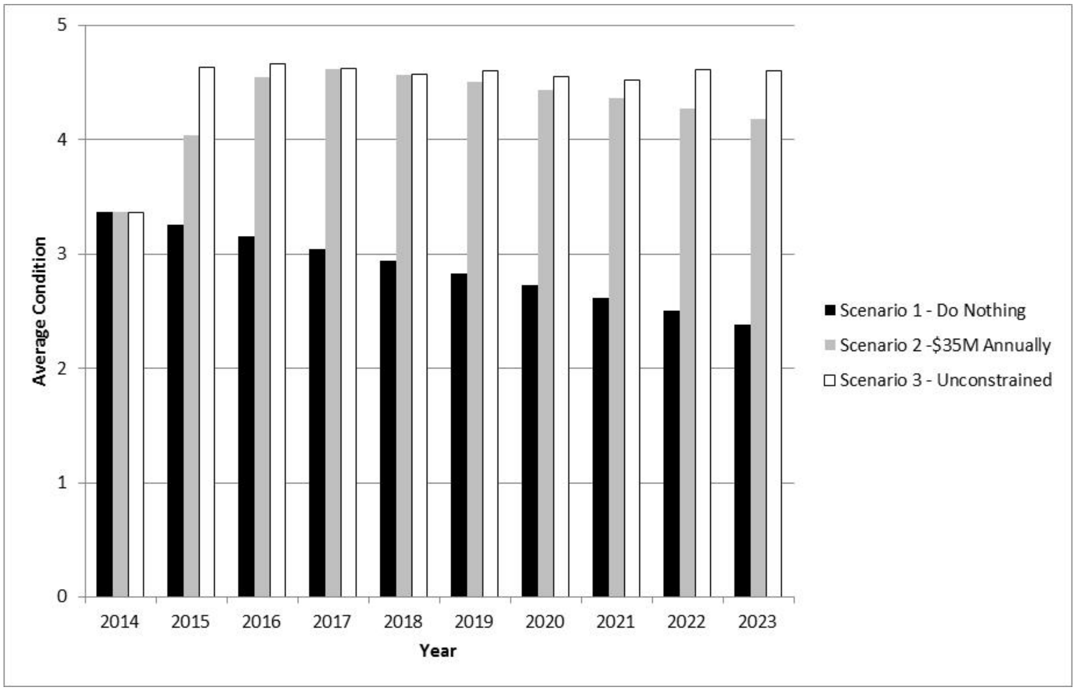

Figure 1. Example Predicted Average Asset Condition for King County Metro

As described for the case of Denver RTD, once the asset-level models were developed the research team used TAPT to predict a range of performance measures and the recommended projects for three different funding scenarios: a "do nothing" scenario in which no money is spent on asset rehabilitation or replacement, a scenario with annual SGR spending of $35 million, and a scenario in which all SGR needs are funded. The analysis showed that the highest priority SGR projects are replacement of roofs in poor condition, followed by replacement of older FMS. Bus replacements are not ranked as highly initially, but over time, most of the projected needs are for bus replacement.

The King County Metro pilot was extremely valuable as a test of the age-based and condition-based models for facilities, as King County Metro has relatively detailed data for these assets, and the models had not been tested for facilities previously. The pilot demonstrated that it is feasible to model facilities at a systems level in TAPT, and that doing this provides greater insights into a transit agency's SGR needs than simply modeling needs for overall facility rehabilitation/replacement. While the overall life of a facility may be 100 years or longer based on the TERM models, individual systems have much shorter lives.

Thus, modeling at a systems level shows more frequent, but lower-cost needs for system rehabilitation/replacement.

Following completion of the pilot the research team met with King County Metro to discuss the pilot results. King County Metro staff indicated the following regarding the pilot:

- The priorities recommended through the pilot corresponded well to actual priorities, to the extent this can be evaluated with the set of asset types modeled.
- The condition-based model is the best way to model facility assets, where condition data are available. King County Metro was in the process of collecting additional condition data during the time of the pilot.
- One issue relevant in replacement decisions for certain asset types (e.g., fire detection systems) is technical obsolescence, but this is difficult to model and not addressed in TAPT.

SEPTA

For SEPTA, the research team focused the pilot on vehicles, including buses, light rail and commuter rail. Bus types modeled included hybrid, diesel and trolley buses. Of particular interest to SEPTA was determining the impact of transitioning to CNG buses in the future.

For modeling buses, the research team used SEPTA's NTD data, disaggregated to distinguish between diesel and hybrid buses, which are combined for NTD reporting. SEPTA does not currently operate CNG buses, but is considering these as an alternative in the future. To develop the model for CNG, the research team reviewed the available literature comparing CNG and hybrid buses, and modified the hybrid bus model accordingly. Table 7 shows a comparison of unit costs of hybrid and CNG. Table 8 shows the bus model results for SEPTA. Regarding the comparison of CNG and hybrid buses, the table shows that the average annual cost of a CNG bus is approximately $225,000, 23% more than that of hybrid buses. Not the results for diesel buses include both 40-foot and articulated buses (increasing the average annual cost), whereas for the other types all buses are assumed to be 40 feet long.

Table 7. Comparison of Hybrid and CNG Model Parameters

	Hybrid Motorbus	CNG Motorbus	Percent Change: Hybrid to CNG
Purchase cost ($)	743,00	552,000	-25.7%
Fuel cost ($/gal)	2.58	2.00	-22.5%
Fuel mileage (mi/gal)	3.00	1.70	-43.3%
Energy cost ($/mi)	0.86	1.18	37.2%
Maintenance cost ($/mi)	0.75	1.29	72.0%

Table 8. SEPTA Bus Model Results

Vehicle Type	Optimal Replacement Mileage (000)	Optimal Replacement Age (years)	Average Annual Cost (000)
Hybrid	471	14	183
CNG	404	12	225

Diesel	523	15	195
Trolley Bus	624	25	228

For developing the LRV models, the research team disaggregated the available NTD data and used SEPTA data on vehicle failures to establish different models for three types of LRVs used on different lines: the Subway Surface Lines (SSL), the Media-Sharon Hill Line (MSHL) and Route 15 (RT15). For SSL and MSHL similar vehicles are used (1980-82 Kawasaki LRVs), while for RT15 SEPTA uses recently-rehabilitated President's Conference Committee (PCC) streetcars manufactured in the 1940's. The commuter rail car model was developed using NTD data, which combines data for 13 commuter rail car subfleets dating from 1963 to 2010. The age of SEPTA's fleet presented an issue in developing the vehicle models, and revisions were made to the models to accommodate older vehicles with greater mileage than supported using the original models included with TCRP Report 157.

As described for the other pilots, once the asset-level models were developed the research team used TAPT to predict a range of performance measures and the recommended projects for three different funding scenarios: a "do nothing" scenario in which no money is spent on asset rehabilitation or replacement, a scenario with annual SGR spending of $150 million, and a scenario in which all SGR needs are funded. The analysis showed that the highest priority SGR projects are replacement of older commuter rail cars, followed by replacement of the RT15 LRVs, and replacement of older diesel buses. SEPTA staff indicated that these priorities are generally consistent with SEPTA's experience. In fact, the transit agency has recently replaced its older commuter rail cars. The RT15 LRVs are historic streetcars that were recently rehabilitated and not scheduled for replacement. However, SEPTA's experience is that these are, indeed, costly to maintain.

The SEPTA pilot was useful for testing the models with vehicles of widely varying age, as well as for testing development of emissions models in TAPT. Figure 2 illustrates the prediction of CO_2 emissions for the three different scenarios tested. The figure shows that in the "Do Nothing" case emissions gradually increase over time as the fuel efficiency of older vehicles degrades. In comparison, in the unconstrained case, initially emissions are high, as the model for buses accounts for the emissions from bus manufacture as a one-time cost, but subsequently emissions drop significantly. In the $150 million scenario, emissions are gradually reduced as older vehicles are replaced over time.

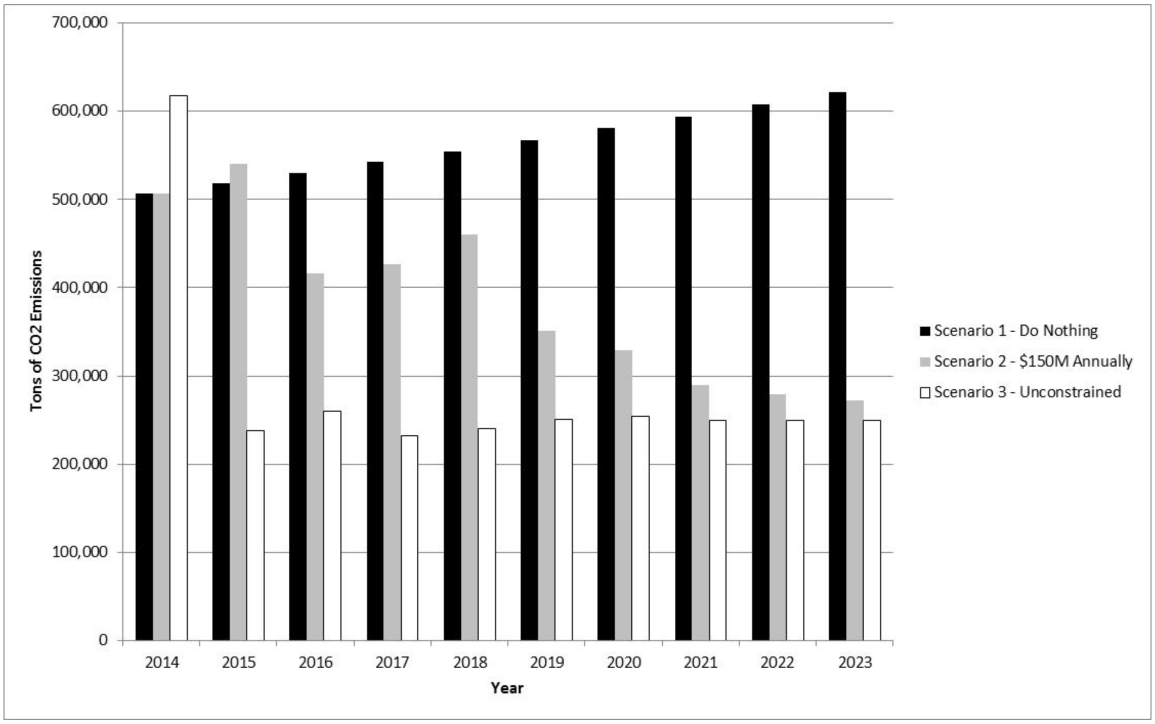

Figure 2. Example Predicted CO_2 Emissions for SEPTA

Following completion of the pilot the research team met with SEPTA to discuss the pilot results, yielding the following observations:

- The priorities recommended through the pilot agreed well with actual priorities. In particular, the commuter rail coach replacements recommended in the pilot were completed, and the other priorities are included in SEPTA's capital plan.
- The recommended replacement ages are often misleading in TAPT, though the ages themselves are not used for generating replacement recommendations or priorities. These ages are calculated by dividing the optimal replacement mileage by the annual mileage. However, older vehicles are often operated at reduced mileage, which causes an artificially high value to be reported for optimal replacement age.
- Additional priorities for SEPTA include replacement of heavy rail vehicles and commuter rail locomotives not modeled in the pilot.

CONCLUSIONS

The pilots served to inform a number of enhancements and revisions to the models described in the subsequent section, and provided the research team with realistic data for testing and illustrating the use of TAPT. Major enhancements that resulted from or informed by the pilots included:

- Addition of new performance measures to the outputs of the models, including MDBF and TERM condition ratings
- Improving the vehicle models to handle older assets and mid-life renewals for rail vehicles
- Simplifying the inputs required for the age-based and model; and

- Addition of the prediction of CO_2 emissions to the vehicle, age-based and condition-based models.

4. Tool Development

OVERVIEW

This section details the enhancements made as part of Task 3 to the SGR tools detailed in TCRP Report 157. A major goal of the task was to integrate the four tools developed previously into a single tool, the Transit Asset Prioritization Tool (TAPT). A number of other enhancements were made to facilitate integration, improve the modeling approach, and/or incorporate experience gained through performing the pilots described previously. The new tool serves the same function as the previous four spreadsheets. That is, it is intended to support development of a series of models for different asset types that recommend when to rehabilitate or replace an asset, and the conditions and performance predicted for the asset over time. Also, the tool supports prediction of the overall performance resulting for a specified funding scenario, and recommends a prioritized list of projects to fund given a budget constraint.

Figure 3 is a diagram illustrating the structure of TAPT. As shown in the figure, the tool has a single start screen that supports navigation, generation of new models, and performing an analysis. The tool has templates for vehicle models, age-based-models, and condition-based models. Previously these were three separate spreadsheets. With the revised tool, one creates a new model by clicking a button on the start screen and selecting a model type. The system then creates a copy of one of the templates as a new worksheet and navigates to the new model.

TAPT also includes a single worksheet for entry of major parameters and budgets, as well as worksheets for viewing summary and detailed outputs of an analysis. The tool creates new worksheets with summary outputs and detailed outputs (the program list) for each analysis a user performs.

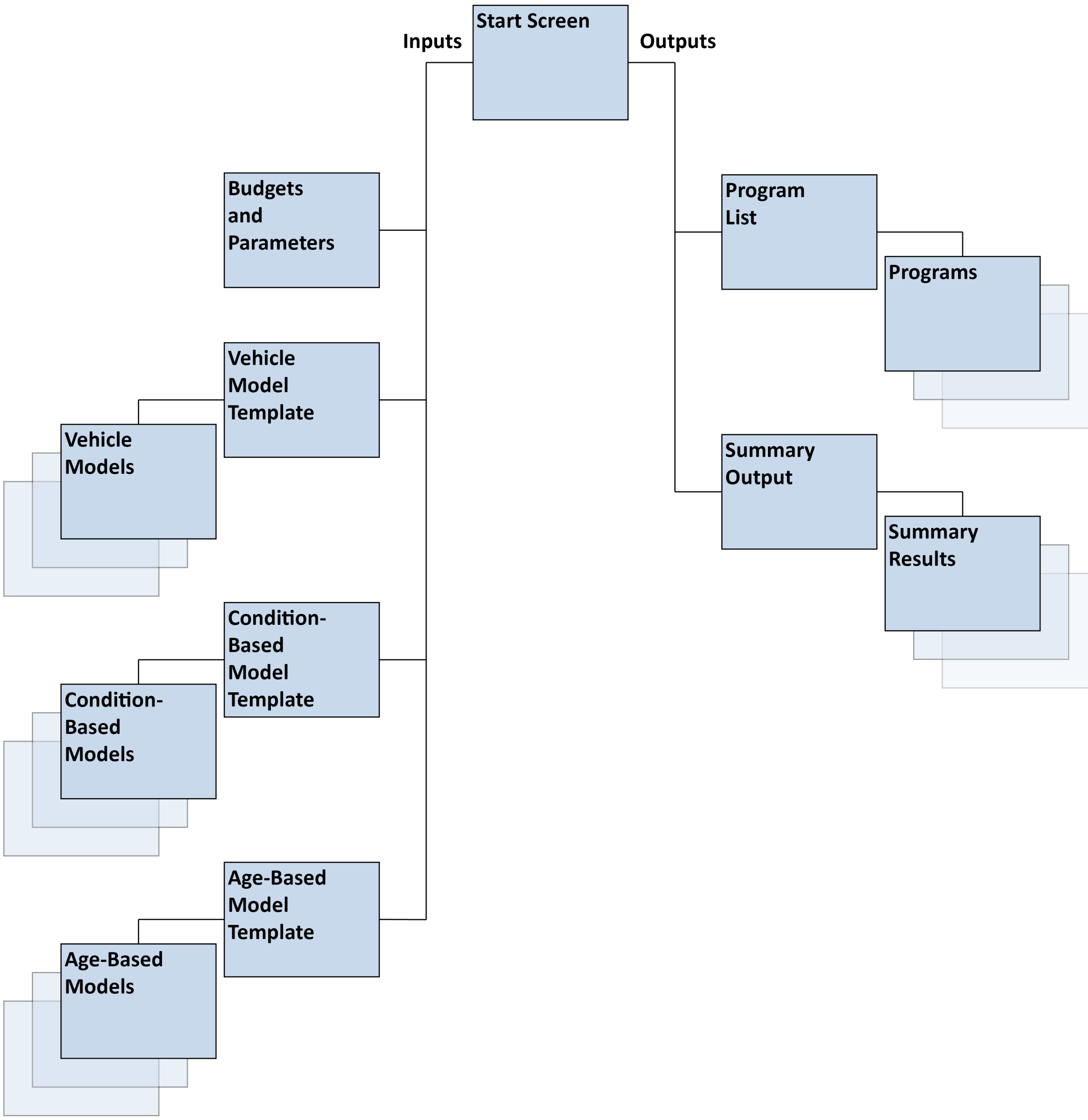

Figure 3. TAPT User Interface Organization

Table 9 summarizes major enhancements to the tool, including user interface enhancements, changes to the models, and improvements to tool outputs. The following sections describe these enhancements further. Step-by-step instructions for using TAPT and a set of training tutorials are included in the *Guidance for Developing a Transit Asset Management Plan.*

Table 9. Summary of SGR Tool Enhancements

Type	Major Enhancements
User Interface	• Four separate spreadsheets have been integrated into a single tool, with results from the asset models transferred to the prioritization model. • A start screen was created for facilitating navigation and data entry. • Entry of common assumptions across asset types is supported in the Budgets and Parameters worksheet, including weights on transit agency and user costs. • Support has been added for generating charts with summary level results and comparing results of two analyses.
Vehicle Model	• The model predicts CO_2 emissions. • The user can specify that replacement vehicles are more energy efficient and produce less CO_2 than the vehicles they replace. • The analysis time period in the vehicle model has been extended to allow for the possibility of vehicle ages up to 120 years (the previous version allowed for vehicle ages up to 60 years). • The capability to input costs and intervals for periodic vehicle rehabilitations has been added to the vehicle model. Periodic rehab cost is entered as a percentage of replacement cost and rehab interval is entered in miles. The periodic rehab cost is assumed to be a lump sum cost incurred when the interval is reached. • Default per vehicle mile rehab costs are now indexed to replacement costs. • The inputs to the vehicle model have been revised so that the user can specify percentage increases in maintenance, energy consumption, roadcalls/failures and other costs for a vehicle. Previously, the inputs were in the form of model coefficients that were difficult to review without first converting them to annual percentage increases (or some other more easily understood units).
Age-Based Model	• Instead of using Monte Carlo simulation, the age-based model determines the optimal age for asset replacement and calculates the costs and benefits of replacing the asset at different ages. • The age-based model has been modified to allow for the possibility that maintenance and other annual costs increase with asset age. • In the age-based model, instead of default "shape" and "scale" parameters for the Weibull probability distribution, the user is presented with the TERM model and default expected survival ages. For most users, it would be difficult to evaluate the reasonableness of the shape and scale parameters without converting them to expected survival ages (or some other more easily understood units). • The model predicts condition over time using the 5-point TERM rating by default. • The model supports prediction of CO_2 emissions if defined by the user.

Condition-Based Model	• Instead of using the Excel Solver, the condition-based model explicitly calculates life-cycle costs for individual strategies to determine an optimal asset replacement/rehabilitation strategy. • The condition-based model has been modified to allow for the possibility that assets might transition to a worse condition during the budget period. • The model predicts condition over time using the 5-point TERM rating by default. • The model supports prediction of CO_2 emissions if defined by the user.
Prioritization Model	• The concept of a project was introduced to allow the user to specify that the replacement of certain assets should be considered jointly. If assets are grouped into a project, either all or none of them are replaced in a given year. • The user can adjust the prioritization index for individual assets to account for factors that may not be explicitly dealt with in the vehicle, age-based, or condition-based models. • The inputs for each asset include a switch so that, if the user chooses, the asset will not be included in runs of the prioritization model. • The user can specify a threshold prioritization index (PI) below which assets should not be replaced (even if budgets are such that funds would be available for their replacement). • The prioritization model budget period has been increased to 20 years. • The prioritization model has been modified so that an asset might be replaced more than once if its PI exceeds the PI threshold
Outputs	The tool now predicts the following additional measures: • Mean Distance Between Failures (MDBF) for vehicles. • Average TERM condition rating for non-vehicle assets. • Hours of passenger delay. • CO_2 emissions. • Needs by year. • Backlog of needs. • Total transit agency and user costs by year.

USER INTERFACE ENHANCEMENTS

As discussed above, a major enhancement to TAPT was the integration of the four SGR tools developed previously, and the creation of a start screen for facilitating navigation. Using the new start screen, one clicks a button to create a new asset group. When entering data for a new asset group, the user specifies an identification code for the asset and whether the vehicle, age-based, or condition-based model should be used to analyze the asset. The user then selects the type of asset from a pull-down list and, optionally, enters a brief description of the asset group (to be used in TAPT outputs). For assets to be analyzed using the vehicle model, the user enters the number of vehicles by lifetime-to-date mileage. For the age-based model, the user enters the number of assets by age. For the condition-based model, the user enters the number of assets by condition rating. The only other mandatory inputs are unit replacement costs for asset groups analyzed using the age-based and condition-based models. TAPT provides default values for all other inputs based on the type of asset selected from the pull-down lists. Regarding overall analysis assumptions, the only mandatory inputs are budget amounts by year. Default values are provided for all other analysis assumptions.

The user interface allows users to specify other passenger and external costs for assets depending on their lifetime mileage, age, or condition. These costs are included in each of the four models and TAPT outputs. However, in the current implementation of TAPT, the default values for these costs are all zero. The capability to analyze these costs was built into TAPT to allow users to specify costs and account for such things as passenger amenities associated with new vehicles, bus stops, or stations as well as the possibility that transit asset replacement projects might promote mode shifts and, as a consequence, reduce the external costs of auto use. The user interface allows the user to specify different weights for transit agency, passenger, and external costs. The same weights are applied in the vehicle, age-based, condition-based, and prioritization models.

When the user wishes to perform an analysis they click the corresponding button on the start screen and give the analysis a name. A new analysis is created using the current asset models, budgets and other parameters. Once the analysis has been run the user can view results in a table or through charts. To generate a chart the user clicks a button to generate a chart with results from one or two model runs. They then choose which run(s) to chart, and the output variable.

VEHICLE MODEL ENHANCEMENTS

The vehicle model was enhanced to account for the effects of vehicle replacement decisions on CO_2 emissions. For vehicle operations, CO_2 emissions are based on energy use. Default values for converting energy use are 0.0111 tons per gallon of diesel fuel *(46)* and 0.0008 tons per kilowatt hour *(47)*.

The vehicle model also account for CO_2 emissions associated with the production of replacement vehicles. Default values per vehicle are 70 tons for bus, 160 tons for light rail, and 240 tons for heavy rail. These default values were developed using an approach and data provided by Boudart and Figliozzi *(42)*. They recommend estimating vehicle production CO_2 emissions based on vehicle weights. The default values assume vehicle weights of 30,000 pounds for bus, 67,000 pounds for light rail, and 85,000 for heavy rail.

The vehicle model was also enhanced to allow users to specify that replacement vehicles are more energy efficient and produce less CO_2 than the vehicles they replace. This input is provided as a percentage reduction to the energy consumed and CO_2 produced by vehicles currently in use.

In the previous version of the vehicle model, rehabilitation costs were estimated on a per vehicle mile basis as a function of lifetime-to-date mileage. Default values for bus rehabilitation cost per vehicle mile were developed using data on the expected lives and replacement costs for individual bus components detailed in *Useful Life of Transit Buses and Vans (48)*. No default values were provided for rehabilitation of light and heavy rail vehicles.

In addition to per vehicle mile rehabilitation costs, the enhanced vehicle model provides the capability to input costs and intervals for periodic vehicle rehabilitations. Periodic rehabilitation (rehab) cost is entered as a percentage of replacement cost and rehab interval is entered in miles. The periodic rehab cost can be treated as a lump sum cost incurred when the interval is reached, or can be spread out over time as per mile rehab costs.

In the enhanced version of the vehicle model, the capability to enter rehabilitation costs on a per vehicle mile basis remains in place, along with the default per vehicle mile bus rehab costs. However, the default bus rehabilitation costs are now indexed to new vehicle costs. That is, if the user overrides the default new vehicle costs, the default bus rehab costs are adjusted in direct proportion to the change in new vehicle costs.

In the enhanced vehicle model, periodic and per vehicle mile rehab costs are added to produce total rehab costs. For buses, the default values for periodic maintenance are zero and the default values for per vehicle mile maintenance are determined as described above. For rail, default per vehicle mile rehab costs are zero. Default costs for periodic rail rehabs are 50% of the new vehicle price and are assumed to occur every 350,000 miles.

The analysis time period in the vehicle model has been extended to allow for the possibility of vehicle ages up to 120 years (the previous version allowed for vehicle ages up to 60 years).

Finally, the inputs to the vehicle model have been revised so that the user can specify annual percentage increases in maintenance, energy consumption, roadcalls/failures and other costs for a vehicle. Previously, the inputs were in the form of model coefficients that were difficult to review without first converting them to annual percentage increases (or some other more easily understood units).

AGE-BASED MODEL ENHANCEMENTS

In the age-based model, the likelihood of asset failure is modeled using a Weibull distribution. Under this distribution, the cumulative probability of asset failure is given by the following equation:

$$f(t) = 1 - e^{-(t/\lambda)^k}$$

where:

f(t) = cumulative probability of asset failure

t = asset age in years

k = shape parameter

λ = scale parameter

In the enhanced age-based model, instead of default shape and scale parameters, the user is presented with the TERM curve used to describe the asset's decay by default, and the corresponding values derived from the TERM curve for the ages to which 50% and 25% of the assets are expected to survive. The user can then change the TERM curve and/or override the survival ages. For most users, it would be difficult to evaluate the reasonableness of the shape and scale parameters without first converting them to expected survival ages (or some other more easily understood units).

The shape and scale parameters are calculated from the survival ages as follows:

$$k = \frac{\ln(\ln(0.50)/\ln(0.25))}{\ln(A_{50}/A_{25})}$$

$$\lambda = \frac{A_{50}}{(-\ln(0.50))^{1/k}}$$

where:

A_{50} = the age to which 50% of the assets are expected to survive

A_{25} = the age to which 25% of the assets are expected to survive

In the enhanced age-based model, annual asset maintenance cost is assumed to increase exponentially over an asset's life:

$$m_t = k_0 e^{k_1 t}$$

where:

m_t = maintenance cost in year t

k_0 = a parameter based on average maintenance costs experienced for the asset

k_1 = a parameter reflecting the rate at which maintenance costs increase with asset age.

In the previous version of the age-based model, annual maintenance cost was assumed to be constant over time.

The model was also enhanced to allow users to specify other annual costs for the asset, including passenger delay, other passenger costs, CO_2 emissions, and other external costs. Like maintenance, these other costs are assumed to increase exponentially over time.

For an asset that is replaced at age A (either because it fails in year A or because A is the age at which the asset is replaced if it does not fail before then), the present value of maintenance and other annual costs between time t=0 and t=A is calculated as follows:

$$C_A = \sum_{t=1}^{A} \frac{m_t}{(1+i)^t}$$

where:

A = the age at which the asset is replaced

C_A = the present value of maintenance costs and other costs for the asset over the A years of its life

m_t = maintenance and other costs in year t of the asset's life

i = discount rate

In the previous version of the age-based model, the annualized life cycle cost for an asset was estimated using Monte Carlo simulation. In the enhanced version, the annualized life cycle cost is calculated based on the following equation for determining the net present value of all future costs for the asset depending on asset replacement policy:

$$N_A = R + \sum_{t=1}^{A} P_t \left(C_t + \frac{F - R + N_A}{(1+i)^t} \right) + (1 - \sum_{t=1}^{A} P_t)(C_A + \frac{N_A}{(1+i)^A})$$

where:

A = the age at which the asset will be replaced (if it does not fail beforehand)

N_A = the present value of all future costs under the policy of replacing the asset at age A. It is assumed that the asset is replaced at time t = 0 and all future costs are discounted back to that time.

R = replacement cost if the asset does not fail

F = cost of an asset failure (including the cost to replace the asset)

P_t = probability that the asset will fail in year t

C_t = present value of maintenance and other costs over the life of an asset that fails in year t

C_A = present value of maintenance and other costs over the life of an asset that is replaced at age A

i = discount rate

The second term in the above equation (i.e., the summation from t=1 to A) accounts for the possibility that the asset will fail before it reaches age A. The terms in that summation are the probability that the asset will fail in year t times the present value of costs that would be incurred if the asset failed in that year. These costs include the present value of maintenance and other annual costs, discounted value of the extra cost that is incurred due to asset failure, and the present value of all costs that would be incurred when and after the asset is replaced at time t, which is $N_A/(1+i)^t$.

The third term in the above equation accounts for the possibility that the asset will survive to age A and then be replaced. It is the probability of the asset surviving times the present value of costs that would be incurred in this case. These costs include the present value of maintenance and other annual costs plus the present value of all costs incurred when and after the asset is replaced at time A, which is $N_A/(1+i)^A$.

Solving the above equation for N_A, we obtain

$$N_A = \frac{R + \sum_{t=1}^{A} P_t(C_t + (F-R)/(1+i)^t) + (1 + \sum_{t=1}^{A} P_t)C_A}{1 - \sum_{t=1}^{A} P_t/(1+i)^t - (1 - \sum_{t=1}^{A} P_t)/(1+i)^A}$$

N_A can be converted to an annualized cost by applying the discount rate i, i.e.,

$$AC_A = N_A i$$

where:

AC_A = the annualized cost of a policy in which assets are replaced at age A if they do not fail before then.

In the enhanced age-based model, this annualized cost is calculated for ages ranging from A=1 to A=120, to determine an optimum replacement policy, designated as $\widetilde{A}$.

Next, the net benefit associated with replacing an asset now vs. the alternative of replacing the asset a year from now is calculated for assets of different ages. As discussed in Appendix E of TCRP Report 157, the net benefit of replacing an asset now relative to keeping the asset in place for an additional year can be approximated as the difference between the expected cost of keeping the asset in place an additional year and the annualized life cycle cost under an optimum asset replacement policy. In the enhanced age-based model,

$$B_t = P(t+1|t)(F-R) + c_{t+1} - AC_{\ddot{A}}$$

where:

B_t = net benefit of replacing an asset at age t relative to keeping the asset in place for an additional year

$P(t+1\,|\,t)$ = probability that the asset will fail by time t+1 given that it has survived to time t

R = replacement cost if the asset does not fail

F = cost of an asset failure (including the cost to replace the asset)

c_{t+1} = maintenance and other costs in year t+1 of the asset's life

$AC_{\ddot{A}}$ = annualized life cycle cost with an optimum asset replacement policy

For the Weibull distribution,

$$P(t+1|t) = 1 - \frac{e^{-(\frac{t+1}{\lambda})^k}}{e^{-(\frac{t}{\lambda})^k}}$$

The benefits of asset replacement as a function of asset age are passed from the age-based model to the prioritization model and, along with replacement cost, are used to calculate the prioritization index (PI).

CONDITION-BASED MODEL ENHANCEMENTS

For each of five possible condition states, the condition-based model selects an optimal action from among three possible actions (replace, rehabilitate, or do-minimum). The selection is based on costs incurred by assets in each state and state-to-state transition probabilities depending on the action selected. In the previous version of the condition-based model, optimal actions were determined using Excel's Solver. Because of the complexities in running the Solver and possible compatibility problems on other computers, the enhanced version of the condition-based model no longer uses the Solver. Instead, all possible combinations of actions are evaluated and an optimal combination is selected.

The condition-based model was also enhanced to allow for the possibility that assets in a given state at the beginning of the budget period might transition to a worse state if they are not rehabilitated or replaced. This is done using the state-to-state transition probabilities under the Do-Minimum action:

$$p_{ij}(y+1) = \sum_{k=1}^{5} p_{ik}(y)\ \ t_{kj}$$

where:

y = a year of the budget period

$p_{ij}(y)$ = the probability that an asset in state i at the beginning of the budget period will be in state *j* in year *y* of the budget period, assuming that it is not replaced or rehabilitated before then.

t_{jk} = the probability that an asset in state *k* at the beginning of a year will be in state *j* at the end of the year under the Do-Minimum action.

Over the budget period, the expected net benefit of replacing or rehabilitating an asset that was in state I at the beginning of the budget period is calculated using these probabilities:

$$b_i(y) = \sum_{j=1}^{5} p_{ij}(y)B_j$$

where:

$b_i(y)$ = the expected net benefit in year *y* of replacing or rehabilitating an asset that was in state *i* at the beginning of the budget period

B_j= the net benefit of replacing or rehabilitating an asset known to be in state *j*

PRIORITIZATION MODEL ENHANCEMENTS

Several enhancements were introduced to the prioritization model. The concept of a project was introduced to allow the user to specify that the replacement of certain assets should be considered jointly. If assets are grouped into a project, either all or none of them are replaced in a given year. This feature is implemented so that all of the individual assets in a project have exactly the same prioritization index (PI), so that the prioritization model will select all or none of them.

$$PI_{project} = \frac{\sum_{n=1}^{N} B_n}{\sum_{n=1}^{N} R_n}$$

where:

$PI_{project}$ = the prioritization index for the project

N = the number of assets in the project

B_n = the net benefits of replacing asset *n*

R_n = the cost of replacing asset *n*

Another enhancement to the prioritization model allows the user to adjust the prioritization index for replacing individual assets to account for factors that may not be explicitly dealt with in the vehicle, age-based, or condition-based model. Also, in the enhanced prioritization model, the user can specify a threshold prioritization index below which assets will not be replaced (even if budgets are such that funds would be available for their replacement).

The prioritization model has also been enhanced to extend the budget period to 20 years and to allow for the possibility that assets can be replaced or rehabilitated more than once during the budget period. When an asset is replaced, its age is reset to 1 in the year following its replacement. For assets modeled using the condition-based model, their condition is also reset to 5-Excellent if they are to be replaced and 4-Good if they are to be rehabilitated.

TOOL OUTPUTS

For each run of the prioritization model, TAPT produces and saves a summary table showing system outputs by budget year. The output variables provided in the summary table for each budget period year are:

- The net present value of the asset replacements projects implemented in that year
- Passenger hours of delay due to road calls and other failures for the assets under consideration
- CO_2 emissions associated with the production and use of assets
- Expenditures from the capital budget for asset replacement
- Other agency costs including maintenance, fuel, etc.
- Costs of passenger delay
- Other passenger costs
- Cost of CO_2 emissions
- Other external costs
- Total agency, passenger, and external costs
- Needs, which are defined as the total cost of replacing all assets for which the PI threshold set by the user. Needs are presented both in dollar terms and as a percentage of total replacement cost for all assets.
- Backlog of needs, or needs left unmet at the end of the year.
- Mean Distance Between Failures (MDBF) for vehicle assets
- Average condition rating of non-vehicle assets, with assets rated on the 5-point TERM scale (where 5 is Excellent and 1 is Poor)

TAPT also produces a listing of assets replaced in each year of the budget period. The listing indicates:

- The year in which the assets are replaced
- The asset group identification code and description entered by the user
- The number of assets replaced
- Replacement costs for these assets
- The ranking of the asset replacement project (relative to other asset replacement projects)
- The prioritization index of the project
- Whether or not the project was "pipe-lined" (TAPT allows users to pipeline projects, such that they must be done in a given year regardless of their PI or available budget).

5. Workshop Overview

This section describes the project workshop that was held on Tuesday, February 25, 2014 at the Keck Center in Washington, DC. In attendance were seven members of the project panel, liaison members from the FTA and APTA, and 18 industry participants representing eleven transit properties. Table 10 lists the workshop participants.

Table 9. Workshop Participants

Name	Company	Workshop Role
Susan Altshuler	ACI	Industry Participant
Melanie Choy	MTC	Industry Participant
Lou Cripps	Denver RTD	Industry Participant
Rolando Cruz	Long Beach Transit	Industry Participant
Roderick Diaz	Metrolink	Industry Participant
Caroline Downing	AECOM	Panel Member
Carolyn Flowers	Charlotte Area Transit System	Industry Participant
Josh Goldwitz	NY MTA	Industry Participant
Jeffrey Gonneville	MBTA	Panel Member
Patricia Hendren	WMATA	Industry Participant
Jeff Hiott	APTA	APTA Liaison
Charles Hopper	King County Metro Transit	Industry Participant
Kim Johnson	Michigan DOT	Panel Member
John Merrigan	SEPTA	Industry Participant
Robert Peskin	AECOM	Industry Participant
James Plomin		Panel Member
Diane Ratcliff	Maryland Transit Administration	Industry Participant
Carl Rokos	Chapel Hill Transit	Industry Participant
James Rubin	FTA	Industry Participant
Jerry Rutledge	King County Metro	Panel Member
Joel Slavit	San Mateo County Transit District	Panel Member
David Springstead	MARTA	Industry Participant

Name	Company	Workshop Role
Jim Sutton	Denver RTD	Industry Participant
Dr. Waheed Uddin	University of Mississippi	Panel Member
Alan Warde (on the phone)	New York State DOT	Panel Member
Laura Zale	SEPTA	Industry Participant
Bob Zerillo	New York Public Transit Association	Industry Participant

The objective of the workshop was to provide training on the use of TAPT, review the draft guidance document, and to gather feedback from participants on the research products. Table 10 details the workshop agenda. As shown in the table, the workshop included background on the research, an overview of TAPT, a set of hands-on exercises using TAPT, and presentations from each of the three pilot agencies on their experiences.

Table 10. Workshop Agenda

Agenda	
8:30	**Introduction and Overview**
8:45	**Transit Asset Management Framework and Plan Development**
9:30	**Transit Asset Prioritization Tool (TAPT) Walk-Through**
10:30	**Pilot Agency Presentation – Southeastern Pennsylvania Transportation Authority (SEPTA)**
11:00	**Q&A Session**
12:00	**Lunch**
1:00	**Pilot Agency Presentation – King County Metro**
1:30	**TAPT Exercises**
2:45	**Pilot Agency Presentation – Denver Regional Transit District (RTD)**
3:15	**Recommendations and Feedback Session**
4:00	**Adjourn**

The materials presented at the workshop are provided in Appendix C. Note the TAPT exercises are not included in the appendix, as the exercises closely mirror the tutorials published separately in the guidance document. Major outcomes of the workshop were as follows:

- Participants found the research products to be useful and well executed;
- The pilot projects resulted in excellent examples of the use of TAPT, and participants found the presentations to be very informative;
- Participants completed a shortened version of the tutorials, and found that they were a helpful training exercise; and
- Participants provided comments and suggested revisions to the research products (particularly minor changes to TAPT and the tutorials) which have been implemented into the final research products.

6. Recommendations for Implementation and Future Research

This research described in this report provides transit agencies with guidance and developing transit asset management plans, expanding on the SGR framework in TCRP Report 157, and provides the Transit Asset Prioritization Tool (TAPT) for analyzing and prioritizing SGR needs. The products were developed by updating and enhancing the review, framework and tools described in TCRP Report 157, informed by a set of three transit agency pilots meant to test the framework and tools.

The research is intended to be of immediate value to transit agencies analyzing their SGR needs and developing asset management plans. Nonetheless, several areas have been identified through this effort where additional research may be merited to support further improvements in assessing and addressing state-of-good-repair concerns. These areas include:

- Improving the TAPT models for vehicles to include component-level modeling, distinguishing between the vehicle body, engine/propulsion system, and other major systems.
- Reviewing the assumptions concerning vehicle rehabilitation. Further review is merited to evaluate the impact of treating rehabilitation as a single event versus a series of actions spread out over time, and to determine the impact of rehabilitation on failures and costs.
- Adding support for specifying vehicle condition based on visual inspection, and incorporating inspection data in the models.
- Evaluating the default assumptions for the models for fixed assets, such as assumptions for maintenance, failure costs, and decay rates.
- Evaluating the sensitivity of the results to changes in model parameters such as maintenance and failure costs.
- Implementing a number of user convenience features in TAPT. Included on this list of priorities is the ability to import and export data in standard formats, exploration of migrating the tool to a relational database platform, and a verification prompt function for data entry.
- Adding fields to adjust predicted costs to account for soft costs.
- Providing additional implementation guidance describing the benefits of use to small, medium and large transit agencies.
- Though not a research need, another need identified through the research is to provide ongoing technical support and training for TAPT.

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12. Rivas, Victor. "Massachusetts Bay Transportation Authority Approach to State of Good Repair. Presented at the TRB 91st Annual Meeting. TRB 2012.
13. Springstead, David, John Elsberry and Susan Thomas. "Asset Management 'Hands-On Approach': MARTA's Asset Management System." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.
14. Springstead, David M. "MARTA's AMP Evolution." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.
15. Springstead, David. "Streamlining Assessment and Capital Planning with Standardization, Coordination, and New Technologies: Metropolitan Atlanta Rapid Transit Authority's Approach." Presented at the 9th National Conference on Asset Management. TRB, 2012.
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17. Berrang, Stephen. "Metropolitan Transportation Authority: Successful Evolution of Long-Term Capital Needs Assessments." Presented at the 9th National Conference on Asset Management. TRB 2012.

