APPENDIX H: TECHNOLOGY RECOMMENDATIONS

MEMORANDUM

To: Stephen Falbel, Steadman Hill **From:** Carol Schweiger, Schweiger Consulting

Date: September 10, 2019 **Subject:** Technology Task – Subtasks 3 and 4

CC:

Purpose of the Memo

The New Hampshire Department of Transportation (NHDOT), Bureau of Rail and Transit, tasked Steadman Hill Consulting to identify appropriate technology investments for the coming ten-year period, and document how technology investments could help lead to the success of existing transit/paratransit services (e.g., possibly encourage ridership), and how they would be used to facilitate any new proposed transit/paratransit services. In order to accomplish these subtasks, Schweiger Consulting determined the relative priority of technologies that are relevant to urban and rural transit agencies in NH. Further, Schweiger Consulting determined the cost of these technologies that could be deployed in the future so that the most appropriate investments can be identified.

1. Review Appropriate Technologies and Their Interactions

In Technical Memo 1, the technologies shown in Table 1 were identified as being applicable to fixed-route, paratransit and flexibly-routed services in NH, as shown in Table 1.

Table 1. Technology Applicability

Category/Component	Applicability (R=Rural, U=Urban and LU=Large Urban[1])
Fleet Operations and Management:	
Communications technologies	R, U, LU
Automatic vehicle location (AVL)	R, U, LU
Computer-aided dispatch (CAD)	R, U, LU
Automatic passenger counters (APCs)	R, U, LU
Scheduling (fixed-route and paratransit) systems	U, LU
Transfer connection protection (TCP)	U, LU
Transit signal priority (TSP)	U, LU
Yard management	LU
Intelligent vehicle technologies (e.g., collision warning and precision docking)	R, U, LU
Lane control technologies	R, U, LU

[1] There are no Large Urban transit operations in NH, but we still provide a description of the technologies that are only applicable to Large Urban operations.

Category/Component	Applicability (R=Rural, U=Urban and LU=Large Urban[1])
Traveler Information:	
On-board automated voice announcements (AVA)	R, U, LU
En-route/wayside traveler information, including real-time arrival/departure information in a variety of dissemination media	R, U, LU
On-board Internet access for passengers	R, U, LU
511, 311 and 211 systems, and Google Transit	R, U, LU
Third-party smartphone applications	R, U, LU
Safety and Security:	
Mobile (on-board and exterior) and fixed video surveillance	R, U, LU
Covert emergency alarm and covert live audio monitoring	R, U, LU
On-board digital video recorders	R, U, LU
G-force monitoring (aka electronic data recording system [EDRS])	R, U, LU
Automated Fare Payment:	
Automated fare media (e.g., magnetic stripe cards, contact smartcards, contactless smartcards and smartphone-based payment methods)	R, U, LU
Automated fareboxes and faregates	U, LU
Ticket vending machines	U, LU
Maintenance:	
Engine and drivetrain systems monitoring (aka vehicle component monitoring [VCM])	R, U, LU
Maintenance software to schedule and track scheduled and unscheduled maintenance activities, and manage parts inventory	R, U, LU
Other:	
Data management and reporting	R, U, LU
Technology integration	R, U, LU
Geographic information system (GIS) application	R, U, LU
Service coordination facilitated by technology	R, U, LU
Open data for third-party application development	R, U, LU

Further, Table 2 shows the dependencies among the technologies.

Table 2. Dependencies Among Transit ITS Technologies

Category	System/Technology	Dependent on
Fleet Operations and Management	Communications technologies	Public/private voice and data communication backbones
	Computer-aided dispatch (CAD)	• Voice and data communications technologies • Automatic vehicle location (AVL) system • Route and vehicle schedule data

Category	System/Technology	Dependent on
	Automatic vehicle location (AVL)	• Data communications technologies • Global positioning system (GPS) or other location enabling technologies, such as WiFi
	Automatic passenger counters (APCs)	• AVL system • Route and vehicle schedule data
	Scheduling (fixed-route and paratransit) systems	Stop database (contains data such as stop name, location, routes that stop at this stop, direction of travel from this stop, list of amenities available at this stop)
	Transfer connection protection (TCP)	• AVL system • CAD system
	Transit signal priority (TSP)	• AVL system • CAD system (when TSP used based on schedule adherence status) • Roadside signal infrastructure
	Yard management	Indoor positioning systems (e.g., radio frequency identification [RFID]-based, WiFi-based)
	Intelligent vehicle technologies (e.g., collision warning and precision docking)	Varies by technology application and deployment
	Lane control technologies	• AVL system • CAD • Virtual mirror • Lane guidance systems • Roadside signal infrastructure
Traveler Information	On-board automated voice announcements (AVA)	• AVL system • Route and vehicle schedule data
	En-route/wayside traveler information, including real-time arrival/departure information in a variety of dissemination media	• Route and vehicle schedule data • AVL system • CAD system • Data communications technologies
	On-board Internet access for passengers	Data communications technologies
	511, 311 and 211 systems, and Google Transit	Open data
	Third-party smartphone applications	Open data

Category	System/Technology	Dependent on
Safety and Security	Fixed video surveillance	Data communications technologies
	Covert emergency alarm and covert live audio monitoring	• Voice and data communication technologies • CAD system • AVL system
	On-board digital video surveillance	No dependence on other systems
	G-force monitoring (EDRS)	AVL system
Automated Fare Payment	Automated fare media (e.g., magnetic stripe cards, contact smartcards, contactless smartcards and smartphone-based payment methods)	Fare media processing units
	Automated fareboxes	No dependence on other systems
	Automated faregates	Data communications technologies
	Ticket vending machines (TVMs)	Data communications technologies
Maintenance	Vehicle component monitoring (VCM)	OBD-II[2] or Society of Automotive Engineers (SAE) J1708/J1939 compatibility of on-board computers within engine and drivetrain
	Maintenance software to schedule and track scheduled and unscheduled maintenance activities, and manage parts inventory	No dependence on other systems
	Fuel Management System	No dependence on other systems
Other	Enterprise database/ data warehouse and reporting	• Open databases • Data dictionary
	Technology integration	Multiple dependencies[3]
	Geographic information system (GIS) application	Spatial data recording and management systems
	Service coordination facilitated by technology	• CAD/AVL systems shared across participants • Voice and data communications technologies
	Open data for third-party application development	Standard format for data such as General Transit Feed Specification (GTFS) and GTFS-real time

[2] OBD-II is a standard that monitors engine, chassis, body and accessory devices in a vehicle
[3] To be defined later in this memo

2. Hierarchy/Level of Technologies

In order to determine the relative priority among these technologies for deployment in NH transit agencies, it is important to identify the "core" technologies and their relationships (see Figure 1). Please note that Table 3 summarizes the technology hierarchy and components of each tier.

