4.0 EQUIPMENT SYSTEMS

4.1 INTRODUCTION

The maintenance equipment used by state transportation agencies to conduct their maintenance activities varies with each organization, the geographic region served and its associated climate, and general state policies governing public capital investment in extensive equipment fleets. Maintenance equipment could include a wide range of equipment, tools, instruments, and technologies. This chapter, however, will be restricted primarily to trucks and field equipment.

General equipment management organization varies with each individual state. However, there are typically two common management structures: (1) a subdivision of the maintenance structure under the state maintenance engineer and (2) a separate equipment management division within the department of transportation with a state equipment engineer or manager as the principal manager.

Most states operate garage facilities as part of their maintenance facilities and operations. Other states have garage facilities available to them through a separate state agency or as a separate organization within their transportation agency that is neither a part of nor the responsibility of their maintenance structure. Some states have field mechanics for field service of equipment problems as part of their maintenance field organization.

All states have formal equipment replacement programs and criteria established for the replacement of maintenance trucks and field equipment. Criteria for replacement range from a combination of age and mileage, mileage only, age or hours used, present value for sale and recovery of initial capital investment in comparison to replacement cost, and annual maintenance cost (basically a cash stream analysis on a life-cycle cost basis). Most states use "present condition" of equipment to be replaced as part of their replacement criteria. TRB e-circular *E-C047* presents a summary of the various ways of financing equipment acquisition [1], including rental, operating lease, cash purchase, lease purchase, and cash purchase with trade or buy-back guarantee. A brief discussion of cost factors, including life-cycle cost and cash flow analysis, is presented. For gaining a fundamental grasp of the financial principles guiding equipment acquisition, this document is especially helpful to persons new to maintenance equipment engineering and management.

In most states, the actual purchasing of maintenance equipment is handled by another state agency but is processed on the request and recommendation of the transportation agency's maintenance organization. In many states, the specifications used for the purchase of maintenance equipment are prepared by either the maintenance organization or in cooperation with the maintenance organization. Most states receive specific appropriations for the purchase of trucks and equipment.

Requests and recommendations for types of maintenance equipment normally originate in the state transportation department's district or division offices and are then reviewed by central office personnel. Most maintenance equipment is acquired for use in specific districts or divisions. Some specialized equipment is acquired for central office control because it requires statewide use to generate a level of use that justifies ownership.

A maintenance truck is the most common item of maintenance equipment. The types of attachments, allied equipment, and associated modifications purchased with maintenance trucks vary widely among the states. Some states supplement their state-owned maintenance truck and equipment fleets with rented equipment on an as-needed basis. The second most prevalent item in the maintenance equipment inventory is the tractor (used in right-of-way maintenance operations). As with trucks, the attachments and modifications purchased with tractors vary greatly among the states. A recent survey of all U.S. state and Canadian provincial DOTs found the 10 most needed pieces of equipment to conduct their maintenance responsibilities to be (in order): dump trucks, snowplows, loaders, spreaders/salters, pickup trucks, motor graders, impact attenuators, mowers, excavators, and street sweepers [2].

All states have some type of cost record system for their maintenance trucks and equipment, but the extent of the system and the level of detail varies. Most states have some type of preventive maintenance program for their trucks and equipment. Training programs for truck drivers and equipment operators are provided in most states.

Most states have an equipment management system (EMS), either in the developmental stage or moving into the mature implementation stage. Integration of an EMS with the agency's maintenance management system (MMS) and bridge management system (BMS) will greatly enhance the agency's ability to determine what is the optimal equipment fleet to support the functional mission of the maintenance division. EMSs are intended to monitor such things as equipment use levels, equipment operating costs, fuel consumption, and equipment maintenance as well as to assist in developing replacement criteria.