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Appendix A. Annotated Bibliography

This section details material reviewed as part of Task 1 of the project to supplement the literature review and interviews performed previously in TCRP Project E-09. Section A.1 describes materials from the third and fourth Federal Transit Administration (FTA) State of Good Repair (SGR) Roundtables. Section A.2 describes presentations from the 2012 Transportation Asset Management Conference. Section A.3 describes materials related to establishing sustainability measures not addressed in the E-09 review, and Section A.4 describes other relevant materials.

A.1 PRESENTATIONS FROM THE THIRD AND FOURTH FTA SGR ROUNDTABLES

Brown, Terry. "Developing an Asset Management Plan (AMP) – VDRPT Practices and Plans." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation describes the development of an asset management system for the Virginia Department of Rail and Public Transportation (DRPT). The goals of the asset management system are to calculate long-term capital needs and to develop a method of prioritizing projects given limited funding. DRPT uses the Program Guidance and Grant Evaluation System (PROGGRES) to assess funding. The benefits of this project include the ability to justify and optimize expenditures while incorporating SGR principles into planning. DRPT received a FTA grant to enhance the PROGGRES system, to be renamed Trans-AM. The new software will incorporate requirements from the transit community. New components will include the ability to assess the capital impacts of expansion and complex policies, such as combining replacements and linking FTA funding sources to determine needs. Trans-AM will be released online as Open Source software to benefit DRPT as well as other organizations.

Dawson, Leah. "CTA's Plans for Condition Assessment Process Improvements and Enhancement of Their Enterprise Asset Management System." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation discusses the Chicago Transit Authority's (CTA's) asset management goals and outlines how CTA will use the funds from it FTA Bus State of Good Repair grant. The first phase will involve adding initial data into the existing EAM system and creating new fields to add inventory and condition information. The second phase will consist of an engineering condition assessment where data will be collected and standards for future data collection will be developed. During the third phase CTA will create modeling and reporting capabilities, allowing the agency to rank projects based on the newly collected data. Finally, CTA will develop a plan to maintain data in the future. The presentation includes a history of asset management at CTA and a timeline depicting the current status of the project, including future goals.

Edwards, Paul. "Asset Condition Monitoring and Rating – UTA's Practices and Plans." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation describes the software capabilities of the Utah Transit Authority (UTA) InspectTech system. UTA uses a ten-point rating scale to describe the condition of assets, and uses the data to create trend models. UTA manages assets using a risk-based approach, where projects are prioritized based on level of risk and tolerance for risk. The goal is to maintain assets in order to avoid having to perform unscheduled maintenance. The presentation outlines the analysis behind the risk-management approach, in addition to providing examples of potential risk areas. UTA concludes that risk-based analysis is the best approach to maximizing cost efficiency by performing routine maintenance to avoid large-scale failures.

Gallucci, Grace and John Goodworth. "Developing a Transit Inventory/Database – RTA's Practices and Plans." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation describes the Regional Transportation Authority's (RTA's) effort to develop its capital inventory and analyze the backlog of SGR needs. The materials in the presentation were incorporated in a more detailed paper by Galluci, Goodworth and Allen (2012) described subsequently in this document.

Gates, Keith and Rick Laver. "TERM Lite Demonstration." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation outlines the history of the FTA's Transit Economic Requirements Model (TERM) and describes the new TERM Lite software, available from FTA. The presentation gives examples of the TERM Lite screens, options, and reports. It also uses sample data to show the system's analytical capabilities.

Humphrey, Ron and Tracy Beidleman. "Condition Assessment Methodology Research." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation focuses on a research project performed by St. Louis Metro to determine methods for leveraging data in a maintenance management system. The goal is to increase asset visibility through documenting the asset inventory and asset lifecycles. St. Louis Metro is using an Asset Inspection and Maintenance System (AIMS) to store and access all asset and maintenance data. Assets are assigned a condition rating and investments are prioritized based on critical needs. At the time of the presentation, the Metro had developed a detailed work plan and was conducting research and interviews.

Ito, Darton and Drew Howard. "SFMTA's Asset Inventory Development and Implementation Plans for an Enterprise Asset Management System." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation describes San Francisco Municipal Transportation Authority's (SFMTA's) asset management process. Using a previously-established asset inventory, SFMTA identified capital projects by grouping together maintenance tasks for like-assets. SFMTA inputs the projects into the Decision Lens consensus-based decision support tool. This allows the executive team to develop priority scores for individual projects. SFMTA also closely monitors its backlog and the effects of different potential funding levels. SFMTA is developing an Enterprise Asset Management System (EAM) that will allow the agency to maintain a detailed asset database using a repeatable condition assessment approach. The EAM System implementation was projected to be complete by 2013.

Knueppel, Jeff. "SEPTA's Plans for Development of a System-Wide Asset Management Program and Improved Process for Prioritization of Renewal and Replacement Investment Decisions." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation explains SEPTA's asset management practices. The agency plans to use a FTA grant to create a transit asset management program. SEPTA's goals, as outlined in its capital investment strategy, are to ensure that safety is a priority and that fixing current infrastructure is ranked over expansion. SEPTA will use the grant money to prioritize investments using a vehicle maintenance information system (VMIS) upgrade and a new maintenance management system. Currently, the asset inventory is being developed and inventory data is being collected, organized, and stored.

Parsons Brinkerhoff. "Transit Asset Management Framework Research Project." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation describes the development of an asset management framework and business model that incorporates enterprise and asset class level activities. Current industry drivers are discussed, including the need for asset management to be an important aspect of an agency's goals. The presentation outlines the results of the asset management framework and business processes, as well as an asset-specific framework that uses a lifecycle management process to lead to better decision-making and business outcomes.

Springstead, David, John Elsberry and Susan Thomas. "Asset Management 'Hands-On Approach': MARTA's Asset Management System." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation describes MARTA's approach to asset management. The agency's goal was to create a condition-based asset management system aligned with MARTA's strategic priorities and developed a systematic approach to prioritizing projects in the long-range Capital Improvement Plan. An organization chart depicting the project team structure is provided. The process of creating the asset management infrastructure began with identifying assets and developing priority and condition criteria for each asset. This information was used to conduct initial SGR analysis. MARTA is developing requirements to supplement the current EAM system. The presentation emphasizes the importance of developing SGR-related policies and procedures before implementing new software so that agency goals are clear and asset management can be emphasized on an agency-wide level.

Waaramaa, Eric. "Capital Project Prioritization – MBTA's Practices and Plans." Presented at the 3rd State of Good Repair Roundtable. FTA, 2011.

This presentation explains the new MBTA process for prioritizing and selecting capital projects. The agency's current process involves scoring projects by weighting evaluation criteria, which are reviewed and ranked by management then adjusted based on the CIP and available funding. While this system has been beneficial, it does not yet represent a systematic approach that balances modes, purpose, and preservation. The MBTA will be undergoing a capital project evaluation to develop a comprehensive Transit Asset Management (TAM) system.

Balter, Jacob. "Asset Management System Implementation and Integration." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation outlines the history of the Long Island Railroad (LIRR) and the recent conditions that have resulted in the development of an asset management plan. LIRR is focusing on minimizing life-cycle costs, refocusing their inspection and maintenance practices and developing a more comprehensive method for prioritizing asset maintenance. LIRR plans on implementing an EAM to improve its asset data and asset management-related business processes.

Cruz, Rolando. "Whole Life Asset Management." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation outlines asset management practices at Long Beach Transit (LBT) and describes how facilities were integrated into the asset management philosophy. The goals of the Comprehensive Facility Master Plan (CFMP) are to develop a comprehensive inventory with condition data, an annual maintenance plan, and capital plan forecasting. The presentation includes the equipment attributes that are incorporated into the Equipment Register, including asset criticality. LBT established a set of Key Performance Indicators (KPI's) to measure performance over time. The presentation includes a summary of the software LBT uses to support its approach.

Edwards, Paul. "Organizational Needs and Building Management Support for Effective Asset Management." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation outlines important components of implementing an asset management approach and summarizes UTA's experience in this area. UTA developed an Asset Management Core Committee with representatives from all areas to promote inter-department communication and create a single unified approach to defining asset management. The challenges UTA has faced include integrating legacy data and systems, and building trust between staff in different organizational units (e.g., Capital Development Planning, and Operations) necessary to enable data sharing and cooperation.

Gates, Keith. "National Transit Database (NTD): Collecting Asset Data and Forecasting SGR Needs." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation summarizes FTA's uses of the NTD and describes a project to develop a NTD Asset Inventory Module (AIM). This module will help improve FTA's SGR forecasting and encourage agencies to create asset inventories for their capital planning. The presentation summarizes findings from a set of pre-pilots of the AIM.

Headen, Devinitia. "Best Practices for Managing Asset Life Cycle Cost." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation discusses WMATA's approach for tracking life cycle cost data. WMATA tracks costs in a number of systems, including Maximo, PeopleSoft, Fleet Watch, Rail Performance Monitoring, and Optram. Costs and related data that are tracked include operation and maintenance costs, age and reliability measures, and asset replacement/renewal disposition. The presentation provides an example of tracking cost data for a bus, and discusses WMATA's plans for future improvements to its cost tracking and business processes.

Henley, David. "Current Asset Management Practices." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation describes the capital planning process used by the Metropolitan Transportation Authority (MTA) New York City Transit (NYCT). NYCT develops a 20-year needs assessment every five years. The first step in developing the needs assessment is to update asset inventory and condition data. For the purpose of the assessment, asset conditions are characterized on a four-point scale. The next step is for each organizational unit to develop investment pace and strategy statements providing a rationale for recommended funding levels and considering other agency planning efforts. NYCT then develops the needs assessment projecting investment levels and asset conditions over a 20-year period. NYCT uses the Project Status Report (PSR) system to manage asset and project data. Future goals include standardizing business processes and developing models for life-cycle costs, while comparing NYCT's approach to available asset management standards, such as PAS 55 and the future ISO 55000 standard.

Hodges, Tina. "Benefits of Climate Adaptation on State of Good Repair Efforts." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation describes the impacts of climate on SGR. Weather conditions, such as heat waves, heavy precipitation, hurricanes, and sea level rise are defined as potential impacts. FTA is helping protect infrastructure through policy, reporting, outreach and pilots. Two pilot projects at MARTA and CTA are focused on asset management. Thus far the pilots have determined that costs from weather damage are not specifically tracked and although agencies have some knowledge of weather impacts, that information is rarely synthesized. The presentation notes steps agencies are taking to collect information on

weather effects and discusses potential benefits of incorporating climate adaptation into SGR practices.

Hubbell, Mike. "State of Good Repair Assessment – Dallas Area Rapid Transit." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation describes the approach used by Dallas Area Rapid Transit (DART) to assess asset conditions. DART performs a condition assessment every five years as part of the process of updating its 20-year financial plan. In performing the assessment DART groups its assets in the following categories: rolling stock, operating facilities, passenger facilities, rail wayside systems, communications, paratransit, commuter rail, and HOV. Assets are ranked on a five-point scale. A team of eight in-house inspectors inspects the assets, sampling conditions of 20 to 100% of the assets, depending on the asset category. The presentation provides examples of the forms used for the assessments, and the analyses performed using assessment data. Also, the presentation summarizes lessons learned from establishing the condition assessment process.

Ito, Darton. "Capital Asset Management Program: Asset Breakdown Structure and Condition Assessment." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation describes the structure the SFMTA uses to categorize and analyze assets. It includes a list of the primary asset classes and the asset attributes collected for each asset. When prioritizing work tasks, asset age is used for SGR analysis and a condition rating is estimated as a function of asset age. In the future SFMTA will implement an Enterprise Asset Management based on condition assessments to help develop long-range maintenance and replacement plans.

James, Aaron C. "FTA SGR Update." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation begins with an overview of SGR practices and strategies, and then summarizes different projects underway related to SGR, including the SGR pilots, TERM Lite, NTD Reporting and SGR Climate Adaptation Pilots.

Knueppel, Jeffrey D. "Building an Organizational Culture for State of Good Repair." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation summarizes the SGR-related efforts of SEPTA's United Infrastructure Division, created in 2006. SEPTA's capital investment strategy outlines a safety-first prioritization model, which incorporates the principles of limited debt, and addressing SGR needs before expansion. SEPTA is building on its existing programs such as the Vehicle Management Information System (VMIS) that tracks maintenance activities and helps make funding decisions and is being expanded to include subway, light rail and railroad locations.

Rose, David and Lauren Isaac. "Transit Asset Management Manual – Overview." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation summarizes FTA's Transit Asset Management Manual, which defines transit asset management and describes how to implement asset management concepts. It details an asset management framework, showing potential business processes, asset class hierarchies, and asset class lifecycle considerations. The presentation also outlines the asset management implementation process, showing different prototypical implementation approaches.

Ruffa, Frank. "Asset Management at S.F. BART." Presented at the 4rd State of Good Repair Roundtable. FTA, 2012.

This presentation describes efforts undertaken by Bay Area Rapid Transit (BART) to improve its asset management approach. It describes three different components of BART's approach: the engine (systems), framework and practices. BART's efforts to develop its systems are in progress. An asset hierarchy has been defined following the TERM structure, and TERM Lite has been used to support an SGR analysis. In establishing a framework for asset management, BART performed a self-assessment of its existing practices. The presentation provides an example assessment. Also, it lists steps planned to improve asset management practices.

Smith, Allen. "Organizational Needs and Building Management Support for Asset Management Initiative." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation describes the process of developing a state of good repair plan for the Metropolitan Transit Authority of Harris County (Houston METRO). METRO's action plan includes implementing asset management practices, maintaining inventory to adhere to a specified level of service, performing work according to agency policy, reducing backlog and establishing a life cycle policy for assets. The presentation notes the benefit of "starting at the top" to ensure that executive management is invested in the process. The presentation also describes METRO's plans, which include moving all asset data into a single EAM database to assist in future asset management analysis and reporting.

Springstead, David M. "MARTA's AMP Evolution." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation outlines MARTA's asset management program (AMP) goals, implementation process, and supporting tools. MARTA's vision is to develop a condition-based asset management approach through a systematic program that identifies and prioritizes projects based on the Capital Improvement Plan and life-cycle costs. MARTA's AMP System Model includes an enterprise asset management asset database (implemented using FASuite) and project prioritization system (Expert Choice) integrated with other agency systems. The presentation includes a comprehensive set of "takeaway" points and lists the benefits of implementing asset management.

Thiessen, Carl. "Metro Provides Transportation to the St. Louis Metropolitan Region." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation provides an overview of the St. Louis Metro's assets and describes the agency's redesigned Fleet Maintenance strategy, which incorporates operating and life-cycle costs. To manage life-cycle costs, St. Louis Metro determines the expected life for each asset type and creates maintenance plans based on ensuring the maximum expected life. The plan incorporates standard procedures, materials, training and tools. The presentation highlights results of implementing maintenance plans, such helping control capital and operating costs.

Ziring, Emily. "Transit Asset Management System." Presented at the 4th State of Good Repair Roundtable. FTA, 2012.

This presentation reviews the history of transit asset management practices at CTA. It describes CTA's effort to improve its TAM practices, focusing primarily on bus facilities. CTA has defined its asset hierarchy, classifying asset types and standardizing data collection and maintenance practices. CTA also has defined condition assessment criteria to be compatible with the Transit Economic Requirements Model (TERM). In the future, CTA hopes to develop a comprehensive asset management plan that includes maintenance schedules, staffing and warranty information, and work order prioritization. CTA also hopes to incorporate rail infrastructure into the program. The presentation includes a more detailed description of the existing systems, including a MMIS and EAM.

A.2 PRESENTATIONS FROM THE TRB 9TH NATIONAL CONFERENCE ON ASSET MANAGEMENT

Berrang, Stephen. "Metropolitan Transportation Authority: Successful Evolution of Long-Term Capital Needs Assessments." Presented at the 9th National Conference on Asset Management. TRB 2012.

This presentation describes the Metropolitan Transportation Authority's (MTA's) transit system and approach to capital planning. Since 1982 MTA has been mandated by the New York State Legislature to develop a capital investment plan every five years. The presentation describes the approach being used to develop the latest 20-year plan, including updating inventory and condition data, analyzing long-term needs and priorities over a 20-year period in five-year increments, integrating use of an off-the-shelf asset management model to improve the analysis supporting the plan, and performing a regional strategic review. The presentation concludes with a description of the benefits from MTA's capital planning and investments in improving its system realized since 1982. The table below, reproduced from the presentation, summarizes measures of system condition in 1982 and 2012, following $72.4 billion of investment ($107.5 billion in 2012 dollars).

	1982	Today
Subways		
• Ridership (in millions)	989.0	1,640
• On Time Performance %	50	85.4
• Train Delays	319,500	18,502
• MDBF (miles)	10,800	172,700
• Major Felonies	17,497 [1]	2,034
Buses		
• Ridership (in millions)	584.5	784.0
• On Time Performance %	83.8 [2]	89.1
• Bus Delays	276,958 [2]	216,503
• MDBF (miles)	2,466	3,910
Long Island Rail Road		
• Ridership (in millions)	71.4	80.9
• On Time Performance %	86.5	95.2
• Train delays	7852 [3]	4118
• MDBF (miles)	16,168	169,724
Metro-North Railroad		
• Ridership (in millions)	48.7	82.0
• On Time Performance %	80.5	96.9
• Train delays	16,064 [4]	2,414
• MDBF (miles)	18,520	114,347

[1] As of 1990; [2] As of 1989; [3] As of 1996; [4] As of 1985.

Coley, Nathaniel D. "Maryland Transit Administration's Strategy: Applying Multimodal Methods to Transportation Infrastructure Maintenance." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation highlights the lessons learned during Maryland Transit Administration's (MTA) implementation of an asset management system. MTA's implementation process included analyzing existing business processes, inventorying assets, and streamlining work processes, in addition to implementing an asset management system. The presentation also summarizes basic concepts in asset management and economic analysis applicable to transit asset management.

Cooney, Sharon. "Expansion and State of Good Repair: Balancing Priorities." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation discusses the challenges the San Diego Metropolitan Transit System (MTS) faces regarding maintenance of existing assets. Though a number of expansion projects are currently underway, the agency also needs to maintain its existing system. MTS is planning the San Diego Trolley System Renewal Project that will use $572 in funding to purchase 65 new cars, retrofit station platforms, and improve infrastructure assets. The agency's approach to addressing SGR needs includes a comprehensive needs assessment, and emphasizes the importance of communicating agency goals to MPOs, government officials, and the public.

Cruz, Rolando. "Performance Measures for a Comprehensive Facility Maintenance Plan and Incorporation into Business Applications Software." Presented at the 9th National Conference on Asset Management. TRB 2012.

This presentation describes Long Beach Transit's (LBT's) asset management program and details its recent efforts to define key performance indicators (KPIs) for managing facilities. LBT's asset management philosophy is to maintain assets in "like-new" condition where possible, prioritizing investments first in vehicles, then in facilities, right-of-way and support facilities. LBT manages its assets using the Ventyx Ellipse 8 software. The agency received an FTA grant to upgrade Ellipse and extend its use of the system to support development of a Comprehensive Facility Master Plan (CFMP). Development of the CFMP included performing an inventory/condition assessment, developing an annual maintenance plan, forecasting the capital plan, and performing an energy study to incorporate sustainability considerations. An important aspect of developing the CFMP was to define a set of KPIs for facilities. In addition to basic measures of financial performance, LBT has adopted the following KPIs in its CFMP, grouped by category with specific targets shown where these have been established:

- Facility Condition Index
    - Deficiency over replacement value
    - Maintenance costs over replacement value
- Equipment Condition Assessment
    - 100% of assessments done annually
    - Maintain a 2.5 or higher on 100% of all assets deemed critical
- Equipment Replacement
    - 100% of critical equipment replaced within its useful life as dictated by plan
    - 100% Projects completed on budget/time
- Maintenance Performance
    - Backlog of Maintenance – amount of ready work / hours of weekly crew capacity < 2 wks
    - % of planned/proactive vs total work > 70%
    - Ratio of actual number of work orders completed to the number on weekly schedule
    - Work order aging (>10% over 30 days)
- Customer Satisfaction
    - Customer Response – 100% of standard
    - Customer Survey – 85% good / excellent
- Resource Use
    - Electricity - annual reduction of 2% kwh
    - Natural Gas – annual reduction of 3%
    - Water – annual reduction of 4%
    - Recycling – increase by 10% each year
- Energy Plan
    - Equipment replacement evaluations done 100% of the time when replaced

- Complete energy projects as proposed by the employee green team

Ebersohn, Willem and Valerie Marcolongo. "Asset Management System Information to Maintain Service Delivery and to Assess State of Good Repair." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation discusses Enterprise Asset Management and the steps required to implement a successful asset management program. It provides an example of an asset hierarchy for a typical rail system, provides an example of a typical maintenance business process flow, and discusses the integration of an enterprise resource planning and asset management systems. An example is provided based on experience implementing SAP and Maximo for Amtrak.

Gallucci, Grace. "Lessons from the Northeastern Illinois Regional Transportation Authority: Case Study for Regional Applications of Asset Management." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation summarizes the Regional Transit Authority's (RTA's) recent capital asset condition assessment also detailed in Galluci, Goodworth and Allen (2012). Further, it describes RTA's plans to develop a prioritization tool for prioritizing capital projects based on asset condition, riders impacted, service reliability, safety and security, and operating and maintenance costs. RTA has piloted the prioritization approach and is now building the prioritization tool.

Gates, Keith. "Forecasting Asset Conditions with Transit Decay Curves." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes how decay curves are use in TERM, and how these curves were established. The presentation shows a series of decay curves and explains how useful life was determined, where the threshold for useful life is currently defined as having a condition rating of 2.5 or above on the TERM five-point scale.

Giorgis, John. "Proposed Asset Inventory Template for the National Transit Database." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes the process of creating an asset inventory template for transit agency NTD reporting. FTA proposes agencies maintain inventories for both fixed and linear assets, collecting information regarding asset type, year built, estimated useful life, replacement and rehabilitation costs, and the agency responsible for each asset. To streamline the process of data collection, FTA would establish an inventory template that included asset categories with default values for useful life and percent costs for the component details, allowing agencies to customize the input values if necessary. A set of seven agencies have participated in pre-pilot testing of the proposed template.

Grant, Yonel and Josh Shaw. "State of California 2020 Transit Capital Needs." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation summarizes an analysis of transit funding needs for the State of California. The analysis considered needs from 2011 for preservation of existing assets, service expansion, and major new service. FTA's TERM was used to support the analysis of preservation and service expansion. A supplemental analysis was performed to determine funds required for major new service. The analysis indicated that the expected level of funding for California transit agencies from 2011 to 2020 is $87.5 billion for operating expenses, and $30.9 billion for capital expenses. Ten-year funding needs total $110 billion for capital expenses and $73 billion for capital expenses including planned major new service. Thus, there is a significant gap between investment needs and available funding.

Hendren, Patricia G. "Moving from "Build It and They Will Come" to "Maintain It So It Will Last." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes efforts by the Washington Metropolitan Area Transit Authority (WMATA) to address its SGR needs. After a period of system expansion and increasing ridership, in 2009 WMATA experienced a slide decrease in ridership. The flattening out of ridership coincided with a pause on system expansion, decreasing reliability of WMATA's rail fleet (responsible for 50% of system delays), and an unfortunate accident in 2009 which drew attention to the agency's SGR needs. More recently WMATA has focused on addressing its maintenance and rehabilitation needs. The presentation describes the agency's actions and upcoming plans for the rail fleet and escalators, as well as its approach for scheduling track maintenance work. The agency has become more proactive about performing repairs, bringing the hours spent on unscheduled maintenance down from 70% of total maintenance hours to 50%. The improvements to the agency's maintenance practices are expected to be of benefit for maintaining the new Silver Line, helping the agency better maintain the line from the start of service.

Hursh, Michael. "Santa Clara Valley Transportation Authority's Comprehensive Asset Inventory and Prioritization." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes Santa Clara Valley Transportation Authority's (VTA's) effort to develop its asset inventory and prioritize its SGR needs. VTA used data from the MTC Regional Transit Capital Inventory (RTCI) as a starting point for defining its asset inventory. The agency used the MBTA SGR Database to help analyze its SGR needs. VTA then used DecisionLens to prioritize proposed capital projects, using its short range plan and results from the SGR Database to identify potential projects. In DecisionLens projects were prioritized based on the objectives of preservation, improvement, increasing ridership, enhancing safety and security, environmental sustainability, and cost impact. The presentation shows sample results from the DecisionLens illustrating project rankings, as well as results from the SGR Database showing projected needs and spending over time by asset category.

Knueppel, Jeffery, Laura Zale, Robert Peskin, Aaron Kozuki, and Adrian Merceron. "Assembling the Southeastern Pennsylvania Transportation Authority Asset Inventory." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes SETPA's efforts to build its asset inventory as part of its transit asset management program. The asset management program was initiated in 2010 through a grant from FTA. The initial focus of the program is to build an asset database using data from SEPTA's Infrastructure Maintenance Management System and Vehicle Maintenance Information System. Through its existing databases SEPTA has data on asset inventory and age for most assets, but the data are not integrated and typically do not include data on asset condition. SEPTA's consultant AECOM is working with the agency to populate the database using available data, estimate asset condition based on the age data, determine the appropriate level of aggregation for modeling assets in the database, and estimate SGR needs. Next steps include implementing the analysis functionality in the database to predict future funding needs, illustrate impacts of deferring maintenance, and help prioritize investments.

Louch, Hugh, Eric A. Ziering and Joseph A. Guerre. "Trans-AM: Customizable, Open-Source Software for Transit Asset Management." Presented at the 9th National Conference on Transit Asset Management. TRB 2012.

This presentation describes the Program Guidance and Grant Evaluation System (PROGGRES) developed for the Virginia Department of Rail and Public Transportation (DRPT). The system estimates capital needs for buses based on age data. Virginia DRPT uses the system to evaluate capital grant applications from local transit agencies. Work is now underway to additional functionality to the system. The enhanced system will have open-source databases and interfaces to support use by other agencies, and will be called "Trans-AM."

Nicholson, Kyle. "Overview of the Federal Transit Administration State of Good Repair Initiative." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation summarizes the current status of FTA's transit asset management-related activities. It summarizes FTA's work using TERM to analyze transit capital needs, as detailed in the biannual Conditions and Performance Report, as well as supplemental reports in 2009 and 2010. It also lists other studies and events sponsored by FTA, such as an asset management scan and the annual SGR roundtables. A number of transit asset management pilots are now underway, as well as research projects to develop the Transit Asset Management Guide and examine condition assessment approaches. Other current initiatives include the National Transit Institute course on asset management, development of an asset inventory module for the National Transit Database (NTD), and a set of climate adaptation pilots planned for 2012-2013. Upcoming initiatives include continuing the SGR roundtables, performing an independent review of TERM (this will be performed by the Transportation Research Board), and disseminating lessons learned from the pilots now underway.

Noori, Kourosh and Susan Cox. "Obsolescence Management and System Safety Steer Intelligent Asset Management for Rail Transit Systems." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation discusses the challenge of addressing equipment obsolescence in the context of maintaining rail transit systems. It describes factors that lead to obsolescence, such as new technology, bankruptcies and mergers of suppliers, and changing regulations. It recommends approaches to addressing obsolescence proactively, and strategies for managing risk of obsolescence during equipment procurement.

Springstead, David. "Streamlining Assessment and Capital Planning with Standardization, Coordination, and New Technologies: Metropolitan Atlanta Rapid Transit Authority's Approach." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation summarizes Metropolitan Atlanta Rapid Transit Authority (MARTA) efforts to implement a system for condition-based asset management. It is similar to the presentation given by Springstead titled "MARTA's AMP Evolution" at the FTA's 4th State of Good Repair Roundtable in 2012.

Tepke, Glen. "Planning and Programming for State of Good Repair at the Regional Level." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation details the current status of the Metropolitan Transportation Commission (MTC) Regional Transit Capital Inventory (RTCI), and describes how the RTCI was used to update MTC's Regional Transportation Plan (RTP). The RTCI was first developed in 2006. Subsequently the system was updated in 2010 to 2011 to utilize TERM for its analysis. MTC analyzes three basic scenarios using the system when developing the RTP: 10 Years to SGR, in which the backlog of needs is addressed over 10 years while normal recurring needs are met on schedule; Maintain Current State of Repair, in which the backlog and other SGR measures remain constant; and Revenue Constrained, which uses projected funding levels. The presentation shows results for each of the scenarios in terms of the resulting backlog and weighted average asset age (age as a percent of useful life). It also illustrates how the analysis results were incorporated into the RTP and discusses next steps for MTC.

Weaver, Rich. "American Public Transportation Association Standards Program Update: Asset Management and State of Good Repair." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes the American Public Transportation Association (APTA) effort underway to develop asset management and SGR standards. Standards are being developed through a structured process built on achieving consensus, with incorporation of a balanced representation of stakeholders, as well as formal processes for public comments, balloting, and appeals. APTA has formed a SGR working group to develop the standards. The group is comprised of twenty members from a range of transit agencies, consulting agencies and the FTA. The group includes sub-groups for developing SGR and asset management standards.

Williams, Terrell. "Introduction to the Federal Transit Administration's Transit Asset Management Manual." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation describes FTA's Transit Asset Management Manual, and summarizes a project to integrate data from different maintenance management systems. Materials on the manual are similar to those described previously in the presentation by Rose and Isaac at the 4th FTA State of Good Repair Roundtable in 2012.

Witter, Benjamin, Jeremy Shaffer and Michael Schellhase. "New Transit Asset Management System for the Utah Transit Authority." Presented at the 9th National Conference on Asset Management. TRB, 2012.

This presentation outlines the development of a Transit Asset Management (TAM) system for the Utah Transit Authority (UTA). The system is intended to support inventory and inspection of a range of asset types, including bridges, bus garages, elevators, escalators, parking garages, right-of-way (ROW)/fences, ROW/walls, service pits, shafts, stations and tunnels. The presentations shows screen shots from the system which is being implemented, shows example inspection forms and discusses planned future functionality.

A.3 SUSTAINABILITY-RELATED REFERENCES

Cambridge Systematics. Guidelines for Environmental Performance Measurements: Final Report for NCHRP Project 25-25(23). ASSHTO 2008. Accessed at the URL: http://onlinepubs.trb.org/onlinepubs/archive/notesdocs/25-25(23)_fr.pdf, accessed December 2012.

This report describes the process of developing environmental performance measures at state departments of transportation. It includes detailed literature review of current practice, results from a survey of transportation agencies on environmental performance measures, and a series of case studies highlighting the use of sustainable performance measures at various DOTs, MPOs, state environmental agencies, and international organizations. Examples are given of different alternative measures of fuel consumption and emissions which could be adapted for use in evaluating SGR investments.

Gudmundsson, Henrik. *Indicators and Performance Measures for Transportation, Environment and Sustainability in North America*. Ministry of Environmental and Energy National Environmental Research Institute, 2001. Accessed at the URL http://www2.dmu.dk/1_viden/2_publikationer/3_arbrapporter/rapporter/ar148.pdf, December 2012.

This report details the results of a review of environmental and sustainability measures used for transportation applications in the U.S. and Canada. It describes measures used by the Department of Transportation, and Environmental Protection Agency (EPA), as well as by agencies in Canada and selected agencies at the state/province and local level. Sustainability measures listed in the report potentially applicable to analysis of replacement of existing

capital assets include: different measures of emissions (e.g., tons of CO2 emissions); total energy use; and fuel consumption (e.g., fuel consumed per trip or vehicle).

ICF International. ***Guide to Sustainable Transportation Performance Measures*****. EPA, 2011. Accessed at the URL:**
http://www.epa.gov/dced/pdf/Sustainable_Transpo_Performance.pdfm**, December 2012.**

This guide outlines the benefits of developing environmental performance measures and suggests 12 basic types of sustainability measures related to transportation. Examples, potential metrics, and data sources are provided for each of the suggested types of measures. A list of benefits resulting from effective performance measures is also provided, including identifying agency goals and targets, providing project performance assessment, and evaluating plans. The one type detailed in the report potentially applicable to analysis of replacement of existing capital assets is carbon intensity, typically measured in terms of CO2 emissions per capita (e.g., per day, per vehicle mile, etc…).

Jeon, Christy Mihyeon and Adjo Amekudzi. "Addressing Sustainability in Transportation Systems: Definitions, Indicators, Metrics." In ***Journal of Infrastructure Systems*****, Volume 11, Number 1. ASCE, 2005.**

This paper examines initiatives in North America, Europe, and Oceania to encourage and measure sustainability. Agency mission statements featuring the environment are highlighted and their major environmental initiatives are summarized. It is determined that no standard definition of sustainability exists, but effective initiatives focus on the potential impacts to the economy, environment, and social well-being. The paper also describes major frameworks used to analyze sustainable progress, including linkages-based, impacts-based, and influence-oriented frameworks. Specific measures from major environmental initiatives are also listed and sorted into economic, transportation, environmental, safety, and social-cultural equity related categories. Sustainability measures listed in the report potentially applicable to analysis of replacement of existing capital assets include: fleet composition, percent of low-emission vehicles purchased as a fraction of the total; emissions (e.g. of CO2, greenhouse gases, NOX and/or Volatile Organic Compounds); fuel consumption; and energy efficiency.

Jeon, Christy Mihyeon, Adjo A. Amekudzi and Randall L. Guensler. "Evalutating Transportation System Sustainability: Atlanta Metropolitan Region." Presented at the TRB 86th Annual Meeting. TRB 2007.

This presentation discusses the development of sustainability measures in the metro Atlanta region. The presentation refers to definitions of sustainable development, sustainable transportation and comprehensive sustainability that were used to frame the framework. It lists performance measures used to characterize system sustainability. These measures were used to analyze projects and construct a sustainability index. The index helped planners to effectively quantify sustainability, allowing comparisons between projects and the incorporation of sustainability in the decision-making process. Measures applicable to analysis of the replacement of existing capital assets listed in the presentation include VOC and NOx emissions.

Pei, Yi Lin, Ado Amekudzi, Michael Meyer, Elise Barrella, and Catherine Ross. "Performance Measurement Frameworks and the Development of Effective Sustainable Transport Strategies and Indicators." Presented at the TRB 89th Annual Meeting. TRB 2010.

This paper reviews multiple sustainability performance measure frameworks, and presents case studies illustrating how the frameworks have been applied. Frameworks reviewed include the Triple Bottom Line Framework, the Driving Forces-Pressures-State-Impacts-Responses Framework, the Tri-Axial Framework for Technological Sustainability, Influence-Oriented Frameworks, Balanced Scorecard and the Performance Prism. Three case studies are detailed, for the European Union, United Kingdom, and Texas Department of Transportation. The case studies illustrate how different frameworks have been applied, but do not detail specific performance measures.

Ramanai, Tara. "Sustainability Performance Measures for El Paso's Transit Corridors." Presented at the Conference on Performance Measures for Transportation and Livable Communities. TRB, 2011. Accessed at the URL: http://utcm.tamu.edu/LivabilityConference/presentations/pdfs/Ramani.pdf

, December 2012.

This presentation outlines the process of creating environmental performance measures as part of the process of implementing a rapid transit system for the City of El Paso. The process included definition of sustainability goals, and development of performance measures. While these performance measures are yet to be applied, the agency has already benefited from the practice of linking these measures to existing long-term plans, encouraging agency-wide support. Measures listed in the presentation potentially applicable to analysis of replacement of existing capital assets include daily emissions per mile of the system of C02, particulate matter (PM), CO and ozone precursors.

Volpe National Transportation Systems Center. "Comparing the Environmental Benefits of Transit Projects: Proceedings from a Colloquium – October 28 & 29, 2008." FTA, 2009. Accessed at the URL: http://www.fta.dot.gov/documents/FTA_EnvironmentalBenefitProceedings.pdf**, December 2012.**

This report documents the Colloquium held by the Volpe National Transportation Systems Center to determine measures assessing the environmental benefits of transit projects. Proposed measures were broken into categories including energy use, air quality, land use, and physical activity measures. The document lists the measures by category and discusses considerations, benefits, and challenges of using the measures. The focus of the colloquium was to identify measures for evaluating new service, so most of the measures are not directly applicable for use in evaluating SGR investments. Sustainability measures listed in the report potentially applicable to analysis of replacement of existing capital assets include: energy used per vehicle, passenger, or per revenue mile traveled; CO_2 emissions per passenger mile traveled (or revenue mile) traveled; and emissions of NOx, VOC, and PM emitted per mile per passenger (or normalized by cost).

Zietsman, Josias, Tara Ramani, Joanna Potter, Virginia Reeder, and Joshua DeFlorio. *NCHRP Report 708: A Guidebook for Sustainability Performance Measurement for Transportation Agencies.* **TRB 2011.**

This report defines sustainable transport and outlines the process of developing and utilizing a sustainable performance measurement framework. The report determines measures based on sustainability goals such as safety, accessibility, equality, system efficiency, security, prosperity, economic viability, ecosystems, waste generation, resource consumption, and emissions. The report also suggests relating goals and performance measures to agency focus areas, such as planning, programming, project development, construction, maintenance, and system operations departments. The report includes a compendium of sustainability performance measures, organized by goal and focus area. Sustainability measures listed in the report potentially applicable to analysis of replacement of existing capital assets include:

- Change in average design or actual life of project assets (note this measure is motivated by the goal of reducing waste)
- Change in the percentage of zero/low emissions vehicles in a fleet
- Change in the amount and percentage of green energy purchased
- Change in total energy consumed
- Change in emissions by criteria pollutant, total, and by mode/ton mile

A.4 OTHER REFERENCES

Boudart, Jess and Miguel Figliozzi. "Key Variables Affecting Decisions of Bus Replacement Age and Total Cost." In *Transportation Research Record 2274.* **TRB, 2012.**

This paper details an optimization model designed to determine the age at which to replace a bus in order to minimize bus life cycle costs. The model considers purchase cost, emissions costs (for purchase and fuel consumption), salvage value of the bus, operations and maintenance costs, fuel costs, and passenger costs from road calls. Maintenance costs are assumed to increase by 1.5% a year due to deterioration and the salvage value of a bus is assumed to decrease as a function of age, but other parameters are assumed to be constant as a bus ages. The paper illustrates application of the model for King County transit buses, and concludes for the example illustrated the optimal replacement age is approximately 21.5 years.

Ebersohn, Willem. "Amtrak's Strategic Asset Management Program." Presented at the TRB 91st Annual Meeting. TRB 2012.

This presentation summarizes Amtrak's strategic asset management program. It includes some of the materials from the presentation by Ebersohn and Marcolongo at the TRB 91st Annual 9th National Conference on Asset Management described previously in this document, as well as additional materials illustrating Amtrak business processes related to asset management.

Gallucci, Grace, John Goodworth and John G. Allen. "Asset Condition Assessment at Chicago's Regional Transportation Authority." In *Transportation Research Record 2289*. TRB, 2012.

This paper describes the growth of interest over time in asset management within the transit industry, spurred by high profile incidents faced by a number of agencies in which deteriorated asset conditions resulted in increased costs and service impacts. The paper reviews the asset management challenges faced by the three Chicago-area transit agencies, the Chicago Transit Authority (CTA), Metra and Pace. In response to concerns of achieving a state of good repair, and with encouragement from FTA, in 2009 RTA began assessing transit asset conditions for the three Chicago transit agencies, resulting in publication of the *Regional Transportation Authority Capital Asset Condition Assessment* in 2010. Assets in the study were grouped into five categories:

- Track and structures,
- Electrical and subway equipment,
- Signals, communication and fare collection,
- Stations, garages and facilities; and
- Rolling stock.

RTA rated assets using a five-point scale. However, as limited data were available on asset condition, age was used as a proxy for condition, supplemented by a sampling of condition data for 1% of the assets. The condition assessment was used to establish RTA's backlog of transit investment needs. Moving forward, RTA intends to build upon the condition assessment to work with the Chicago transit agencies to improve their asset data, incorporate condition data into its regional transit performance measures, and develop a decision support tool for prioritizing investments.

Gates, Keith and Richard Laver. "TERM Lite Update." Presented at the TRB 91st Annual Meeting. TRB, 2012.

This presentation summarizes the functionality of TERM Lite, and describes planned enhancements to the system. The description of TERM Lite is similar to that described previously in the presentation by Gates at the FTA 3rd State of Good Repair Roundtable in 2011. The next version of the system is expected to have additional functionality for prioritizing investments considering asset condition, riders impacted, service reliability safety and security, and operations and maintenance costs.

Kubicek, David. "State of Good Repair: Stations and Vertical Transportation." Presented at the TRB 91st Annual Meeting. TRB, 2012.

This presentation describes the Washington Metropolitan Area Transit Agency's (WMATA's) approach to achieving a state of good repair for its escalators. WMATA has the most escalators (588) of any transit system in North America. The WMATA system, as designed, relies heavily on escalators. 75% of the system's escalators are 25 years old, and they have become a significant maintenance concern. WMATA has taken a number of steps to improve the maintenance of its escalators, following a period of neglect. Four basic measures are used to track the quality of service the escalators provide: system-wide availability; preventive maintenance compliance; mean time to repair; and mean time between failure. More aggressive maintenance of the escalator inventory has improved performance, and yielded a number of benefits to WMATA's customers.