Abbreviations:

- Computer-aided dispatch (CAD)
- Automatic vehicle location (AVL)
- Automatic passenger counter (APC)
- Route and schedule adherence (RSA)
- Estimated time of arrival (ETA)
- Automated voice announcements (AVA)
- Public service announcement (PSA)
- Real-time information system (RTIS)

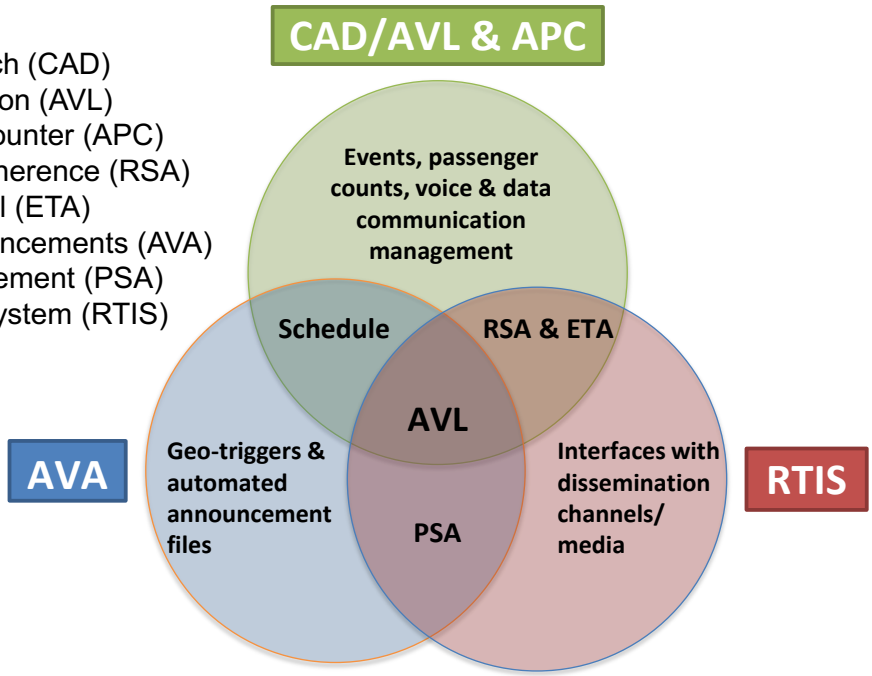

Figure 1. Core Technology Dependencies

The most important backbone technology that enables these core technologies is voice and data communication. Most NH agencies have this already, although a few agencies may be moving away from radio frequency (RF) communication and toward cellular communication. In any case, voice and data communication is the number one priority for all NH transit agencies.

NH transit agencies that do not already have the core technologies shown in Figure 1, which bridge the Fleet Operations and Management, and Traveler Information categories, should consider deployment of these specific technologies first (Tier 1), particularly CAD/AVL, which provides the backbone needed for the use of the other core technologies. Procuring these technologies together can be less costly than purchasing them separately and having to integrate them separately. For example, computing and providing real-time information to customers can only be accomplished when the system knows where transit vehicles are located (requiring AVL) and where they should be located according to the schedule (can require scheduling software for larger agencies). Once real-time information is available, it can be disseminated using a wide variety of media as indicated in the Traveler Information technology category.

Another example is automatic passenger counters (APCs). The implementation of this technology is typically less expensive if implemented at the same time as CAD/AVL. Also, APCs are typically integrated with CAD/AVL so ridership counts are tagged with a location, date and time. However, this technology is considered a Tier 2 priority, so we will identify the cost if this item is procured separately from CAD/AVL technology.

Another Tier 1 technology is a third-party smartphone application. If an agency wishes to have a mobile traveler information application developed by a third-party, it is highly recommended that the agency provides its operational data to the public (a.k.a. open data, which is in the Other technology category). This requires staff effort to "clean" the data that is being made available to the public. While there are several resources available to transit agencies that are considering opening their operational data to the public, one background document that could be helpful is TCRP Synthesis 91 "Use and Deployment of Mobile Device Technology for Real-Time Transit Information."[4]

One other technology that is in the Other technology category should be considered as Tier 1 as well: technology integration. Technology integration is required among the Tier 1 on-board technologies as well as among some centrally-located technologies (e.g., CAD integrated with AVL).

The next most desirable technologies (Tier 2) are mostly in the Safety and Security category. As shown in Table 2, a covert emergency alarm and covert live audio monitoring is dependent, in part, on CAD/AVL. On-board digital video surveillance, while not dependent on other technologies is often integrated with AVL in order to identify the specific location(s) where an event or events of note have taken place. Also, buses can be procured with camera systems already installed, which can be less expensive than procuring them later. Finally, fixed video surveillance, such as that installed at a bus stop or terminal location requires data communication in order to be remotely monitored.

Two technologies in the Other category that should be considered in Tier 2 are GIS and service coordination facilitated by technology (including paratransit CAD/AVL). GIS greatly facilitates data analysis. Rather than procure GIS, NH transit agencies may be able to access and use GIS software from the Regional Planning Commission in their area.

The next most desirable technologies (Tier 3) are in the Maintenance, Safety and Traveler Information categories. In the Maintenance category, there typically is no dependence on other technologies – technology integration with, for example, CAD/AVL, is not required. However, real-time VCM requires integration with the on-board vehicle area network (VAN) so that if on-board technologies experience out-of-

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[4] Carol Schweiger, "Use and Deployment of Mobile Device Technology for Real-Time Transit Information," TCRP Synthesis 91, Transportation Research Board, 2011, https://www.pcb.its.dot.gov/t3/s120626/tcrp_syn_91.pdf

tolerance conditions, the situation can immediately be communicated to dispatch/operations and maintenance.

In the Safety category, G-force monitoring, which measures sudden acceleration and deceleration (and is often associated with an event data recording system [EDRS]), is dependent on the AVL system.

In the Traveler Information category, the Tier 3 technologies are on-board Internet for passengers; 511, 311 and 211 systems; and Google Transit (or similar third-party itinerary planners). In terms of on-board Internet for passengers, the following should be considered when determining whether or not on-board Internet should be procured:

- If multiple on-board technologies are integrated using a mobile router or wireless gateway platform, on-board passenger Internet can be added easily for a small marginal cost;
- For longer bus routes, on-board Internet for passengers should be considered;
- On-board Internet for passengers can enhance the rider experience, attract choice riders and reward loyal riders;
- If college and university students are a significant portion of an agency's ridership, on-board Internet should be considered; and
- Current cellular providers are providing more large data plans at very reasonable prices, meaning that riders may not take advantage of on-board Internet, particularly if the passenger has to pay for Internet access.