Most states have fabricated or developed specialized maintenance equipment in their own shops. For instance, the Nevada DOT modified an existing striping unit to change to waterborne paints for improved environmental control, the West Virginia DOT modified mowing units to truck-mounted boom units, and the Minnesota DOT developed a remote-controlled mowing unit for increased operator safety on steep slopes. The Montana DOT (and several others) modified various truck units to use chemical de-icers and salt brines directly on the pavement for snow and ice control [3]. Many DOTs are also cooperating in joint efforts to conduct research and development seeking new, improved equipment systems to support the maintenance function. These cooperative efforts across an entire region having similar maintenance activity needs offer the potential to create a large enough market, and the purchasing power, to interest equipment manufacturers to provide equipment tailored to maintenance agency needs. Estimates of the annual expenditures of all state agencies combined for the purchase of new maintenance equipment have ranged as high as over $200 million. Efforts to optimize the functional return on this large investment are an important part of an overall budget management strategy to achieve maximum return on the public's transportation investment. An evaluation of new equipment systems for precise distribution and placement of de-icing materials on pavement has found that these newer equipment systems use less chemicals (which is better for the environment and reduces materials costs) and provide more effective snow and ice control than older equipment designs (which increases traveling public safety) [4].

A thorough survey of the various states' practices in fleet equipment management and equipment selection methods has been reported in *NCHRP Synthesis 283* [5]. The fleet management process must deal with factors such as a lack of skilled mechanics, parts inventory, and general budget decreases, among others. Defining equipment replacement needs, equipment selection systems, and alternatives to equipment replacement are all discussed, as well as the influence of computer systems on the process. Putnam [6] offers an example from the North Carolina DOT that illustrates a process by which an equipment

engineer or manager might develop a request for proposals to procure a computerized system for fleet management corresponding to the agency's functional needs. Nelson [7] explains how Total Quality Management (TQM) principles and the benchmarking process can be used to drive a major paradigm shift in fleet management.

A variety of equipment-related issues are opportunities for research and innovation among maintenance engineers and maintenance managers. The scope and range of these challenges and opportunities constantly shifts; however, at the time of this manual revision, the following represent a selected set of equipment systems topics considered worthy of review.

Alternative fuel vehicles: In the recent past, alternative fuel suggested 10 percent blend with ethanol or methanol and 90 percent gasoline. Ethanol producers are anticipating methanol being phased out as an oxygenation agent for gasoline and are simultaneously anticipating that nationally required oxygenation levels will increase to 15 percent. For example, in Tucson, Arizona, the sale of gasoline from late fall to early spring is limited to only 90–10 oxygenated fuel. Soybean producers throughout the Midwest continue to fund research and promote the development of soybean-oil-based bio-diesel fuel. Hydrogen has begun to gain favor again in promotions of clean fuels. Maintenance leaders need to be examining what alternative fuels suggest will be the likely vehicle characteristics, and whether the expected vehicle characteristics will provide the vehicle performance required for maintenance tasks.

Mandated requirements on fleets: Environmental regulations and safety regulations are often established for fleet vehicles prior to making any new regulation apply to the general vehicle population. It behooves maintenance leaders to track proposed fleet vehicle regulations for (1) immediate application of requirements to public agency vehicle fleets, and (2) later expanded application to the general vehicle population, which will obviously affect any vehicles that maintenance forces obtain.

"Clean Air Act" requirements: Most people think of regulations on the generation of automotive emissions when the subject of "clean air requirements" arises. There has been a gradual and almost continuous expansion of the activities that are subject to clean air environmental standards. Some of them affect the way maintenance personnel do business, such as the need to control the dust that results from vehicle traffic grinding down the sand left on the roadway after snow and ice control measures have been completed, or drifting of volatile hydrocarbons from the curing of the completion of a seal coat operation, just to name two activities. Forward thinking maintenance engineers and maintenance managers need to examine current regulations as applied to their programs and to be anticipating what impact developing regulations may have on their operations.

Alternative fuel supply infrastructure: As what are known today as "alternative fuels" become main stream, a transition to a modified infrastructure for fuel supply may be required for maintenance agencies. For blended fuels, the fuel will still be blended at the refinery or energy company depot and the distribution within the maintenance agency should remain the same. However, for fuels that come in compressed vapor form or liquefied form for a natural state vapor (hydrogen, LNG or liquefied natural gas, butane, propane) the distribution infrastructure will likely be significantly different. Many individual vehicles and some fleet vehicles already have been fitted with tanks to accommodate LPG, but these units tend to not have the wide range of operation that maintenance forces have. If a maintenance agency adopts LNG, will crews have to tow a "trailer" tank of fuel to the field to re-supply individual units during the work activity, much as construction companies now often send a tank truck to the job site with their equipment system that they mobilize for a job?