McCollom, Brian and Stephen Berrang. *TCRP Synthesis 92: Transit Asset Condition Reporting*. **TRB, 2011.**

This report describes the current state of the practice in transit asset condition reporting at large transit agencies. It includes a literature review and results from surveys of 41 agencies. It concludes that though there is concern about consequences of underinvestment in existing transit assets, at most transit agencies the asset management systems in use are "elementary and limited," particularly with respect to estimating consequences of not making needed asset replacements and testing impacts of different funding scenarios. It includes cases studies of asset management condition reporting at two agencies: MBTA and New York City Transit (NYCT).

Rivas, Victor. "Massachusetts Bay Transportation Authority Approach to State of Good Repair. Presented at the TRB 91st Annual Meeting. TRB 2012.

This presentation describes the accomplishments of the MBTA in implementing its SGR database, as well as plans for improving the MBTA's asset management approach. Implementation of the SGR Database has helped increase awareness of SGR needs, and resulted in a greater percentage of MBTA's funds being dedicated to addressing SGR needs. Challenges that the MBTA is currently facing include the manual and inconsistent process of updating their data, the SGR backlog is defined mostly by age, the lack of integration between the existing SGR database and EAM systems, and the absence of condition data. MBTA is preparing to embark upon the next phase of developing its SGR Database. As part of this phase the agency will develop a comprehensive asset management plan, enhance the SGR Database, and implement a decision support tool to create a consistent framework for decision-making which is aligned with the agency's strategic goals.

Rose, David, Lauren Isaac, Keyur Shar and Tagan Blake. *Asset Management Guide: Focusing on the Management of Our Transit Investments*. **FTA 2012.**

This guide provides an overview of transit asset management, and offers a framework that can be implemented by individual assets, or at a system level. The framework is referred to as "best practice" guidance, and offers details on major asset class and other practical guidance for agencies interested in improving the performance and effectiveness of their asset management practices. It offers details of an asset management plan, which in this case, refers to a document which will detail and determine an agency's approach to managing assets. The plan, as described, does not include selected projects and funding for moving forward.

Appendix B. Pilot Memoranda

This appendix includes the memoranda sent to pilot agencies detailing the results of the transit agency pilots. Since completion of the pilots there have been further changes to TAPT, and in some cases changes were made to the pilot results following completion of the pilot memoranda. Thus, while the memoranda in this appendix document process and methodology utilized during the course of the pilots, the specific data and model results shown here should not be considered authoritative.

spy pond partners, llc

Memorandum

To: Jim Sutton and Lou Cripps, Denver RTD
From: Bill Robert, Spy Pond Partners
Date: June 28, 2013
Re: Denver RTD SGR Pilot Results

This memorandum summarizes the results of the State of Good Repair (SGR) pilot performed for the Denver Regional Transportation District (RTD) for Transit Cooperative Research Program (TCRP) Project E-09A. The following sections describe the scope of the pilot, data used for the pilot, the asset inventory that was included, asset-specific models, and results. Also, the memo summarizes the results of an analysis of SGR needs performed using the Federal Transit Administration (FTA) Transit Economic Requirements Model (TERM) Lite. The final section of the memorandum discusses revisions to the analysis made since the draft, and potential future enhancements.

Pilot Scope

The basic goal of the TCRP Project E-09A pilot program is to test the SGR framework and supporting tools developed previously through TCRP Project E-09. The framework and tools are intended to help agencies quantify the impacts of investing in rehabilitation and replacement of existing transit capital assets, and to help prioritize SGR investments. These tools help support the following tasks:

- Quantifying a transit agency's asset inventory.
- Developing models for each individual asset type. These models predict the life cycle costs of the asset, compute a variety of performance measures, and recommend when to rehabilitate or replace the asset.
- Prioritizing asset rehabilitation/replacement given details on the asset inventory, the asset type models, and an assumed budget.
- Predicting the conditions and performance that will result from a given set of asset replacement projects.

The interim report on the project provides additional information on the SGR framework. Also, the report details use of the SGR tools, now integrated into a single spreadsheet called the Transit Asset Prioritization Tool (TAPT), and describes the measures calculated by the tool.

Three agencies are participating in the pilots: King County Metro, Denver RTD and the Southeastern Pennsylvania Transportation Authority (SEPTA). For each of the agencies the research team is conducting the following activities, at a minimum:

- Developing asset rehabilitation/replacement models using TAPT for as many asset types as possible, with the exact set of assets addressed based on available data.
- Determining how SGR investments should be prioritized based on the models, and comparing this to any data or insights on how each transit agency currently prioritizes.
- Defining investment scenarios to illustrate the impacts over time of alternative investment levels.

Additional activities are being performed as part of the pilots, pending available data and staff time, such as calibrating deterioration models, predicting additional performance measures, and comparing results to those generated using TERM Lite.

In the case of Denver RTD, the pilot is addressing as wide a range as assets as feasible, including buses, light rail vehicles, facilities and track. The memorandum dated January 25th details the planned scope. The scope has been conducted consistently with the initial plan, with the following exceptions:

- Initially we planned to model track without distinguishing between tracks and guideway. Instead, we have modeled track and guideway as separate assets, as this is consistent with the approach used in TERM.
- Our intent was to model facilities at the system level (e.g., roof, HVAC, etc…). However, sufficient data are not available to model facilities at this level of detail. Thus, instead we are modeling at the overall facility level, consistent with the available data in RTD's Enterprise Asset Management (EAM) system.

Data Received

This section describes data received from Denver RTD to support the pilot. Basic data used for the pilot are from RTD's 2011 National Transit Database (NTD) submittal. Table 1 lists additional materials provided by RTD. With the exception of the draft strategic budget plan, all materials were provided electronically.

Table 1. Pilot Data Provided by RTD

Category	Document	Notes
EAM Codes	001-COVER PAGE.doc	Details on codes used in the EAM system, including symptom, status, task, inventory, component, work class, and repair reason codes
	002-Explanation of Guide and Coding.doc	
	003-Table of Contents.doc	
	004-SYMPTOM CODES.xls	
	005-RAIL WAC CODES.xls	
	006-LRV MAJOR CATEGORY LIST.xls	
	007-MAXIMUS LRV TASK CODES.xls	
	008-WORK CLASS CODES.xls	

Category	Document	Notes
	009-REPAIR REASON CODES.xls	
Vehicle Inventory	Bus Inventory.xls	Inventory data for directly operated buses.
	BUS-PC Inventory.xls	Inventory data for buses operating under private contract
	LRV Inventory.xls	Light rail vehicle inventory
	Support-VEH Inventory.xls	Support vehicle inventory
Facility Inventory	Facility Inventory for TCRP.xls	Facility inventory supplemented with additional data on acquisition cost, rehabilitation costs, and other fields (replaces an earlier version of the same data)
	facility square footage.doc	Facility square footage by building
Track Inventory	Track Works.xlsx	Length of track by corridor and track type (replaces an earlier version of the same data)
Maintenance Data	number of roadcalls – BUS.pdf	Road calls and service delay by bus and month
	number of roadcalls – RAIL.pdf	Road calls and service delay by light rail vehicle and month
	vehicle maintenance cost – BUS.pdf	Parts cost and maintenance labor hours by month and bus
	vehicle maintenance cost – RAIL.pdf	Parts cost and maintenance labor hours by month and light rail vehicle
	SRV_MAIN.xls	Detailed work order data
	Copy of MIDLIFE project detailed plan Shawn (2).xls	Estimate for cost of a light rail vehicle renewal
Service Data	Aug11 SV Recap -- All Operations.pdf	Details on the number of trips, vehicles and vehicle miles by route for different periods in 2011 - 2012
	Aug12 SV Recap -- All Operations.pdf	
	Jan12 SV Recap - All Operations.pdf	
	May12 SV Recap -- All Operations.pdf	
	Chart of Routes Done Per Runboard.xls	Indicates which routes were run by month on weekdays and weekends
	RTD 2011 service performance report.pdf	Report downloaded from the RTD web site documenting boardings and service hours by route

Category	Document	Notes
	Jan13 vehicle types by route, branch and trip start time.xls	Documents vehicle types used by route in January 2013
	vehicle miles – BUS.pdf	Monthly mileage and lifetime mileage by bus
	vehicle miles – RAIL.pdf	Monthly mileage and lifetime mileage by light rail vehicle
	LRV_miles.xlsx	Monthly mileage totals by light rail vehicle for January 2013 and May 2013.
Project Data	2013-2018 Strategic Budget Plan	Draft strategic budget plan listing proposed projects by year
	Jan13 vehicle types by route, branch and trip start time.xls	Vehicle Type, Route, Start Time
	richards 2012 projects.xls	2012 operations and maintenance projects
TERM Input	TERM Lite Expansion BETA (Denver)_LargeRec.accde	RTD asset inventory used by FTA in running TERM, provided by FTA

Existing Assets

A basic step in performing the pilot analysis was to establish RTD's asset inventory. Tables 2 to 5 detail the inventory included in the pilot, including directly operated buses, light rail vehicles, track, guideway and facilities. For each asset the tables provide an ID used in the SGR prioritization tool and a description of the asset, as well as other fields provided depending on asset type.

Table 2 lists the bus inventory, grouping buses by subfleet. This table shows the type of bus, the number of vehicles in the subfleet, age of the subfleet (in years as of 2012), and average accumulated mileage per vehicle. 2011 NTD data were used to establish the inventory.

Table 3 lists the light rail vehicle inventory, grouping vehicles by subfleet. It shows the number of vehicles in the subfleet, age of the subfleet (in years as of 2012) and average accumulated mileage per vehicle. 2011 NTD data were used to establish the inventory.

Table 4 summarizes the length of guideway and track by type and line for each of 6 lines: Central, Southwest (SW), Central Platte Valley (CPV), Southeast (SE), I-225, and the new West Line. Note that guideway quantities are expressed in terms of lineal feet, while track quantities are expressed in terms of track feet. Thus, for a double-tracked line, the quantity of track should be double the quantity of guideway. The table also shows the year each line went into service. For track the table distinguishes between track with typical amounts of traffic, and track on the Central Line, labeled "intensive use," which handles increased traffic. Data in this table were taken from the Track Works.xlsx spreadsheet provided by RTD.

Table 5 lists the inventory of facilities, based on data provided by RTD. The table lists an ID for the facility, facility type (administrative, maintenance, or station), facility age, and approximate square footage.

Table 2. Bus Inventory

Type	ID	Description	#	Age (years)	Avg. Accum. Mileage
Articulated	Bus-Artic 1	2000 NABI 436.09	118	12	330,900
Mall	Bus-Mall 1	2000 TRANSTEQ Mall Shuttle	18	12	138,904
	Bus-Mall 2	2001 TRANSTEQ Mall Shuttle	15	11	141,193
	Bus-Mall 3	2002 TRANSTEQ Mall Shuttle	3	10	130,023
Intercity	Bus IC 1	1998 MCI 102DL3	67	14	1,024,371
	Bus-IC 2	2001 NEOPLAN AN3453	85	11	493,701
	Bus-IC 3	2009 Blue Bird Corporation EXPRESS45000	6	3	55,487
	Bus-IC 4	2010 MCI D45000	6	2	84,036
40' Transit	Bus-Transit 1	2000 ORION V Coach Transit	199	12	482,740
	Bus-Transit 2	2005 Gilig (G21D102N4)	42	7	295,447
	Bus-Transit 3	2006 Gilig Hybrid (19D102N4)	4	6	171,153
	Bus-Transit 4	2006 Gilig (G21D102N4)	7	6	249,523
	Bus-Transit 5	2008 Gilig (G27D102N4)	6	4	170,629
	Bus-Transit 6	2008 Gilig Hybrid (G30D102N4)	5	4	115,508

Table 3. Light Rail Vehicle Inventory

ID	Description	#	Age (years)	Avg. Accum. Mileage
LRVSD100 1	1993 Siemens SD100	11	19	1,143,942
LRVSD100 2	1996 Siemens SD100	6	16	1,075,332
LRVSD100 3	1999 Siemens SD100	14	13	922,818
LRVSD100 4	2001 Siemens SD100	17	11	768,884
LRVSD100 5	2002 Siemens SD100	1	10	723,946
LRVSD160 1	2005 Siemens SD160	15	7	439,464
LRVSD160 2	2006 Siemens SD160	19	6	414,681
LRVSD160 3	2007 Siemens SD160	9	5	289,253
LRVSD160 4	2008 Siemens SD160	25	4	204,248
LRVSD160 5	2009 Siemens SD160	5	3	117,642
LRVSD160 6	2010 Siemens SD160	32	2	78,711
LRVSD160 7	2011 Siemens SD160	18	1	24,087

Table 4. Guideway and Track Inventory

Description	Value by Line					
	Central	SW	CPV	SE	I-225	West
Year Line Went Into Service	1994	2000	2002	2006	2006	2013
Guideway Quantity (thousands of ft)						
Ballasted	28,491	166,884	14,329	146,219	52,937	110,148
Bridge	23,370	67,873	3,369	150,436	55,446	131,648
Embedded	37,797	2,700	5,267	2,371	0	2,167
Grade Crossing	306	0	600	0	0	5,611
Track Quantity (thousands of ft)						
Tangent Ballasted	6,043	88,363	1,630	44,172	20,176	43,633
Tangent Ballasted-Intensive Use	990	0	0	0	0	0
Curved Ballasted	7,176	22,915	10,766	67,526	21,862	32,669
Curved Ballasted-Intensive Use	6,656	0	0	0	0	0
Embedded	19,104	1,410	2,750	1,238	0	1,132
Embedded-Intensive Use	631	0	0	0	0	0
Grade Crossing	0	0	313	0	0	2,930
Grade Crossing-Intensive Use	160	0	0	0	0	0
Special	2,175	10,429	3,417	23,913	3,028	7,816
Special-Intensive Use	5,928	0	0	0	0	0
Tangent Direct	130	840	0	5,145	397	3,438
Yard	1,097	2,796	0	0	0	0

Table 5. Facilities Inventory

ID	Type	Description	Age (as of 2012)	Square Footage
Fac-Admin 1	Administrative	Blake Street Offices	31	62,393
Fac-Admin 2		Security Center	9	3,768
Fac-Admin 3		Treasury Building	25	7,968
Fac-Admin 4		Wellness Center	26	
Fac-Maint 1	Maintenance	Boulder Facility	33	165,184
Fac-Maint 2		District Shops Facility	22	271,643
Fac-Maint 3		East Metro Facility	32	397,040
Fac-Maint 4		Elati Facility	1	125,110
Fac-Maint 5		Mariposa Facility	1	44,103
Fac-Maint 6		Platte	1	256,832
Fac-Stations 1	Station	Boulder Transit	30	5,243
Fac-Stations 2		Civic Center Station	28	153,722
Fac-Stations 3		LRV Station at DUS	1	21,000
Fac-Stations 4		Union Station	11	136,281

Asset Model Development

The following subsections describe the approach used to develop the asset-specific models, including models for buses, light rail vehicles, guideway, track and facilities. For each asset type the research team used the TCRP models, but some amount of effort was involved in populating the model inputs. For vehicles the research team used the TCRP vehicle model, which requires data reported in the NTD. However, in the case of buses it was necessary to disaggregate the NTD-reported data to model different bus types. For other assets, the research team used the age-based TCRP model. No additional data were available to use to develop Denver-specific models, so the defaults derived from TERM were used. Once the asset-specific models were developed, these were used to prioritize investments and simulate future conditions, as described in the next section.

Vehicles

For buses, four different types of buses operated by RTD were included in the pilot: articulated buses, mall shuttles, intercity buses, and 40-foot transit buses. RTD also has a number of 30-foot and smaller vehicles, but these were excluded from the analysis. Also excluded were vehicles operated under contract, though we expect that the vehicle models developed for the four bus types can be applied without revision to these vehicles. Table 6 summarizes the data required for the vehicle model and notes the approach used to obtaining the data for the different bus types.

Table 6. Bus Model Inputs

Category	Data Item	Approach Used for Quantifying the Item	Notes
Fleet Description	Number of vehicles by subfleet	2011 NTD data	See Table 1
	Average accumulated mileage per vehicle		
Operating Data	Passenger miles	2011 NTD data, prorated using service data	Service data were adjusted to exclude 30-ft buses and privately contracted buses
	Unlinked trips		
	Revenue vehicle miles		
	Revenue vehicle hours		
	Vehicle miles	2011 NTD data, prorated using bus-specific data from the EAM system	For mall buses EAM data were further analyzed to determine number of roadcalls generating delay
	Total road calls		
Cost Data	Vehicle replacement cost	Strategic Budget Plan (SBP)	
	Gallons of fuel	2011 NTD data, prorated using bus-specific data from the EAM system	
	Vehicle maintenance cost		

Table 7 below details the vehicle model inputs calculated for each bus type. The spreadsheet vehicle_analysis.xlsx details how NTD data were prorated. A discount rate of 5% was used for the analysis. Defaults were used for all other model parameters. However, for articulated buses, the rehabilitation cost per mile was increased by 50% for accumulated mileage of 400,000 or greater based on RTD experience with these vehicles.

Table 7. Bus Model Data

Parameter	Value by Bus Type			
	Artic	Mall	Intercity	40 foot
Passenger miles (000)	49,548	5,010	99,787	116,795
Unlinked trips (000)	8,814	15,183	3,858	18,891
Vehicle miles (000)	4,200	527	9,888	11,667
Revenue vehicle miles (000)	2,857	421	7,399	9,906
Revenue vehicle hours (000)	203	97	319	821
Road calls	88	65	87	317
Replacement cost	634,000	384,000	562,000	384,000
Gallons of fuel (000)	976	160	1,661	2,605
Vehicle maintenance cost (000)	9,492	2,596	9,732	15,761

Generally the NTD and EAM-reported numbers agreed well, after adjusting for buses excluded from the analysis. However, one concern is the difference between road calls reported to NTD and tracked in the EAM. A total of 517 road calls were reported in the NTD for 2011 for all directly operated motor buses (including 30-foot buses). However, in the EAM approximately 140,000 incidents are logged annually. This difference is a reflection of the fact that not every incident tracked in the EAM meets the criteria for reporting to the NTD. The discrepancy has the biggest impact on mall buses. Thus, in this case, the EAM-reported road calls were further analyzed to assess how many road calls generated delay, regardless of whether or not they were reported to the NTD, resulting in the estimate of 65 road calls annually.

Figures for bus replacement are taken from the Strategic Budget Plan (SBP). For mall buses, the replacement cost for a typical transit bus was used. In actuality, the mall buses are custom-made buses, but they include a number of features not captured in the model (e.g., right side drive). Thus, the replacement cost for a standard transit bus was used to provide a more realistic indication of when these buses should be replaced, setting aside extra costs for customizations.

For light rail vehicles NTD data were used, prorated between the SD100 and SD160 fleets. Table 8 details the inputs used for the LRV models.

Table 8. LRV Model Inputs

Category	Data Item	Approach Used for Quantifying the Item	Notes
Fleet Description	Number of vehicles by subfleet	2011 NTD data May 2013 operations data	See Table 2. NTD-reported mileage was used to prorate data between fleets. May 2013 operations data were used to predict future mileage.
	Average accumulated mileage per vehicle		
Operating Data	Passenger miles		
	Unlinked trips		
	Revenue vehicle miles		
	Revenue vehicle hours		
	Vehicle miles		
	Total failures	2011 NTD data EAM system	NTD data were prorated based on failures reported in the EAM. Also, EAM data were used to calculate the annual increase in failures
Cost Data	Vehicle replacement cost	TERM Lite	
	Energy consumption	2011 NTD data EAM system	NTD data were prorated based on NTD-reported mileage
	Vehicle maintenance cost	2011 NTD data	NTD data were reported

		EAM system	based on maintenance costs reported in the EAM

Table 9 below details the vehicle model inputs calculated for each LRV fleet. In most cases, 36% of the NTD-reported value for each item was attributed to the SD100 fleet, and 64 % was attributed to the SD160 fleet, based on both the NTD-reported mileage and distribution of failures reported in the EAM. However, maintenance costs for the SD100 fleet are slightly higher based on EAM data, approximately 38% of the total. For predicting future conditions, operating data from May 2013 were used to predict annual mileage, and EAM data were used to predict the annual percentage increase in failures.

Table 9. LRV Model Data

Parameter	Value by LRV Type		Notes
	SD100	SD160I	
Passenger miles (000)	59,235	105,306	36% attributed to SD100 fleet based on NTD-reported vehicle mileage
Unlinked trips (000)	7,450	13,245	
Vehicle miles (000)	1,209	2,150	
Revenue vehicle miles (000)	1,152	2,049	
Revenue vehicle hours (000)	62	110	
Failures	33	59	36% attributed to SD100 fleet based on EAM data
Replacement cost	4,500,000		
Energy Consumption in kwh (000)	18,150	32,267	36% attributed to SD100 fleet based on NTD-reported vehicle mileage
Vehicle maintenance cost (000)	4,336	7,075	38% attributed to SD100 fleet based on EAM data
Annual miles per vehicle	47,611	75,399	Used for calculating future conditions
Failure recovery time (minutes)	120		
Annual increase in failures	3.96%		
Rehab cost	$0.40/mile for mileage of 1M miles or greater		Assumes a $400K rehab is required every 1M miles

Table 10 summarizes the results of the vehicle models. For each vehicle type the table shows the optimal replacement mileage, corresponding age, and average annual cost over the lifecycle of the vehicle assuming it is replaced at the optimal point. The average annual cost includes maintenance, rehabilitation and energy costs incurred by the transit agency, as well as user costs, costs from emissions, and the annualized purchase price of the vehicle. As shown in the table, the optimal replacement age is 15-18 years for buses. For LRVs the

SD100s are expected to require replacement at an age of approximately 45 years, or 2.1 million miles. SD160s are expected to require replacement at a lower age, 31 years, but a higher mileage, 2.3 million, as a result of the fact that these are accumulating mileage at a higher rate than the SD100s.

Table 10. Vehicle Model Results

Vehicle Type		Optimal Replacement Mileage (000)	Optimal Replacement Age (years)	Average Annual Cost (000)
Bus	Artic	569	16	191
	Mall	219	15	128
	Intercity	1,085	18	177
	40-ft	665	15	142
LRV	SD100	2,142	45	532
	SD160	2,337	31	847

Besides predicting the optimal replacement/renewal mileage and average annual lifecycle cost, the vehicle model also predicts a number of other measures, such as mean distance between failures (MDBF), user costs, and a prioritization index which is used to determine how vehicle replacement should be prioritizing relative to replacement of other assets. Figure 1 shows predicted MDBF by age for each vehicle type. The next section shows results for this and other measures for different investment scenarios.

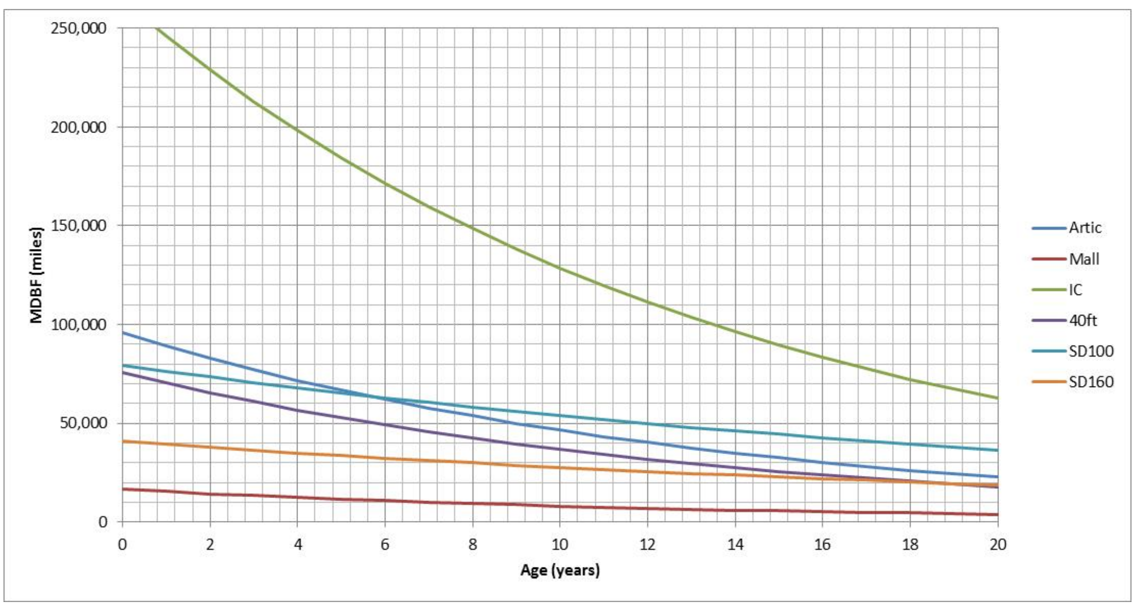

Figure 1. MDBF by Vehicle Type

Guideway and Track

TERM models were used for modeling guideway and track, with adjustment for more intensively-used track along the Central Line. Note that TERM models guideway and track separately. Generally the guideway is much longer-lived than the track, implying that the track along an alignment may be replaced multiple times before it is necessary to renew or replace other guideway elements. However, in the case of embedded rail and grade crossing, the TERM models predict that the track lasts longer than the guideway. As noted previously, guideway is measured per lineal foot, and track is measured per track foot.

Table 11 summarizes the models inputs for each guideway and track type, including the TERM model used, median survival age (age to which the asset is expected to survive with 50% confidence, approximated as the point when the 5-point TERM rating drops to 2.5) and the unit replacement cost. Model parameters were determined as follows:

- By default the TERM decay curves were used with a usage factor of 100%. For intensively-used track, TERM decay curves were used with a usage factor of 200%. Survival ages were calculated based on the TERM curves.
- The replacement cost is that specified in TERM, adjusted for inflation.
- The annual maintenance cost was determined by analysis of freight rail industry data (R-1 reports). Based on these reports, the freight railroads replace approximately 1% of their Class I railroads operating in the Eastern U.S. This value was used for all track and guideway types.
- The failure cost as a percentage of replacement cost was set to 150% for agency and user costs, which the default value from the original TCRP tools. The user failure cost was doubled to 300% for intensively-used track.

Table 11. Guideway and Track Model Data

Type	TERM Model	Median Survival Life (years)	Replacement Cost ($/ft)
Guideway			
Ballasted	10113	83	2,009
Bridge	10333	83	26,955
Embedded/Grade Crossing	10210	18	3,141
Track			
Tangent Ballasted	11201	40	639
Tangent Ballasted-Intensive Use		38	
Curved Ballasted	11202	34	1,386
Curved Ballasted-Intensive Use		32	
Embedded/Grade Crossing	11303	28	820
Embedded/Grade Crossing-Intensive Use		27	
Special Trackwork	11400	32	3,776
Special Trackwork-Intensive Use		30	
Tangent Direct	11101	45	706
Yard	11500	36	731

The age-based asset model predicts the average annual cost over the lifecycle of the asset, as well as the optimal replacement age. The average annual costs range from $141 to $1,903 per lineal foot for guideway, from $55 to $440 per track foot for track. Optimal replacement ages range from 14 years for embedded guideway and grade crossings to 72 years for ballasted guideway and bridges, with other results falling between these two extremes. These results are provided in Table 12. Figure 2 shows the predicted condition as a function of age on the 5-point TERM condition scale for guideway. Figures 3 and 4 show predicted condition for standard and intensive use track, respectively.

Table 12. Guideway and Track Model Results

Type	Optimal Replacement Age (years)	Average Annual Cost
Guideway		
Ballasted	72	141
Bridge	72	1,903
Embedded	14	447
Grade Crossing	14	455
Track		
Tangent Ballasted	33	55
Tangent Ballasted-Intensive Use	26	61
Curved Ballasted	27	89
Curved Ballasted-Intensive Use	21	101
Embedded	23	88
Embedded-Intensive Use	18	105
Grade Crossing	23	91
Grade Crossing-Intensive Use	18	105
Special Trackwork	26	380
Special Trackwork-Intensive Use	20	440
Tangent Direct	36	58
Yard	29	66

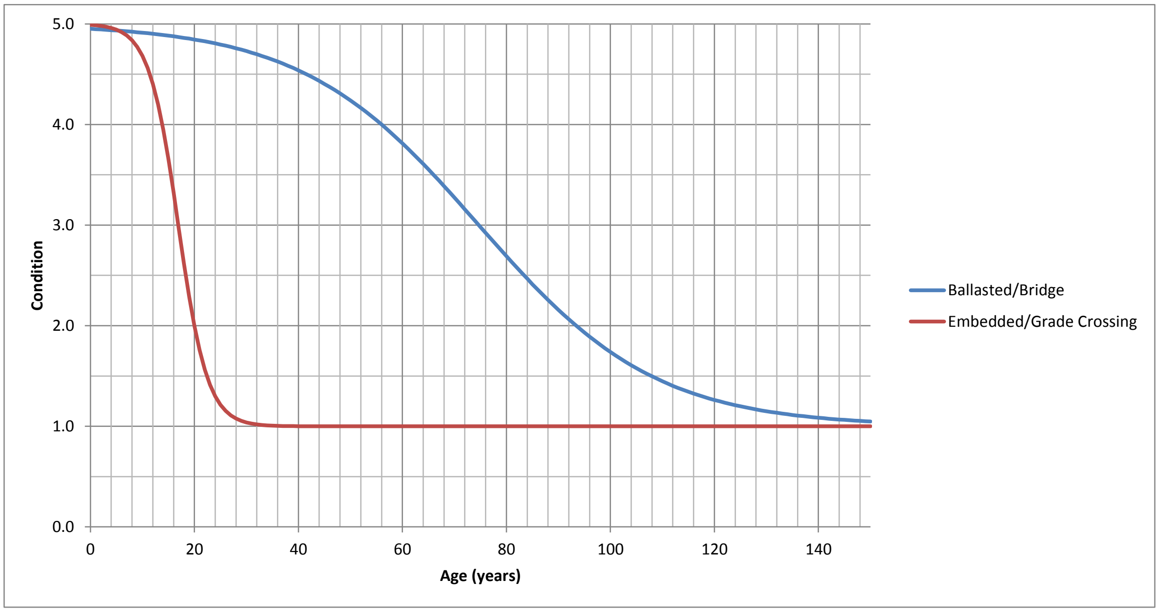

Figure 2. TERM Decay Curves by Guideway Type

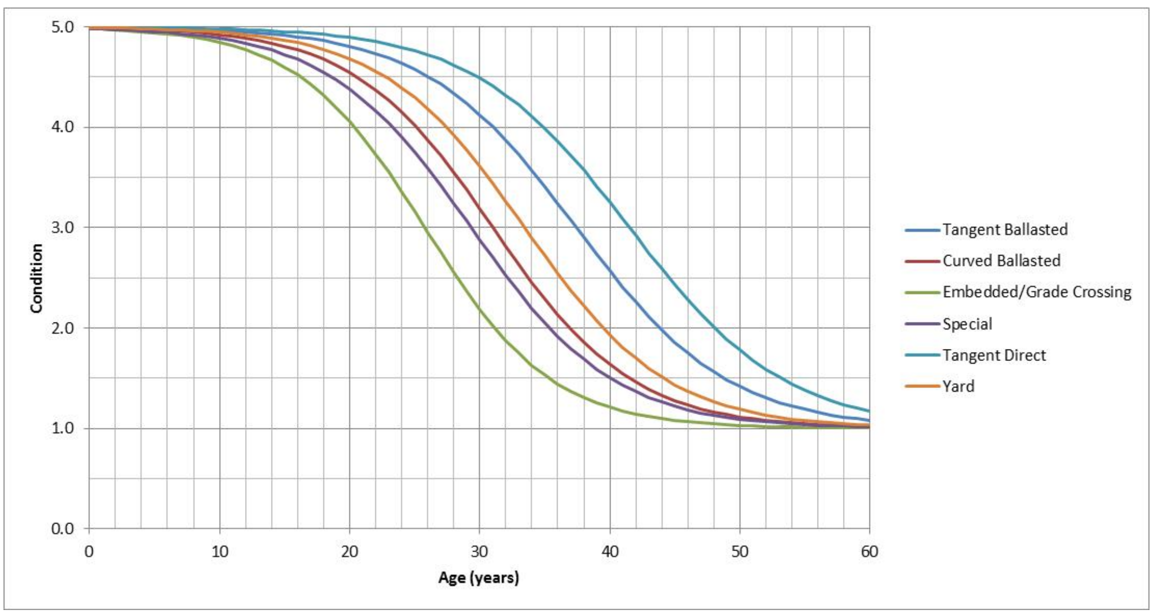

Figure 3. TERM Decay Curves by Track Type

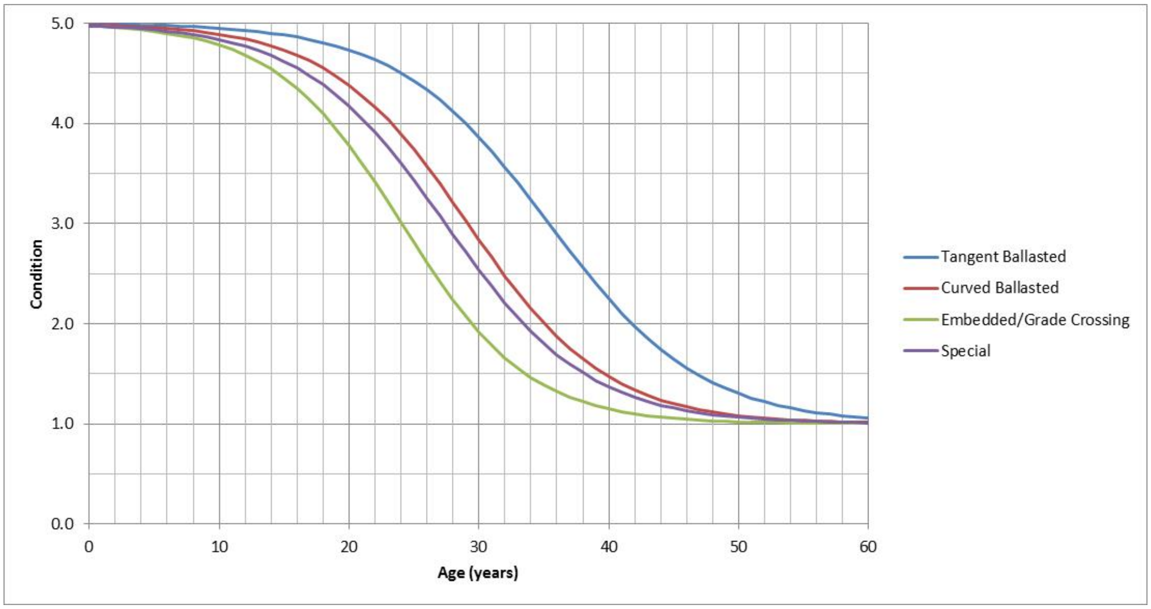

Figure 4. TERM Decay Curves by Track Type – Intensive Use

Facilities

For the pilot, facilities were modeled at the whole facility level (rather than at the system level) due to limitations in the available data. This implies that the model predicts needs for overall facility renewal or replacement rather than rehabilitation or replacement of individual systems. TERM deterioration models for administrative, maintenance and station facilities were used for the analysis.

Table 13 summarizes the models inputs for each facility type, including the replacement cost and assumed replacement age. Model inputs were determined as follows:

- Default TERM decay curves were used, and survival ages were calculated based on the TERM curves.
- The replacement cost is an average of the facility acquisition and rehabilitation costs reported by RTD. Note that for the prioritization model, actual costs per facility were used rather than these averages.
- To determine the annual maintenance cost, the costs of facilities-related projects in the SBP were summed. These totaled approximately $48 million, or $8 million per year (this greater than the $2.4 million reported for 2012). The $8 million figure was divided by the inflation adjusted total replacement cost of $397 million to obtain an average maintenance cost of 2% used for all facility types.
- For stations the failure cost as a percentage of replacement cost was set to 150% for agency and user costs, which the default value from the original TCRP tools. For administrative and maintenance facilities the agency failure cost was set to 200% of the replacement cost and not user cost was modeled.

Table 13. Facility Model Data

Type	TERM Model	Median Survival Life (years)	Replacement Cost (average)
Administrative	21100	89	6,417,762
Maintenance	21210	48	46,409,622
Stations	42201	44	23,319,669

Table 14 summarizes the results of the model results. The average annual costs range from \$459,000 to \$2,227,000 per facility. Optimal replacement ages range from 40 years for stations to 81 years for administrative buildings. Figure 5 shows the predicted condition as a function of age on the 5-point TERM condition scale for the different facility types.

Table 14. Facility Model Results

Type	Optimal Replacement Age (years)	Average Annual Cost (000)
Administrative	81	459
Maintenance	51	3,913
Stations	40	2,227

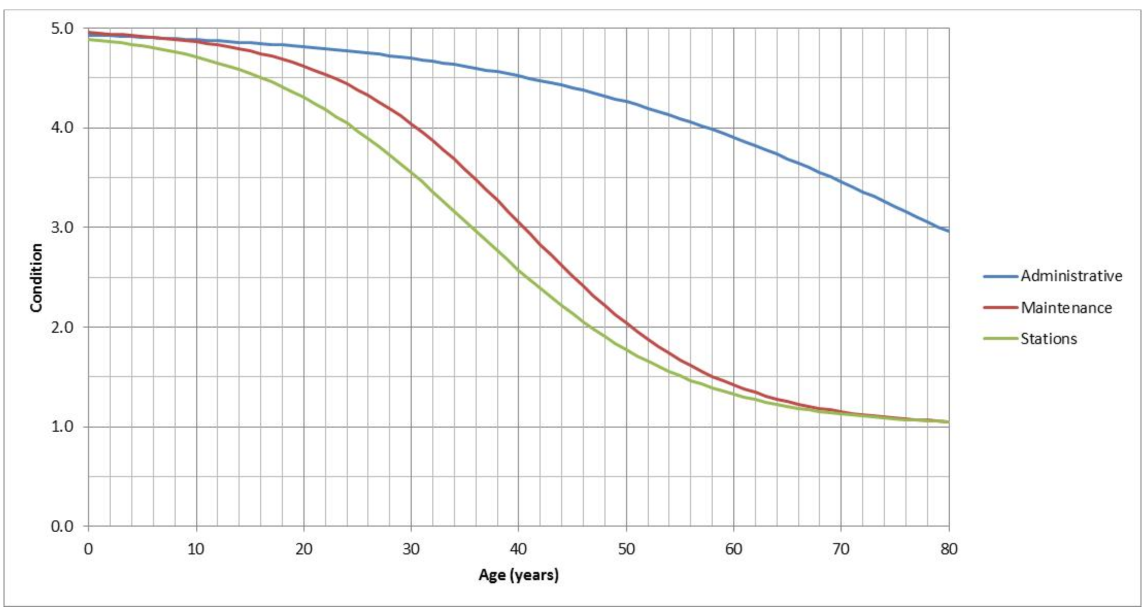

Figure 5. TERM Decay Curves by Facility Type

Prioritization Results

The asset models described in the previous section are used as inputs to the prioritization model. This model simulates what work will occur given a set of potential projects and a specified budget by year. Projects are prioritized with the objective of minimizing overall transit agency and user lifecycle costs, accounting for any adjustments to the priorities made by the user (e.g., to adjust for factors not considered in the models). To use the prioritization model it is necessary to specify an annual budget by year for a 20-year period, and a cutoff value for prioritization index (PI).

When an asset is replaced at its cost-minimizing point the PI has a value of 0 (it then increases as replacement is deferred) so the default value is 0 for the PI cutoff. However, one may specify a lower value if replacement is assumed to have additional benefits not factored into the asset-level models. A PI cutoff of 0 was used for the analysis, so that a project was considered needed only when the replacement age of the asset had exceeded that calculated in the asset model.

Given the vehicle data were predominantly from 2011, the analysis was run for the period from 2012 to 2031, with funds allocated beginning in 2014. Table 15 lists the highest priority projects based on the analysis. The table shows the project ID listed in the prioritization model, a brief description, the project cost (in thousands), rank of the project if performed in 2014, and rank of the project if all work were deferred until 2023. A value of "N/A" for the rank indicates the project is not recommended in 2014. The changes in ranking from 2014 to 2023 reflect the relative criticality of different types of work. For instance, work on the embedded guideway and grade crossings of the Central Corridor are highly ranked projects, and will continue to be highly ranked if they are deferred. However, other track and guideway work is projected to become more critical over time (relative to work on vehicles and facilities) and thus tends to increase in the rank if deferred.