The next most desirable technologies (Tier 4) are in the Automated Fare Payment category. With the advent of account-based and mobile fare payment, the cost of fare collection and payment has been reduced over the past five years (see next section). However, equity and accessibility issues must be addressed when utilizing technology-enabled fare payment. For example, customers who can only afford to pay on a trip-by-trip basis or do not have a smartphone will need a way to add cash to their fare payment media or pay using media other than a smartphone (e.g., smartcard).

The next group of technologies (Tier 5) are in the Fleet Operations and Management, and Other categories. These are as follows:

- **Transfer connection protection (TCP)** – this functionality can facilitate customers' transfers between bus routes. While this functionality has been in existence for many years, it has not always been successfully deployed. Agencies wishing this technology should examine current deployments to determine the feasibility and benefits of TCP.
- **TSP** – There are several types of TSP, including the following:
  - Passive priority: "Passive priority does not require the hardware and software investment of active and adaptive priority treatments. Passive priority operates continuously, regardless, based on knowledge of transit route and ridership patterns, and does not require a transit detection / priority request generation system. In general, when transit operations are predictable with a good

understanding of routes, passenger loads, schedule, and/or dwell times, passive priority strategies can be an efficient form of TSP."[5]

- Active Priority: "Active priority strategies provide priority treatment to a specific transit vehicle following detection and subsequent priority request activation. Various types of active priority strategies may be used if available within the traffic control environment, including a green extension and early green.

- **Enterprise database/ data warehouse and reporting** – these are strategies to facilitate the storage, use and reporting of data generated by transit technologies. "Data warehousing is defined as a technique for collecting and managing data from varied sources to provide meaningful business insights. It is a blend of technologies and components which aids the strategic use of data. It is electronic storage of a large amount of information by a business which is designed for query and analysis instead of transaction processing."[6]

The final technologies to be considered for deployment (Tier 6) are two Fleet Operations and Management technologies, intelligent vehicle technologies (e.g., collision warning) and lane control technologies. Collision warning is available for detecting side and front objects, as well as passenger detection when the vehicle is turning. Lane control technologies assist with vehicle operation on highway lanes, particularly when operating in a breakdown lane (which is less wide than a normal highway lane). Please note that these technologies may become standard in transit buses in the near future due to their standardization and deployment in the passenger car market.

Table 3 summarizes the technology hierarchy and components of each tier.

Table 3. Tier Technology Components

Tier	Technology Component
1	Communications technologies
1	Automatic vehicle location (AVL)
1	Computer-aided dispatch (CAD)
1	On-board automated voice announcements (AVA)
1	En-route/wayside traveler information, including real-time arrival/departure information in a variety of dissemination media
1	Technology integration
1	Third-party smartphone applications
1	Open data for third-party application development
2	Automatic passenger counters (APCs)
2	Scheduling (fixed-route and paratransit) systems
2	Mobile (on-board and exterior) and fixed video surveillance

[5] Harriet R. Smith, Brendon Hemily, PhD and Miomir Ivanovic, ***Transit Signal Priority (TSP): A Planning and Implementation Handbook***, prepared for the United States Department of Transportation, May 2005, https://nacto.org/wp-content/uploads/2015/04/transit_signal_priority_handbook_smith.pdf

[6] https://www.guru99.com/data-warehousing.html

Tier	Technology Component
2	Covert emergency alarm and covert live audio monitoring
2	On-board digital video recorders
2	Geographic information system (GIS) application
2	Service coordination facilitated by technology (includes paratransit CAD/AVL)
3	Vehicle component monitoring (VCM)
3	G-force monitoring (EDRS)
3	Maintenance software to schedule and track scheduled and unscheduled maintenance activities, and manage parts inventory
3	On-board Internet access for passengers
3	511, 311 and 211 systems, and Google Transit
4	Automated fare media (e.g., magnetic stripe cards, contact smartcards, contactless smartcards and smartphone-based payment methods)
4	Automated fareboxes and faregates
4	Ticket vending machines
5	Transfer connection protection (TCP)
5	Transit signal priority (TSP)
5	Data management and reporting
6	Intelligent vehicle technologies (e.g., collision warning and precision docking)
6	Lane control technologies

3. Technology Costs

The unit costs of the technologies that comprise each tier are defined in this section. Capital costs and operations and maintenance costs are included, as well as agency labor/staff costs, implementation management costs (for agency staff and the vendor) and contingency costs. Further, we provide a cost range for each technology. The cost estimates are based on actual procurements of these technologies by a variety of transit agencies across the US over the past five years.

Table 4 shows a summary of available unit costs (in 2019 dollars). The detailed components of the unit costs are shown in Appendix A. Within Table 4, the reader can use the hyperlink in the second column to go to the specific table in Appendix A that contains the detailed components. These costs assume "one of each" component and appropriate interfaces to other technologies as are presented in Appendix A.

Table 4. Available Technology Unit Costs

Tier	Technology (hyperlinked to relevant Appendix A table)	Capital Unit Cost (low)	Capital Unit Cost (high)	Annual Operations and Maintenance Cost (low)	Annual Operations and Maintenance Cost (high)
1	CAD/AVL (including MDT) Unit Costs	$298,000	$599,000	$52,818	$98,493
1	AVA Unit Costs	31,000	67,000	17,000	26,200
1	Real-time Information System Unit Costs (including one of each of three types of dynamic message signs and IVR)	379,000	953,000	74,750	160,450
2	APC Unit Costs	30,000	66,000	30,725	44,900
2	On-board Surveillance Unit Costs	78,000	166,000	31,400	49,525
2	Paratransit Scheduling Software Unit Costs	131,000	313,000	14,120	37,620
2	Service coordination facilitated by technology (Paratransit CAD/AVL Unit Costs)	38,000	62,000	18,185	27,065
3	VCM and EDRS Unit Costs	128,000	250,000	31,788	45,900
3	Maintenance Management Unit Costs	170,000	406,000	35,250	71,550
3	Fuel Management Unit Costs	100,000	284,000	22,100	45,000
4	Automated Fare Payment Unit Costs	950,000		107,090	
5	TCP Unit Costs	288,000	497,000	7,746	11,620
5	TSP Unit Costs	22,000	72,000	6,063	13,450

4. Current Technology Status of NH Transit Agencies

As identified in the first memorandum, several NH transit agencies already have some of the technologies described previously. The following table shows which tier each agency has already reached.