Handling alternative fuels: When fuels that are now considered "alternative" become adopted by maintenance agencies, the fuel characteristics will have to be considered in planning any changes to fuel storage and supply infrastructure and in policies governing how personnel handle these fuels. Fuels that are in the liquefied state behave differently when they make a phase transformation to the vapor state. Some fuels (e.g., propane) are heavier than air in the vapor state and will collect in low places in buildings and even the ground surface; others (e.g., LNG, hydrogen) are lighter than air in the vapor state and rise to collect in the upper areas of a building or to dissipate in the open air. If an underground supply or distribution line springs a leak, the vapor state of many of these fuels will migrate in the soil along the pipe to collect in a building. These are only a few of the characteristics maintenance agencies will need to consider when a decision is made to adopt the use of alternative fuels.

Mechanic training: While the technology of changing a traditional gasoline-powered or diesel-powered engine over to an alternative fuel is usually relatively simple, there are changes in equipment maintenance cycles that are already known. Some alternative fuels require rubber components in the fuel line to be checked more frequently; some require different maintenance cycles on fuel injection systems. Again, these are only two examples. Maintenance agencies anticipating adoption of alternative fuels need to thoroughly prepare their mechanic personnel to deal with equipment maintenance issues that will be unique to the use of alternative fuels.

Computer control systems: All vehicles are becoming increasingly computer-based. Computer elements control components in a host of ways already: regulating the shifting of complex transmission systems, sensing exhaust emissions and adjusting the fuel injection system to maintain proper emissions control, continuously performing electrical and electronic systems check for proper operation, for example. Additionally, as AVL, GPS, GIS sensing, and other advanced technologies are added to maintenance vehicles, the level of computerization of the vehicle increases. While many of these computer-based equipment advances enable maintenance agencies to perform their work faster, more efficiently, and more effectively, these operational gains can only be realized if the computer components themselves are operating properly. Discussing the maintenance of computer systems is far beyond the scope of this manual. However, maintenance agencies need to plan for such maintenance. Maybe the computer systems on their vehicles should all be maintained by "quick change out components" much like the USA military services do; maybe the maintenance agency should develop and train their own in-house computer technicians; maybe the agency should acquire contract equipment maintenance services for this work. Maintenance agencies need to plan to manage this equipment technology.

4.2 EQUIPMENT APPLICATION

The application of equipment to a maintenance activity will be largely governed by the standards defined in each agency's maintenance management system. However, some typical categories of equipment that are assigned to different kinds of maintenance jobs are listed below to provide an apppreciation for how the transportation agency's equipment inventory is so extensive and varied compared to the equipment inventory of a contractor who specializes in a limited scope of work.

Job	Equipment
Hauling	Trucks, Trailers, Scrapers
Ditching and Diking	Bulldozers, Drag Lines, Hydraulic Excavators, Graders, Rotary Ditchers, Backhoes
Road Grading	Graders, Bulldozers, Tractor Drags, Maintainers
Truck Loading	Tractor End Loaders, Drag Lines, Hydraulic Excavators, Beltloaders
Mixing Road Materials	Graders, Special Mixing Machines
Dirt Moving	Bulldozers, Tractor Scrapers, Drag Lines, Front-end Loaders, Backhoes
Excavation	Bulldozers, Power Shovels, Drag Lines, Tractor Scrapers, Front-end Loaders, Hydraulic Excavators
Snow Removal	Snowplows, Rotary Brushes, Snow Blowers, Graders, Front-end Loaders, Bulldozers, Trucks, Belt Loaders
Scarifying and Shaping	Graders with Attachments, Tractors with Attachments, Rippers, Hydraulic Excavators
Backfilling	Bulldozers, End Loaders, Backhoes, Trenchers
Compaction	Crawler Tractors, Flat-Wheel Rollers, Rubber-Tired Rollers, Sheeps Foot Tamping Rollers, Pneumatic Rollers
Stockpile Maintenance	Bulldozers, Drag Lines, End Loaders
Pipeline Laying	Tractor Winches, Bulldozers, Tractor Side Booms, Backhoes, Drag Lines
Watering Gravel or Fill	Water Truck with Pressure Pump
Flushing Pipe	Water Truck with High-Pressure Pump and Hoses
Crushing Rock or Gravel	Jaw Crusher, Gyratory Crusher Rolls
Spreading Asphalt for Treatments	Distributor Trucks and Tanks, Trailer-type Distributors
Heating Asphalt	Steam Generators, Heating Kettles
Spreading Rock Chips	Dump-bed Truck with Spreader Box Attachment, Self-Propelled Spreaders with Trucks
Traffic Striping	Truck-Mounted Striping Unit or Hand-Operated Unit, Shadow Vehicles
Pavement Joint Sealing	Trucks, Trailer-Mounted Sealant Applicator Unit, Shadow Vehicles, Trailer-Mounted Air Compressor with Lances, Joint Router, Attenuators