Table 15. Project Rankings for High Priority Projects

ID	Description	Cost ($ 000)	Rank	
			2014	2023
Guideway-XC 1	Guideway - Grade Crossings – Central	306	1	1
Guideway-Embedded 1	Guideway – Embedded – Central	37,797	2	2
Guideway-Embedded 2	Guideway – Embedded – SW	2,700	3	3
Track-XC Int 1	Track – Grade Crossing – Intensive Use – Central	160	4	6
Track-Embedded Int 1	Track – Embedded – Intensive Use – Central	631	5	7
Track-Special Int 1	Track – Special Trackwork – Intensive Use – Central	5,928	6	9
Guideway-XC 2	Guideway – Grade Crossing – CPV	600	7	4
Guideway-Embedded 3	Guideway – Embedded – CPV	5,267	8	5

ID	Description	Cost ($ 000)	Rank	
			2014	2023
Track-Curved Ballasted Int 1	Track – Curved Ballasted – Intensive Use - Central	6,656	9	10
Bus-IC 1	1998 MCI 102DL3	37,654	10	12
Track-Embedded 1	Track – Embedded - Central	19,104	11	16
Guideway-Embedded 4	Guideway – Embedded - SE	2,371	N/A	8
Bus-Mall 2	2001 TRANSTEQ Mall Shuttle	5,760	N/A	11
Bus-Transit 1	2000 ORION V Coach Transit	76,416	N/A	13
Bus-Mall 1	2000 TRANSTEQ Mall Shuttle	6,912	N/A	14
Bus-Mall 3	2002 TRANSTEQ Mall Shuttle	1,152	N/A	15
Bus-Artic 1	2000 NABI 436.09	74,812	N/A	17
Track-Tangent Ballasted Int 1	Track – Ballasted – Intensive Use – Central	990	N/A	18
Bus-Transit 2	2005 Gilig (G21D102N4)	16,128	N/A	19
Track-Special 1	Track – Special Trackwork – Central	2,175	N/A	20
Bus-Transit 4	2006 Gilig (G21D102N4)	2,688	N/A	21
Track-Curved Ballasted 1	Track – Curved Ballasted – Central	7,176	N/A	22
Track-Embedded 2	Track – Embedded – SW	1,410	N/A	23
Track-Yard 1	Track – Yard – Central	1,097	N/A	24
Bus-IC 2	2001 NEOPLAN AN3453	47,770	N/A	25
Bus-Transit 3	2006 Gilig Hybrid (19D102N4)	1,536	N/A	26
Bus-Transit 5	2008 Gilig (G27D102N4)	2,304	N/A	26
Track-XC 1	Track – Grade Crossing – Central	313	N/A	28
Track-Embedded 3	Track – Embedded – CPV	2,750	N/A	29
Fac-Stations 1	Boulder Transit	2,569	N/A	30
Fac-Stations 2	Civic Center	53,937	N/A	31
Track-Special 2	Track – Special Trackwork – SW	10,429	N/A	32
Bus-Transit 6	2008 Gilig Hybrid (G30D102N4)	1,920	N/A	33

Three different funding scenarios were evaluated as part of the pilot. These include:

- Scenario 1: Do Nothing
- Scenario 2: $25 Million Annually
- Scenario 3: Fund All Needs

Table 12 summarizes the initial conditions (as of 2014) and results predicted in 2023 for each of the scenarios. Results are shown for the following measures:

- Unmet needs: cost of performing all replacement work needed at the end of the period.
- Cumulative spent on replacement work through the end of the period.

- Mean Distance Between Failures (MDBF)for vehicles in miles
- Average TERM condition for non-vehicle assets
- Passenger delay from roadcalls/failures in hours
- C02 emissions from operations and new assets in tons. These have been specified for vehicles only.
- Other Agency Costs, including costs of maintenance, vehicle rehabilitation, energy and any unplanned work resulting for asset failures.
- Total Agency and User Costs, including the other agency costs described above delay costs, emissions costs, and any other external costs (but not including capital expenditures).

Note that all costs are in constant dollars, and the projections do not account for future increases in ridership. As indicated in the table, under Scenarios 1 and 2, average conditions worsen, resulting in increased needs and costs. In Scenario 3, more money is spent on asset replacement ($439 million cumulatively versus $209 million in Scenario 2 and $0 in Scenario 1), but this results in better conditions and lower agency and user costs.

Table 16. Scenario Summary

Scenario	Initial Value (2014)	Value in 2023		
		1-Do Nothing	2-$25M Annually	3-Unconstrained
Unmet Needs ($ 000)	116,803	439,419	233,004	0
Cumulative Spent ($ 000)	N/A	0	209,415	439,419
MDBF (miles)	35,649	20,407	33,033	39,791
Average TERM Condition (non-vehicle assets)	4.68	4.39	4.54	4.62
Passenger Delay (hrs)	113,682	170,399	150,781	146,801
C02 Emissions (tons)	248,160	294,722	278,009	271,134
Other Agency Costs ($ 000)	196,292	278,332	219,534	197,762
Total Agency and User and External Costs ($ 000)	207,750	293,654	233,504	211,374

Figures 6 and 7 show additional information on two key measures. Figure 6 shows how MDBF is expected to vary over time for the three scenarios. Figure 7 shows the predicted average TERM rating (for non-vehicle assets) for the three scenarios. Figure 8 shows the distribution of funding between different asset types for Scenario 2, and Figure 9 shows this information for Scenario 3. In these figures the funding by category is shown in millions. As illustrated in the figures, in both scenarios the bulk of the funding is spent on vehicle replacements, with most other funds spent on guideway and track. The reduced funding in Scenario 2 relative to Scenario 3 results primarily in deferral of replacement of facilities and articulated buses.

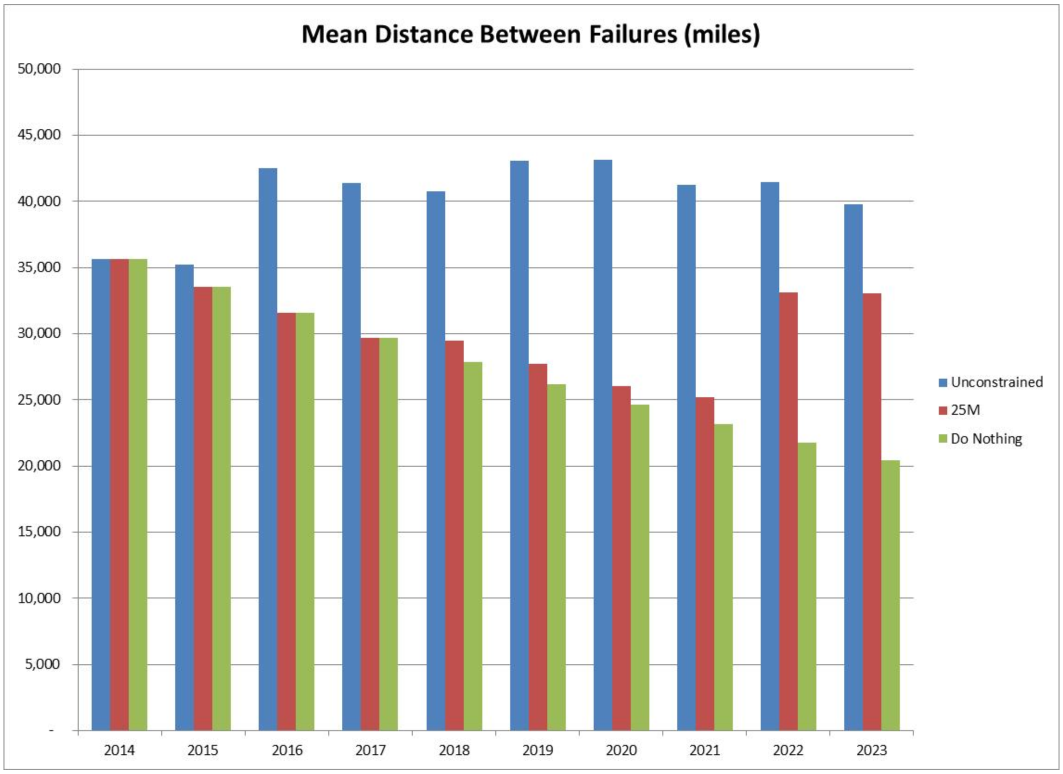

Figure 6. Predicted MDBF by Scenario

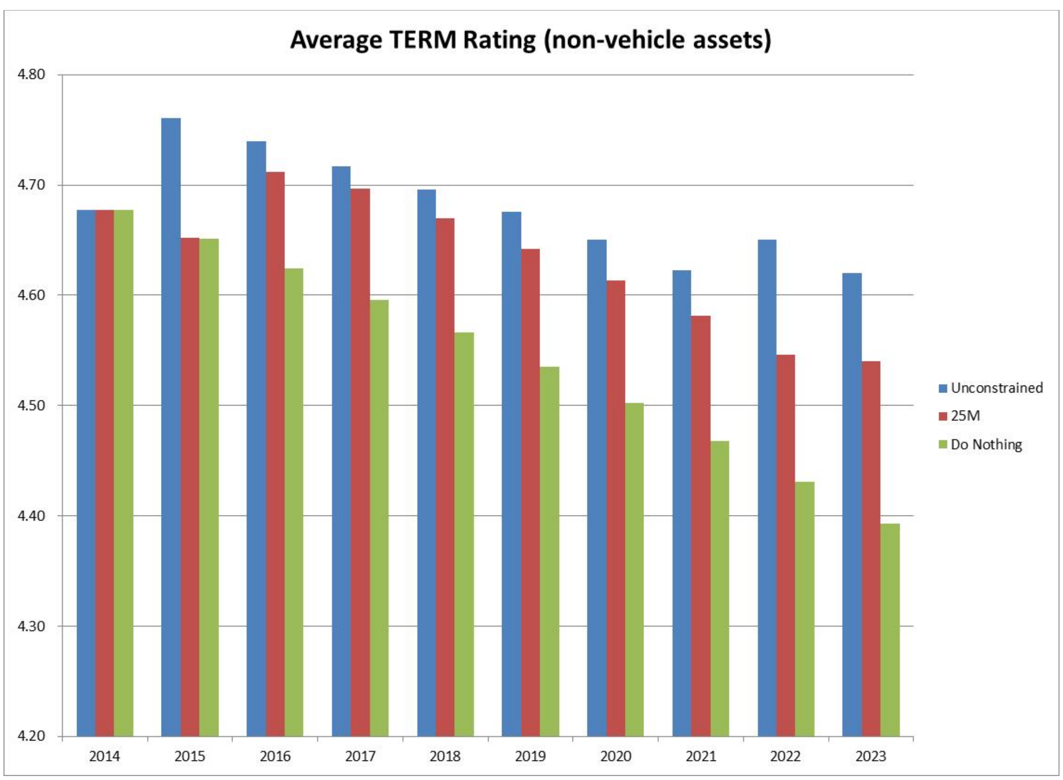

Figure 7. Predicted Average TERM Rating by Scenario

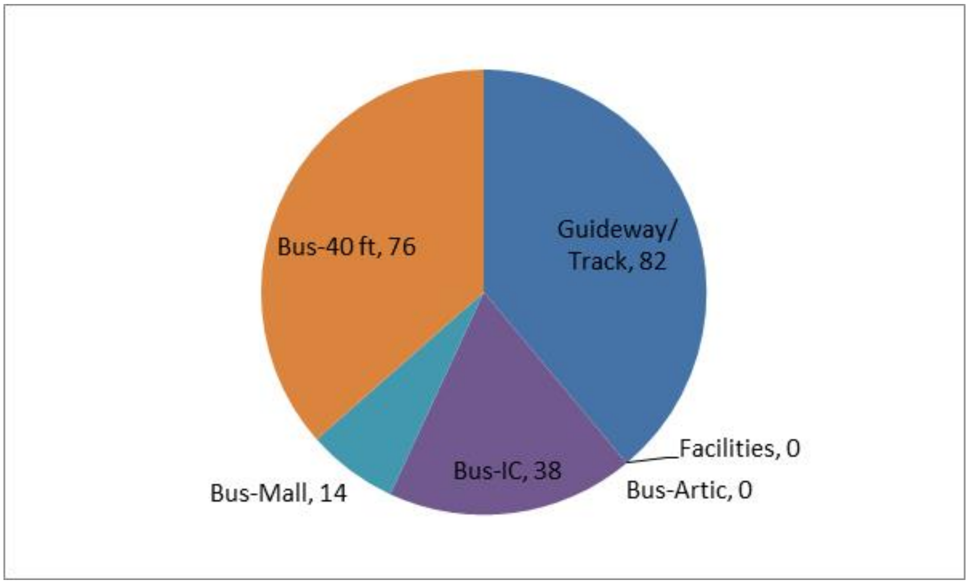

Figure 8. Distribution of Funding by Asset Type, Scenario 2

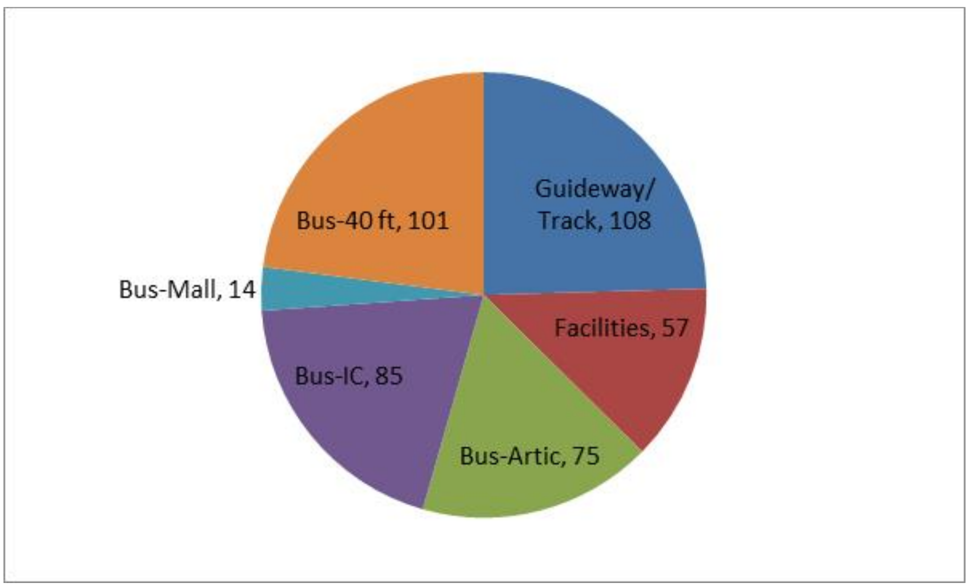

Figure 9. Distribution of Funding by Asset Type, Scenario 3

TERM Lite Results

As an additional step the research team obtained data from FTA on what assets FTA models for RTD when running TERM Lite, and used this data to run TERM Lite for the same scenarios as those analyzed in TAPT. For this analysis TERM Lite was used with default values for all parameters. The start year of the analysis was set to 2012, and the analysis was run with $0 budget in the first program year (2013). Thus, expenditure of funds was modeled to occur beginning in 2014, as in TAPT.

Note that TERM Lite models all of Denver RTD's assets, not just those included in the pilot, and models rehabilitation as a capital cost. Thus, one would expect TERM Lite to predict somewhat higher needs. Specifically, the replacement value of the assets in TERM Lite is $3.7 billion, versus $2.9 in TAPT. Table 17 summarizes the results of the analysis in TERM Lite. The table shows the initial value (in 2014) and results in 2023 for the three scenarios. Measures shown in the table include:

- Unmet needs: cost of performing all replacement work needed at the end of the period.
- Cumulative spent on rehabilitation/replacement work through the end of the period.
- Percent of assets exceeding their useful life (shown for 2024).
- Percent of assets in marginal or poor condition (2 or less on the 5-point TERM rating scale, shown for 2024).

Table 17. TERM Lite Scenario Summary

Scenario	Initial Value (2014)	Value in 2023		
		1-Do Nothing	2-$25M Annually	3-Uncon-strained
Unmet Needs ($ 000)	761,500	1,513,800	1,281,900	0
Cumulative Spent ($ 000)	N/A	0	250,000	1,775,200
Percent of Assets Exceeding Useful Life	4.6%	28.4%	22.0%	0.0%
Percent of Assets in Marginal or Poor Condition	18.6%	37.2%	31.0%	22.7%

As indicated in the table, TERM Lite predicts an initial backlog for RTD of approximately $762 million. This backlog is projected to double if work is deferred for 10 years, or increase 68% to $1.28 billion if the annual budget is $25 million. By comparison, TAPT predicts a much lower initial backlog ($117 million) and greater percentage increases in the backlog over time.

Figures 10 and 11 show the distribution of funding by asset type for Scenarios 2 and 3(with actual values shown in millions). Comparing the TERM results with TAPT, for Scenario 2 TERM allocates somewhat less money than TAPT to vehicles and facilities, and budgets approximately $72 million for stations and facilities. In Scenario 3 spending on guideway and track is comparable between the two tools, but TERM spending projections in the unconstrained case are significantly higher in other categories.

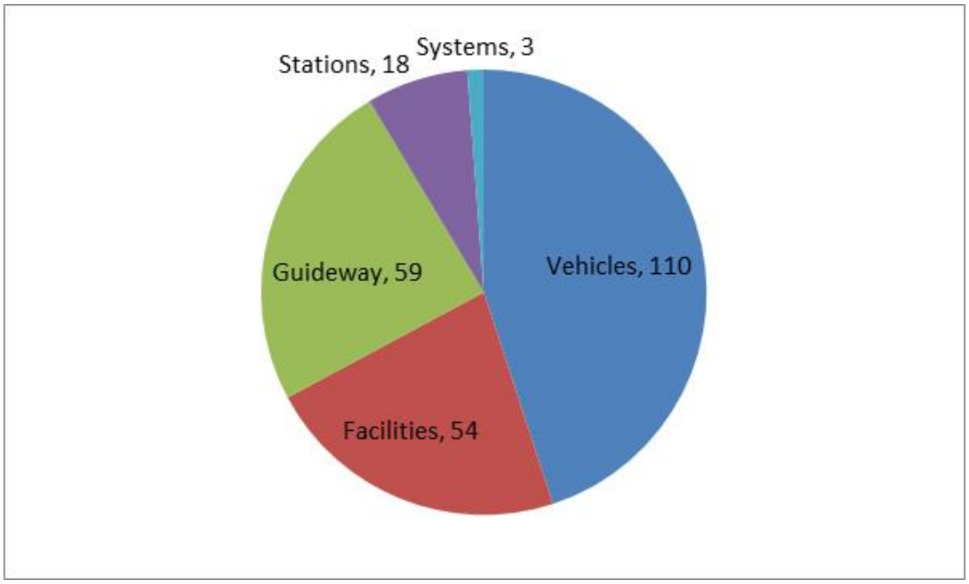

Figure 10. Distribution of Funding by Asset Type, TERM Lite Scenario 2

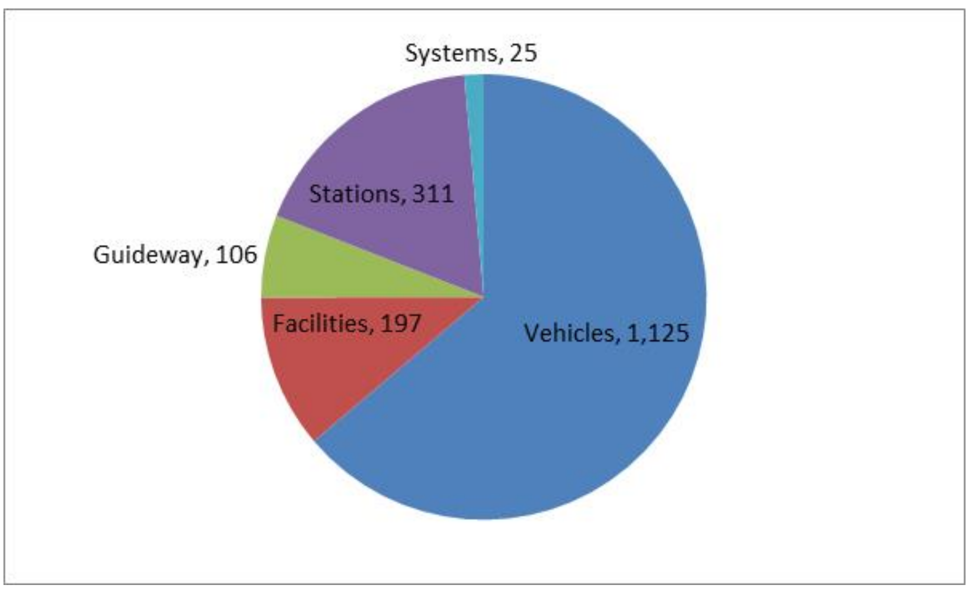

Figure 11. Distribution of Funding by Asset Type, TERM Lite Scenario 3

Discussion

The analysis results presented here reflect a number of changes relative to the draft version provided previously. Major revisions include:

- The revised TAPT has been used for the analysis rather than the original TCRP tools. TAPT is an integrated version of the TCRP tools, predicts a number of additional performance measures, and incorporates several enhancements made as a result of the experience gained from the pilots. The interim report on the project details enhancements in TAPT.
- The vehicle models now predict CO2 emissions, and the cost of emissions is incorporated in the calculation of lifecycle costs.
- The model for mall buses was revised to include a revised value for road calls, based on EAM rather than NTD data.
- The LRV model was revised, and separate models were developed for SD100s and SD160s. The revised LRV models accounts for the annual increase in failures reported in the EAM, and accounts for the fact that annual mileage has recently increased due to system expansion.
- The TERM Lite analysis was added to the pilot.

The pilot was instructive for illustrating the use of the TCRP models, and helping guide enhancements to the modeling approach incorporated in TAPT. However, a number of further enhancements may be considered for the future, either as a next step in the TCRP Project E-09A research, or as a future effort. These include:

- Evaluating the potential for modeling vehicles, at a component level, distinguishing between the vehicle body, engine/propulsion system, and other major systems.
- Working with Denver RTD further to evaluate how well the priorities recommended by TAPT match transit agency experience, and evaluating how consideration of other factors outside the scope of TAPT, such as risk and asset criticality, impact transit agency priorities.
- Further analyzing the differences between TERM and TAPT projections to better characterize the degree to which these result from differences in inventory data versus modeling approaches.

spy pond partners, llc

Memorandum

To: Jerry Rutledge, King County Metro
From: Bill Robert, Spy Pond Partners
Date: July 10, 2013
Re: King County SGR Pilot Results

This memorandum summarizes the results of the State of Good Repair (SGR) pilot performed for King County Metro for Transit Cooperative Research Program (TCRP) Project E-09A. The following sections describe the scope of the pilot, data used for the pilot, the asset inventory that was included, asset-specific models, and results. The final section of the memorandum discusses revisions to the analysis made since the draft, and potential future enhancements.

Pilot Scope

The basic goal of the TCRP Project E-09A pilot program is to test the SGR framework and supporting tools developed previously through TCRP Project E-09. The framework and tools are intended to help agencies quantify the impacts of investing in rehabilitation and replacement of existing transit capital assets, and to help prioritize SGR investments. These tools help support the following tasks:

- Quantifying a transit agency's asset inventory.
- Developing models for each individual asset type. These models predict the life cycle costs of the asset, compute a variety of performance measures, and recommend when to rehabilitate or replace the asset.
- Prioritizing asset rehabilitation/replacement given details on the asset inventory, the asset type models, and an assumed budget.
- Predicting the conditions and performance that will result from a given set of asset replacement projects.

The interim report on the project provides additional information on the SGR framework. Also, the report details use of the SGR tools, now integrated into a single spreadsheet called the Transit Asset Prioritization Tool (TAPT), and describes the measures calculated by the tool.

Three agencies are participating in the pilots: King County, Denver Regional Transportation District (RTD) and the Southeastern Pennsylvania Transportation Authority (SEPTA). For each of the agencies the research team is conducting the following activities, at a minimum:

- Developing asset rehabilitation/replacement models using TAPT for as many asset types as possible, with the exact set of assets addressed based on available data.
- Determining how SGR investments should be prioritized based on the models, and comparing this to any data or insights on how each transit agency currently prioritizes.
- Defining investment scenarios to illustrate the impacts over time of alternative investment levels.

Additional activities are being performed as part of the pilots, pending available data and staff time, such as calibrating deterioration models, predicting additional performance measures, and comparing results to those generated using TERM Lite.

In the case of King County, the pilot is addressing King County's vehicles and selected facility assets. For vehicles, three types are included: motorbuses (include articulated and 40 ft buses), bus rapid transit, and trolley buses. For facilities we are specifically focusing on four representative facility types: roofs; fire detection/protection systems; fuel management systems (FMS); and heating, ventilation and air conditioning (HVAC) systems.

Data Received

This section describes data received from King County to support the pilot. Basic data used for the pilot for vehicles are from King County's 2011 National Transit Database (NTD) submittal. Table 1 lists additional materials provided by King County or obtained from King County's web site. All materials were provided electronically.

Table 1. Pilot Data Provided by King County

Category	Document	Notes
Enterprise Asset Management (EAM) System Data	EAM Class and Category.xls	Extract from the EAM of equipment class, category and description
	Systems FIRESYS.xls	List of fire protection systems
	Systems FMS.xls	List of FMS
	Systems HVAC.xls	List of HVAC systems
Facilities Condition Report (FCR) Data	Transit Facilities Condition Report 2007-2014.pdf	Most recent FCR
	Asset Condition Rating.xls	Asset and pavement condition rating criteria used in the FCR
	DisciplineSystems.xls	List of facility systems from the FCR
	TAMPAssessmentWorksheet_JointDiscipline(wCRelectinput).xls	Asset data from the FCR, including inventory and condition data for structural, mechanical and electrical systems.
	TAMPWorkplan_CivilTab.xls	
	TAMPWorkplan_StructuralTab.xls	

Category	Document	Notes
Other Data	FTA 9 24 09.xls	Facilities data reported to FTA in 2009.
	King County Trolley Bus Evaluation	Obtained from http://metro.kingcounty.gov/up/projects/pdf/Metro_TB_20110527_Final_LowRes.pdf

Existing Assets

A basic step in performing the pilot analysis was to quantify the asset inventory. Table 2 lists the bus inventory, grouping buses by subfleet. This table shows the type of bus, an ID for each subfleet, a subfleet description, the number of vehicles in the subfleet, age of the subfleet (in years as of 2012), and average accumulated mileage per vehicle. 2011 NTD data were used to establish the inventory. The NTD includes data for three bus modes: motorbus; bus rapid transit (the RapidRide routes) and electric trolley bus. Each of these is further divided into subfleets, with each bus in a subfleet purchased from the same manufacturer in the same year.

Table 2. Bus Inventory

Type	ID	Description	#	Age (years)	Avg. Accum. Mileage
Motorbus	BUS01	1999 New Flyer D60HF (Articulated)	258	13	399,134
	BUS02	2004 New Flyer DE60LF (Articulated)	212	8	273,046
	BUS03	2004 New Flyer D60LF (Articulated)	30	8	252,404
	BUS04	2011 New Flyer DE60LFR (Articulated)	68	1	12,310
	BUS05	2008 New Flyer DE60LF (Articulated)	22	4	175,692
	BUS06	2009 New Flyer DE60LF (Articulated)	16	3	41,166
	BUS07	2010 New Flyer DE60LF (Articulated)	15	2	46,414
	BUS08	1999 Gillig C18A096N4	94	13	507,832
	BUS09	1998 Gillig C21D102N4	23	14	568,322
	BUS11	1996 Gillig M11T40102	267	16	518,760
	BUS12	1997 Gillig M11T35102	11	15	26,733
	BUS13	2003 New Flyer D40LF	100	8	291,253
	BUS14	2010 Starcraft PresidentLF	35	2	14,443
	BUS15	2011 Diamond Coach OrionVII	87	1	9,019

Type	ID	Description	#	Age (years)	Avg. Accum. Mileage
Bus Rapid Transit	RT1	2011 New Flyer DE60LFA	16	1	9,738
	RT2	2010 New Flyer DE60LFA	20	2	55,633
Trolleybus	TB1	2002 Gillig Trolley	100	10	178,846
	TB2	1991 Breda ADPB350	58	22	267,944

Table 3 lists the facilities inventory. For each of the three types of facilities modeled the table lists the facility type, ID used in the prioritization tool, a description, the asset age as of 2012 (or condition, in the case of roofs), and extent. For roofs conditions are specified using a 5 point scale ranging from 1-Poor to 5-Excellent. For fire detection, HVAC and roofs the extent specified is the roof area of the facility in square feet. For FMS the extent is the fuel tank capacity in gallons. The set of assets and their ages are based on the available EAM data. Information from the FCR was used to determine asset extent.

Table 3. Facilities Inventory

Type	ID	Description	Age (years) or Condition	Extent
Fire Detection	FIRE01	Atlantic Base	1	9,913
	FIRE02	Central Base	21	71,751
	FIRE03	Bellevue Base	28	23,368
	FIRE04	Burien	1	42
	FIRE05	East Base	16	74,576
	FIRE06	Exchange	3	1,000
	FIRE07	Issaquah	3	1,000
	FIRE08	North Base	5	78,666
	FIRE09	North Facilities	2	19,925
	FIRE10	Power Distribution	13	18,984
	FIRE11	Ryerson Base	3	45,425
	FIRE12	South Facilities	25	58,732
	FIRE13	South Base	32	152,740
	FIRE14	Van Distribution Center	15	13,793
	FIRE15	Radio Sites	2	6,000
	FIRE16	TRCC-FS	6	1,000
FMS	FUEL01	Atlantic Base Fuel & Wash Building	17	30,000
	FUEL02	Atlantic Base Vehicle Maintenance Building	17	2,000
	FUEL03	Bellevue Base Fuel Building	15	42,000
	FUEL04	Central Base Fuel Building	23	15,000
	FUEL05	Central Base Vehicle Maintenance Building	23	38,000
	FUEL06	South Base Component Supply Center	18	20,000
	FUEL07	Non-Revenue Vehicle Building	23	8,000
	FUEL08	East Base Fuel & Wash Building	21	80,000
	FUEL09	North Base	23	550
	FUEL10	North Base Vehicle Maintenance	23	73,500

Type	ID	Description	Age (years) or Condition	Extent
		Building		
	FUEL11	Power Distribution Headquarters	7	7,000
	FUEL12	Ryerson Base Fuel Building	15	36,000
	FUEL13	Ryerson Base Vehicle Maintenance Building	15	2,000
	FUEL14	South Base	23	2,000
	FUEL15	South Base Fuel & Wash Building	18	62,000
	FUEL16	South Base Vehicle Maintenance Building	18	24,000
	FUEL017	South Facilities Maintenance	15	6,000
HVAC	HVAC01	Atlantic Base Fuel & Wash Building	32	9,913
	HVAC02	Atlantic Base Tire Shop	1	1,000
	HVAC03	Atlantic Base Vehicle Maintenance Building	11	51,520
	HVAC04	Atlantic/Central Base Operations Building	1	9,298
	HVAC05	Bellevue Base Fuel Building	3	3,660
	HVAC06	Bellevue Base Operations & Vehicle Maintenance Building	28	15,947
	HVAC07	Bellevue Base Wash Building	25	3,761
	HVAC08	Burien Transit Center/Park & Ride	1	42
	HVAC09	Central Operations Building	3	9,298
	HVAC10	Central Base Bus Wash	1	3,600
	HVAC11	Central Base Fuel Building	21	4,208
	HVAC12	Central Base Revenue Processing	3	6,150
	HVAC13	Central Base Vehicle Maintenance Building	1	33,275
	HVAC14	Central Base Communications & Control Center	1	13,900
	HVAC15	South Base Component Supply Center	8	88,651
	HVAC16	Central Marketing Distribution Building	3	7,160
	HVAC17	Central Non-Revenue Vehicle Building	21	5,312
	HVAC18	East Base Fuel & Wash Building	3	9,742
	HVAC19	East Base Operations Building	3	9,125
	HVAC20	Eastgate Parking Garage	1	1,000
	HVAC21	East Base Vehicle Maintenance Building	22	54,709
	HVAC22	Issaquah Highlands Parking Garage	1	1,000
	HVAC23	North Base Garage Lid	23	126
	HVAC24	North Base Trailer	21	1,000
	HVAC25	North Base Operations Building	21	28,443
	HVAC26	North Base Vehicle Maintenance Building	21	39,612
	HVAC27	North Facilities	2	19,925
	HVAC28	Power Distribution Headquarters	9	12,504
	HVAC29	Ryerson Base Fuel Building	25	5,365
	HVAC30	Ryerson Base Operations Building	2	16,410

Type	ID	Description	Age (years) or Condition	Extent
	HVAC31	Ryerson Base Vehicle Maintenance Building	2	18,530
	HVAC32	Ryerson Base Wash Building	25	4,800
	HVAC33	South Facilities Safety & Training Facility	25	13,914
	HVAC34	Facilities Maintenance South	25	41,413
	HVAC35	South Base Fuel & Wash Building	32	9,700
	HVAC36	South Base Operations Building	32	9,125
	HVAC37	South Base Vehicle Maintenance Building	14	45,264
	HVAC38	South Facilities Warehouse	3	6,224
	HVAC39	South Facilities Construction Trailer at South Facilities	3	2,405
	HVAC40	Van Distribution Center	15	13,793
	HVAC41	TPAF	3	1,000
Roof	ROOF01	Atlantic Base Farebox	2	150
	ROOF02	Atlantic Base Fuel & Wash Bldng	2	9,913
	ROOF03	Atlantic Base Hostler Shack	1	329
	ROOF04	Atlantic Base Vehicle Maintenance Bldng	2	51,520
	ROOF05	Atlantic/Central Base Operations Bldng	2	9,298
	ROOF06	Bellvue Base Fuel Bldng	5	3,660
	ROOF07	Bellvue Base Operations & Vehicle Maintenance Bldngs	4	15,947
	ROOF08	Bellvue Base Wash Building	5	3,761
	ROOF09	Bellvue Transit Center	4	50
	ROOF10	Burlen Transit Center/Park & Ride	4	42
	ROOF11	Central Base Bus Wash	2	3,600
	ROOF12	Central Base Fuel Bldng	3	3,757
	ROOF13	Central Base Fuel Bldng - Canopy	3	451
	ROOF14	Central Base Hostler Shack	2	320
	ROOF15	Central Base Revenue Processing	5	6,150
	ROOF16	Central Base Vehicle Maintenance Bldng	2	33,275
	ROOF17	Communications & Control Center	5	13,900
	ROOF18	Component Supply Center	1	88,651
	ROOF19	Component Supply Center - Hazmat Shed	1	1,645
	ROOF20	Construction Trailer at South Facilities	1	2,405
	ROOF21	East Base Fuel & Wash Bldng	2	9,742
	ROOF22	East Base Hostler Shack	3	320
	ROOF23	East Base Operations Bldng	3	9,125
	ROOF24	East Base Storage Shed	3	1,298
	ROOF25	East Base Vehicle Maintenance Bldng	3	54,709
	ROOF26	Educted Solids Area	5	2,460
	ROOF27	Facilities Maintenance South	5	41,413

Type	ID	Description	Age (years) or Condition	Extent
	ROOF28	Madrona DC Substation [04]	4	1,375
	ROOF29	Marketing Distribution Bldng	2	7,160
	ROOF30	Non-Revenue Vehicle Bldng	2	5,312
	ROOF31	North Base Garage Lid	1	126
	ROOF32	North Base Hostler Shack	2	320
	ROOF33	North Base Lid	1	152,787
	ROOF34	North Base Operations Bldng	1	28,443
	ROOF35	North Base Vehicle Maintenance Bldng	2	39,612
	ROOF36	North Facilities	1	19,925
	ROOF37	Northgate Park & Ride (5th Ave)	4	2,003
	ROOF38	Northgate Transit Center/Park & Ride	3	5,400
	ROOF39	Power Distribution Headquarters	5	19,345
	ROOF40	Ryerson Base Fuel Bldng	1	5,365
	ROOF41	Ryerson Base Hostler Shack	5	320
	ROOF42	Ryerson Base Operations Building	2	16,410
	ROOF43	Ryerson Base Vehicle Maintenance Bldng	2	18,530
	ROOF44	Ryerson Base Wash Building	1	4,800
	ROOF45	Safety & Training Facility	5	13,914
	ROOF46	South Base Fuel & Wash Bldng	3	9,700
	ROOF47	South Base Hostler Shack	2	320
	ROOF48	South Base Operations Bldng	5	9,125
	ROOF49	South Base Storage Shed	3	1,298
	ROOF50	South Base Vehicle Maintenance Bldng	3	45,264
	ROOF51	South Facilities Flammable Storage	1	150
	ROOF52	South Facilities Warehouse	4	6,224
	ROOF53	Training Bldng #4	4	1,020
	ROOF54	Van Distribution Center	3	13,793
	ROOF55	Westlake Station	3	1,365

Asset Model Development

The following subsections describe the approach used to develop the asset-specific models, including models for buses, fire protection, FMS, HVAC and roofs. For each asset type the research team used the TCRP models, but some amount of effort was involved in populating the model inputs. Once the asset-specific models were developed, these were used to prioritize investments and simulate future conditions, as described in the next section.

Vehicles

For buses, separate models were developed for motorbuses, bus rapid transit and trolley buses using the available NTD data, as well as data from the recent trolley bus evaluation performed by Parametrix and LTK.[1] Table 4 summarizes the data required for the vehicle model and notes the approach used to obtaining the data for the different bus types.

Table 4. Bus Model Inputs

Category	Data Item	Approach Used for Quantifying the Item	Notes
Fleet Description	Number of vehicles by subfleet	2011 NTD data	See Table 1
	Average accumulated mileage per vehicle		
Operating Data	Passenger miles	2011 NTD data	Motorbus values include 40-foot and articulated buses
	Unlinked trips		
	Revenue vehicle miles		
	Revenue vehicle hours		
	Vehicle miles		
	Total road calls		
Cost Data	Vehicle replacement cost	Trolley bus evaluation	Costs for trolley buses include auxiliary power
	Energy cost	Energy unit costs from the trolley bus evaluation, 2011 NTD data on energy consumption	Motorbus values include 40-foot and articulated buses
	Vehicle maintenance cost	2011 NTD data	

Table 5 below details the vehicle model inputs calculated for each bus type. A discount rate of 5% was used for the analysis, consistent with the other pilots. Energy costs were calculated based on energy consumption and the unit costs in the trolley bus evaluation. The replacement costs were based on the trolley bus evaluation. Note the cost for a new trolley bus includes the addition of auxiliary power not available in King County's existing fleet.

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[1] Parametrix and LTK, *King County Trolley Bus Evaluation*, technical report prepared for King County, 2011.

Table 5. Bus Model Data

Parameter	Value by Bus Type		
	Motorbus	Bus Rapid Transit	Trolleybus
Passenger miles (000)	426,832	12,239	37,661
Unlinked trips (000)	87,686	2,901	20,582
Vehicle miles (000)	39,517	1,008	3,050
Revenue vehicle miles (000)	31,204	874	2,907
Revenue vehicle hours (000)	2,537	74	419
Road calls	6,743	109	1,881
Replacement cost	604,468	785,000	1,124,241
Gallons of fuel (000)	10,157	296	0
Energy Consumption in kwh (000)	0	0	17,011
Vehicle maintenance cost (000)	66,898	2,279	10,266
Typical schedule headway (min)	30	15	30
Typical recovery time after a road call (min)	60	30	60

Table 6 summarizes the results of the bus models. For each vehicle type the table shows the optimal replacement mileage, corresponding age, and average annual cost over the lifecycle of the vehicle assuming it is replaced at the optimal point. The average annual cost includes maintenance, rehabilitation and energy costs incurred by the transit agency, as well as user costs, costs from emissions, and the annualized purchase price of the vehicle. As shown in the table, bus replacement is recommended at a mileage of 425 to 606 thousand miles, corresponding to an age of 18 to 22 years. Average annual costs per bus range from $165,000 for motorbuses to $221,000 for bus rapid transit.

Table 6. Bus Model Results

Vehicle Type	Optimal Replacement Mileage (000)	Optimal Replacement Age (years)	Average Annual Cost (000)
Motorbus	606	19	165
Bus Rapid Transit	504	18	221
Trolleybus	425	22	220

Besides predicting the optimal replacement/renewal mileage and average annual lifecycle cost, the vehicle model also predicts a number of other measures, such as mean distance between failures (MDBF), user costs, and a prioritization index which is used to determine how vehicle replacement should be prioritizing relative to replacement of other assets.

Figure 1 shows predicted MDBF by age for each vehicle type. The next section shows results for this and other measures for different investment scenarios.