Table 5. Current Technology Status[7]

Agency Name	Tier Reached

Advance Transit	• Part of Tier 1:
	  ○ Communications system
	  ○ AVL
	  ○ Real-time information
	  ○ Third-party smartphone applications
	• Part of Tier 2:
	  ○ Paratransit scheduling software
	  ○ Security cameras (later in 2019)
	• Part of Tier 3:
	  ○ Maintenance software
	  ○ Accounting and maintenance software (expected in 2020)

Cooperative Alliance for Seacoast Transportation (COAST)	• Part of Tier 1:
	  ○ Communications system
	  ○ Computer-aided Dispatch (CAD)/AVL
	  ○ Real-time information
	  ○ Third-party smartphone applications
	  ○ AVA
	• Part of Tier 2: Paratransit scheduling and dispatching and on-board tablets
	• Part of Tier 3: Maintenance software

Manchester Transit Authority (MTA)	• Part of Tier 1:
	  ○ Communications system
	  ○ AVL
	  ○ AVA
	• Part of Tier 2: Paratransit scheduling software is HBSS
	• Part of Tier 3: Maintenance software

Sullivan County Transportation (SCT)	• Part of Tier 2:
	  ○ Paratransit scheduling software
	  ○ On-board security cameras (on new vehicle to be delivered in 2020)

Tri-County Community Action Program (CAP) Transit	• Part of Tier 2: Paratransit scheduling and dispatching software • Part of Tier 3: Maintenance software

[7] Please note that if an agency that indicated that they had a communications system through the email survey conducted on April 3, this was listed in Table 5.

Agency Name	Tier Reached
Visiting Nurse Association (VNA)- Home Healthcare, Hospice & Community Services (HCS)	• Part of Tier 2: Paratransit scheduling software from RouteMatch

Nashua Transit System	• Part of Tier 1:
	  ○ Limited AVL
	  ○ AVA
	• Part of Tier 2: Paratransit scheduling software
	• Part of Tier 4: Automated fare collection

Cooperative Alliance for Transportation (CART)	• Part of Tier 2: Paratransit scheduling software • Part of Tier 3: Maintenance software

Concord Area Transit (CAT)	• Part of Tier 1: Communications system
	• Part of Tier 2: Paratransit scheduling software
	• Part of Tier 3:
	  ○ Maintenance software
	  ○ Fuel management software
	• Part of Tier 4: Automated fare collection

UNH Wildcat Transit	• Tier 1:
	  ○ Communications system
	  ○ CAD/AVL
	  ○ Real time information
	  ○ Third-party smartphone applications
	• Part of Tier 2: APC
	• Part of Tier 3:
	  ○ Limited maintenance/VCM
	  ○ Maintenance tracking

5. Recommended Minimum Level of Technology: 2020 through 2029

In examining the current level of technology in each NH transit agency and the relative technology priorities identified earlier in this memorandum, the following table identifies the minimal level of technology that should be considered for deployment at each agency within the next ten years. The capital cost includes the cost of spares at a 10% level.

Please note that the recommendations for deploying Tier 4, 5 and 6 technologies are considered after the next ten years, with the exception of Advance Transit, which currently is interested in TSP at one location in Lebanon, NH.

Further, please note that if a communications system is recommended, the cost of a communications system is not included in the figures because of the uncertain cost associated with communications systems. The technology components of a communications vary widely as do the operations and maintenance (O&M) costs.

Finally, a statewide cost summary by goal/deployment year is included in Table 16 at the end of this section. Please note that the actual spending might happen in increments leading to the deployment year, but for the purpose of simplicity, all capital spending is assumed to be a lump sum in the deployment year. Further, Annual O&M costs begin in the year after the deployment year.

Table 6. Advance Transit

Tier	Elements	Goal Year	Total Capital Cost (min)	Total Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• AVA • Open data • Technology Integration	2022	$118,000	$211,000	$20,000	$31,200
2	• APCs • Covert emergency alarm • Covert live audio monitoring	2025	107,250	196,750	33,488	49,688
3	• VCM • G-force monitoring • Fuel management	2029	257,000	607,000	55,688	95,000
5	• TSP[8]	2021	72,000	162,000	6,963	15,700

Table 7. COAST

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• Open data • Technology Integration	2022	Not available	Not available	Not available	Not available

[8] Assumes one intersection equipped with appropriate infrastructure. The infrastructure cost is included in the capital cost.

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • GIS • Service coordination facilitated by technology	2025	$633,000	$1,236,000	$104,755	$164,935
3	• VCM • G-force monitoring • Fuel management	2029	268,000	631,000	56,850	97,400

Table 8. MTA

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• CAD • Traveler information • Open data • Technology Integration	2022	$395,750	$1,012,250	$101,148	$201,445
2	• APCs • Covert emergency alarm • Covert live audio monitoring • Fixed video surveillance	2025	76,250	143,750	32,388	47,788
3	• VCM • G-force monitoring • Fuel management	2029	250,000	585,000	55,488	94,400

Table 9. SCT

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• Communications technology (see earlier note regarding the cost of this technology) • AVL • CAD • AVA • Traveler information • Third-party smartphone applications • Open data • Technology Integration	2023	$564,000	$1,282,000	$122,355	$232,468

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
2	• APCs • Covert emergency alarm • Covert live audio monitoring • Fixed video surveillance • GIS • Service coordination facilitated by technology[9]	2026	53,750	106,250	31,563	46,363
3	• VCM • G-force monitoring • Maintenance management • Fuel management	2029	407,000	962,000	89,563	163,450

Table 10. Tri-County CAP Transit

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• Communications technology • AVL • CAD • AVA • Traveler information • Open data • Technology Integration	2023	$666,000	$1,506,000	$126,938	$242,183
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • Fixed video surveillance • GIS • Service coordination facilitated by technology[7]	2027	92,250	170,750	32,938	48,738
3	• VCM • G-force monitoring • Fuel management	2029	250,000	590,000	55,088	93,800

[9] Included in CAD/AVL in Tier 1

Table 11. VNA — Home Healthcare HCS

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• Communications technology • AVL • CAD • AVA • Traveler information • Third-party smartphone applications • Open data • Technology Integration	2022	$585,000	$1,326,000	$123,265	$234,425
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • Fixed video surveillance • GIS • Service coordination facilitated by technology[7]	2027	210,250	399,750	65,763	100,538