Note: *Bridge maintenance equipment for typical operations is noted in the bridge maintenance section because of the equipment's specialized application and the frequent use of contracting as a means of administering bridge work.*

When using equipment in the vicinity of moving traffic, maintenance personnel safety is always an issue for maintenance engineers and managers. Technological developments have resulted in warning equipment systems being added to inventory; these warning systems have the potential to reduce accidents significantly when personnel are operating equipment. One development is "radar emulation," in which a fake radar pulse is emitted in advance of the maintenance work and makes drivers with radar detectors think they are being tracked by police units [8]. A second development is a device that tracks the speed of vehicles approaching work zone protective devices to predict a vehicle impact in advance and sound an alarm to workers before the vehicle actually intrudes into the workers' area [9]. If such devices are to be effective, they must be maintained in a high state of readiness by persons assigned to maintain such equipment.

Originally laser control of grade and alignment of equipment was considered applicable only to paving machines associated with the construction process. However, laser beam control systems and sonic beam control systems are becoming flexible enough and sufficiently varied in the types of equipment units to which they can be applied that maintenance equipment used in pavement repair, ditch grading, and slope repairs are candidates for these equipment control systems [10].

Following the lead of the construction industry, maintenance is beginning to incorporate multiple-use equipment in areas beyond trucks. One example is the versatile small front-end loader known as the skid steer [11–13]. While these units are typically thought of as a front-end loader, a wide range of attachments are available for them, and they can be hauled to the job site on a trailer behind a truck, making them a preferred choice for many repair activities. Flexibility in maintenance functions with smaller crews requires maintenance agencies to review profit-motivated organizations for examples in their equipment inventory that can be adapted to support public efficiency.

A number of developments in equipment applications have altered the character and use of maintenance fleets. Through a jointly funded research program, several organizations in the major snow belt states have collaborated in creating a snowplow/truck unit specially designed for their needs [14]. To the casual observer, something as simple as the warning lights and visibility markers on maintenance vehicles seem obvious, but Ullman and Lewis [15] have described the Texas DOT's experience in attempting to standardize and optimize such warning lights for lowest cost and maximum effectiveness. Lorenc and Bernold [16] have reported advances in fleet equipment the North Carolina DOT has made by applying robotic technology to various pieces of equipment to improve safety and efficiency. Advanced technology is also being applied to things as mundane as street sweepers to make their operation less environmentally intrusive [17]. Bennett et al. [18] describe the development of a robotic highway crack-sealing machine. Continued budget pressures to do more work with fewer people on the roadway, increased safety, and higher unit productivity will undoubtedly increase the rate at which similar innovations enter equipment fleets, requiring faster replacement with better units.

4.3 MAINTENANCE OF EQUIPMENT

Equipment maintenance involves considering innovations, not necessarily high-tech ones, that reduce the cost of maintaining a vast equipment fleet [19]. For example, one agency found that low-cost tires with a thin recap provided better wear and service than more expensive new tires in urban service. Another agency found that corrosion damage to trucks could be significantly reduced in a snow and ice belt area by resealing all units with silicone sealants at new delivery before putting them on the road.