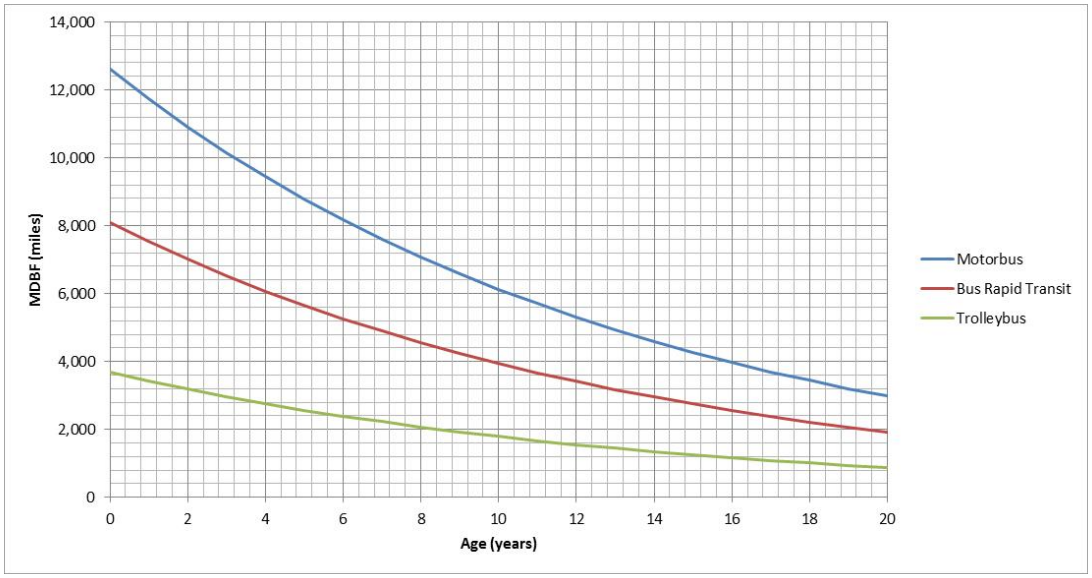


Figure 1. MDBF by Vehicle Type

Facilities

For the pilot the TCRP age-based model was used for the three facility asset types: fire protection, FMS, and HVAC. The TCRP condition-based model was used for roofs, given King County has condition data on this asset type. Both types of models require on the deterioration rate of an asset (with TERM deterioration curves available as a default), in addition to basic information on asset costs. Table 7 summarizes the model inputs by asset type, as well as the model results. The following approach was used to developing these models:

- For fire protection, FMS and HVAC, the TERM deterioration rates were reviewed, but appeared too slow (predicted too little deterioration) based on the data in the FCR and supporting spreadsheets. Alternative deterioration models were developed by estimating the percentage of assets expected to fail by a given age. These estimates are summarized in the table. They were developed through review of the data in the FCR; if the FCR reported that assets of a given type or age were in poor condition and/or recommended for replacement in the near term, this was used as an indication that asset failure was more likely. Note that in the context of this analysis, the type of failure being modeled is not necessarily the catastrophic failure of an asset, but instead a case where the asset reaches a state where rehabilitation or replacement must be performed regardless of whether or not such an action was planned.
- For roofs King County has established definitions for each condition rating. Specifically: a condition of 1 indicates the asset needs action this year; 2 indicates in needs action in 2-4 years; 3 indicates it needs action in 5-7 years; 4 indicates it needs

action in 8-15 years; and 5 indicates it needs action in 15-20 years. The transition probabilities in the condition-based model were set such that the resulting model was consistent with these ranges.

- For fire protection, HVAC and roofs replacement unit costs (dollars per square foot of roof area) were determined by averaging project costs in the FCR, adjusting for inflation. Using this approach, the unit cost for rehabilitation or replacement of fire protection was estimated to be $2.44 per square foot, the unit cost for HVAC rehabilitation/replacement was estimated to be $200/square foot, and the unit cost for roof rehabilitation/replacement was estimated to be $20.75/square foot.
- For FMS the unit rehabilitation/replacement cost was estimated to be $300,000 for a 30,000 gallon facility based on data in TERM (rounded off and adjusted for inflation). This cost was scaled based on facility size. Thus, the cost for rehabilitation/replacement of FMS was estimated to be $10 per gallon of storage capacity.
- The default for the failure cost (as a percent of replacement cost) is 300%. This means that the price of asset failure is by default three times the cost of replacing an asset in advance of failure. A value of 650% was used for FMS to approximate the criticality of this asset, and the impact of the temporary loss of a fuel management facility, coupled with the environmental damage that could be caused by leaking fuel.

Table 7. Facility Model Inputs

Parameter	Value by Asset Type Fire Protection	FMS	HVAC	Roof
Inputs				
Unit replacement cost	2.44	10.00	200.00	20.75
Failure cost (as a % of the replacement cost)	200%	650%	200%	200%
Decay curve assumptions	50% likely to fail by 20 yrs, 75% likely to fail by 30 yrs	25% likely to fail by 20 years, 75% likely to fail by 30 years		Likelihood of decay in 1 year by condition – 5: 88.1% 4: 79.7% 3: 68.5% 2: 52.3%
Results				
Optimal replacement point	27	15	20	Condition=2
Average annual cost per unit	0.40	1.24	20.50	1.19

As summarized in the table, the optimal rehabilitation/replacement time is 27 years for fire protection, 15 years for FMS, and 20 years for HVAC. For roofs, the optimal time to replace a roof is when it reaches a condition of 2 (marginal), which is predicted to occur at approximately 15-20 years. Figure 2 shows the predicted condition as a function of age on the 5-point TERM condition scale for the different asset types.

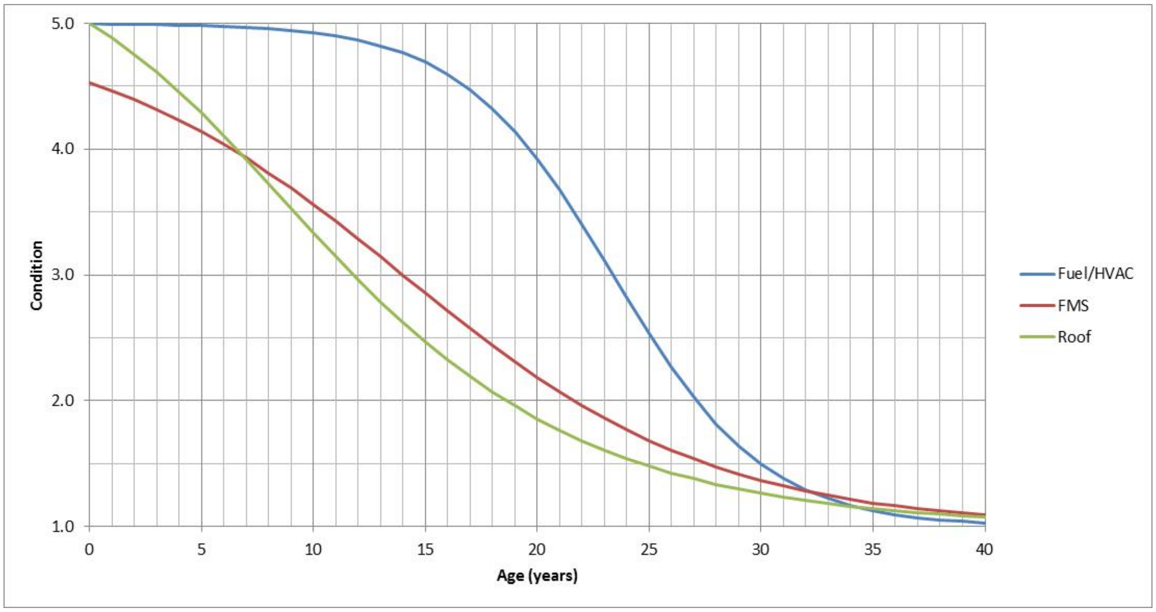


Figure 2. Decay Curves by Asset Type

Prioritization Results

The asset models described in the previous section are used as inputs to the prioritization model. This model simulates what work will occur given a set of potential projects and a specified budget by year. Projects are prioritized with the objective of minimizing overall transit agency and user lifecycle costs, accounting for any adjustments to the priorities made by the user (e.g., to adjust for factors not considered in the models). To use the prioritization model it is necessary to specify an annual budget by year for a 20-year period, and a cutoff value for prioritization index (PI).

When an asset is replaced at its cost-minimizing point the PI has a value of 0 (it then increases as replacement is deferred) so the default value is 0 for the PI cutoff. However, one may specify a lower value if replacement is assumed to have additional benefits not factored into the asset-level models. A PI cutoff of 0 was used for the analysis, so that a project was considered needed only when the replacement age of the asset had exceeded that calculated in the asset model.

Given much of the data used for the analysis were from 2011 or earlier, the analysis was run for the period from 2012 to 2031, with funds allocated beginning in 2014. Table 8 lists the highest priority projects based on the analysis. The table shows the project ID listed in the prioritization model, a brief description, the project cost (in thousands), rank of the project if performed in 2014, and rank of the project if all work were deferred until 2023. The changes in ranking from 2014 to 2023 reflect the relative criticality of different types of work. For instance, in 2014 the highest ranked projects are for roofs, followed by FMS. However, if all work is deferred, FMS increases in criticality relative to work on roofs and other assets

Table 8. Project Rankings for High Priority Projects

ID	Description	Cost ($ 000)	Rank	
			2014	2023
ROOF21	East Base Fuel & Wash Bldng	202	1	13
ROOF01	Atlantic Base Farebox	3	2	18
ROOF02	Atlantic Base Fuel & Wash Bldng	206	2	18
ROOF04	Atlantic Base Vehicle Maintenance Bldng	1,069	2	18
ROOF05	Atlantic/Central Base Operations Bldng	193	2	13
ROOF11	Central Base Bus Wash	75	2	13
ROOF14	Central Base Hostler Shack	7	2	18
ROOF16	Central Base Vehicle Maintenance Bldng	690	2	13
ROOF29	Marketing Distribution Bldng	149	2	13
ROOF30	Non-Revenue Vehicle Bldng	110	2	18
ROOF03	Atlantic Base Hostler Shack	7	11	23
ROOF18	Component Supply Center	1,840	11	25
ROOF19	Component Supply Center - Hazmat Shed	34	11	23
ROOF20	Contruction Trailer at South Facilities	50	11	25
FUEL04	Central Base Fuel Building	150	15	2
FUEL05	Central Base Vehicle Maintenance Building	380	15	2
FUEL07	Non-Revenue Vehicle Building	80	15	2
FUEL09	North Base	6	15	2
FUEL10	North Base Vehicle Maintenance Building	735	15	1
FUEL14	South Base	20	15	2
FUEL08	East Base Fuel & Wash Building	800	21	7
HVAC01	Atlantic Base Fuel & Wash Building	1,983	22	33
HVAC35	South Base Fuel & Wash Building	1,940	23	34
HVAC36	South Base Operations Building	1,825	23	34
FUEL16	South Base Vehicle Maintenance Building	240	25	8
FUEL06	South Base Component Supply Center	200	26	8
FUEL15	South Base Fuel & Wash Building	620	26	8
ROOF23	East Base Operations Bldng	189	28	30
ROOF24	East Base Storage Shed	27	28	27
ROOF25	East Base Vehicle Maintenance Bldng	1,135	28	27
ROOF12	Central Base Fuel Bldng	78	31	30
ROOF13	Central Base Fuel Bldng - Canopy	9	31	27

ID	Description	Cost ($ 000)	Rank	
			2014	2023
ROOF22	East Base Hostler Shack	7	31	30
HVAC06	Bellevue Base Operations & Vehicle Maintenance Building	3,189	34	40
FUEL01	Atlantic Base Fuel & Wash	300	35	11
FUEL02	Atlantic Base Vehicle Maintenance	20	35	12
HVAC29	Ryerson Base Fuel Building	1,073	37	46
HVAC07	Bellevue Base Wash Building	752	38	45
HVAC32	Ryerson Base Wash Building	960	39	47
HVAC33	South Facilities Safety & Training Facility	2,783	39	48

Three different funding scenarios were evaluated as part of the pilot. These include:

- Scenario 1: Do Nothing
- Scenario 2: $35 Million Annually
- Scenario 3: Unconstrained (Fund All Needs)

Table 9 summarizes the initial conditions (as of 2014) and results predicted in 2023 for each of the scenarios. Results are shown for the following measures:

- Unmet needs: cost of performing all replacement work needed at the end of the period.
- Cumulative spent on replacement work through the end of the period.
- Mean Distance Between Failures (MDBF)for vehicles in miles
- Average TERM condition for non-vehicle assets
- Passenger delay from roadcalls/failures in hours
- CO2 emissions from operations and new assets in tons. These have been specified for vehicles only.
- Other Agency Costs, including costs of maintenance, vehicle rehabilitation, energy and any unplanned work resulting for asset failures.
- Total Agency and User Costs, including the other agency costs described above delay costs, emissions costs, and any other external costs (but not including capital expenditures).

Note that all costs are in constant dollars, and the projections do not account for future increases in ridership. As indicated in the table, under Scenarios 1 and 2, average conditions tend to worsen, resulting in increased needs and costs, though average facility condition improves sin Scenario 2. In Scenario 3, more money is spent on asset rehabilitation/replacement ($802 million cumulatively versus $329 million in Scenario 2 and $0 in Scenario 1), but this results in better conditions and lower agency and user costs.

Table 9. Scenario Summary

Scenario	Initial Value (2014)	Value in 2023		
		1-Do Nothing	2-$35M Annually	3-Unconstrained
Unmet Needs ($ 000)	309,231	801,867	472,799	0
Cumulative Spent ($ 000)	N/A	0	329,068	801,867
MDBF (miles)	3,770	1,970	2,159	4,971
Average TERM Condition (non-vehicle assets)	3.37	2.39	4.18	4.60
Passenger Delay (hrs)	292,965	560,675	513,912	227,311
CO2 Emissions (tons)	180,113	188,200	167,995	138,691
Other Agency Costs ($ 000)	205,648	305,668	238,689	153,006
Total Agency and User and External Costs ($ 000)	224,151	337,322	268,365	167,336

Figures 3 and 4 show additional information on two key measures. Figure 3 shows how MDBF is expected to vary over time for the three scenarios. Figure 4 shows the predicted average TERM rating (for non-vehicle assets) for the three scenarios. Figure 5 shows the distribution of funding between different asset types for Scenario 2, and Figure 6 shows this information for Scenario 3. In these figures the funding by category is shown in millions. As illustrated in the figures, in both scenarios the bulk of the funding is spent on vehicle replacements, with most other funds spent on HVAC. The reduced funding in Scenario 2 relative to Scenario 3 results primarily in deferral of replacement of vehicles and some HVAC and fire protection work. However, the funding for roofs and FMS is the same in both scenarios.

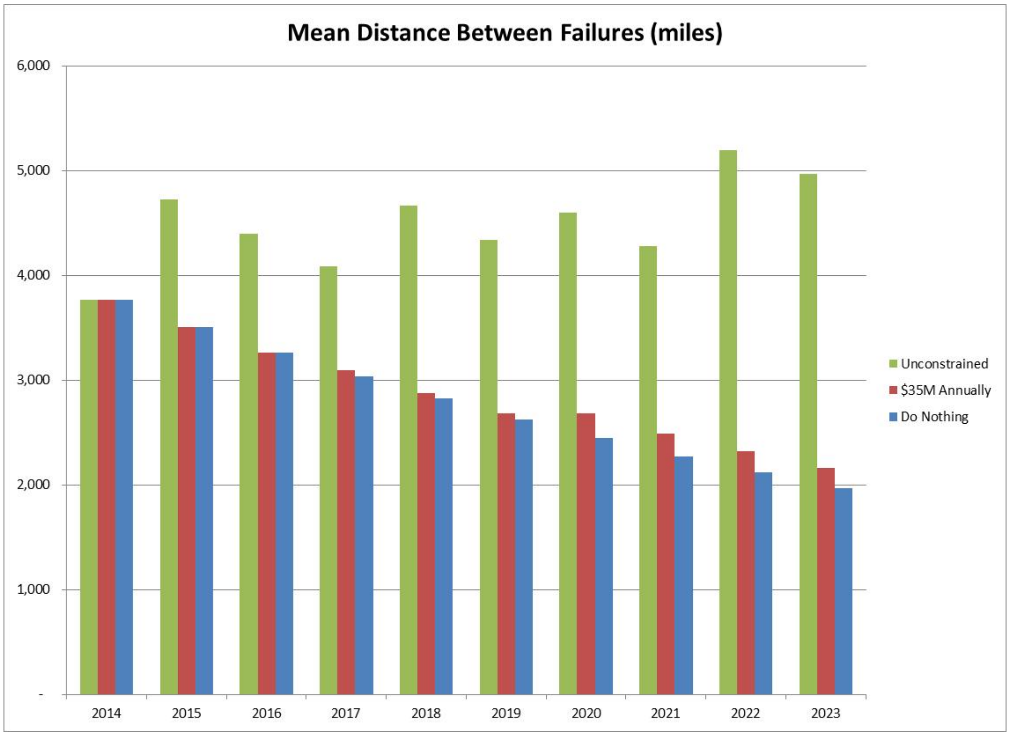


Figure 6. Predicted MDBF by Scenario

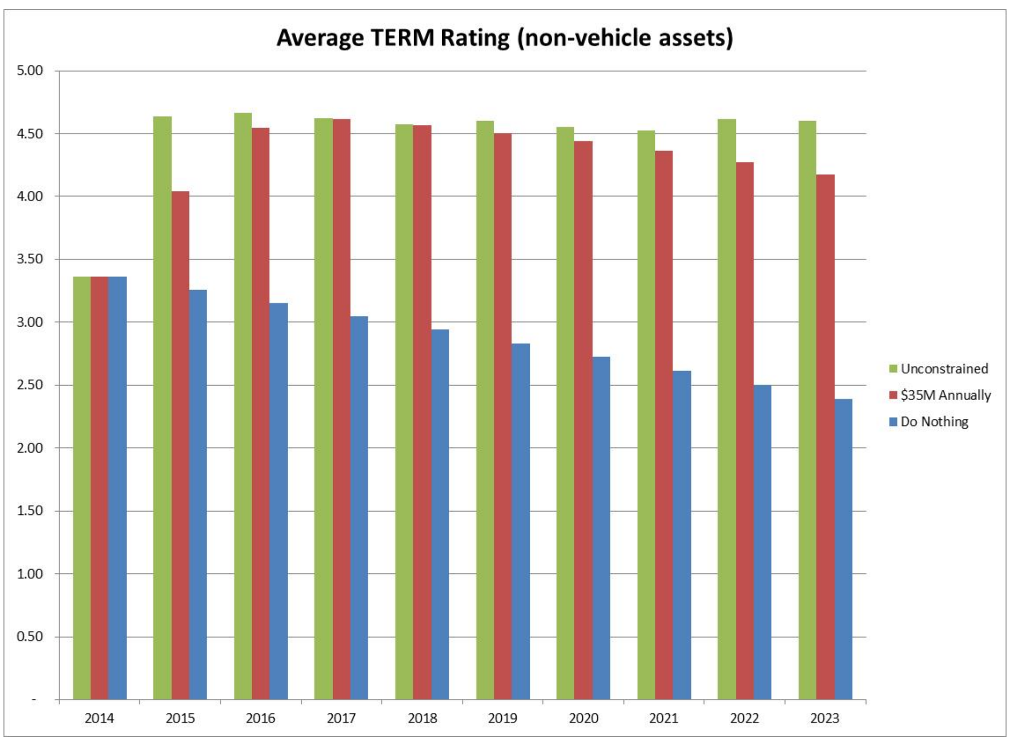


Figure 7. Predicted Average TERM Rating by Scenario

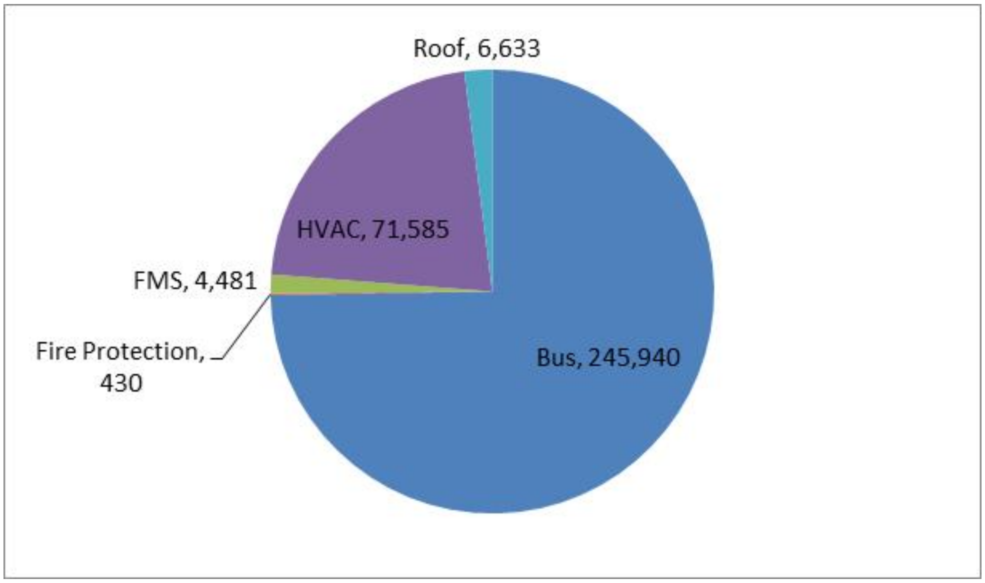


Figure 8. Distribution of Funding by Asset Type, Scenario 2

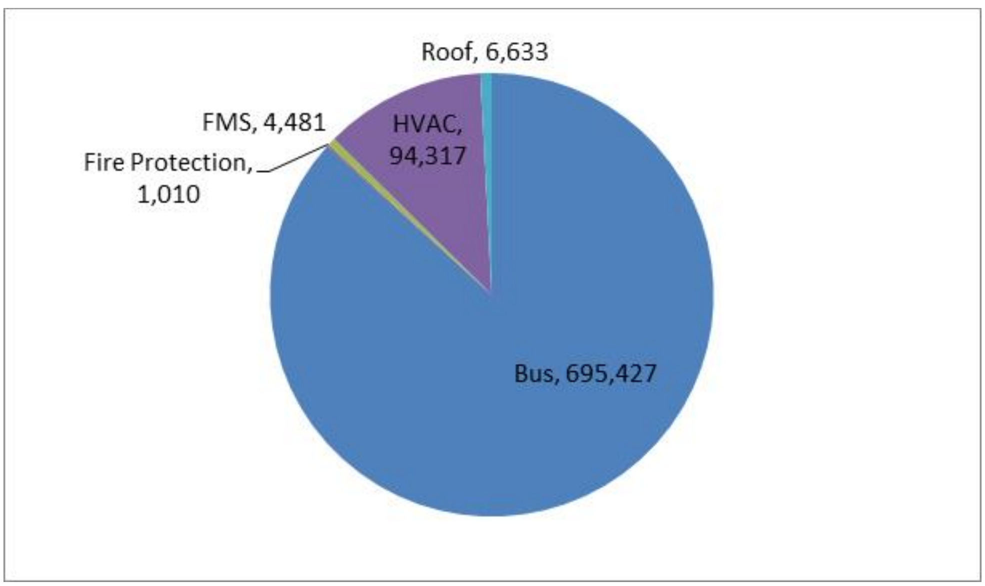


Figure 9. Distribution of Funding by Asset Type, Scenario 3

Discussion

The analysis results presented here reflect a number of changes relative to the draft version provided previously. Major revisions include:

- The revised TAPT has been used for the analysis rather than the original TCRP tools. TAPT is an integrated version of the TCRP tools, predicts a number of additional performance measures, and incorporates several enhancements made as a result of the experience gained from the pilots. The interim report on the project details enhancements in TAPT.
- Additional assets were added in the prioritization model. The previous version of the tool limited the number of assets that could be prioritized at once.
- The vehicle models now predict CO2 emissions, and the cost of emissions is incorporated in the calculation of lifecycle costs.
- A model was added for roofs, utilizing King County Metro's roof condition data.

The pilot was instructive for illustrating the use of the TCRP models, and helping guide enhancements to the modeling approach incorporated in TAPT. However, a number of further enhancements may be considered for the future, either as a next step in the TCRP Project E-09A research, or as a future effort. These include:

- Evaluating the default assumptions for facility models, such as assumptions for maintenance, failure costs, and decay rates.
- Working with King County Metro further to evaluate how well the priorities recommended by TAPT match transit agency experience, and evaluating how consideration of other factors outside the scope of TAPT, such as risk and asset criticality, impact transit agency priorities.
- Evaluating the sensitivity of the results to changes in model parameters such as assumed costs.

spy pond partners, llc

Memorandum

To: John Merrigan and Laura Zale, SEPTA
From: Bill Robert, Spy Pond Partners
Date: July 3, 2013
Re: SEPTA SGR Pilot Results

This memorandum summarizes the results of the State of Good Repair (SGR) pilot performed for the Southeastern Pennsylvania Transportation Authority (SEPTA) for Transit Cooperative Research Program (TCRP) Project E-09A. The following sections describe the scope of the pilot, data used for the pilot, the asset inventory that was included, asset-specific models, and results. The final section of the memorandum discusses revisions to the analysis made since the draft, and potential future enhancements.

Pilot Scope

The basic goal of the TCRP Project E-09A pilot program is to test the SGR framework and supporting tools developed previously through TCRP Project E-09. The framework and tools are intended to help agencies quantify the impacts of investing in rehabilitation and replacement of existing transit capital assets, and to help prioritize SGR investments. These tools help support the following tasks:

- Quantifying a transit agency's asset inventory.
- Developing models for each individual asset type. These models predict the life cycle costs of the asset, compute a variety of performance measures, and recommend when to rehabilitate or replace the asset.
- Prioritizing asset rehabilitation/replacement given details on the asset inventory, the asset type models, and an assumed budget.
- Predicting the conditions and performance that will result from a given set of asset replacement projects.

The interim report on the project provides additional information on the SGR framework. Also, the report details use of the SGR tools, now integrated into a single spreadsheet called the Transit Asset Prioritization Tool (TAPT), and describes the measures calculated by the tool.

Three agencies are participating in the pilots: King County Metro, Denver Regional Transportation District (RTD) and SEPTA. For each of the agencies the research team is conducting the following activities, at a minimum:

- Developing asset rehabilitation/replacement models using TAPT for as many asset types as possible, with the exact set of assets addressed based on available data.
- Determining how SGR investments should be prioritized based on the models, and comparing this to any data or insights on how each transit agency currently prioritizes.
- Defining investment scenarios to illustrate the impacts over time of alternative investment levels.

Additional activities are being performed as part of the pilots, pending available data and staff time, such as calibrating deterioration models, predicting additional performance measures, and comparing results to those generated using TERM Lite.

Based on an initial meeting with SEPTA, the research team focused the pilot on SEPTA's vehicles, including buses, light rail and commuter rail. Bus types modeled included hybrid, diesel and trolley buses. Of particular interest to SEPTA was determining the impact of transitioning to Compressed Natural Gas (CNG) buses in the future, in terms of costs and emissions. The team used the TCRP vehicle model to develop models for each bus type. The model requires data reported to NTD, but this data had to be disaggregated by type of bus.

For the light rail fleet, three types of light rail vehicle were modeled: the Subway Surface Lines (SSL), Media/Sharon Hill Lines (MSHL) and Route 15 (RT15). SSL and MSHL both use Kawaski vehicles purchased in the early 1980's, but have different operating characteristics. RT15 uses PCC cars that were recently rehabilitated and retrofitted with wheelchair lifts. SEPTA provided failure data for each line. The TCRP vehicle model was used to model each fleet, substituting default data on failure rates with SEPTA-specific data, and disaggregating NTD data using information provided by SEPTA.

For commuter rail a single model was developed for the entire fleet using NTD data and the TCRP model. Note the vehicle model accounts for the fact that there are numerous subfleets with different ages and accumulated mileage.

For each of the vehicle types considered, the TCRP models predict agency and user costs that will be incurred over time, including maintenance, rehabilitation, energy, and delay costs. The model considers how these costs, measured on a per mile basis, tend to increase as a vehicle accumulates mileage. The models use this information to determine the cost-minimizing replacement interval in miles, and the average annual cost for vehicles replaced at the recommended mileage. Also, the models predict additional measures, such as Mean Distance Between Failures (MDBF), C02 emissions, and passenger hours of delay.

Data Received

This section describes data received from SEPTA to support the pilot. Basic data used for the pilot are from SEPTA's National Transit Database (NTD) submittal. Table 1 lists additional materials provided by SEPTA, as well as other information sources.

Table 1. Pilot Data

Category	Document	Notes
SEPTA Bus Fleet Data	130118 SEPTA Bus Fleet Data.xls	Bus models and number of buses, total accumulated miles and average miles per bus, accumulated maintenance costs, accumulated fuel costs and quantities, average miles per gallon
SEPTA Light Rail Data	LIGHT RAIL – RAILROAD – STATE OF GOOD REPAIR – FY'12 OPERATING DATA.xls	Passenger miles, unlinked trips, vehicle miles, vehicle revenue miles and hours, energy costs, and vehicle maintenance costs for each line
	PCC-II-RT-15-SSL-MSHL-RAILROAD-FY'07-13 MDBF.xls	
	TCRP E-09 Project (State of Good Repair) Operating Statistics – From M. Rose and D. Layton.xls	
SEPTA Capital Plans	SEPTA. Fiscal Year 010 Capital Budget & Fiscal Years 2010-2021 Capital Program. May 2009.	Vehicle replacement costs
	SEPTA. Fiscal Year 2008 Capital Budget & Fiscal Years 2008-2019 Capital Program and Comprehensive Plan. May 2007.	
External Sources	Lowell, Dana. "Clean Diesel versus CNG Buses: Cost, Air Quality, & Climate Impacts," memorandum prepared by MJB&A for the Clean Air Task Force, 2012.	Replacement cost of CNG relative to diesel
	U.S. Department of Transportation Federal Transit Administration. "Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid-Electric and Fuel Cells." August 2005.	Replacement cost of CNG relative to diesel
	Barnitt, Robb A. National Renewable Energy Laboratory-U.S. Department of Energy. "In-Use Performance Comparison of Hybrid Electric, CNG, and Diesel Buses at New York City Transit." June 2008.	Comparison of energy and maintenance costs of hybrid, CNG, and diesel buses

Existing Assets

A basic step in performing the pilot analysis was to quantify the asset inventory. Table 2 lists the active bus inventory. Separate models were established for hybrid, diesel and trolley buses, with each type further divided into subfleets purchased from the same manufacturer in the same year. The table shows the type of bus, ID(s) used in the prioritization tool for each subfleet, a subfleet description, the number of vehicles in the subfleet, age of the subfleet (in years as of 2012), and average accumulated mileage per vehicle. 2011 NTD data were used to establish the inventory. For hybrid and trolley buses, all of the buses are 40 ft buses. The diesel bus category includes a mix of 40 ft and articulated buses.

Table 2. Bus Inventory

Type	ID	Description	#	Age (years)	Avg. Accum. Mileage
Hybrid Motorbus	HYBRD1	2002 New Flyer of America DE40LF	2	10	192,289
	HYBRD2	2003 New Flyer of America DE40LF	10	9	181,486
	HYBRD3	2004 New Flyer of America DE40LF	20	8	178,785
	HYBRD4	2008 New Flyer of America DE40LF	100	4	93,071
	HYBRD5	2009 New Flyer of America DE40LF	120	3	71,691
	HYBRD6	2010 New Flyer of America DE40LF	120	2	45,017
	HYBRD7	2011 New Flyer of America DE40LF	100	1	3,496
Diesel Motorbus	DSL1	2001 New Flyer of America D40LF	100	11	351,606
	DSL2	2002 New Flyer of America D40LF	200	10	345,249
	DSL3	2004 New Flyer of America D40LF	218	8	293,068
	DSL4	2005 New Flyer of America D40LF	119	7	181,341
	DSL5	2000 Neoplan USA Corporation AN460	155	12	336,189
Trolley Bus	TB1	2008 New Flyer of America SR113	38	4	76,037

Table 3 lists the active fleet inventory data for rail assets. These assets were divided into four categories: MSHL light rail, RT15 light rail, SSL light rail, and commuter rail. Each rail type was divided into subfleets purchased from the same manufacturer in the same year. Note that SEPTA has replaced its Silverliner commuter rail cars since the data below were reported to NTD. Thus, one would expect commuter rail replacement to be of relatively high priority in the pilot analysis.

Table 3. Rail Inventory

Type	ID	Description	#	Age (years)	Avg. Accum. Mileage
Light Rail (MSHL)	MSHL	1982 Kawasaki Rail Car Inc. KWLRVDE	29	30	525,600
Light Rail (RT15)	RT15A	1947 St. Louis Car Company PCCA44A45	14	65	1,226,119
	RT15B	1948 St. Louis Car Company PCCA46	4	64	1,218,119
Light Rail (SSL)	SSL	1980 Kawasaki Rail Car Inc. LRV	112	32	650,396
Commuter Rail	CR01	1987 Bombardier Corporation JWC3C	10	25	572,173
	CR02	1987 Bombardier Corporation JWC3T	25	25	558,173
	CR03	2000 Bombardier Corporation JWC3T	10	12	255,173
	CR04	1963 Budd Company SILVERLINERII	28	49	1,835,132
	CR05	1964 Budd Company SILVERLINERII	17	48	1,802,291
	CR06	1974 General Electric Corporation SILVERLINERIV	47	38	1,600,291
	CR07	1975 General Electric Corporation SILVERLINERIV	96	37	1,550,291
	CR08	1976 General Electric Corporation SILVERLINERIV	60	36	1,522,291
	CR09	1976 General Electric Corporation SILVERLINERIV	28	36	1,555,291
	CR10	2010 “Other Manufacturers” SILVERLINERVSC	8	2	9,968
	CR11	2010 “Other Manufacturers” SILVERLINERVMP	18	2	9,968
	CR12	1973 Pullman-Standard Comet1	8	39	52,746
	CR13	1967 St. Louis Car Company SILVERLINERIII	16	45	1,731,291

Asset Model Development

The following subsections describe the approach used to develop the asset-specific models, including models for buses, light rail vehicles, and commuter rail vehicles. For each asset type the research team used the TCRP models, but some amount of effort was involved in populating the model inputs.

Bus

For buses, separate models were developed for hybrid, diesel and trolley, and CNG buses. NTD data were the primary input to the models for hybrid, diesel and trolley buses. However, in the NTD hybrid and diesel data are combined. The following approach was taken to disaggregate NTD data between these two types:

- Vehicle miles, revenue vehicle miles, vehicle hours, road calls and maintenance costs were disaggregated using the subfleet data on vehicle mileage reported in the NTD
- Passenger miles and unlinked trips were disaggregated using the subfleet data on seat miles reported in the NTD.
- Energy costs were disaggregated using vehicle miles calculated as described above and data on fuel efficiency by subfleet provided by SEPTA. Fuel consumption was estimated based on the fuel efficiency factors shown in Table 5.

Table 4 below details the bus model inputs calculated for each bus type. Note that replacement costs used were from SEPTA capital plans, adjusted where necessary for inflation. For diesel buses, the replacement cost is a weighted average of the replacement cost for a 40 ft bus ($482,000) and articulated bus ($732,000). Rehabilitation costs were assumed to be minimal for hybrid buses (and CNG) for the first five years, as these buses are under warranty. Defaults were used for other model parameters.

Table 4. Bus Model Data

Parameter	Value by Bus Type		
	Hybrid	Diesel	Trolley
Passenger miles	166,865,000	345,282,000	12,810,000
Unlinked trips	56,021,000	115,921,000	6,584,000
Vehicle miles	14,703,000	27,606,000	949,000
Revenue vehicle miles	13,123,000	24,639,000	930,000
Revenue vehicle hours	1,287,000	2,416,000	109,000
Road calls	1,627	4,076	176
Replacement cost	743,000	531,000	1,281,165
Gallons of fuel (000)	4,901	11,017	0
Energy consumption in kwH (000)	0	0	8,226
Vehicle maintenance cost	25,727,000	64,434,000	1,332,000

CNG buses were modeled as an alternative to hybrid. The model inputs were identical to that used for hybrid, with the exception of the replacement cost, fuel cost and maintenance cost. The replacement cost for CNG buses was estimated to be $552,000 for a 40-ft bus, a $70,000 premium over the estimated cost of a 40-ft diesel bus. The premium for a CNG bus relative to diesel was calculated based on data in the 2012 memorandum to the Clean Air Task Force prepared in 2012 by MJB&A. This analysis was based on analysis of 2010 data in the American Public Transit Association (APTA) Transit Vehicle Database. This difference is consistent with that reported in the 2005 FTA report listed in Table 1, which reported a difference of $10,000 to $80,000.

Table 5 summarizes key parameters used to adjust energy and maintenance costs for CNG buses relative to hybrid. The fuel prices shown in the table are recent average values for the Philadelphia area. Other parameters shown are from the 2008 Department of Energy report listed in Table 1. Based on the data in this report, energy costs for CNG are approximately 37% higher than for hybrid, and maintenance costs are approximately 72% higher.

Table 5. Comparison of Hybrid and CNG Energy and Maintenance Costs

	Hybrid Motorbus	CNG Motorbus	Percent Change: Hybrid to CNG
Fuel cost ($/gal)	2.58	2.00	-22.5%
Fuel mileage (mi/gal)	3.00	1.70	-43.3%
Energy cost ($/mi)	0.86	1.18	37.2%
Maintenance cost ($/mi)	0.75	1.29	72.0%

Table 6 summarizes the results of the bus models. For each bus type the table shows the optimal replacement mileage, corresponding age, and average annual cost over the lifecycle of the vehicle assuming it is replaced at the optimal point. The average annual cost includes maintenance, rehabilitation and energy costs incurred by the transit agency, as well as user costs, costs from emissions, and the annualized purchase price of the vehicle. . Regarding the comparison of CNG and hybrid buses, the table shows that the average annual cost of a CNG bus is approximately $225,000, 23% more than that of hybrid buses, even accounting for the additional cost of a hybrid bus.

Table 6. Bus Model Results

Vehicle Type	Optimal Replacement Mileage (000)	Optimal Replacement Age (years)	Average Annual Cost (000)
Hybrid	471	14	183
CNG	404	12	225
Diesel	523	15	195
Trolley Bus	624	25	228

Besides predicting the optimal replacement/renewal mileage and average annual lifecycle cost, the vehicle model also predicts a number of other measures, such as MDBF, user costs, and a prioritization index which is used to determine how vehicle replacement should be prioritizing relative to replacement of other assets. Figure 1 shows predicted MDBF by age for each bus type. The next section shows results for this and other measures for different investment scenarios.

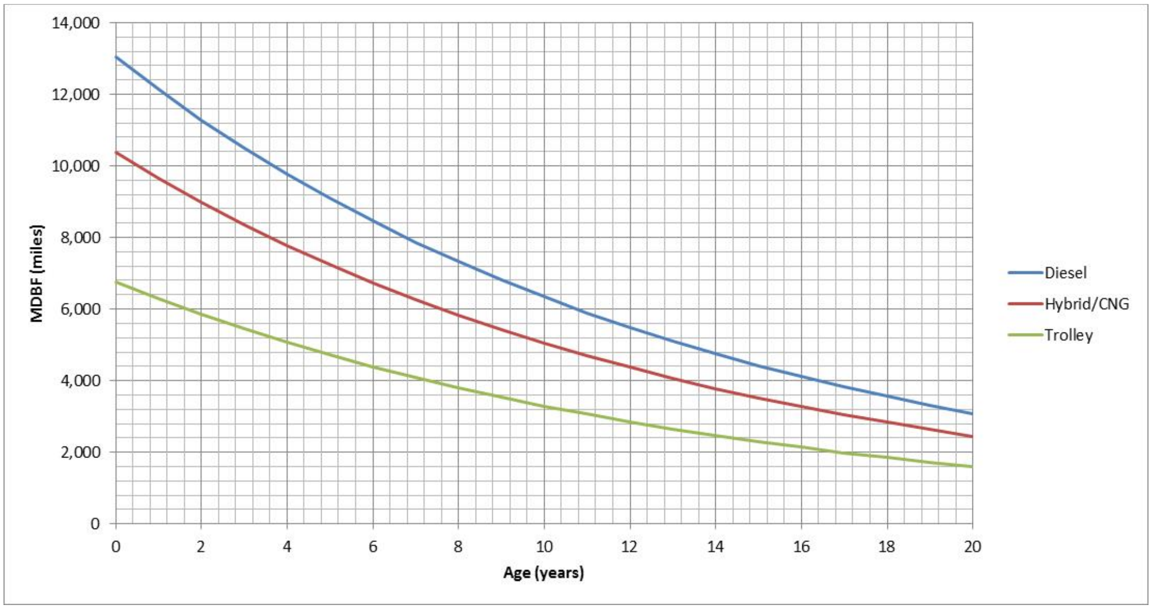


Figure 1. MDBF by Bus Type

Rail

For rail assets, separate models were developed for three types of light rail vehicles (SSL, MSHL, and RT15) and commuter rail. The data sources used to populate the models are detailed in Table 7. As in the case of hybrid and diesel buses, for light rail it was necessary to disaggregate the NTD data, in this case using data provided by SEPTA.

Table 7. Rail Model Inputs

Category	Data Item	Approach Used for Quantifying the Item
Fleet Description	Number of vehicles by subfleet	NTD data
	Average accumulated mileage per vehicle	
Operating Data	Passenger miles	TCRP E-09 Project (State of Good Repair Operating Statistics – From M. Rose and D. Layton.xls
	Unlinked trips	
	Revenue vehicle miles	
	Revenue vehicle hours	
	Vehicle miles	
	Total road calls	
Cost Data	Vehicle replacement cost	TERM estimates and SEPTA

		Capital Plan estimate
	Energy cost	TCRP E-09 Project (State of Good Repair Operating Statistics – From M. Rose and D. Layton.xls
	Vehicle maintenance cost	

Table 8 details the rail model inputs calculated for each rail vehicle type. Note the following regarding the model inputs:

- Vehicle replacement costs were estimated as $3.5 million and $2.75 million for light rail and commuter rail, respectively, based on SEPTA's capital plan.
- The vehicle model allows for specifying rehab costs but does not have defaults for rail vehicle rehab. We assumed that a rehabilitation equivalent to 50% of the cost of a new vehicle would be required every 500,000 miles.
- The vehicle model has default curves for predicting vehicle failures. The annual percentage increase was calculated based on the data provided by SEPTA. For the three light rail fleets data for the SSL fleet were used for all three vehicle types.