Table 12. Nashua Transit System

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• AVL • CAD • Traveler information (including a third-party smartphone application) • Open data • Technology Integration	2022	$528,000	$1,226,000	$105,675	$207,595
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • Fixed video surveillance • GIS • Service coordination facilitated by technology[7]	2025	171,750	384,250	56,063	85,598
3	• VCM • G-force monitoring • Maintenance management • Fuel management	2028	416,000	983,000	90,513	165,450

Table 13. CART

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• Communications technology • AVL • CAD • AVA • Traveler information • Third-party smartphone applications • Open data • Technology Integration	2023	$585,000	$1,326,000	$123,265	$234,425
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • Fixed video surveillance • GIS • Service coordination facilitated by technology[7]	2026	210,250	399,750	65,763	100,538
3	• VCM • G-force monitoring • Fuel management	2029	239,000	563,000	54,488	92,300

Table 14. CAT

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• AVL • CAD • AVA • Traveler information • Third-party smartphone applications • Open data • Technology Integration	2022	$518,000	$1,184,000	$120,080	$227,880
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • Fixed video surveillance • GIS • Service coordination facilitated by technology[7]	2025	261,500	540,500	86,340	132,580
3	• VCM • G-force monitoring	2028	130,000	253,000	31,825	46,000

Table 15. UNH Wildcat Transit

Tier	Elements	Goal Year	Capital Cost (min)	Capital Cost (max)	Annual O&M Cost (min)	Annual O&M Cost (max)
1	• AVA • Open data • Technology Integration	2021	$152,000	$269,000	$21,200	$33,200
2	• APCs • Covert emergency alarm • Covert live audio monitoring • On-board video surveillance • Fixed video surveillance • GIS • Service coordination facilitated by technology	2023	551,250	1,005,750	96,113	148,523
3	• VCM • G-force monitoring • Fuel management	2025	268,000	638,000	56,488	96,800

Table 16. Statewide Capital and O&M Costs by Goal Year for Urban Agencies

Goal Year	Total Capital Cost (min)	Total Capital Cost (max)	Total O&M Cost (min)	Total O&M Cost (max)
2021	$152,000	$269,000	$0	$0
2022	923,750	2,238,250	21,200	33,200
2023	1,136,250	2,331,750	228,023	442,240
2024	0	0	447,401	825,188
2025	1,149,000	2,402,000	447,401	825,188
2026	210,250	399,750	697,095	1,220,309
2027	0	0	762,858	1,320,847
2028	416,000	983,000	762,858	1,320,847
2029	507,000	1,194,000	853,371	1,486,297
2030	N/A	N/A	964,709	1,675,997
TOTAL	$4,494,250	$9,817,750	$5,184,916	$9,150,113

Table 17. Statewide Capital and O&M Costs by Goal Year for Rural Agencies

Goal Year	Total Capital Cost (min)	Total Capital Cost (max)	Total O&M Cost (min)	Total O&M Cost (max)
2021	$72,000	$162,000	$0	$0
2022	1,221,000	2,721,000	6,963	15,700
2023	1,230,000	2,788,000	270,308	509,205
2024	0	0	519,601	983,856
2025	368,750	737,250	519,601	983,856
2026	53,750	106,250	639,429	1,166,124
2027	302,500	570,500	670,992	1,212,487
2028	130,000	253,000	769,693	1,361,763
2029	914,000	2,159,000	801,518	1,407,763
2030	N/A	N/A	1,001,857	1,760,013
TOTAL	$4,292,000	$9,497,000	$5,199,962	$9,400,767

6. Next Steps

As each agency considers technology deployment, they will need a technology strategy that summarizes the results of a business and technical needs assessment, identifies technology integration needs, and reconfirms a suite of technologies which addresses the agency's goals, objectives and needs. Further, the relative priorities of each recommendation presented in this memorandum should be re-evaluated.

Finally, while deployment is not recommended specifically in 2020, agencies should be pursuing funding opportunities immediately at the Federal, state and local level to cover the recommended technology investments. Funding from non-traditional sources should be considered in addition to traditional funding programs, including the American Association of Retired Persons (AARP), National Aging and Disability Transportation Center (NADTC), National Center for Mobility Management (NCMM) and health foundation grants (e.g., Tufts Health Plan Foundation).

7. List of Abbreviations and Acronyms

APC	Automatic passenger counter/counting
ASA	Automatic stop announcement
AVA	Automatic voice announcement
AVL	Automatic vehicle location
CAD	Computer-aided dispatch
CAP	Community Action Program
COAST	Cooperative Alliance for Seacoast Transportation
CART	Cooperative Alliance for Transportation
CAT	Concord Area Transit
DMS	Dynamic message sign
DVR	Digital video recorder
EDRS	Event data recording system
GIS	Geographic information system
GPS	Global positioning system
GTFS	General Transit Feed Specification
HCS	Home Healthcare, Hospice & Community Services
IVR	Interactive voice response
LAN	Local area network
MDC	Mobile data computer
MDT	Mobile data terminal
MTA	Manchester Transit Authority
NHDOT	New Hampshire Department of Transportation
RF	Radio frequency
RTIS	Real-time Information System
SCT	Sullivan County Transportation
TCP	Transfer connection protection
TSP	Transit signal priority
TVM	Ticket vending machine
VCM	Vehicle component monitoring
VNA	Visiting Nurse Association
WAN	Wide area network
WLAN	Wireless local area network

Appendix A. Unit Cost Details

A.1 Tier 1

The costs associated with the Tier 1 technologies are shown in Table 18 through Table 20. The costs associated with providing open data and technology integration are not provided in this table due to the wide range of costs associated with these two items. For example, providing open data typically requires more labor resources than software or hardware. The costs associated with technology integration typically is included in the costs of on-board hardware. However, when procuring services to integrate on-board technologies, agencies should always require that potential vendors/contractors identify costs in addition to on-board hardware or central software, such as technology integration.

A.2 Tier 2

The costs associated with the Tier 2 technologies are shown in Table 21 through Table 24. No cost is identified for GIS as it is available to all transit agencies through the regional planning commissions. The cost of paratransit service coordination is a combination of the costs for paratransit scheduling software and paratransit CAD/AVL.

A.3 Tier 3

The costs of maintenance and safety technologies are shown in Table 25 and Table 27.

A.4 Tier 4

The costs associated with automated fare payment is shown in Table 28.

A.5 Tier 5

The costs associated with TCP and TSP are shown in Table 29 and Table 30. The TSP costs assume that roadside TSP infrastructure exists at a cost of $25,000 per intersection.