Table 8. Rail Model Data

Parameter	Value by Vehicle Type			
	Light Rail (SSL)	Light Rail (MSHL)	Light Rail (RT15)	Commuter Rail
Passenger miles (000)	62,453	9,216	6,199	538,650
Unlinked trips (000)	25,788	2,405	3,444	37,821
Vehicle miles (000)	2,555	559	280	5,475
Revenue vehicle miles (000)	2,448	557	268	5,160
Revenue vehicle hours (000)	272	53	30	192
Failures	375	21	47	486
Replacement cost (000)	3,500			2,750
Energy consumption in kwH (000)	20,538	5,084	2,031	200,668
Vehicle maintenance cost (000)	10,820	1,653	1,070	42,390
Annual increase in failure rate (%)	9.50			5.70

Table 9 below summarizes the results of the vehicle models. For each vehicle type the table shows the optimal replacement mileage, corresponding age, and average annual cost over the lifecycle of the vehicle assuming it is replaced at the cost-minimizing mileage.

Table 9. Rail Model Results

Vehicle Type	Optimal Replacement Mileage (000)	Optimal Replacement Age (years)	Average Annual Cost (000)
SSL	1,004	44	321
MSHL	1,176	61	271
RT15	1,446	93	212
Commuter Rail	1,092	74	188

Figures 2 and 3 show predicted MDBF by age for each rail vehicle type. Figure 2 shows the Kawasaki vehicles (SSL and MSHL), and Figure 3 shows RT15 and commuter rail vehicles. These are shown in separate figures as their ages vary significantly. The effective age for the Kawasaki vehicles (SSL and MSHL) is 27-28 years. For RT15 the effective age is 79 years, and for commuter rail it is 90 years.

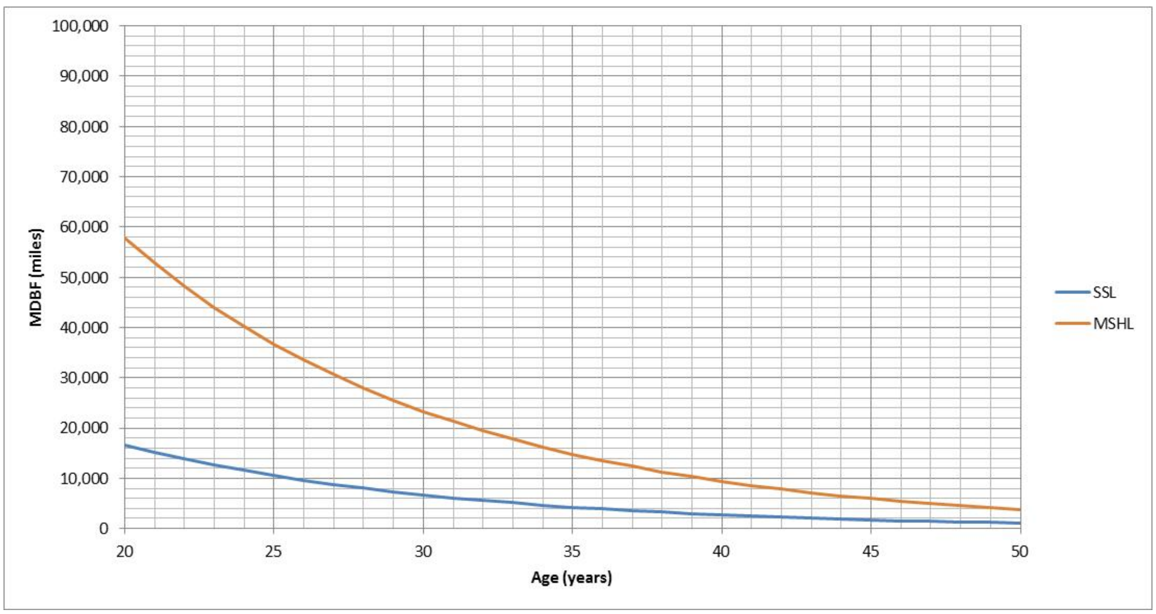


Figure 2. MDBF for SSL and MSHL Rail Vehicles

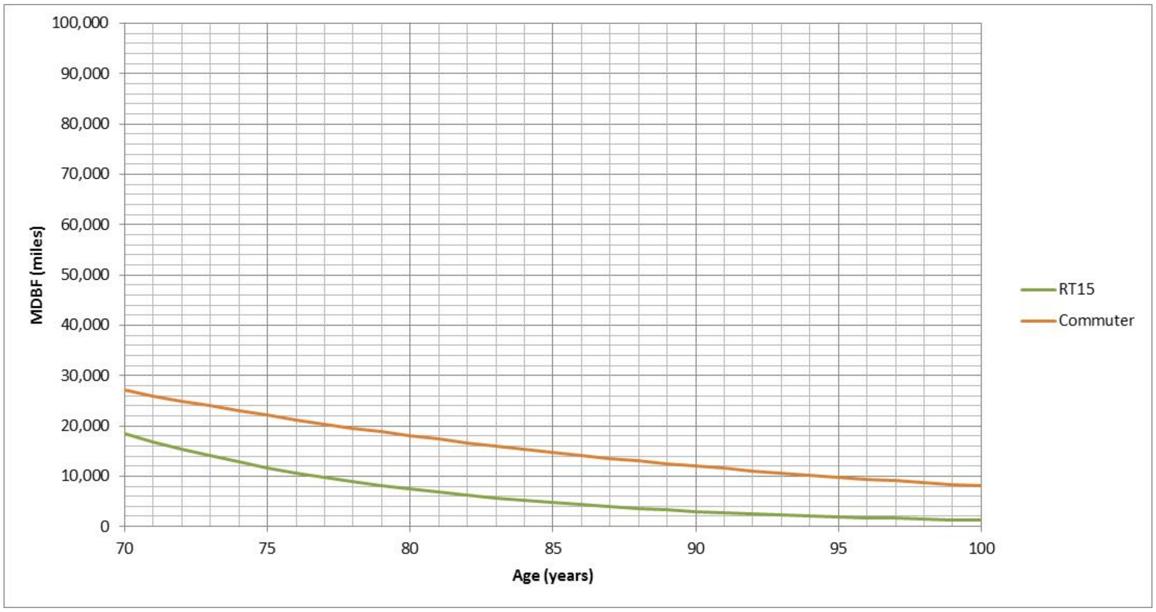


Figure 3. MDBF for RT15 and Commuter Rail Vehicles

Prioritization Results

The asset models described in the previous section are used as inputs to the prioritization model. This model simulates what work will occur given a set of potential projects and a specified budget by year. Projects are prioritized with the objective of minimizing overall transit agency and user lifecycle costs, accounting for any adjustments to the priorities made by the user (e.g., to adjust for factors not considered in the models). To use the prioritization model it is necessary to specify an annual budget by year for a 20-year period, and a cutoff value for prioritization index (PI).

When an asset is replaced at its cost-minimizing point the PI has a value of 0 (it then increases as replacement is deferred) so the default value is 0 for the PI cutoff. However, one may specify a lower value if replacement is assumed to have additional benefits not factored into the asset-level models. A PI cutoff of -0.3 was used for the analysis rather than 0 to approximate the additional benefits of replacement vehicles relative to the existing older vehicles which are not captured in the models (e.g., ADA compliance, improved public address systems, and various passenger amenities).

Given the vehicle data were predominantly from 2011, the analysis was run for the period from 2012 to 2031, with funds allocated beginning in 2014. Table 10 lists the highest priority projects based on the analysis. The table shows the project ID listed in the prioritization model, a brief description, the project cost (in thousands), rank of the project if performed in 2014, and rank of the project if all work were deferred until 2023. A value of "N/A" for the rank indicates the project is not recommended in 2014.

The changes in ranking from 2014 to 2023 reflect the relative criticality of different types of work. For instance, replacement of older commuter rail cars is highly ranked and would continue to be highly ranked if deferred. However, while replacement of the RT15 LRVs is highly ranked in 2014, if this is deferred other bus replacements increase in criticality relative to LRV replacement and are shown as having higher rank in 2023. The results shown in the table tend to confirm the judgment of SEPTA staff in several respects. First, the table shows that the highest-priority projects are to replace older commuter rail cars, consistent with actions taken by SEPTA. Further, the table shows that another high priority is to replace the 1940's PCC cars (RT15). Although these vehicles were recently refurbished and are historically significant, SEPTA staff confirmed these vehicles have a high failure rate and are expensive to maintain relative to other LRVs.

Table 10. Project Rankings for High Priority Projects

ID	Description	Cost ($ 000)	Rank	
			2014	2023
CR04	1963 Budd Company SILVERLINERII	77,000	1	1
CR05	1964 Budd Company SILVERLINERII	46,750	1	1
CR13	1967 St. Louis Car Company SILVERLINERIII	44,000	1	1
CR06	1974 General Electric Corporation SILVERLINERIV	129,250	4	1
CR07	1975 General Electric Corporation SILVERLINERIV	264,000	5	5
CR09	1976 General Electric Corporation SILVERLINERIV	77,000	5	5
CR08	1976 General Electric Corporation SILVERLINERIV	165,000	7	7
RT15A	1947 St. Louis Car Company PCCA44A45	49,000	8	18
RT15B	1948 St. Louis Car Company PCCA46	14,000	9	19
DSL1	2001 New Flyer of America D40LF	53,100	10	8
DSL2	2002 New Flyer of America D40LF	106,200	10	8
DSL5	2000 Neoplan USA Corporation AN460	82,305	10	8
SSL	1980 Kawasaki Rail Car Inc. LRV	392,000	13	21
DSL3	2004 New Flyer of America D40LF	115,758	N/A	11
HYBRD1	2002 New Flyer of America DE40LF	992	N/A	12
HYBRD2	2003 New Flyer of America DE40LF	4,960	N/A	13
HYBRD3	2004 New Flyer of America DE40LF	9,919	N/A	13
DSL4	2005 New Flyer of America D40LF	63,189	N/A	15
HYBRD4	2008 New Flyer of America DE40LF	49,595	N/A	16
HYBRD5	2009 New Flyer of America DE40LF	59,514	N/A	17
HYBRD6	2010 New Flyer of America DE40LF	59,514	N/A	20
HYBRD7	2011 New Flyer of America DE40LF	49,595	N/A	22

ID	Description	Cost ($ 000)	Rank	
			2014	2023
CR01	1987 Bombardier Corporation JWC3C	27,500	N/A	23
CR02	1987 Bombardier Corporation JWC3T	68,750	N/A	24
MSHL	1982 Kawasaki Rail Car Inc. KWLRVDE	101,500	N/A	25

Three different funding scenarios were evaluated as part of the pilot. These include:

- Scenario 1: Do Nothing
- Scenario 2:$150M Annually
- Scenario 3: Fund All Needs

Table 11 summarizes the initial conditions (as of 2014) and results predicted in 2023 for each of the scenarios. Results are shown for the following measures:

- Unmet needs: cost of performing all replacement work needed at the end of the period.
- Cumulative spent on replacement work through the end of the period.
- Mean Distance Between Failures (MDBF)for vehicles in miles
- Passenger delay from roadcalls/failures in hours
- C02 emissions from operations and new assets in tons. These have been specified for vehicles only.
- Other Agency Costs, including costs of maintenance, vehicle rehabilitation, energy and any unplanned work resulting for asset failures.
- Total Agency and User Costs, including the other agency costs described above delay costs, emissions costs, and any other external costs (but not including capital expenditures).

Note that all costs are in constant dollars, and the projections do not account for future increases in ridership. As indicated in the table, under Scenarios 1 average conditions worsen, resulting in increased needs and costs. In Scenarios 2 and 3, additional investments in asset replacement ($1.3 billion cumulatively in Scenario 2, $2.1 billion in Scenario 3), results in higher MDBF, lower agency costs, and lower user costs.

Table 11. Scenario Summary

Scenario	Initial Value (2014)	Value in 2023		
		1-Do Nothing	2-$150M Annually	3-Fund All Needs
Unmet Needs ($ 000)	1,258,000	2,001,282	639,345	0
Cumulative Spent ($ 000)	N/A	0	1,471,046	2,110,391
MDBF (miles)	6,481	3,421	7,029	8,207
Passenger Delay (hrs)	1,299,829	2,224,675	322,127	206,936
C02 Emissions (tons)	484,389	594,026	272,593	249,718
Other Agency Costs ($ 000)	283,555	373,427	198,714	182,045
Total Agency and User and External Costs ($ 000)	358,087	495,358	220,847	198,064

Figure 4 shows additional information on MDBF, illustrating how this measure is expected to vary over time for the three scenarios. Figure 5 shows the distribution of funding between different asset types for Scenario 2, and Figure 6 shows this information for Scenario 3. In these figures the funding by category is shown in millions. As illustrated in the figures, in both scenarios the largest single category of work is replacement of commuter rail vehicles. The reduced funding in Scenario 2 relative to Scenario 3 results primarily in deferral of replacement of the Kawasaki LRVs (SSL and MSHL).

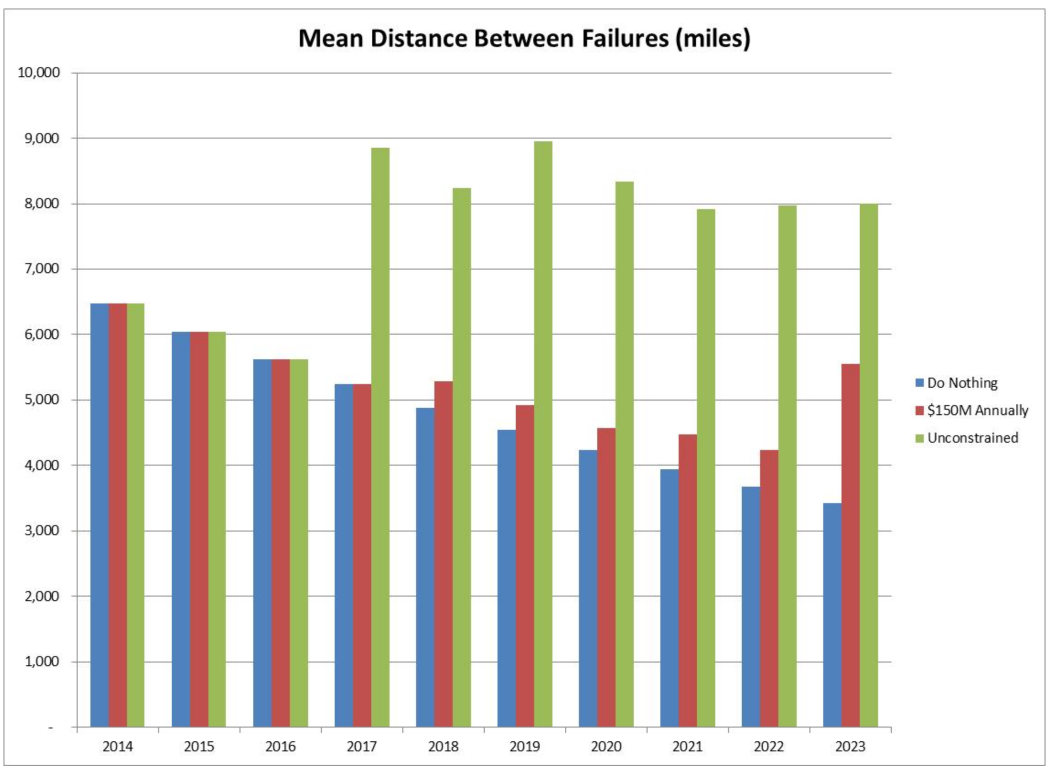


Figure 4. Predicted MDBF by Scenario

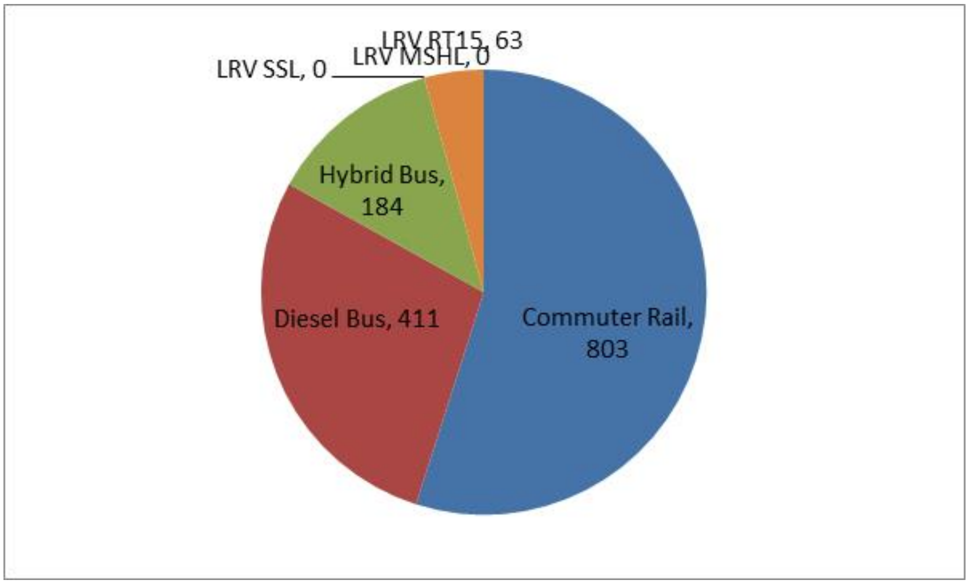


Figure 5. Distribution of Funding by Asset Type, Scenario 2

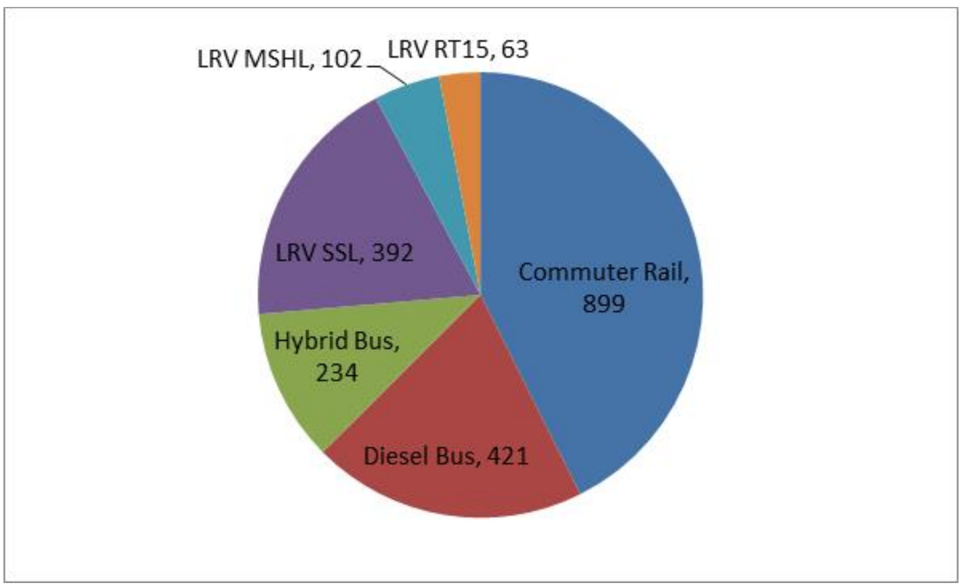


Figure 6. Distribution of Funding by Asset Type, Scenario 3

Discussion

The analysis results presented here reflect a number of changes relative to the draft version provided previously. Major revisions include:

- The revised TAPT has been used for the analysis rather than the original TCRP tools. TAPT is an integrated version of the TCRP tools, predicts a number of additional performance measures, and incorporates several enhancements made as a result of the experience gained from the pilots. The interim report on the project details enhancements in TAPT.

- The vehicle models now predict CO_2 emissions, and the cost of emissions is incorporated in the calculation of lifecycle costs.
- Hybrid and CNG bus models were revised to incorporate a warranty period.
- Adjusted the assumed difference in the purchase price between diesel and CNG buses based on the most recent available data.
- Revised the LRV models based on comments from SEPTA. In particular, the different LRV models now use the same replacement cost.

The pilot was instructive for illustrating the use of the TCRP models, and helping guide enhancements to the modeling approach incorporated in TAPT. However, a number of further enhancements may be considered for the future, either as a next step in the TCRP Project E-09A research, or as a future effort. These include:

- Further evaluating how well the vehicle model works for very old vehicles, such as SEPTA's commuter rail cars and PCC cars.
- Reviewing the assumptions concerning vehicle rehabilitation. Further review is merited to evaluate the impact of treating rehabilitation as a single event versus a series of actions spread out over time, and to determine the impact of rehabilitation on failures and costs.
- Comparing the model results for different bus types (e.g., diesel, hybrid and CNG) to results from other studies of bus life cycle costs.

Appendix C. Workshop Materials

TCRP Project E-09A: Guidance for Applying the State of Good Repair Prioritization Framework and Tools

Project Workshop
February 25, 2014

spy pond partners, llc

Workshop Objectives

- Review the draft products of the TCRP E-09A research projects
- Provide training on the use of the draft Transit Asset Prioritization Tool for prioritizing SGR investments
- Review the draft guidance developed for transit asset management plan development
- Provide feedback to the research team and panel to improve the research products

spy pond partners, llc TCRP E-09A 2

Morning Agenda

- Introduction & Overview
- Transit Asset Management Framework & Plan Development
- TAPT Walk-Through
- Pilot Agency Presentation 1 – SEPTA
- Q&A Session
- Lunch

Afternoon Agenda

- Pilot Agency Presentation 2 – Denver RTD
- TAPT Exercises
- Pilot Agency Presentation 3 – King County
- Feedback Session
- Wrap-Up

TCRP E-09A Project Team

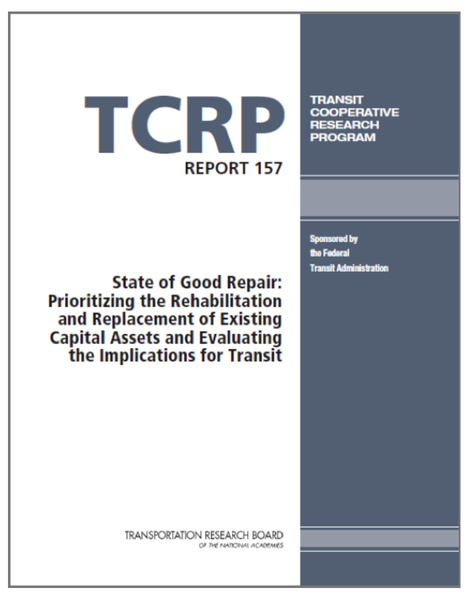
- Spy Pond Partners, LLC
  - Bill Robert, Principal Investigator
  - Ginna Reeder
  - Kat Lawrence
- KKO & Associates, LLC
  - Kay O'Neil
- Harry Cohen

Introduction & Overview: Project Background – TCRP E-09

TRCP Project E-09A builds off of the work completed for TCRP Project E-09 and detailed in TCRP Report 157

Objectives

- Develop a framework for public transportation organizations to use and to prioritize asset rehabilitation and replacement
- Identify methods for assessing the consequences or varying investment levels on key indicators of pubic transportation service and performance



TCRP Report 157 Key Themes

- Achieving SGR is needed to help maximize transit agency performance and minimize life cycle costs
- Better tools and approaches are needed to help prioritize SGR investments and communicate impacts
- Significant work has been performed for transit and other modes that can be adapted to improve analysis and prioritization of SGR needs

TCRP E-09A Project Objectives

- *Demonstrate* application of the TCRP Report 157 SGR framework and tools through a set of transit agency pilots
- *Enhance* the framework and tools
- *Develop* tools for transit agencies to use to help attain a state of good repair (SGR) for their assets
  - Guidance for developing transit asset management plans
    - Builds upon the SGR framework
  - Prioritization tool
    - Builds upon the TCRP Report 157 tools

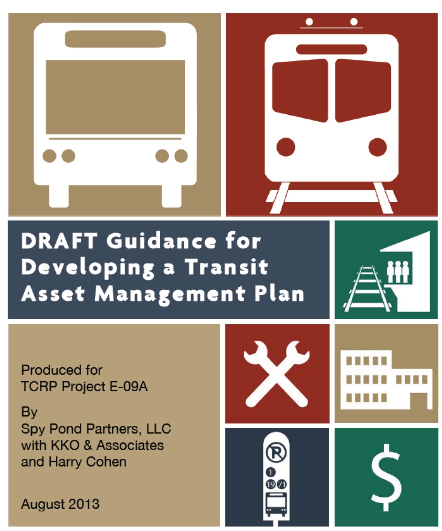
TCRP-E09A Project Scope

- Pilot the tools detailed in Report 157 with three agencies
  - King County Metro
  - Denver RTD
  - SEPTA
- Enhance the tools based on the pilots
  - Integrate the four existing tools into the Transit Asset Prioritization Tool (TAPT)
  - Predict additional measures of performance (e.g., emissions)
- Develop guidance for developing asset management plans using the tools and SGR framework
- Review the guidance and tools in an industry workshop

Guidance Document

Objective:

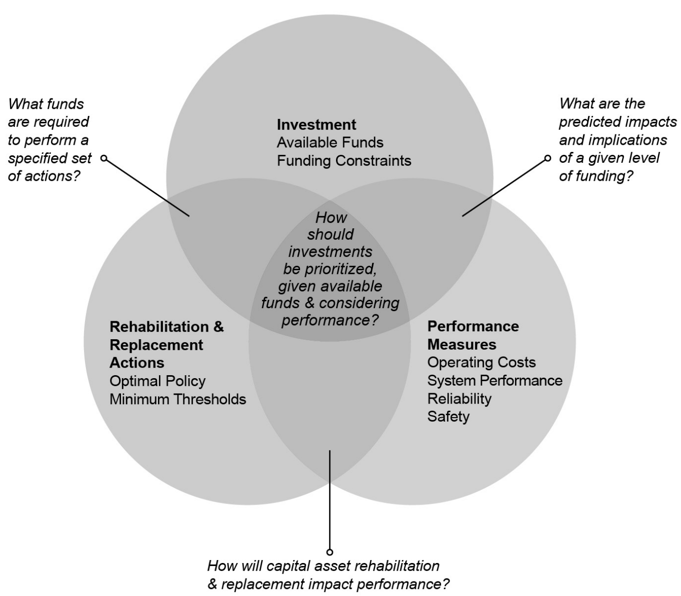
- Assist agencies in developing a Transit Asset Management Plan (TAMP)
  - Applies the SGR Framework
  - Helps meet MAP-21 requirements
- Support agency use of TAPT
- Provide additional references useful for agencies developing a TAMP



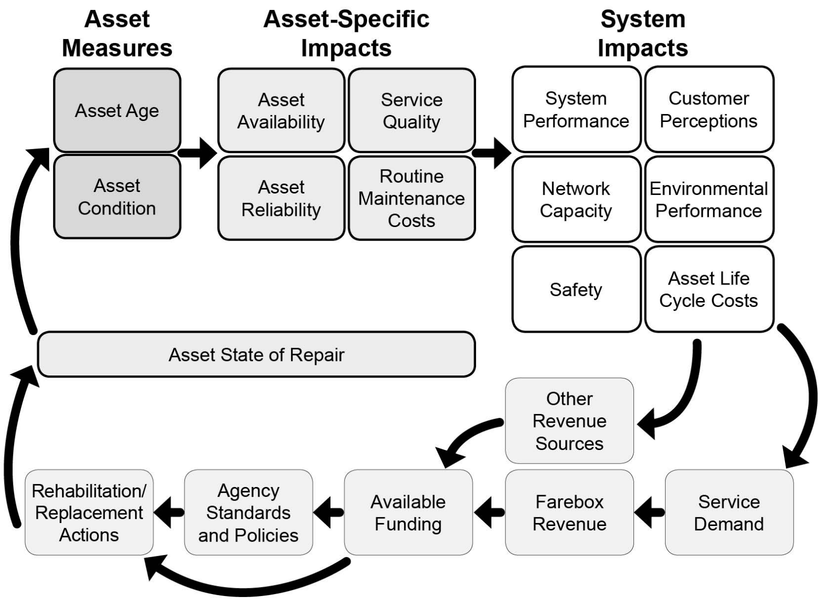
Guidance Document Contents

- A more detailed version of the framework developed previously with step-by-step instructions
- Describes a process that can be implemented regardless of the specific tools used, though noting where TERM or TAPT may be relevant
- Step-by-step instructions for using TAPT
- Tutorials using actual agency data to demonstrate use of TAPT

SGR Framework Elements



Relating SGR to Performance



Relating SGR to Performance Implications

- There is a strong – but indirect – relationship between asset measures (age, condition) and system impacts shown in the figure
- Better analytic methods are needed to:
  - Predict asset-specific and system impacts
  - Relate asset condition to performance, and convert measures of performance to agency and user costs
  - Provide an economic justification for achieving a given state of repair

Transit Asset Management Rehabilitation & Replacement Models

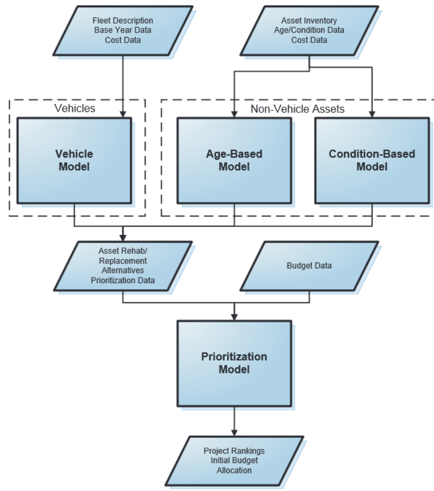
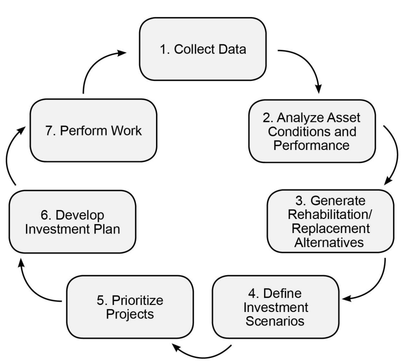


Figure 5-1. Models supporting the asset rehabilitation and replacement framework.

Transit Asset Management Framework Lifecycle



- Process involves seven basic steps for prioritizing
- Result is an asset management plan comparable to the described in MAP-21 legislation (followed by performing planned work)
- The report provides transit agency examples illustrating each of the steps

MAP-21 Requirements Highway AM Plans

All states required to develop a risk-based, performance-based asset management plan for the NHS. States are encouraged to include all infrastructure assets within the right-of-way corridor.

The plan must include:

- Summary list, including condition, of the State's NHS pavements and bridges
- Asset management objectives and measures
- Performance gap identification
- Lifecycle cost and risk management analysis
- Financial plan
- Investment strategies

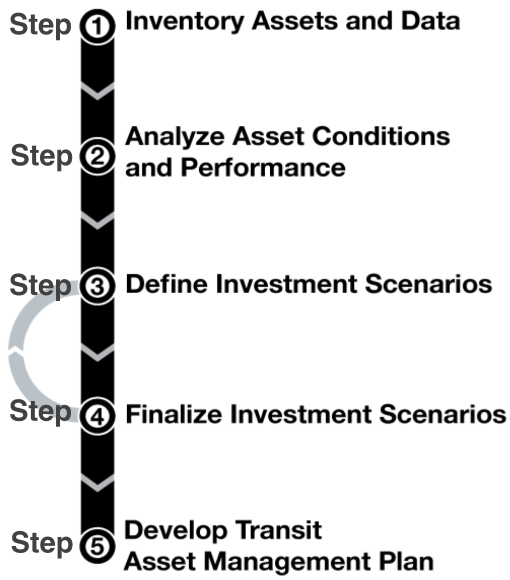
MAP-21 Requirements Transit Asset Management

The term 'transit asset management plan' means a plan developed by a recipient of funding under this chapter that—(A) includes, at a minimum, capital asset inventories and condition assessments, decision support tools, and investment prioritization; and (B) the recipient certifies complies with the rule issued under this section.

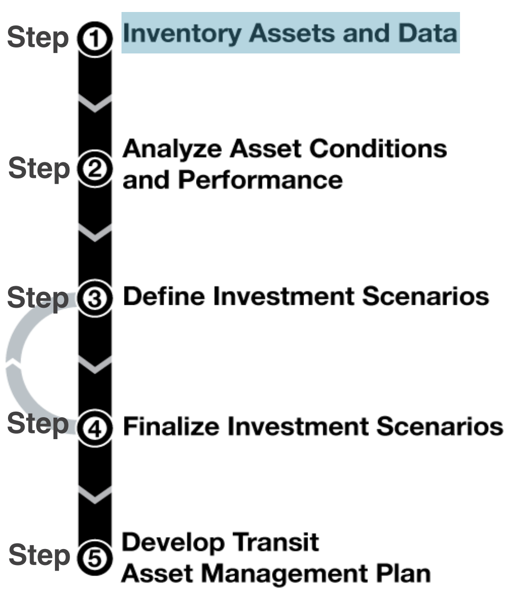
The law also directs the Secretary of Transportation to establish a "national management system including:

- Definition of SGR
- Requirement that recipients and subrecipients of financial assistance develop TAMPs
- Requirement that each recipient report on conditions
- Analytical process or tool to estimate investment needs and assist with prioirtization
- Technical assistance

TAMP Development Steps



TAMP Development Steps



- Step One: Inventory Assets and Data
  - 1.1 Establish the Capital Asset Inventory
  - 1.2 Establish Available Data Resources
  - 1.3 Define State of Good Repair
  - 1.4 Select Performance Measures and Targets
  - 1.5 Define Data Collection Protocols and Reporting Schedule

Step 1.1 Establish the Capital Asset Inventory

Type	ID	Description	#	Age (years)	Average Accumulated Mileage
Articulated	Bus-Artic 1	2000 NABI	118	12	330,900
Mall	Bus-Mall 1	2000 Mall Shuttle	18	12	138,904
	Bus-Mall 2	2001 Mall Shuttle	15	11	141,193
	Bus-Mall 3	2002 Mall Shuttle	3	10	130,023
Intercity	Bus IC 1	1998 MCI	67	14	1,024,371
	Bus-IC 2	2001 Neoplan	85	11	493,701
	Bus-IC 3	2009 Blue Bird	6	3	55,487
	Bus-IC 4	2010 MCI	6	2	84,036
40' Transit	Bus-Transit 1	2000 Orion V	199	12	482,740
	Bus-Transit 2	2005 Gillig Diesel	42	7	295,447
	Bus-Transit 3	2006 Gillig Hybrid	4	6	171,153
	Bus-Transit 4	2006 Gillig Diesel	7	6	249,523
	Bus-Transit 5	2008 Gillig Diesel	6	4	170,629
	Bus-Transit 6	2008 Gillig Hybrid	5	4	115,508

Capital Asset Inventory Example

Step1.4 Select Performance Measures and Targets

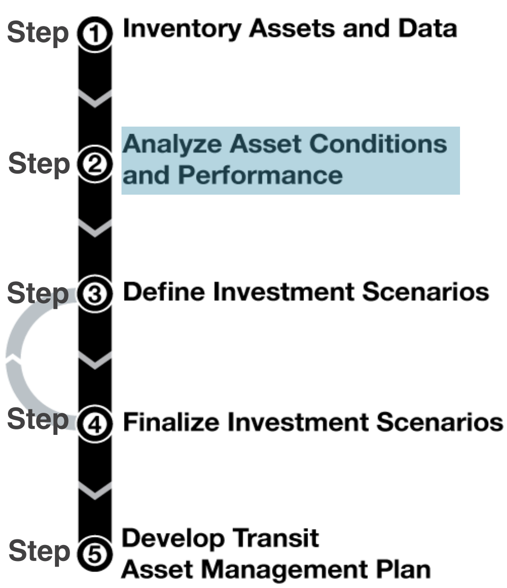
Measure	Use for	How to Measure
Backlog of investment needs	All assets	Sum of costs for unmet needs for achieving SGR
Average asset age	Guideway, stations, facilities, systems	Year of manufacture for vehicles; year of construction or installation for other assets. Weight by asset value when combining assets.
Mean distance between failures (MDBF)	Vehicles	Vehicle-miles traveled/number of road calls or failures
Average accumulated mileage	Vehicles	Total lifetime mileage averaged among all vehicles in the subfleet

Core TAMP Measures

Upon Completion of Step 1 You Will Have:

- A comprehensive list of your transit agency's capital assets, organized by subsystem type to facilitate data collection
- A list, by asset, of the data your transit agency currently collects related to its assets
- An agency-approved definition of State of Good Repair (SGR)
- A selected list of performance measures
- A plan or protocol for gathering, storing and updating the necessary data

TAMP Development Steps



- Step Two: Analyze Asset Conditions and Performance
  - 2.1 Calculate Current Conditions and Performance
  - 2.2 Develop Deterioration Models
  - 2.3 Project Replacement Impacts
  - 2.4 Develop a Replacement Policy

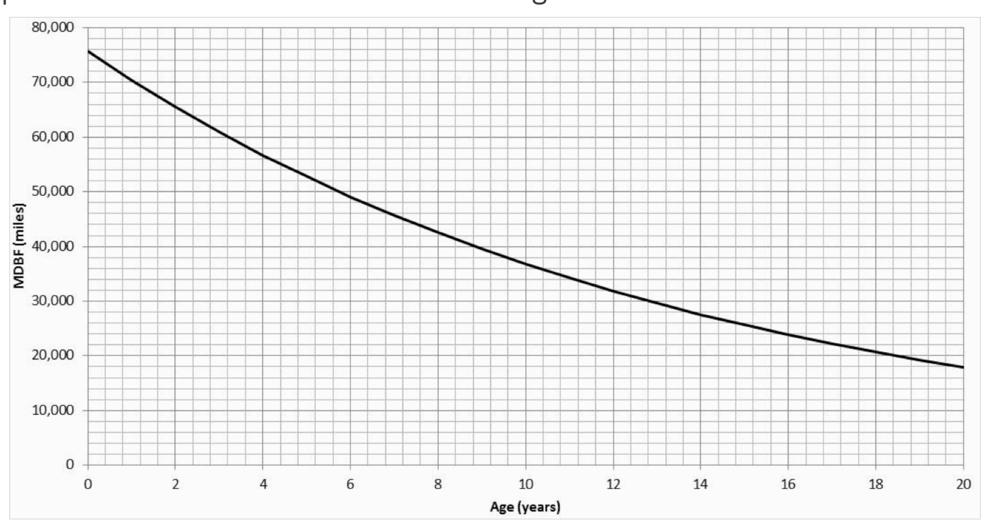
Step 2.1 Calculate Current Conditions and Performance

Measure	Value by Bus Type Artic	Mall	Intercity	40 foot
Backlog of Needs ($ 000)	0	0	37,654	76,416
Average Accumulated Mileage (000)	331	135	679	428
Mechanical Failures (roadcalls)	88	65	87	317
MDBF (miles)	35,649	20,407	33,033	39,791
CO_2 Emissions (tons)	10,843	1,778	18,454	28,942

Current Conditions and Performance Example

Step 2.2 Develop Deterioration Models

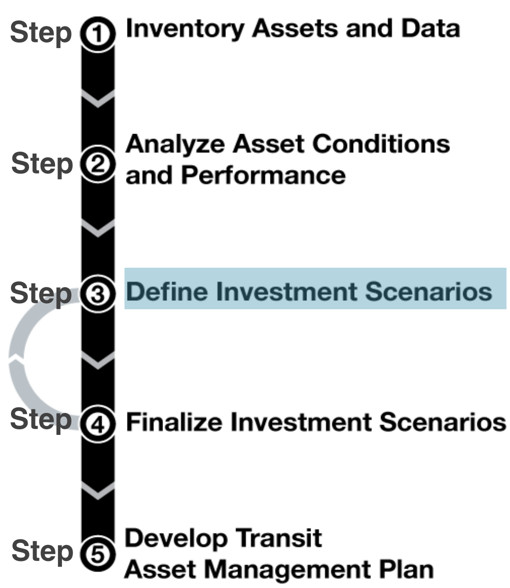
Example Deterioration Curve – MDBF vs. Age



Upon Completion of Step 2 You Will Have:

- A snapshot of where your transit agency stands today, with respect to your chosen performance measures for asset management
- The point in time at which each of your asset types will need replacement, as described by your deterioration model
- A replacement policy, for each asset type, which will guide your investment scenarios and inform your prioritization decisions

TAMP Development Steps



- Step Three: Define Investment Scenarios
  - 3.1 Specify Prioritization Approach
  - 3.2 Develop Funding Assumptions
  - 3.3 Develop Investment Scenarios
  - 3.4 Describe Future Decisions, Conditions and Performance for each Scenario

Step 3.1 Specify Prioritization Approach

ID	Description	Cost ($ 000)	Rank 2014	Rank 2023
Guideway-XC 1	Guideway - Grade Crossings – Central	306	1	1
Guideway-Embedded 1	Guideway – Embedded – Central	37,797	2	2
Guideway-Embedded 2	Guideway – Embedded – SW	2,700	3	3
Track-XC Int 1	Track – Grade Crossing – Intensive Use – Central	160	4	6
Track-Embedded Int 1	Track – Embedded – Intensive Use – Central	631	5	7
Track-Special Int 1	Track – Special Trackwork – Intensive Use – Central	5,928	6	9
Guideway-XC 2	Guideway – Grade Crossing – CPV	600	7	4

Example Project Prioritization

Step 3.4 Describe Future Decisions, Conditions and Performance

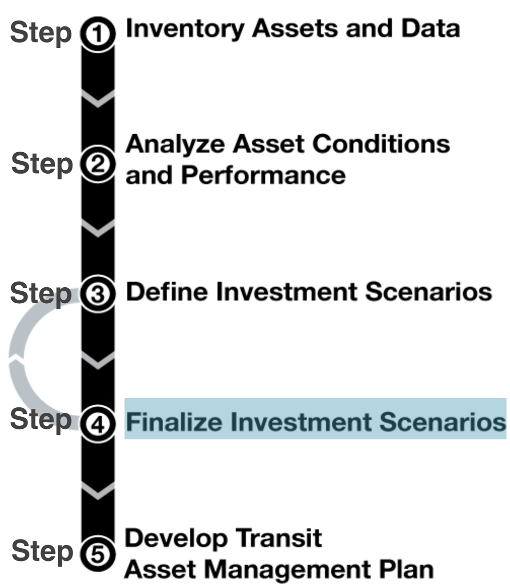
Scenario	Initial Value (2014)	Value in 2023: 1-Do Nothing	Value in 2023: 2-$25M Annually	Value in 2023: 3-Unconstrained
Unmet Needs ($ 000)	116,803	439,419	233,004	0
Cumulative Spent ($ 000)	N/A	0	209,415	439,419
MDBF (miles)	35,649	20,407	33,033	39,791
Average TERM Condition (non-vehicle assets)	4.68	4.39	4.54	4.62
Passenger Delay (hrs)	113,682	170,399	150,781	146,801
CO_2 Emissions (tons)	248,160	294,722	278,009	271,134
Other Agency Costs ($ 000)	196,292	278,332	219,534	197,762
Total Agency and User and External Costs ($ 000)	207,750	293,654	233,504	211,374

Example Scenario Summary

Upon Completion of Step 3 You Will Have:

- A prioritization approach and some basic funding assumptions to guide you in project selection
- Three or more defined investment scenarios which provide an accurate picture of how key funding and policy decisions will impact your transit agency's operations on the ground

TAMP Development Steps

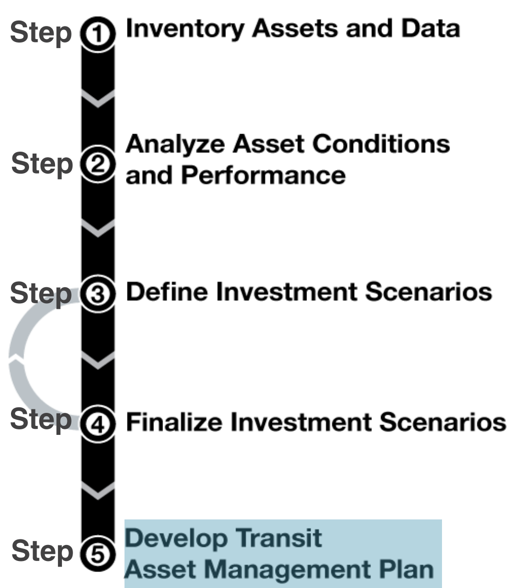


- Step Four: Finalize Investment Scenarios
  - 4.1 Revisit/Revise Replacement Policy, Funding and Prioritization Assumptions
  - 4.2 Finalize and Select the Preferred Scenario

Upon Completion of Step 4 You Will Have:

- A final (and perhaps revised) asset replacement policy
- A final (and perhaps revised) asset prioritization approach
- A preferred asset investment scenario

TAMP Development Steps

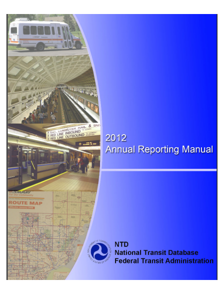


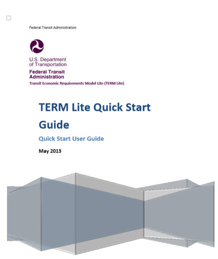
- Step Five: Develop the Asset Management Plan
  - 5.1 Finalize Funding Levels and Constraints
  - 5.2 Select Specific Projects
  - 5.3 Prepare the Plan

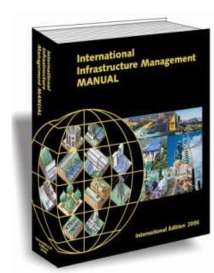
Sample TAMP Table of Contents

- Executive Summary
- Introduction and Background
- Agency Context and Policies
  - Asset Inventory
  - Definition of SGR
  - Performance Measures and Targets
  - Replacement Policy
  - Prioritization Approach
- Current Conditions
  - Asset Conditions and Performance
- Investment Scenario
  - Funding
  - Projects
  - Projected Performance Measures and Targets
- Capital Investment Plan

Other Relevant Resources







Transit Asset Management Rehabilitation & Replacement Models

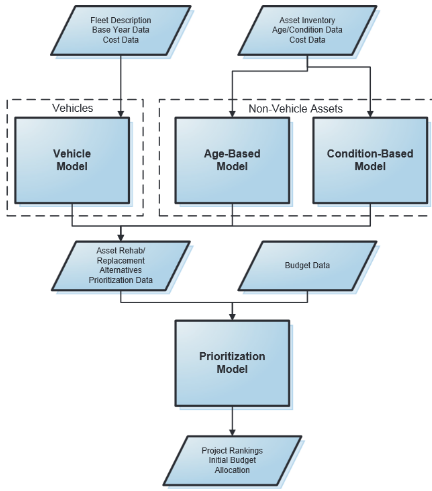


Figure 5-1. Models supporting the asset rehabilitation and replacement framework.

Vehicle Model

- Used to predict replacement needs for all revenue vehicles
- Assumptions:
  - Vehicles deteriorate as a function of mileage
  - Transit agency costs accumulate as a function of mileage
  - Primary user cost is delay from road calls/failures
  - Bus rehabilitation cost varies by accumulated mileage due to common component replacement practice
  - Rail rehabilitation costs are user-specified

Age-Based Model

- Used to predict replacement or rehabilitation of non-vehicle assets when condition data is **not** available
- Model uses Weibull distribution – as failure becomes more likely, the relative benefit of replacing the asset before it reaches a specified age tends to increase
- Default models are based on TERM Lite deterioration data

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Condition-Based Model

- Used to predict replacement or rehabilitation of non-vehicle assets when condition data **is** available
- Model uses Markov Decision Process – commonly used in pavement and bridge management system
- Output is a recommended rehabilitation and replacement policy based on asset condition
- Predicts annualized costs if policy is followed

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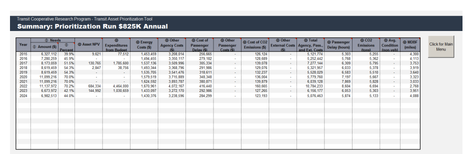
Prioritization Model

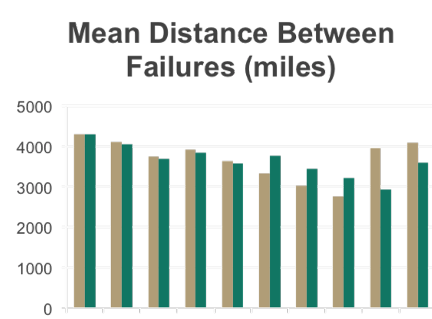
- Recommends a set of rehabilitation and replacement alternatives to return maximum utility
- Calculates one-year benefits of performing work compared to the deferment of action

Transit Asset Prioritization Tool

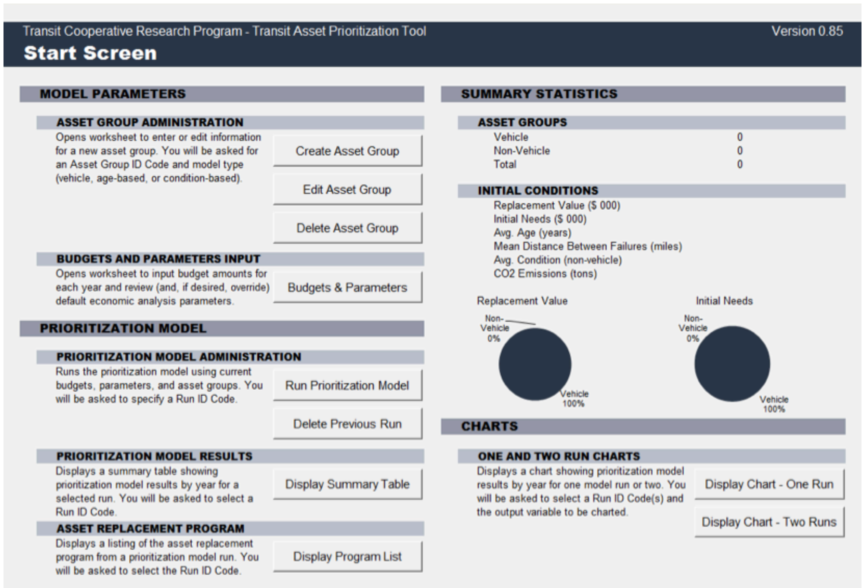
TAPT is designed to:

- Model the rehabilitation and replacement needs for transit capital assets
- Support a range of asset types
- Predict future conditions and performance
- Help prioritize asset rehabilitation and replacement





TAPT Demo



Transit Agency Pilots

Southeastern Pennsylvania Transportation Authority (SEPTA)

Denver Regional Transportation District (RTD)

King County Metro

SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY

SEPTA System Overview

- Operates
  - 119 Fixed Bus Routes
  - 3 Trackless Trolley Routes
  - 8 Trolley Lines
  - 1 Interurban High Speed Line
  - 2 Subway Lines
  - 13 Regional Rail Lines

A Multimodal System Spanning 2,200 Square Miles



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Achieving SGR is a Core Business Goal

- Fix it first to provide safe and reliable service.
- Reinvestment in "core" areas.
- Replacement and rehabilitation of the fleet.

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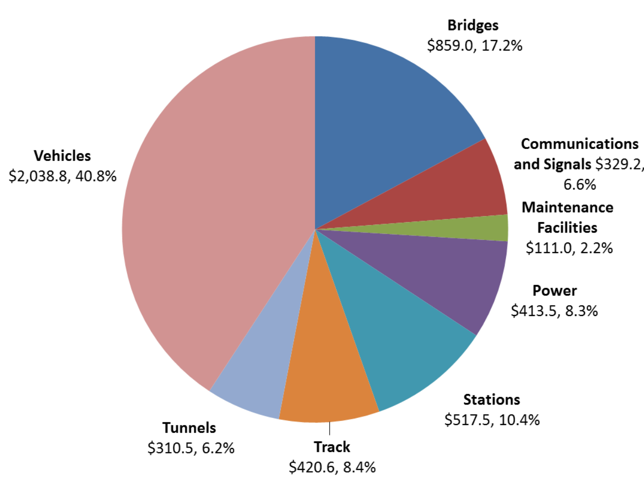
Challenges of Operating a Legacy Transit System

- Created between 1964 and 1983 from consolidation of bankrupt transit providers.
- Recent funding challenges have limited ability to reinvest at necessary levels.

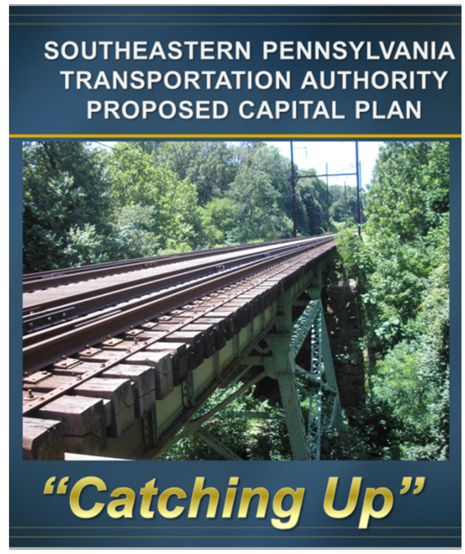
Quantifying Backlog and Future Levels of Investment

Current SGR Backlog ($5.0 B) + 20 Year Rehabilitation/ Replacement Needs ($8.5 B) = Total SGR Needs ($13.5 B)



Impact of New State Funding: "Catching Up"

- SGR needs mapped to capital projects.
  - Work to reduce backlog
  - Sustainable funding sours allows SEPTA to address future SGR needs
- Funding allows strategic investments to promote ridership growth.
  - Infrastructure
  - Vehicle capacity



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TCRP E-09A Pilot Scope

- Create models for selected vehicle types
  - Buses
  - Light Rail
  - Commuter Rail
- Compare TAPT-generated priorities agency priorities
  - Pilot used 2011 data, allowing for comparison to actual projects
- Predict future conditions for different budget scenarios
- Evaluate life cycle cost of CNG buses relative to diesel and hybrid

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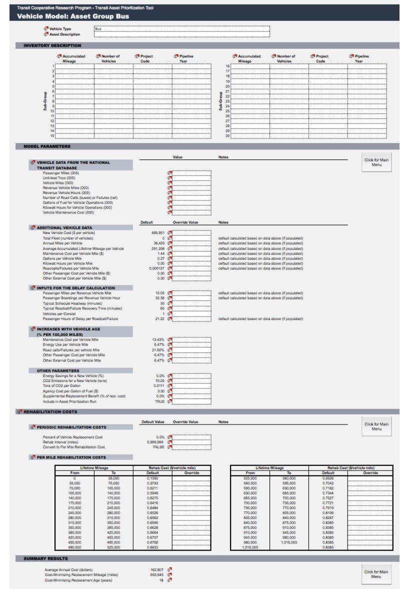
Vehicle Inventory Modeled

- Bus
  - 472 Diesel / Electric Hybrid (40 ft)
  - 883 Diesel (40 ft and articulated)
  - 38 Trolleybus
- Light Rail Vehicles
  - 112 Subway Surface Line (SSL)
  - 29 Media/Sharon Hill Lines (MSHL)
  - 18 Route 15 (RT15) – PCC Cars
- 371 Commuter Rail Coaches



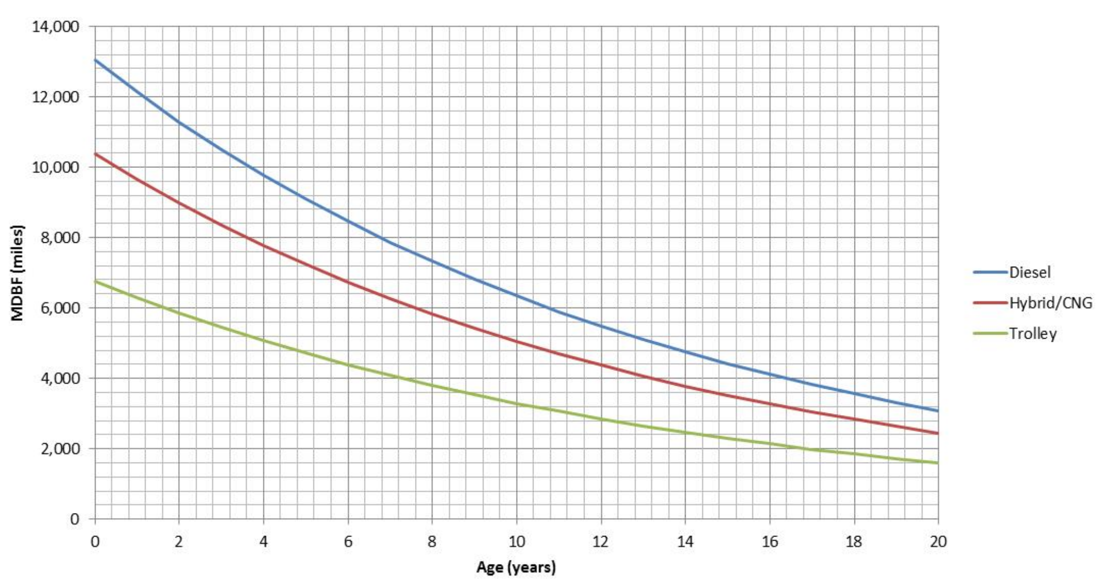
Bus Model Development

- Used 2011 NTD data
  - Vehicles by subfleet
  - Vehicle accumulated mileage
  - Road calls
  - Service data
  - Energy consumption
  - Maintenance cost
- For energy consumption used SEPTA data on fuel efficiency by subfleet to estimate consumption for hybrid and diesel
- For CNG used adjustment factors reported in the literature to predict fuel consumption and maintenance costs relative to hybrid

Bus Model Results

Vehicle Type	Optimal Replacement Mileage	Optimal Replacement Age	Average Annual Cost
Hybrid	471,000	14	$183,000
CNG	404,000	12	$225,000
Diesel	523,000	15	$195,000
Trolley Bus	624,000	25	$228,000

Bus Model Results



Bus Model Observations

- Results representative of that obtained for other bus fleets
  – Recommended replacement age typically somewhat greater than 12 years
- Trolley buses
  – Replacement mileage comparable to that for other bus fleets
  – Higher replacement mileage results primarily from greater replacement cost
  – Replacement age greater as a result of lower annual mileage
- CNG
  – Slightly higher energy cost than hybrid (lower cost per gallon offset by lower fuel efficiency)
  – Significantly higher maintenance cost
  – Ideally would base model on actual data rather than estimates from the literature

Rail Model Development

- Used 2011 NTD data and additional data provided by SEPTA
- SEPTA staff disaggregated NTD data for light rail by subfleet
- Vehicle replacement cost based on TERM estimates and SEPTA capital plan estimates
- Assumed a vehicle rehabilitation every 500,000 miles costing 50% of the replacement cost
- For light rail failures used data on the SSL fleet to determine the percentage increase per year
- For commuter rail allocated all costs to coaches (did not model coaches and locomotives separately)

Rail Model Results

Vehicle Type	Optimal Replacement Mileage	Optimal Replacement Age	Average Annual Cost
SSL	1,004,000	44	$321,000
MSHL	1,176,000	61	$271,000
RT15	1,446,000	93	$212,000
Commuter Rail	1,092,000	74	$188,000

Observations on the Rail Models

- Critical to obtain disaggregated data for light rail
  - Significant differences between characteristics of each sub-fleet
  - Subway Service Line sub-fleet has significantly more use than the other sub-fleets
  - Failure rate higher for the older Route 15 (PCC) subfleet
- Results for replacement ages are misleading
  - A number of vehicles near the end of their life have low annual mileage, skewing average miles per year
  - TAPT considers actual accumulated mileage rather than just vehicle age
  - Can override annual mileage per vehicle to adjust for this

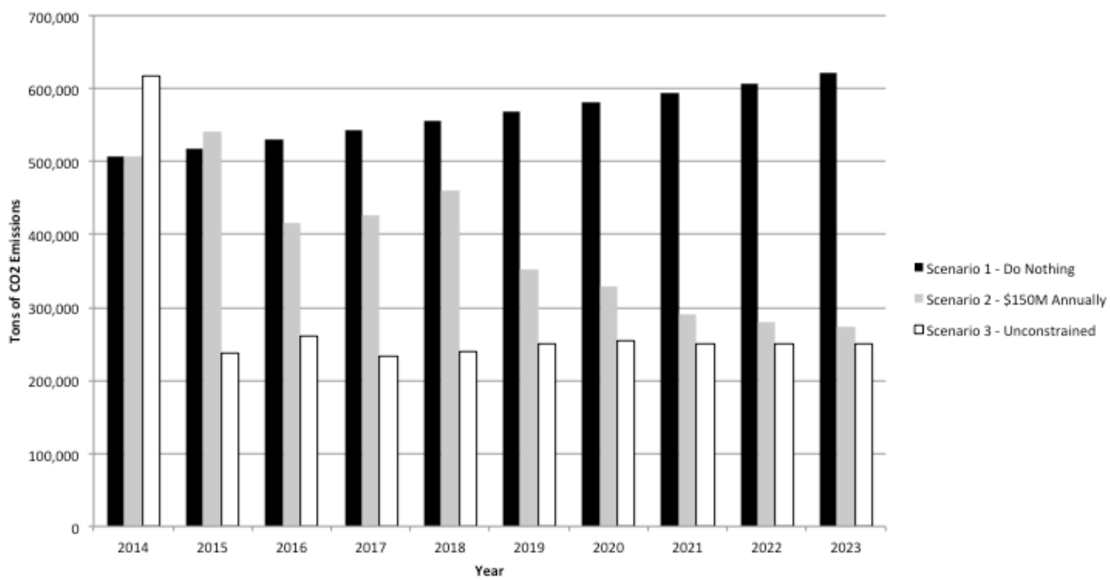
Results – High Priority Projects

- Replacement of Route 15 PCC cars (built in 1947-48)
- Replacement of Silverliner II commuter rail coaches (1963-64)
  Accomplished 2011-12
- Replacement of Media/Sharon Hill Kawasaki light rail vehicles (1982)
- Replacement of Silver Liner III commuter rail coaches (1967)
  Accomplished 2011-12
- Replacement of Silver Liner IV coaches (1974-76)
- Note that if all work is deferred 10 years, replacement of diesel buses becomes the highest priority

Results – Performance by Budget Scenario

Scenario	Initial Value (2014)	Do Nothing Scenario	$150M Annually Scenario	Unconstrained Scenario
Unmet Needs ($000)	1,258,000	2,001,282	639,345	0
Cumulative Spent ($000)	N/A	0	1,471,046	2,110,391
MDBF	6,481	3,421	7,029	8,207
Passenger Delay	1,299,829	2,224,675	322,127	206,936
CO_2 Emissions	484,389	594,026	272,593	249,718
Other Agency Costs	283,555	373,472	198,714	182,045
Total Agency and User External Costs ($000)	358,087	495,358	220,847	198,064

Example Results CO2 by Scenario



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Proposed Fleet Replacement Initiatives

Fleet	Budget	2014	2015	2016	2017	2018	2019+
AEM 7 ***Replace*** ***Locomotives with 13 New All Electric*** *(7.2M per)*	$108.5M	259K	10.7M	74.4M	22.8M	350K	
Multi-Level Trains *Replace Push-Pull with 36 New Multi-Level Cars (2.9M unit)*	$126.1M	350K	12.9M	76M	35.5M	1M	350K
Trolleys/Articulated *Replace LRV's, Doubles, and PCCII Cars (159 units) with 170 New LRV/Articulated Vehicles (Budget 3.75M per unit)*	$712.4M	0	1.2M	224M	275.2M	207M	4.4M
Operational Studies *Two operational studies will be performed, One being an LRV Artic Study investigating infrastructure obstacles. The other study will be for the AEM-7. (Budget 500K per study)*	$1M	1M	0	0	0	0	0
Silverliner VI *Replace Silverliner IV Rail Cars (4.0M per unit)*	$1.1B	0	0	300K	700K	129.5M	972M
Buses *Replace 40' & Articulated Buses (522 units) with 522 New 40' & Articulated Buses. Purchase an additional 30 option Articulated Buses. Investigate all Electric Vehicle Procurement. (Budget 500K 40' & 950K Artic per unit)*	$300M	59.2M	42.7M	88M	60M	50M	0
CCT Vehicles *Replace 12 Passenger, 3+4, and Hi-Cap Mini Buses & Sedans (397 units) with 397 New 12 Passenger, 3+4, and Hi-Cap Mini Buses & Sedans (Budget 12 Pass. 65K, 3+4 67K, Hi-Cap 91K, Sedan 26K per unit)*	$28.4M	4.9M	6.0M	4.4M	5.8M	7.2M	0
Contract Operations *Replace 30' Eldorado & 27' Champion Buses (35 units) with 41 New 27' & 30' Vehicles (Budget 200K 30' & 125K 27' per unit)*	$ 7.3M	4.2M	3.1M	4.4M	5.8M	7.2M	0

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Proposed Capital Improvements

Fleet	Budget	2014	2015	2016	2017	2018	2019+
Vehicle Overhaul Program **Program includes overhauling 45 Push-Pull Cars, 44 MFL Cars, LRV's, and Bus Mini-Hybrid Cooling Retrofit (Budget 65M per year)**	$350M	70M	70M	70M	70M	70M	0
Utility Fleet **Replacement of Equipment including: SUV's, Police Cars, T-Car's, and other additional vehicles (Budget 6M per year)**	$30M	3M	3M	6M	12M	6M	0
Maintenance & Way Equipment Replacements include: Overhead Workcar for the SSL, Tamping Machines, Ballast Cars, and Electric Crane Workcars	$57M	3M	9M	9M	17M	17M	0
Facility Improvements Facility Equipment upgrades include: Vehicle Washers, Paint Booths, Wheel Truing, Water Jet, Lifts & Cranes, Storage Tanks, Dyno, Print Shop, and Surveillance Cameras	$10M	2M	2M	2M	2M	2M	0
Infrastructure Investments **Includes Only: Frazer Shop Expansion, Re-Open Fern Rock Truck Shop Pit #33**	$10M	0	5M	5M	0	0	0
Broad Street Line Upgrade the Advertising/Automatic Stop Announcement System	$8M	8M	0	0	0	0	0
Technology Investments Investments include: AVPA, Clever Devices, Trapeze OPS, Card System, Real Time Info (Budget 5M FY2014, 2M 2015-2018)	$13M	5M	2M	2M	2M	2M	0

SEPTA New Vehicle Capital Planning – Bus Fleet

Fleet		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
40 Foot Bus	Build	0	100	0	0	100	120	100	120	100	0	100	740
	VOH	100	120	0	100	120	120	100	0	0	100	0	760
	Retire	0	0	100	0	100	120	100	120	100	0	100	740
(500K), VOH (100K)	# in Fleet	1210	1310	1210	1210	1210	1210	1210	1210	1210	1210	1210	
60 Foot Articulated Bus	Build	0	55	15	45	40	0	0	0	0	0	0	155
	VOH	0	0	0	0	0	0	55	15	45	40	0	155
	Retire	0	55	15	45	40	0	0	0	0	0	0	155
(950K), VOH (200K)	# in Fleet	155	155	155	155	155	155	155	155	155	155	155	
Trackless Trolley Bus	Build	0	0	0	0	0	0	0	0	0	0	0	0
	VOH	0	0	8	10	10	10	0	0	8	10	10	66
	Retire	0	0	0	0	0	0	0	0	0	0	0	0
(1M), VOH (350K)	# in Fleet	38	38	38	38	38	38	38	38	38	38	38	
Contract Operations	Build	0	0	21	25	0	0	0	0	0	0	0	46
	VOH	0	0	0	0	0	0	0	21	25	0	0	46
	Retire	0	0	14	21	0	0	0	0	0	0	0	35
30' (200K), 27' (125K), VOH - 30' (60K), 27' (50K)	# in Fleet	35	35	42	46	46	46	46	46	46	46	46	
Utility Fleet	Build	0	50	65	72	135	112	90	92	125	135	142	1018
	VOH	0	0	0	0	0	0	0	0	0	0	0	0
*Current Fleet - 899 Rubber Tires, 107 M & W	Retire	0	50	65	72	135	112	90	92	125	135	142	1018
	# in Fleet	899	899	899	899	899	899	899	899	899	899	899	

SEPTA New Vehicle Capital Planning – Rail Fleet

Fleet		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Silverliner VI	Build	0	0	0	27	72	72	72	27	0	0	0	270
	VOH	0	0	0	0	0	0	0	0	27	30	30	87
*81 Single (3.5M), 82 MP (6.5M), VOH(300K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	0	0	0	27	99	171	243	270	270	270	270	
Silverliner IV	Build	0	0	0	0	0	0	0	0	0	0	0	0
	VOH	42	0	0	0	0	0	0	0	0	0	0	42
	Retire	0	0	0	27	72	72	60	0	0	0	0	231
	# in Fleet	231	231	231	204	132	60	0	0	0	0	0	
Silverliner V	Build	60	0	0	0	0	0	0	0	0	0	0	60
	VOH	0	0	0	0	24	24	24	24	24	24	24	168
VOH (300K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	120	120	120	120	120	120	120	120	120	120	120	
NJ Cars	Build	0	0	0	0	0	0	0	0	0	0	0	0
	VOH	0	0	2	2	2	2	0	2	2	2	2	16
VOH (300K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	8	8	8	8	8	8	8	8	8	8	8	
Push-Pull Fleet	Build	0	0	0	0	0	0	0	0	0	0	0	0
	VOH	3	2	15	15	15	8	0	15	15	15	8	111
VOH (200K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	45	45	45	45	45	45	45	45	45	45	45	
Diesel Locomotives	Build	0	0	0	9	0	0	0	0	0	0	0	9
	VOH	0	0	0	0	0	0	0	0	3	3	3	9
(Replace with Diesel-Electric) (8M), VOH (800K)	Retire	0	0	0	7	0	0	0	0	0	0	0	7
	# in Fleet	7	7	7	9	9	9	9	9	9	9	9	

SEPTA New Vehicle Capital Planning – Rail Fleet cont.

Fleet		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
LRV & PCC II	Build	0	0	0	0	0	0	40	40	35	0	0	115
(112 Single, 29 Doubles, 18 PCCII = 159)	VOH	21	21	21	21	0	0	0	0	0	0	0	84
*115 Single (3.5M), VOH (300K)	Retire	0	0	0	0	0	0	53	53	53	0	0	159
	# in Fleet	159	159	159	159	159	159	146	133	115	115	115	
Articulated LRV	Build	0	0	0	0	0	0	20	20	15	0	0	55
	VOH	0	0	0	0	0	0	0	0	0	0	0	0
* 55 Artic (4M), VOH (350K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	0	0	0	0	0	0	20	40	55	55	55	
Broad Street	Build	0	0	0	0	0	0	0	0	0	0	0	0
Subway B-IV	VOH	24	24	24	24	24	24	24	24	24	24	24	264
VOH (173K) *VOH in 2015-18 (300K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	125	125	125	125	125	125	125	125	125	125	125	
Market Frankford	Build	0	0	0	0	0	0	0	0	0	0	0	0
Subway Elevated	VOH	32	32	32	32	32	32	32	32	32	32	32	352
VOH (201K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	220	220	220	220	220	220	220	220	220	220	220	
Norristown N-5	Build	0	0	0	0	0	0	0	0	0	0	0	0
	VOH	5	5	5	5	5	5	5	5	5	5	5	55
(3M) VOH (265K)	Retire	0	0	0	0	0	0	0	0	0	0	0	0
	# in Fleet	26	26	26	26	26	26	26	26	26	26	26	

Key Points: SEPTA

- Focused on vehicles – data limited for other assets
- Good test of a number of extreme cases – e.g., PCC cars, 1960's-era commuter rail coaches
- Demonstrated use of the modeling approach for comparing results for CNG vs. Diesel vs. Hybrid buses
  - Transit agency is considering introducing CNG, but these do not appear to be cost-effective (or more environmentally friendly) relative to the alternatives
- Showed that achieving SGR results in lower projected emissions

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Lunch!

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Afternoon Agenda

- Pilot Agency Presentation 2 – RTD
- TAPT Exercises
- Pilot Agency Presentation 3 – King County
- Feedback Session
- Wrap-Up

DENVER REGIONAL TRANSPORTATION DISTRICT

Outline

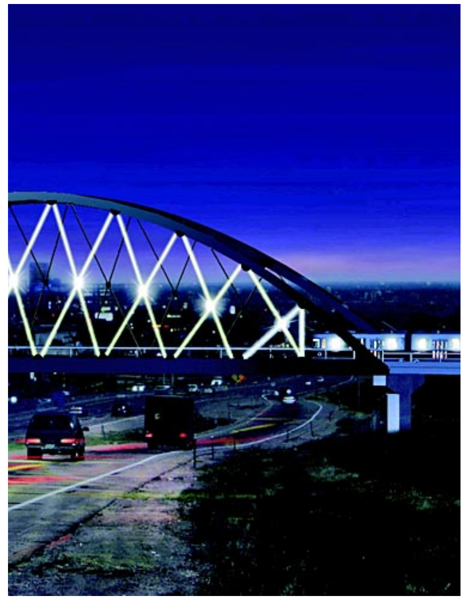
- RTD overview
  - Company overview
  - Asset management overview
- Pilot description
  - Scope
  - Models / development and overview
  - Observations / results
  - Comparison to TERM-LITE
- Relationship of pilots results to RTD practice
  - Prioritization of projects
  - Use and future plans for TAPT and TERM-LITE

RTD Overview

- Regional Transportation District in Denver, or RTD, started operation in 1972
  - Service area of 2,410 square miles in eight counties
  - Employs about 2,500 people
  - Over 140 bus routes, 80 Park-n-Rides, 10,000 stops
  - Approximately 1,200 full size buses, 400 cut-a-way buses, 400 support vehicles.
  - 6 light rail lines, 49 stations
  - 174 Light rail vehicles
  - Accessibility services, call-n-Rides, seasonal rides and many other programs
  - Fastracks will add approximately 110 miles of track for light and commuter rail, and over 40 new Stations and P-n-Rs

RTD Overview

- Operates six light rail lines
  - Central Line (1994)
  - SW (2000)
  - CPV (2002)
  - Se (2006)
  - I-225 (2006)
  - West (2013)
- Bus fleet
  - Includes a mall fleet and intercity bus fleet in addition to regular service



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RTD's Asset Management Program

- 2007 RTD Implemented a company wide ERP system.
- 2010 RTD's board of directors put into place the goal to create an Asset Management (AM) program with a State of Good Repair (SGR) component.
- Created an AM division and began the process of creating and implementing a SGR program in July 2011.
- Pilot successfully completed in Dec. 2011 with program adoption.
- Company wide Asset Management implementation started in 2012.
- Using Enterprise Asset Management (EAM) Data and the modular AM architecture developed during the pilot the program was rolled out.

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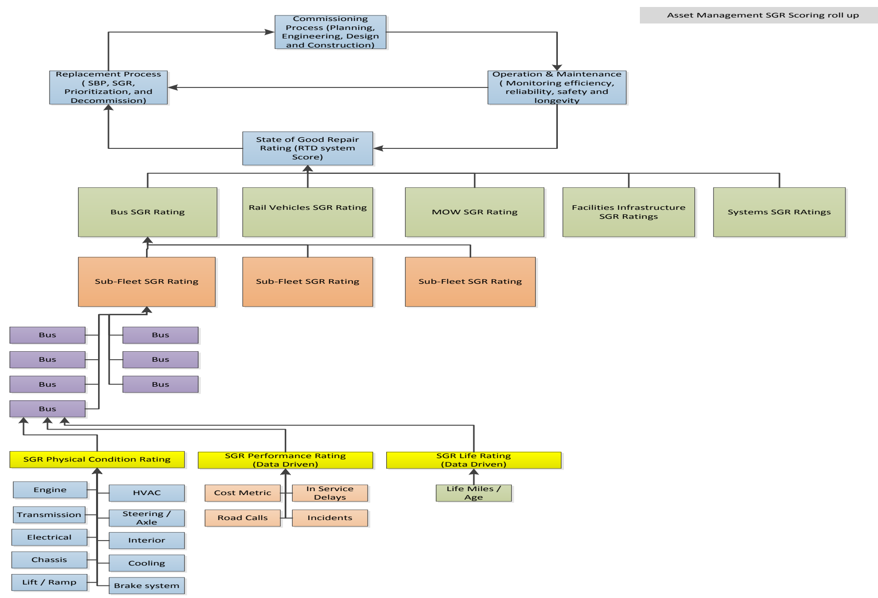
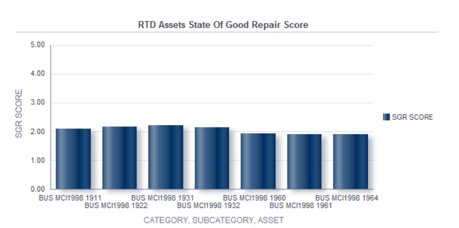
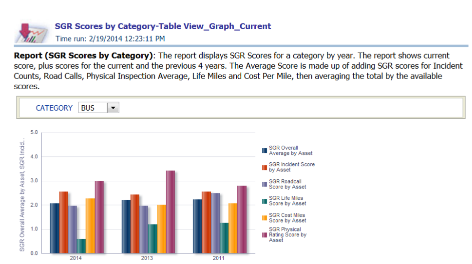
RTD Asset Management Architecture



AM System Output

- Data is housed in an Enterprise Asset Management software (EAM) AssetWorks or Maximus" database (historical data starting in 2007)
- AM and SGR reporting & analysis is preformed using ETLs (Extract, Transform and load process) to a data warehouse and using Oracles Business Intelligence Enterprise Edition (OBIEE 11.5)





TCRP E-09A Pilot Scope

- Create models for selected assets
  - Buses
  - Light Rail Vehicles
  - Guideway and Track
  - Facilities
- Prioritize projects across assets and determine how funding should be allocated across asset-types
- Predict future conditions based on multiple funding scenarios
- Compare TAPT projections to TERM

Vehicle Inventory Modeled

- 118 Articulated Buses
- 36 Mall Buses
- 164 Intercity Buses
- 317 40' Transit Buses

- 49 SD100 Light Rail Vehicles
- 123 SD160 Light Rail Vehicles

Vehicle Model Development

- Data sources
  - 2011 NTD data
  - RTD Strategic Budget Plan (SBP)
  - Enterprise Asset Management (EAM) System data
  - 2013 operations data
  - TERM Lite for cost estimates
- Vehicle data from NTD and replacement costs based on RTD estimate from SBP
- Light rail vehicle data was prorated between SD100 and SD160 fleets
- Defaults used for all other inputs
  - Rehab cost per mile of articulated buses increased based on RTD experience

Vehicle Model Results

Vehicle Type	Optimal Replacement Mileage	Optimal Replacement Age	Average Annual Cost
Articulated	569,000	16	$191,000
Mall	219,000	15	$128,000
Intercity	1,085,000	18	$177,000
40-ft	665,000	15	$142,000

Vehicle Type	Optimal Replacement Mileage	Optimal Replacement Age	Average Annual Cost
SD100	2,142,000	45	$532,000
SD160	2,337,000	31	$847,000

Guideway and Track Inventory

- Guideway (lineal ft)

258,214	Ballasted
16,032	Bridge
16,015	Embedded
2,075	Grade Crossing

- Track (lineal ft)

258,214	Tangent Ballasted
190,709	Curved Ballasted
16,015	Embedded
3,955	Grade Crossing
1,570	Special
14,092	Tangent Direct
5,325	Yard

- Notes
  - Guideway and track modeled separately using TERM default models
    - In practice RTD maintains these together
  - Created separate models for standard and intensive use track
  - 1,570 ft of track are classified as intensive use

Guideway and Track Model Development

- Used aged-based model
- Typically used default values, including decay curves and replacement costs from TERM
- Adjustments for intensive use track
  - TERM decay curves were used with a usage factor of 200%
  - Increased failure cost to account for increased user impacts of track closure

Guideway and Track Model Results

Track Type	Optimal Replacement Age	Average Annual Cost ($/ft)
Tangent Ballasted	33	55
Curved Ballasted	27	89
Embedded	23	88
Grade Crossing	23	91
Special Trackwork	26	380
Tangent Direct	26	58
Yard	29	66

Track Type	Optimal Replacement Age	Average Annual Cost ($/ft)
Tanged Ballasted- Int	26	61
Curved Ballasted- Int	21	101
Embedded- Int	18	105
Grade Crossing- Int	18	105
Special Trackwork- Int	20	440

Guideway Type	Optimal Replacement Age	Average Annual Cost ($/ft)
Ballasted	72	141
Bridge	72	1,903
Embedded	14	447
Grade Crossing	14	455

Facilities Inventory Modeled

- 4 Administrative Facilities
  - Blake Street Offices (built 1902 - remodeled 1983)
  - Security Center (2005)
  - Treasury Building (1989)
  - Wellness Center (1988)
- 4 Stations
  - Boulder Transit (1984)
  - Civic Center Station (1986)
  - LRV Station at DUS (2013)
  - Union Station (1894, major remodel in 2003)
- 6 Maintenance Facilities
  - Boulder Facility (1981)
  - District Shops Facility (1992)
  - East Metro Facility (1982)
  - Elati Facility (1998, major work 2013)
  - Mariposa Facility (1993. major work 2013)
  - Platte (1976, major work 2013)

Facility Model Development

- Age-Based Model
- Data sources
  - 2011 NTD data
  - RTD Strategic Budget Plan (SBP)
  - Enterprise Asset Management (EAM) System data
  - 2013 operations data
  - TERM Lite for cost estimates
- Facilities modeled as a single unit to reflect the best available data
- Default TERM decay curves used

Facility Model Results

Facility Type	Optimal Replacement Age	Average Annual Cost
Administrative	81	$459,000
Maintenance	51	$3,913,000
Stations	40	$2,227,000

Observations on the Models

- Vehicle models
  - A number of adjustments were needed to the vehicle models to generate realistic values for target replacement mileage
  - Mall Shuttles: adjusted failure rate based on EAM data, adjusted replacement cost
  - LRVs: adjusted annual mileage – future mileage will increase as a result of expansion
- Guideway/Track models
  - Required relatively little adjustment to defaults
  - Reduction in life for intensive use track consistent with engineering judgment
- Facilities
  - No adjustments made to defaults

Results – High Priority Projects

- Track and Guideway Projects
  - Guideway (Grade Crossings and Embedded) on Central Line (1994) – Rank 1
  - Guideway (Embedded) on SW Line (2000) PI – Rank 2
  - Intensive Use Track (Grade Crossing, Embedded, Special Trackwork, and Curved Ballasted) on Central Line (1994) – Rank 3
  - Guideway (Grade Crossing and Embedded) on CPV Line (2002) PI Index 5
  - Track (Embedded) on Central Line (1994) – Rank 1 (combine with guideway)
- Replacement of 1998 MCI 102DL3 Intercity Buses *PI Index 1*
- If work is deferred replacement of Mall Shuttles (2000-2002) is the next highest priority

Results – Comparison to TERM

Scenario	Initial Value (2014)	Value in 2023 Do Nothing	Value in 2023 $25M Annually	Value in 2023 Unconstrained
TAPT				
Unmet Needs ($000)	116,803	439,419	223,004	0
Cumulative Spent ($000)	N/A	0	209,415	439,419
MDBF (miles)	35,649	20,407	33,033	39,791
Average TERM Condition (non-vehicle assets)	4.68	4.39	4.54	4.62
TERM				
Unmet Needs ($000)	761,500	1,513,800	1,281,900	0
Cumulative Spent ($000)	N/A	0	250,000	1,775,200
Percent of Assets Exceeding Useful Life	4.6%	24.8%	22.0%	22.7%
Percent of Assets in Marginal or Poor Condition	18.6%	37.2%	31.0%	22.7%

Relationship of Pilot Results to Agency Practice

- TAPT priorities generally consistent with actual priorities
  - Embedded track is a high priority for replacement – (Project started in October of 2013)
  - Intercity buses and mall shuttles are scheduled for replacement or are being replaced (SGR scores 2.1 and 2.4)
- Interested in modifying vehicle models to account for condition
  - Can accomplish this through adjusting accumulated mileage
- Ideally would project facility needs at the system level – complete facility rehab/replacement rare
  - Roll out of new facility coding underway allowing future break down to system level.