The costs of deploying an enterprise database/ data warehouse and reporting functionality varies widely depending on the amount of data that needs to be managed and stored as well as how many reports and the type of reports that are needed.

A.6 Tier 6

The costs associated with technologies in this tier are not available currently. Costs for collision avoidance items were identified by USDOT in 2007, but have not been updated since then. At that time, the estimated cost of acquiring a Forward Collision Warning System for a Transit Bus was $1,500 per unit and $141 in annual operations and maintenance.

Table 18. CAD/AVL (including MDT) Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Onboard computer (fixed-route vehicles)							
Data modem and wireless interface	$250	Cellular and WLAN data only	$1,000	Cellular, WLAN or radio data	$13	$50	5%
Operator interface with logon/logoff, AVL, RSA and event management	$1,000	Tablet; limitations in software (e.g., Android app)	$2,000	High-end software features and management	$50	$100	5%
Vehicle logic unit and vehicle area networking	$1,000	Feature not available	$2,500	VLU to enable communication over data radio and connectivity with DVRs; ability to read smartcards.	$0	$0	0%
Closed-mic and covert alarm	$250		$750		$13	$38	5%
Odometer interface		GPS odometer used-no interface	$500	Dash odometer used	$0	$25	5%
Maintenance network interface (needed for VCM)	$250		$500		$13	$25	5%
Farebox interface	$250		$500		$13	$25	5%
Headsign interface	$250		$500		$13	$25	5%
WLAN	$250	Built in tablet	$500	Separate modem and antenna	$13	$25	5%
DVR interface	$250		$1,000	Only high-end feature since VLU needed	$13	$50	5%
Central CAD/AVL Software	$100,000	100 hours for low-end CAD/AVL interface	$250,000	200 hours for high-end CAD/AVL interface	$20,000	$50,000	20%
Wireless data transfer system (includes 2 access points and data transfer software)							
Access Points	$2,500	May not be rated for heavy duty outdoor use	$5,000	Heavy duty outdoor use equipment	$0	$350	7%
Central software	$5,000	Mostly manual process of preparing and transfering data over wireless network	$25,000	Sophisticated process of preparing and transfering data to vehicles over wireless network	$1,000	$5,000	20%
Servers and SAN-based storage (includes 2 units each [for redundancy] of communications, CAD/AVL, and database servers), and workstations					$4,000	$4,920	4%
H/W and S/W Subtotal	**$204,250**		**$412,750**		**$25,138**	**$60,633**	
Agency Labor/Staff Cost							
Training	$2,400		$4,000				
Operations and Maintenance (0.5 FTE)					$27,500	$37,500	
Cellular Data					$180	$360	
Vendor implementation management	**$20,425**		**$41,275**				
Project Implementation	**$20,425**		**$41,275**				
Contingency	**$50,000**		**$100,000**				
Grand Total	**$298,000**		**$599,000**		**$52,818**	**$98,493**	

Table 19. AVA Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Onboard (fixed route vehicles):							
DMS and on-board interfaces	$500	Cost varies by vendor	$1,000	Cost varies by vendor	$25	$50	5%
AVA controller and interface with MDT/VLU and PA system	$2,500	Mostly support just text-to-speech audio announcements	$4,000	Both text-to-speech and pre-recorded audio announcements supported	$125	$200	5%
Central AVA Software: trigger location management, announcement file creation and management	$15,000	Limitations in the interface used to prepare announcements and create triggers	$35,000	Sophisticated interface to prepare announcements and create triggers	$3,000	$7,000	20%
Central AVA Software workstation	$2,500	Cost varies by vendor	$5,000	Cost varies by vendor	$100	$200	4%
H/W and S/W Subtotal	**$20,500**		**$45,000**		**$3,250**	**$7,450**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.25 FTE)					$13,750	$18,750	
Vendor implementation management	**$2,050**		**$4,500**				
Project Implementation	**$2,050**		**$4,500**				
Contingency	**$5,000**		**$11,000**				
Grand Total	**$31,000**		**$67,000**		**$17,000**	**$26,200**	

Table 20. Real-time Information System Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Real-time information Software							
Arrival prediction	$25,000	Very basic AVL- based "correction" scheduled arrivals; no prediction to account for anomalies	$100,000	Sophistcated algorithm to account for anomalies	$5,000	$20,000	20%
Information dissemination control	$10,000	Limitations in controling media and how information is pushed out.	$50,000	Sophisticated interface for managing information push and pull	$2,000	$10,000	20%
Interface with CAD/AVL and scheduling	$15,000	Cost varies based on complexity	$30,000	Cost varies based on complexity	$3,000	$6,000	20%
Dissemination via dynamic message signs (DMS)							
DMS at the hub (outdoor LCD with 42" screen)	$7,500	H/w cost varies by vendor depending on longevity and ability to monitor remotely	$15,000	H/w cost varies by vendor depending on longevity and ability to monitor remotely	$525	$1,050	7%
DMS at stations (outdoor LCD with 42" screen)	$7,500	H/w cost varies by vendor depending on longevity and ability to monitor remotely	$15,000	H/w cost varies by vendor depending on longevity and ability to monitor remotely	$525	$1,050	7%
DMS at bus stops with shelters (outdoor LED with 3 lines)	$10,000	H/w cost varies by vendor depending on longevity and ability to monitor remotely	$15,000	H/w cost varies by vendor depending on longevity and ability to monitor remotely	$700	$1,050	7%
Dissemination via web and mobile devices							
Website integration	$25,000	Very limited customization Limited flexiblity	$50,000	Embedded in agency website High flexibility	$5,000	$10,000	20%
Google Transit integration	$0	Basic interface; limited support	$15,000	Address both mandatory and optional requirements; provide assistance with Go-live	$0	$3,000	20%
Regional integration	$25,000		$50,000		$5,000	$10,000	20%
Subscription alerts (advanced and real-time)	$10,000	Cost varies by vendor	$25,000	Cost varies by vendor	$2,000	$5,000	20%
Dissemination via IVR							
IVR software	$50,000	DTMF (touchtone) only	$150,000	Includes speech recognition	$10,000	$30,000	20%
IVR software interface with phone system	$15,000	Cost varies based on complexity	$25,000	Cost varies based on complexity	$3,000	$5,000	20%
IVR software interface with prediction system and RTIS	$15,000	Cost varies based on complexity	$25,000	Cost varies based on complexity	$3,000	$5,000	20%
IVR software interface with Routematch	$25,000	Cost varies based on complexity	$50,000	Cost varies based on complexity	$5,000	$10,000	20%
Subcription alerts (advanced and real-time)	$10,000	Cost varies by vendor	$25,000	Cost varies by vendor	$2,000	$5,000	20%
1 server and 1 workstation	$12,500	Cost varies by vendor	$20,000	Cost varies by vendor	$500	$800	4%
H/W and S/W Subtotal	**$262,500**		**$660,000**		**$47,250**	**$122,950**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.5 FTE)					$27,500	$37,500	
Vendor implementation management	**$26,250**		**$66,000**				
Project Implementation	**$26,250**		**$66,000**				
Contingency	**$63,000**		**$159,000**				
Grand Total	**$379,000**		**$953,000**		**$74,750**	**$160,450**	