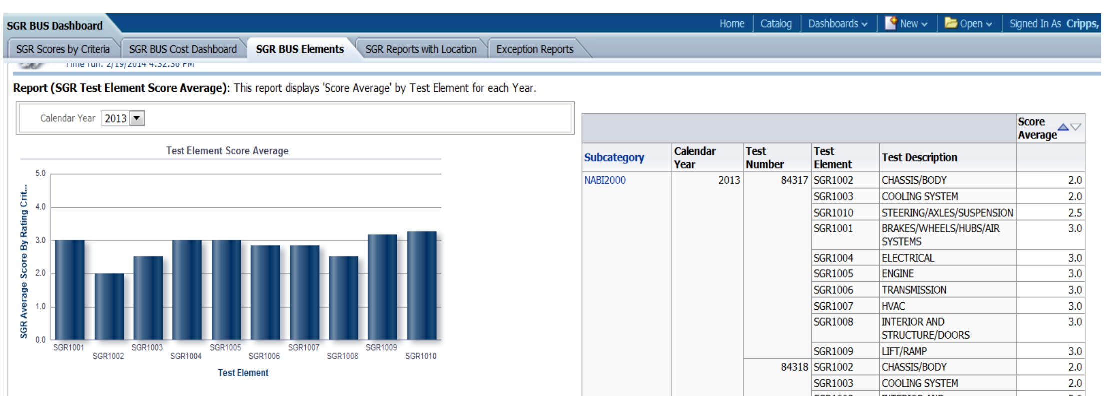
Central Embedded

Using system condition knowledge of embedded track RTD worked with SSP to calibrate the models. This added confidence in the TAPT tool for prioritization of future track projects.

Imbedded track section replaced down town after initial E-09A results.

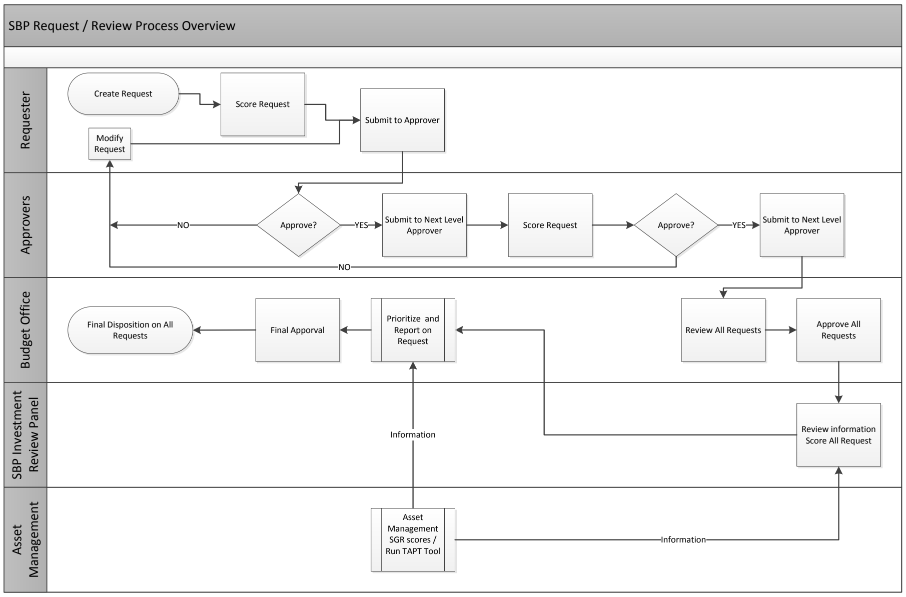
RTD Plans for TAPT

- RTD is using model results as an input into prioritization of strategic budget plans (SBP).
- SGR condition and performance based scores complement TAPT model results



Subcategory	Calendar Year	Test Number	Test Element	Test Description	Score Average
NABI2000	2013	84317	SGR1002	CHASSIS/BODY	2.0
			SGR1003	COOLING SYSTEM	2.0
			SGR1010	STEERING/AXLES/SUSPENSION	2.5
			SGR1001	BRAKES/WHEELS/HUBS/AIR SYSTEMS	3.0
			SGR1004	ELECTRICAL	3.0
			SGR1005	ENGINE	3.0
			SGR1006	TRANSMISSION	3.0
			SGR1007	HVAC	3.0
			SGR1008	INTERIOR AND STRUCTURE/DOORS	3.0
			SGR1009	LIFT/RAMP	3.0
		84318	SGR1002	CHASSIS/BODY	2.0
			SGR1003	COOLING SYSTEM	2.0

Results TAPT and AM as Inputs for Prioritization



Key Points: RTD

- Included a wide range of assets
- In particular experimented with different approaches for modeling vehicles and guideway/track
- Compared TAPT and TERM Lite Results
  - TERM Lite projects greater initial needs, less growth in needs
  - TAPT predicts a wider range of performance measures
  - Good agreement between the models where useful lives are well-aligned (e.g., track)
- Potential for further work to incorporate TAPT into agency business processes

TAPT Exercises

Exercise #1: Main Street Transit

- TAPT_MST for workshop_final.xlms
- Small transit agency reviewing vehicle inventory for transportation asset management plan (TAMP)
- Objectives:
  - Introduction to the tool
  - Using the vehicle model
  - Reviewing the summary statistics, program list, and graphing capabilities

Exercise #2: Springfield Transit Authority (optional)

- TAPT_STA for workshop_final.xlsm
- Mid-sized transit agency developing a cross-asset prioritization plan
- Objectives:
  - Cross-asset prioritization
  - Using the condition- and age-based models
  - Developing pipeline projects
  - Comparing multiple budget scenarios

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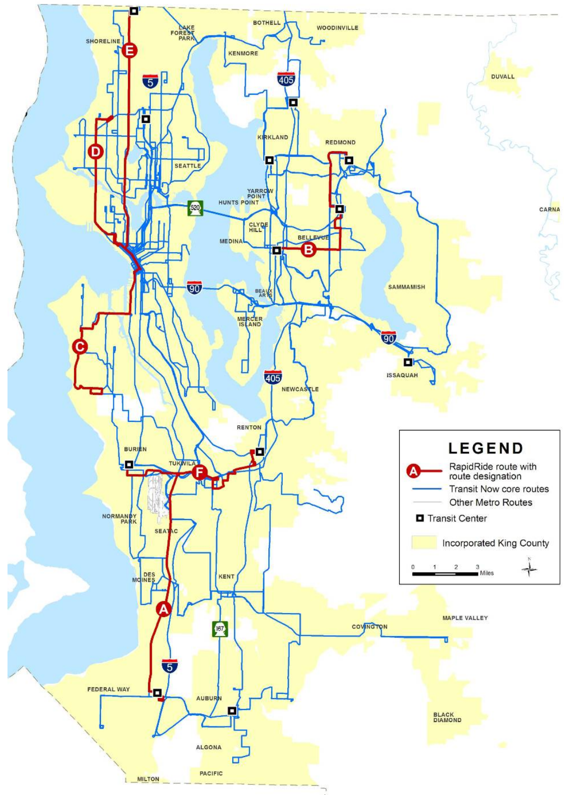
King County Metro Transit

King County Metro Transit

- Service Area
  - 39 cities
  - 2134 sq. miles
  - 1.9m population
- Metro Transit
  - 1350 buses
  - 4500 employees
  - 120m passengers



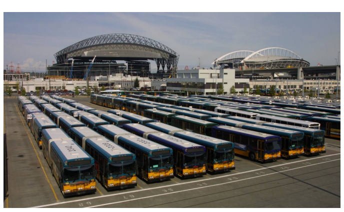
Metro's Services

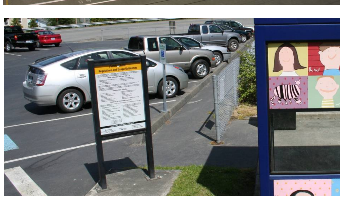
- Bus
- Paratransit
- Commuter vans

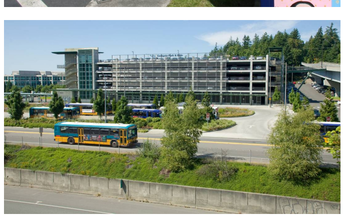
Operates and Maintains

- ST Express Bus
- Streetcar
- Link Light Rail

Major Facilities







- 7 Bases, 14 support facilities
- 54 Park-and-Ride lots, 22,500 spaces
- 6 Parking Garages

Downtown Seattle Transit Tunnel

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Green Fleet

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RapidRide

What's Next for Metro?

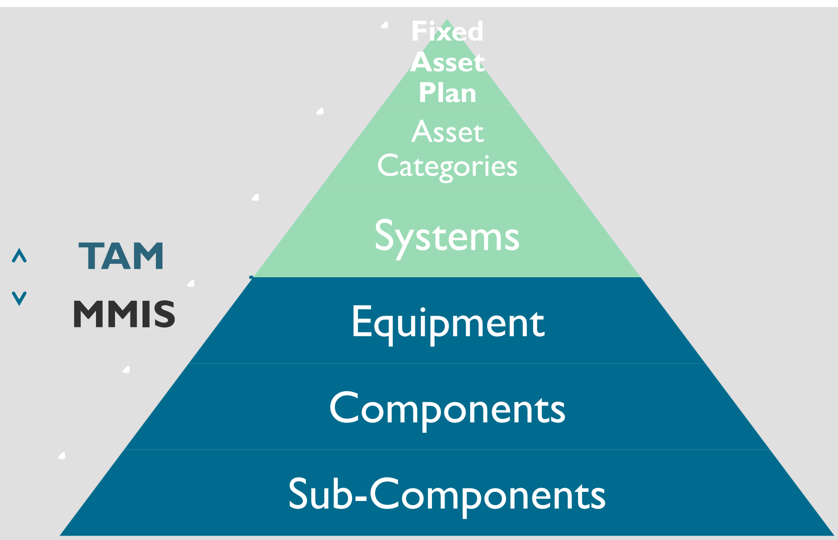
- Growing ridership
- Potential Service reductions
- Seeking sustainable funding
- Maintaining SGR through Asset Management Planning

King County Metro

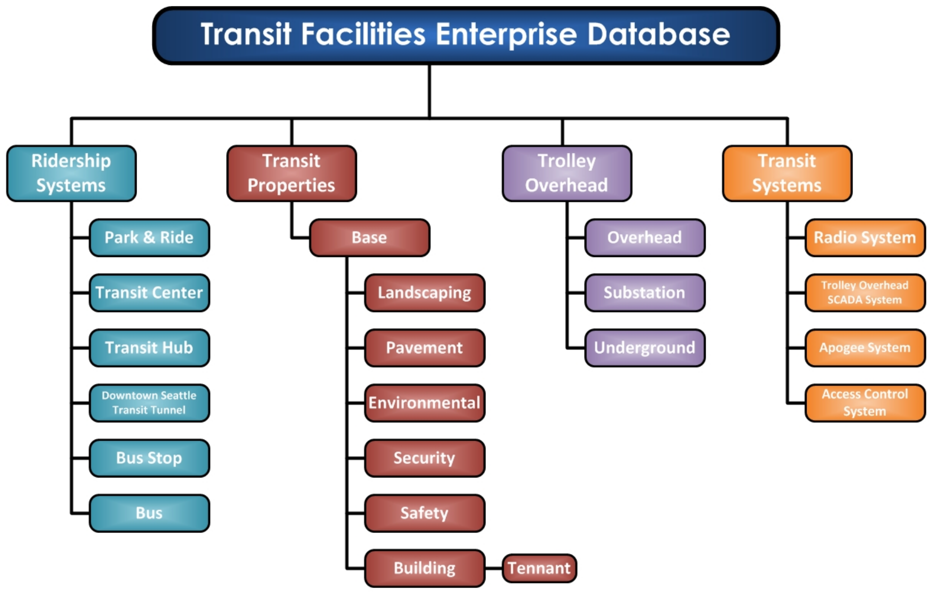
Evolution of Fixed Asset Management Program

- KC Metro – Transit Asset Management Program established in 1985 based on a 6 year planning model
- In 1992 an off the self MMIS system (Datastream MP2) was procured and modified to better track asset data and used primarily as work order system.
- The program to this point was based primarily on asset age with as needed condition assessments
- In 2008 INFOR software system was purchased to provide a more robust and flexible asset management tool for fixed asset data tracking and planning
- In 2012 added INFOR EAM module to support deployment a full asset management program
- Now in the process of being updated to include condition data on all asset categories.
- Metro is currently developing an approach for refining prioritization methods and use of tools for better documentation and decision making

Fixed Asset Management



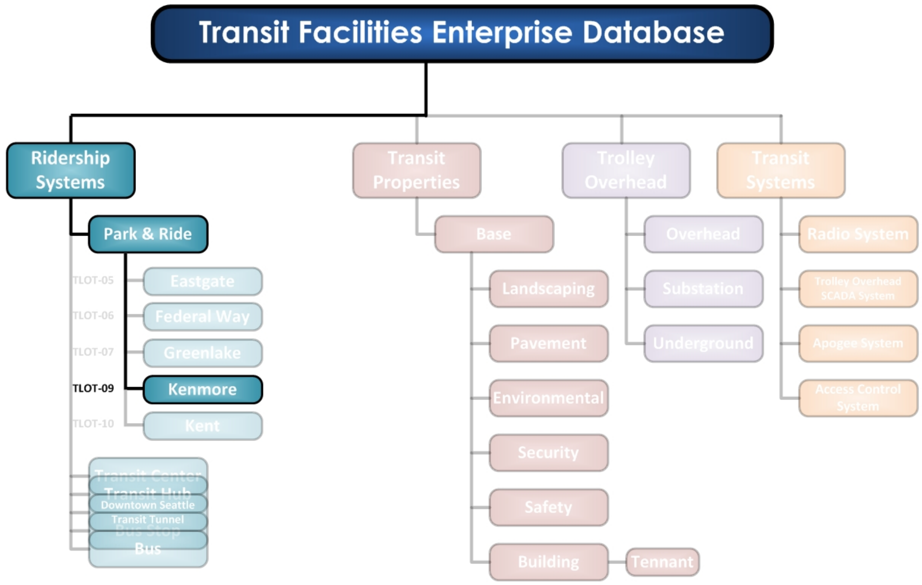
Transit Facilities Enterprise Database



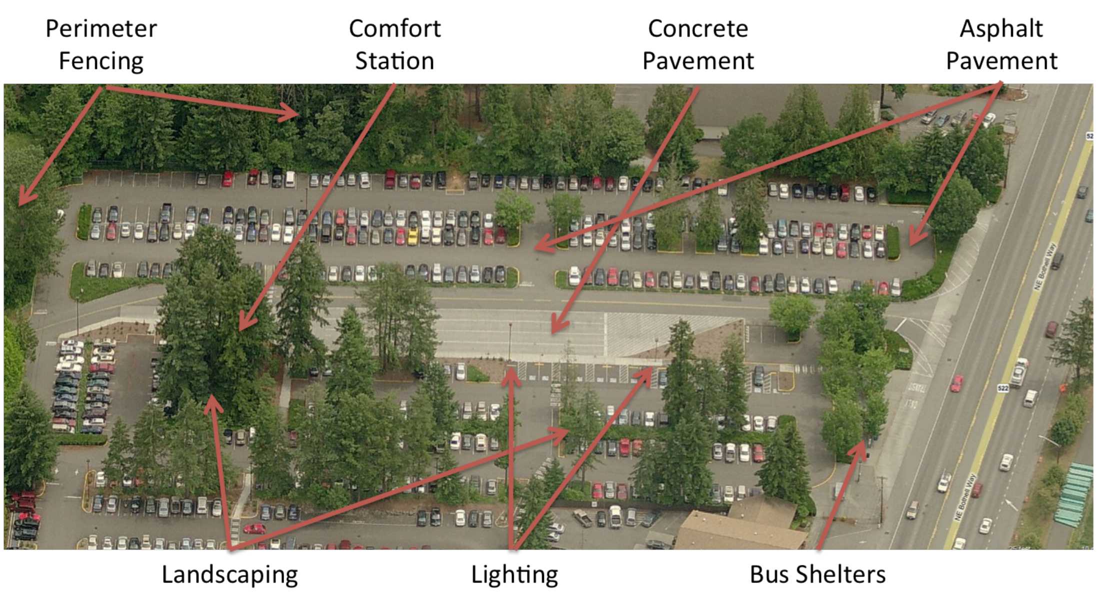
Transit Fixed Asset Management

Ridership Systems

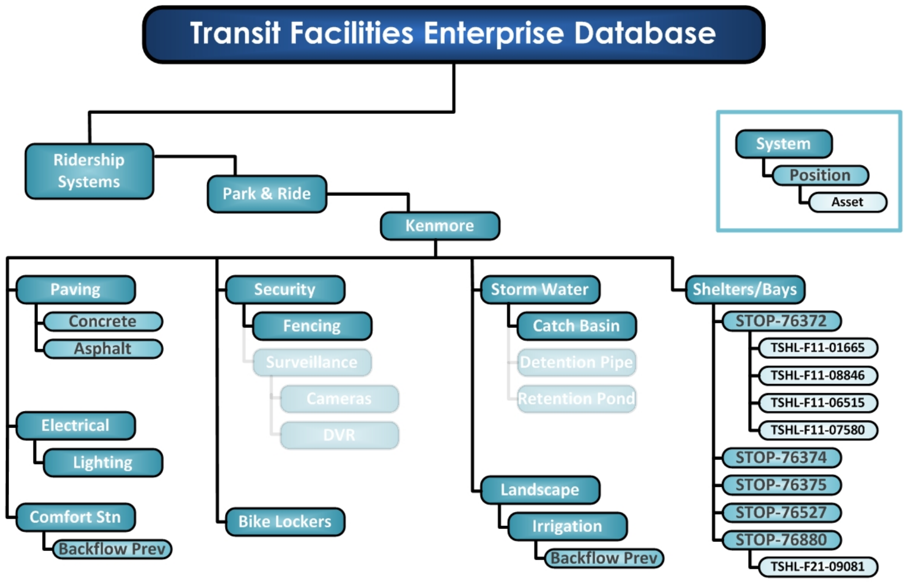
Ridership Systems
Park and Ride



Kenmore Park & Ride
Aerial View



Ridership Systems
Park and Ride



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Transit Fixed Asset Management

Transit Properties

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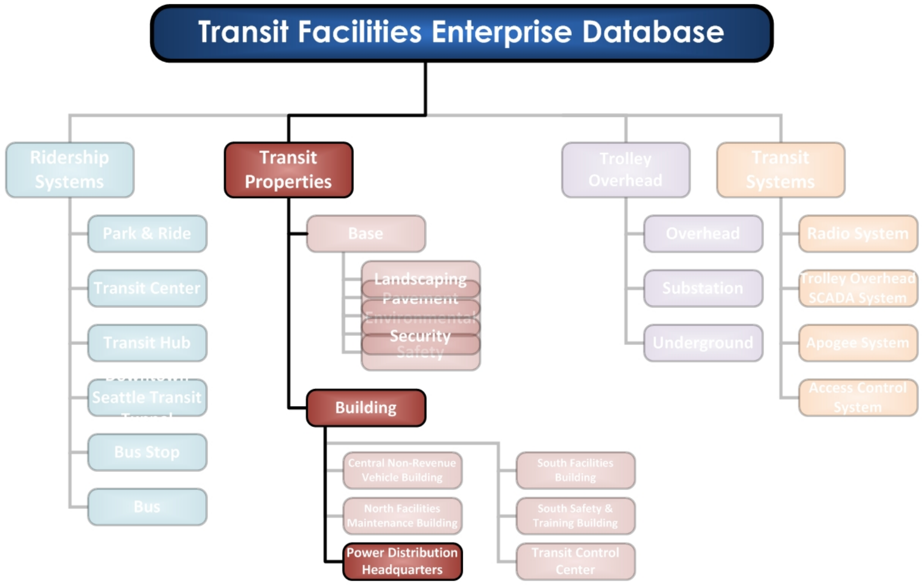
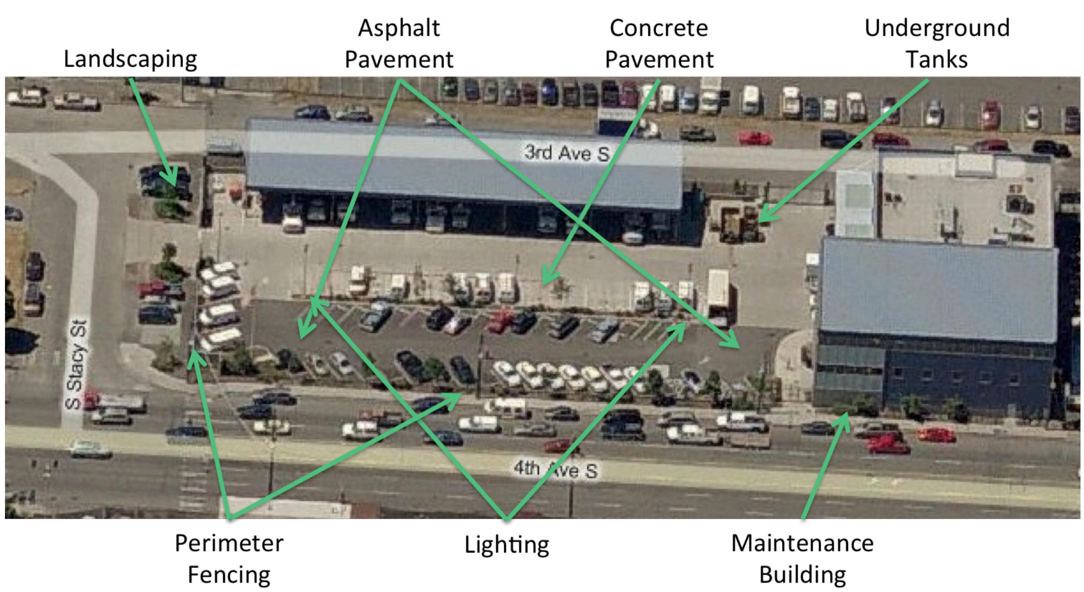
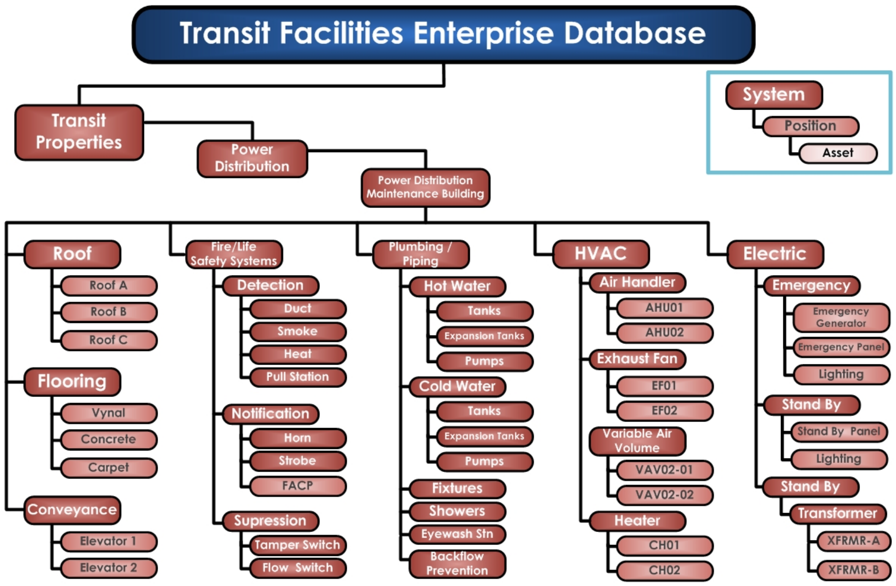
Transit Properties Building



Power Distribution Aerial View



Transit Properties Power Distribution



TCRP E-09A Pilot Scope

- Create models for selected assets
  - Transit/Articulated Buses
  - Bus Rapid Transit
  - Trolleybus
  - Fire Detection Systems
  - Fuel Management Systems
  - HVAC
  - Roofs
- Prioritize projects across asset types
- Predict future conditions based on various funding scenarios
- Demonstrate use of age and condition data for modeling of non-vehicle assets

Vehicle Inventory Modeled

- 617 Transit Buses
- 621 Articulated Buses
- 36 Bus Rapid Transit
- 158 Trolleybuses

Vehicle Model Development

- Data Sources
  - 2011 NTD data
  - King County Trolley Bus Evaluation
- Energy costs based on energy consumption and unit costs in the trolley bus evaluation
- Replacement costs based on the trolley bus evaluation
  - Cost includes the addition of auxiliary power not available in the existing fleet

Vehicle Model Results

Vehicle Type	Optimal Replacement Mileage	Optimal Replacement Age	Average Annual Cost
Transit/Artic Bus	606,000	19	$165,000
Bus Rapid Transit	504,000	18	$221,000
Trolleybus	425,000	22	$220,000

Facility Inventory Modeled

- Facilities
  - 16 Fire Detection Systems
  - 17 Fuel Management Systems (FMS)
  - 41 HVAC Systems
  - 55 Roofs
- Notes
  - Represents a subset of the facility systems at King County Metro's administrative and maintenance facilities
  - Assets quantities specified in gallons for FMS, sq ft for other systems

Facility Model Development

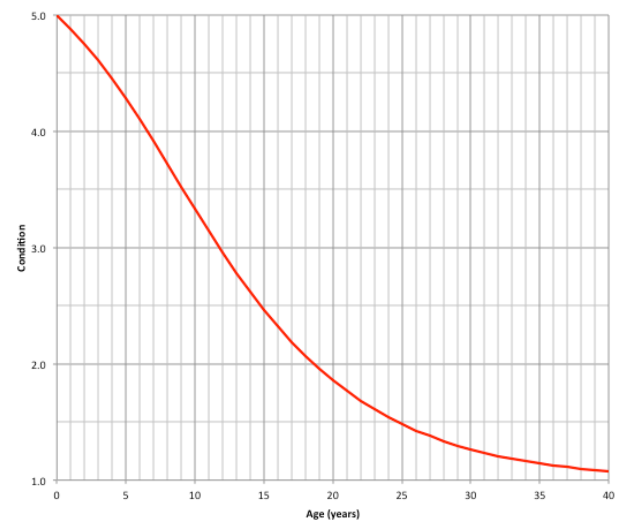
- Age-based model for Fire, FMS, and HVAC
- Condition-based model for Roofs
- Inventory and condition/age data based on King County facility condition reports
- Deterioration models
  - Approximated based on historic timing of actions for Fire, FMS ,HVAC
  - For Roofs determined a set of deterioration probabilities that matched descriptions of each condition state
- Costs
  - Determined unit costs based on project costs
  - Failure costs adjusted based on asset criticality

Facility Model Results

Asset Type	Optimal Replacement Point	Average Annual Cost ($/unit)
Fire Protection System	27 years	$0.40
Fuel Management System	15 years	$1.24
HVAC	20 years	$20.50
Roof	Condition $\leq$ 2	$1.19

Roof Deterioration Model

- King County condition state language
  - 5: needs action in 15-20 years
  - 4: needs action in 8-15 years
  - 3: needs action in 5-7 years
  - 2: needs action in 2-4 years
  - 1: needs action this year
- Translated this into a set of deterioration probabilities

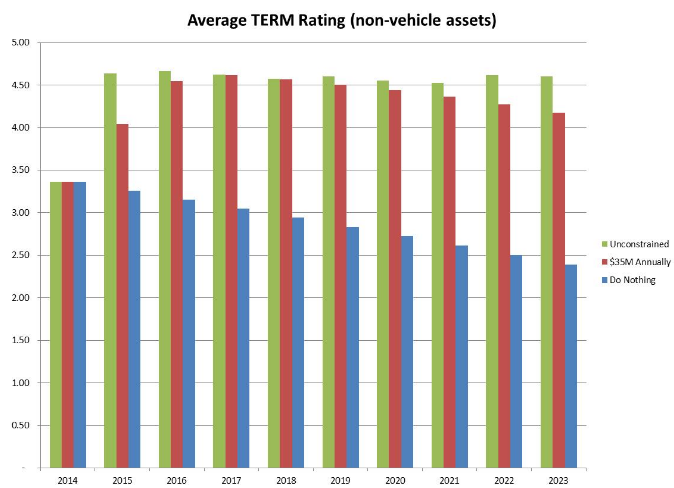


Results – Performance by Budget Scenario

Scenario	Initial Value (2014)	Do Nothing Scenario	$35M Annually Scenario	Unconstrained Scenario
Unmet Needs ($000)	309,231	801,867	472,799	0
Cumulative Spent ($000)	N/A	0	329,068	801,867
MDBF	3,770	1,970	2,159	4,971
Average TERM Condition (non-vehicle)	3.37	2.39	4.18	4.60
Passenger Delay	292,965	560,675	513,912	227,311
CO2 Emissions	180,113	188,200	167,995	138,691
Other Agency Costs	205,648	305,668	238,689	153,006
Total Agency and User External Costs ($000)	224,151	337,322	268,365	167,336

TAPT Results

- Projections of performance over time
  - Financial measures
  - MDBF for buses
  - TERM condition for fixed assets
  - Energy consumption
  - CO_2 emissions
- Highest priority projects
  - Roofs
  - FMS
  - HVAC



Relationship of the Pilot to Agency Practice

- Particularly valuable for demonstrating development of prioritization models for facility systems
- Model recommendations align well with agency practice
  - Replacement intervals for Fire, FMS, HVAC comparable to that observed in practice
  - Condition-based model for roofs yields a result consistent with expert judgment and leverages available condition data
- A number of other issues outside that model are relevant in project scoping – e.g., technical obsolescence

King County Metro

Fixed Asset Replacement/Renovation Prioritization

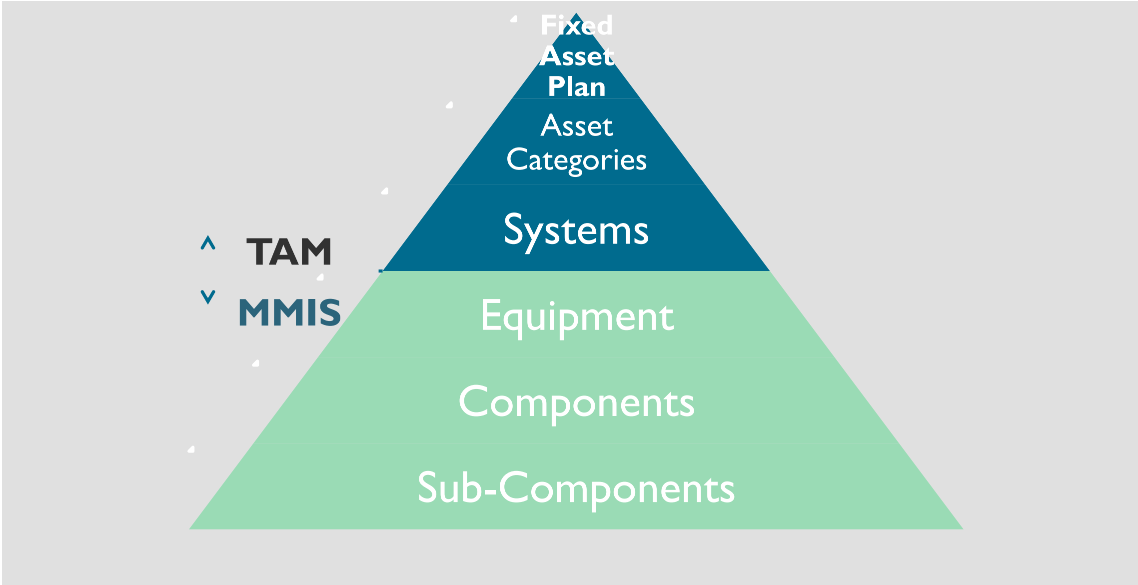
- 1-5 scoring matrix for determining the condition of an asset or category of assets is used based on remaining useful life.
- A priority/criticality weighting of 0-10 is incorporated with the condition ratings.
- Obsolescence and technological compatibility is considered.
- SGR definition: An asset is in a SGR when able to preform the function it was originally constructed/purchased for in a safe and reliable manner.
- The result will be the scoring methodology to be used as part of the TAPT prioritization process.

Criticality Consideration

Criticality Characteristics

- Mission/operational Impact
- Customer impact
- Environmental, health, safety
- Regulatory
- Single point of failure
- Reliability/maintenance
- Spares, inventory
- Financial

Fixed Asset Management



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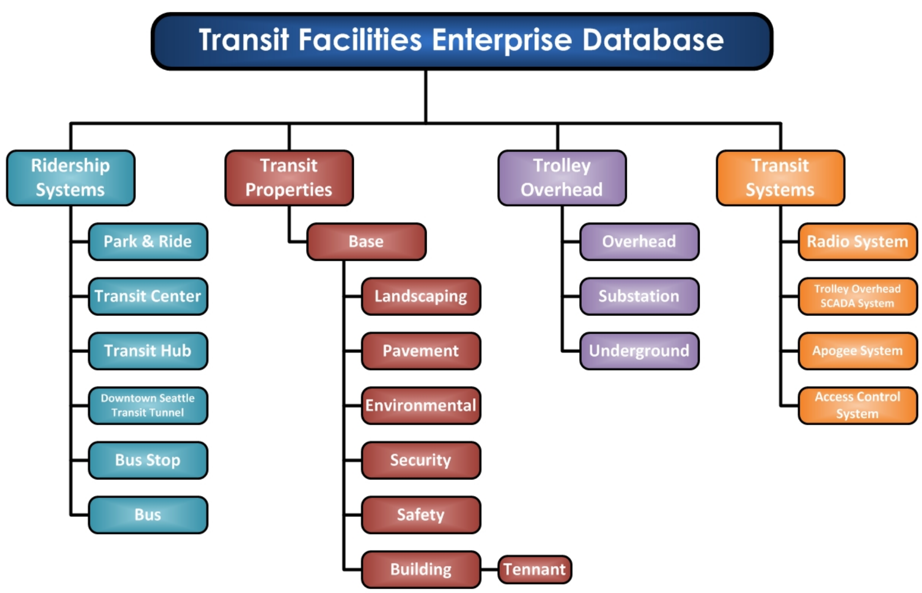
Transit Facilities Enterprise Database



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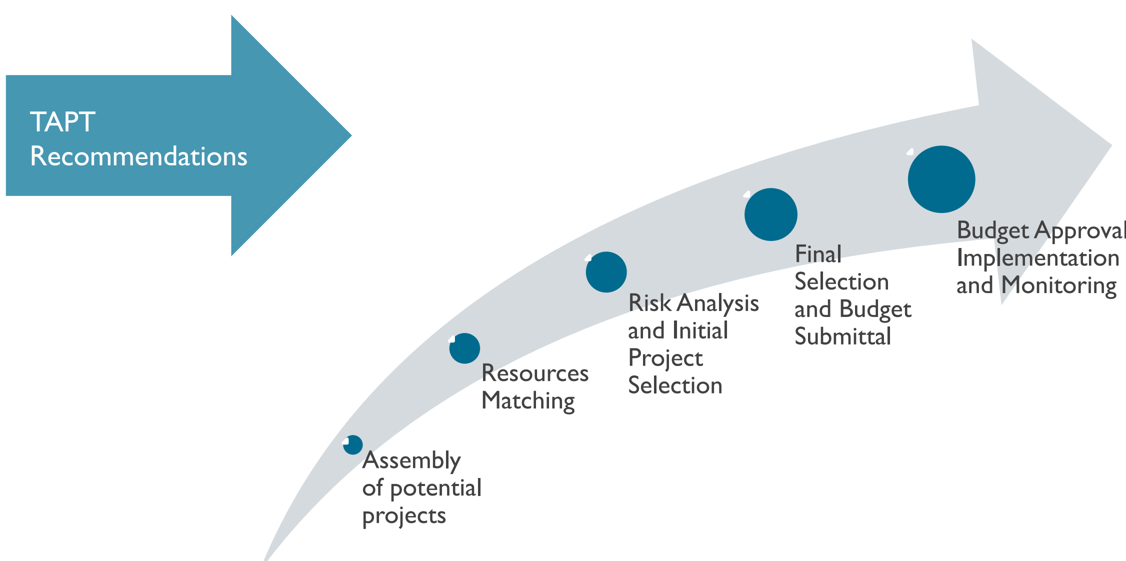
Asset Management Plan Process

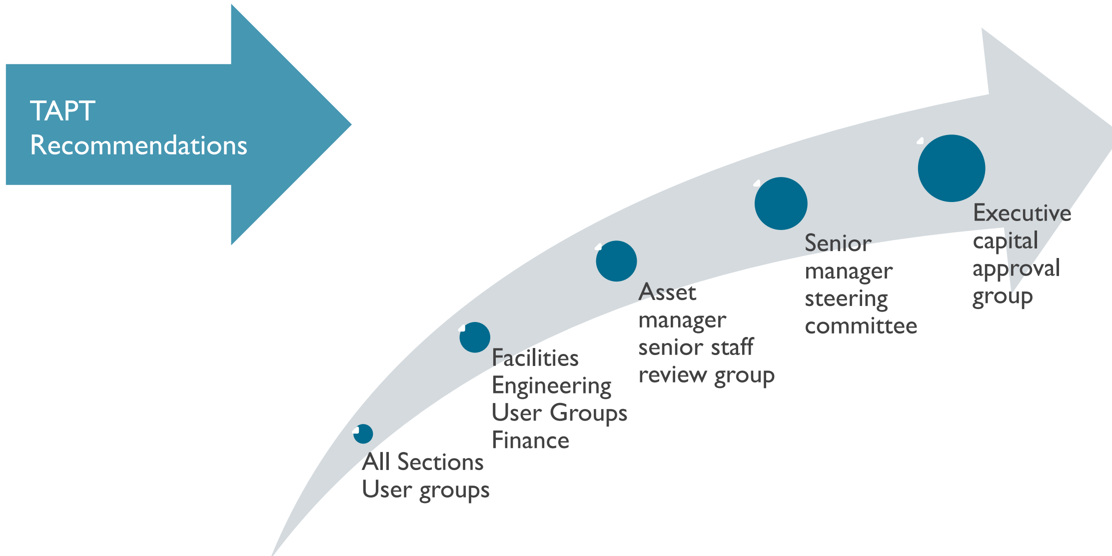
King County Metro

1) Conducts or verifies its inventory of all Fixed Assets annually
2) Is currently conducting an condition assessment of all fixed assets on a continual basis
3) Is updating its Asset Management/MMIS system to seamlessly integrate all asset data
4) Fixed Asset data (using a TAPT) will be analyzed and initially prioritized
5) Capital reinvestment recommendations are made based on asset condition, age, criticality and available funding

Decision Matrix



Decision Process



King County Metro

Further progression towards completing MAP-21 compliant TAM plan

- Complete the current round of condition assessments for fixed assets
- Select and use prioritization tools to assist in planning and prioritizing future asset reinvestment decisions
- Implement processes for the continuous update of asset condition database
- Complete development of targets and performance measures to conform with MAP-21 criteria
- Metro's present approach to Asset Management is flexible and robust enough to incorporate with a written policy and plan to meet MAP-21 requirements

Key Points: King County

- Best test of use of the models for fixed assets
- Only test of the condition-based model (used for modeling roofs)
  - Model performs well where condition data are available
- Pilot informed enhancements to the age and condition-based models – e.g., simplifying entry of deterioration data

Recommendations & Feedback

- Discussion Topics
  - Questions about TAPT functionality
  - Utility of TAPT for transit agencies
  - Benefits of using TAPT
  - Challenges of using TAPT
  - Suggested enhancements