Table 21. APC Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Onboard (fixed route vehicles): APC sensors and controller	$2,500	Door mounted sensors-upto 90% accurate counts	$4,000	Overhead sensors-upto 97% accurate	$125	$200	5%
Central Software:APC data processing, management and reporting	$15,000	Limited post-processingand reporting	$35,000	Sophisticated post-processing and reporting	$3,000	$7,000	20%
1 workstation (CAD/AVL and database servers to be used)	$2,500	Cost varies by vendor	$5,000	Cost varies by vendor	$100	$200	4%
H/W and S/W Subtotal	**$20,000**		**$44,000**		**$3,225**	**$7,400**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.5 FTE)					$27,500	$37,500	
Vendor implementation management	**$2,000**		**$4,400**				
Project Implementation	**$2,000**		**$4,400**				
Contingency	**$5,000**		**$11,000**				
Grand Total	**$30,000**		**$66,000**		**$30,725**	**$44,900**	

Table 22. On-board Surveillance Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Onboard (fixed route vehicles): 8 cameras and one DVR per vehicle	$5,000	Low-end cameras and DVRs have limited capabilities; WLAN download allowed	$8,000	High-end cameras and DVRs are sophisticated WLAN download allowed	$250	$400	5%
Onboard (paratransit vehicles-directly operated): 4 cameras and one DVR per vehicle	$3,500	Low-end cameras and DVRs have limited capabilities	$5,500	High-end cameras and DVRs are sophisticated	$175	$275	5%
Central Playbak and Streaming Software	$5,000	Only playback capabilities	$20,000	Both playback and streaming capabilities	$1,000	$4,000	20%
Wireless data transfer							
Access points	$2,500	May not be rated for heavy duty outdoor use	$5,000	Heavy duty outdoor use equipment	$175	$350	7%
Data Transfer software	$5,000	Mostly manual process of preparing and transfering data over wireless network	$25,000	Sophisticated process of preparing and transfering data to vehicles over wireless network	$1,000	$5,000	20%
1 server, SAN-based storage and 1 video playback workstation	$32,500	Cost varies by vendor	$50,000	Cost varies by vendor	$1,300	$2,000	4%
H/W and S/W Subtotal	**$53,500**		**$113,500**		**$3,900**	**$12,025**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.5 FTE)					$27,500	$37,500	
Vendor implementation management	**$5,350**		**$11,350**				
Project Implementation	**$5,350**		**$11,350**				
Contingency	**$13,000**		**$28,000**				
Grand Total	**$78,000**		**$166,000**		**$31,400**	**$49,525**	

Table 23. Paratransit Scheduling Software Unit Costs

Components	Unit Cost (low)	Low-end Features	Unit Cost (high)	High-end features	Annual Operations and Maintenance Cost (low)	Annual Operations and Maintenance Cost (high)	% for O&M
Central CAD/AVL Software Interface	$15,000	100 hours for low-end CAD/AVL interface	$30,000	200 hours for high-end CAD/AVL interface	$3,000	$6,000	20%
Scheduling software	$50,000		$150,000		$10,000	$30,000	20%
Scheduling software MDT/AVL Module	$1,000		$1,500		$200	$300	20%
Hosting/Servers and workstations	**$23,000**		**$33,000**		$920	$1,320	4%
H/W and S/W Subtotal	**$89,000**		**$214,500**		**$14,120**	**$37,620**	
Agency Labor/Staff Cost							
Training	$2,400		$4,000				%
Vendor implementation management	**$8,900**		**$21,450**				10%
Project Implementation	**$8,900**		**$21,450**				10%
Contingency	**$22,000**		**$52,000**				20%
Grand Total	**$131,000**		**$313,000**		**$14,120**	**$37,620**	

Table 24. Paratransit CAD/AVL Unit Costs

Components	Unit Cost (low)	Unit Cost (high)	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Onboard computer (directly operated vehicles)					
Data modem and wireless interface	$500	$1,000	$25	$50	5%
Operator interface with logon/logoff, AVL, and event/manifest management	$1,000	$2,000	$50	$100	5%
Vehicle logic unit and cabling		$1,500	$0	$0	
Closed-mic and covert alarm		$1,000	$0	$50	5%
Odometer interface		$500	$0	$25	5%
WLAN interface		$500	$0	$25	5%
DVR interface		$500	$0	$25	5%
Servers and workstations	$23,000	$33,000	$920	$1,320	4%
H/W and S/W Subtotal	**$24,500**	**$40,000**	**$4,195**	**$7,895**	
Agency Labor/Staff Cost					
Training	$2,400	$4,000			
System operations and maintenance (0.25 FTE)			$13,750	$18,750	
Cellular Data					
Directly operated vehicles			$240	$420	
Vendor implementation management	**$2,450**	**$4,000**			
Project Implementation	**$2,450**	**$4,000**			
Contingency	**$6,000**	**$10,000**			
Grand Total	**$38,000**	**$62,000**	**$18,185**	**$27,065**	

Table 25. VCM and EDRS Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
On-board hardware							
Event data recorder/G-force sensor (cheaper to purchase with surveillance system)	$250	H/w cost varies by vendor depending on longevity	$500	H/w cost varies by vendor depending on longevity	$13	$25	5%
Interface with maintenance gateway adaptors	$500	Number of alarms that can be tracked are limited	$1,500	Upto 25 alarms in real-time and several other can be tracked offline	$25	$75	5%
Central VCM Management Software	$75,000	Filtering, processing and reporting capabilities are limited	$150,000	Filtering, processing and reporting capabilities are comprehensive.	$3,750	$7,500	5%
1 server and 1 workstation (could also use same hardware as CAD/AVL system)	$12,500	Cost varies by vendor	$20,000	Cost varies by vendor	$500	$800	4%
H/W and S/W Subtotal	$88,250		$172,000		**$4,288**	**$8,400**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.5 FTE)					$27,500	$37,500	
Vendor implementation management	**$8,825**		**$17,200**				
Project Implementation	**$8,825**		**$17,200**				
Contingency	**$21,000**		**$42,000**				
Grand Total	**$128,000**		**$250,000**		**$31,788**	**$45,900**	

Table 26. Maintenance Management Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Maintenance software	$75,000	User interface is basic but basic features are available.	$200,000	User interface is high-end. Advanced features such as interface with financial and accounting software is available.	$15,000	$40,000	20%
Interface with fuel management system	$15,000	Cost varies based on complexity	$30,000	Cost varies based on complexity	$3,000	$6,000	20%
Interface with CAD/AVL	$15,000	Cost varies based on complexity	$30,000	Cost varies based on complexity	$3,000	$6,000	20%
1 server and 1 workstation	$12,500	Cost varies by vendor	$20,000	Cost varies by vendor	$500	$800	4%
H/W and S/W Subtotal	**$117,500**		**$280,000**		**$21,500**	**$52,800**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.25 FTE)					$13,750	$18,750	
Vendor implementation management	**$11,750**		**$28,000**				
Project Implementation	**$11,750**		**$28,000**				
Contingency	**$28,000**		**$68,000**				
Grand Total	**$170,000**		**$406,000**		**$35,250**	**$71,550**	

Table 27. Fuel Management Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)	% for O&M
Central fuel management software	$30,000	User interface is basic but basic features are available.	$100,000	High cost tied to high-end equipment at the fuel island	$6,000	$20,000	20%
Automatic vehicle identification (AVI) hardware (for only DO vehicles)	$250	Very basic identification - authentication process not completely automated	$500	Completely automated authentication	$50	$100	20%
Fuel pump station hardware	$25,000	Low-end Features Limitations on fuel/fluid that can be tracked	$75,000	High-end pumping and fuel/fluid tracking hardware Vide variety of fuel/fluid that can be tracked	$1,750	$5,250	7%
1 server and 1 workstation	$12,500	Cost varies by vendor	$20,000	Cost varies by vendor	$500	$800	4%
H/W and S/W Subtotal	**$67,750**		**$195,500**		**$8,300**	**$26,150**	
Agency Labor/Staff Cost							
Training	$1,200		$2,000				
System operations and maintenance (0.25 FTE)					$13,750	$18,750	
Vendor implementation management	**$6,775**		**$19,550**				
Project Implementation	**$6,775**		**$19,550**				
Contingency	**$17,000**		**$47,000**				
Grand Total	**$100,000**		**$284,000**		**$22,050**	**$44,900**	

Table 28. Automated Fare Payment Unit Costs

Components	Unit Cost	Annual O&M Cost		% for O&M
Farebox	$ 14,350	$1,005		7%
Portable Probe	$ 18,500	$1,295		7%
Cash/Credit Card TVM	$ 63,900	$4,473		7%
Test Bench	$ 13,900	$556		4%
Back Office/Central System	$ 68,000	$13,600		20%
Smart Cards	$ 4.50	$0		0%
Interface to CAD/AVL/APC	$ 18,000	$900		5%
Point of Sale Terminal	$ 16,500	$1,155		7%
Ticket Office Terminal	$ 16,500	$1,155		7%
Mobile Payment (with no transaction fees)	$ 227,000	$45,400		20%
Fixed Vault	$ 39,500	$2,765		7%
Portable Vault	$ 11,000	$770		7%
POS Software License and Support	$ 79,000	$15,800		20%
Smart Card Handheld Validator	$ 3,800	$266		7%
TVM Services	$ 25,000	$0		0%
Wireless Local Area Network (LAN) Access Points and Data Transfer Software	$ 42,000	$4,200		10%
H/W and S/W Subtotal	**$ 656,955**	**$ 93,340**		
Agency Labor/Staff Cost				
Training	$3,500			
System operations and maintenance (0.25 FTE)		$13,750		**%**
Vendor implementation management	**$65,695**			10%
Project Implementation	**$65,695**			10%
Contingency	**$158,000**			20%
Grand Total	**$950,000**	**$107,090**		

Table 29. TCP Unit Costs

Components	Unit Cost (low)	Unit Cost (high)	Annual O&M Cost	Annual O&M Cost (high)		% for O&M
Operating System	$1,000	$1,200	$200	$240		20%
Database License	$1,900	$12,000	$76	$480		4%
System Development	$151,000	$252,000	$0	$0		0%
Server and Related Equipment	$6,000	$10,000	$420	$700		7%
Operator Interface	$3,000	$5,000	$150	$250		5%
Operator Console	$20,000	$35,000	$1,400	$2,450		7%
H/W and S/W Subtotal	**$ 182,900**	**$ 315,200**	**$ 2,246**	**$ 4,120**		
Agency Labor/Staff Cost						
Training	$21,000	$36,000				
System operations and maintenance (0.1 FTE)			$5,500	$7,500		%
Vendor implementation management	**$18,290**	**$31,520**				10%
Project Implementation	**$18,290**	**$31,520**				10%
Contingency	**$48,000**	**$83,000**				20%
Grand Total	**$288,000**	**$497,000**	**$7,746**	**$11,620**		

Table 30. TSP Unit Costs

Components	Unit Cost (low)	Low-end features	Unit Cost (high)	High-end features	Annual O&M Cost (low)	Annual O&M Cost (high)		% for O&M
On-board hardware (emitters)	$1,000	Limited ability to be controlled by MDTs	$2,500	Several rules can be setup on how to emit priority requests	$50	$125		5%
On-board interface with CAD/AVL (typically over Ethernet or J1708)	$250	Cost varies by vendor	$500	Cost varies by vendor	$13	$25		5%
Central configuration software (typically part of CAD/AVL)	$0	Basic features are in the CAD/AVL software	$25,000	Advanced features such as intersections, stops, MDt configuration management etc are available	$0	$5,000		20%
1 server and 1 workstation	$12,500	Cost varies by vendor	$20,000	Cost varies by vendor	$500	$800		4%
H/W and S/W Subtotal	**$13,750**		**$48,000**		**$563**	**$5,950**		
Agency Labor/Staff Cost								
Training	$1,200		$2,000					
System operations and maintenance (0.1 FTE)					$5,500	$7,500		
Vendor implementation management	**$1,375**		**$4,800**					
Project Implementation	**$1,375**		**$4,800**					
Contingency	**$4,000**		**$12,000**					
Grand Total	**$22,000**		**$72,000**		**$6,063**	**$13,450**		