Extending the life and improving the serviceability of engines on equipment units can sometimes be accomplished simply by having the proper oil filter, transmission filter, fuel filter, etc. [20]. Persons responsible for equipment maintenance should coordinate with persons responsible for purchasing, making sure that the filters purchased for routine equipment maintenance meet the manufacturer's specifications for the equipment. As motor oils continue to develop into lubricating fluids that reduce internal engine friction and release less pollutants during the combustion process [21], they must be coupled with the correct filters.

Most agencies are planning for the day when their truck and automobile fleet will be fueled with some alternative to gasoline and diesel fuel [22]. This alternative will require more planning on the fuel storage and dispensing side of the operation but will likely reduce the demands for routine spark plug maintenance and the frequency of oil changes.

4.4 ACQUISITION AND REPLACEMENT

One of the critical elements of any equipment replacement program is the depreciation period, or life, of a particular equipment item. Unlike for a private sector organization, the life over which an equipment item is considered useful to an agency is not bound by Internal Revenue Service regulations on equipment depreciation. Thus, a particular agency should develop depreciation periods for each equipment item on the basis of criteria that match their equipment philosophy and their budget philosophy, considering annual maintenance cost for the item, downtime caused by loss of the item in service, equipment maintenance personnel requirements, recoverable sale value of the item, initial capital cost of replacement, any increase or decrease in equipment maintenance costs associated with replacement of the item, etc. The following typical depreciation periods for various maintenance equipment items are only intended for general comparisons but are also useful in evaluating if an agency's depreciation schedule for some item may be inconsistent with the depreciation periods it uses for other classes of equipment. Weissman et al. describe a computerized system used by the Texas DOT to guide decision making when replacing equipment [23]. The Texas equipment replacement model (TERM) incorporates life-cycle cost analysis—useful in moving to asset management for general DOT principles of management.

Type of Equipment	Depreciation Period (years)
Air Compressor, Truck-Mounted	7
Air Compressor, Wheel-Mounted	7
Air Tools	5
Automobile	4
Batcher, Measuring	6
Batcher, Weighing	5
Bin, Aggregate	10
Blower, Portable	5
Bucket, Clam or Drag Line	6
Bulldozer, Tractor Attachment	7
Concrete Saw	4
Conveyor Belt, on Wheels	5
Crack-Filling Machine	8
Crane, Crawler	10
Crusher, Rock, Portable	8
Crushing and Screening Plant	8
Cultivator, Motor-Driven	5
Distributor, Bitumen	8
Drill, Core	7
Drill, Drifter	5
Drill, Wagon	7
Dryer, Aggregate	8
Dryer, Elevator	8
Engine, Gasoline or Diesel	7
Excavator, Telescoping Boom	10
Finishing Machine, Concrete	5
Generator, Electric, Gasoline, or Diesel	7
Gradation Control Unit	8
Grader, Motor	8
Grader, Pull	10
Guardrail Straightener	10
Heater, Aggregate, Revolving	8
Heater, Bitumen Kettle	8
Heater, Tank Car	8
Hoist, Bucket, Truck-Mounted	5
Hoist, Drum, with Power	7
Joint-Cleaning Machine	4

Type of Equipment	Depreciation Period (years)
Loader, Belt, Blade Feed	6
Loader, Chain Bucket	6
Loader, Scoop, Crawler	7
Loader, Scoop, Wheel Tractor	6
Magnet, Road	5
Maintainer, Self-Propelled	6
Maintainer, Drawn	5
Mixer, Bituminous	7
Mixer, Concrete	7
Mixing Plant, Bituminous	8
Mower, Reel	6
Mower, Rotary	7
Mower, Sickle Bar	5
Mud Jack	6
Nuclear Density Unit	3
Pavement Breaker	5
Paver, Bituminous	8
Spray-Paint Outfit	8
Hammer, Pile	10
Hammer, Sheeting	7
Pump, Asphalt	6
Pump, Water	6
Road Mixer, Digging Rotor	6
Road Mixer, Pug Mill Type	8
Road Roller	10
Roller, Pneumatic	10
Roller, Sheep's Foot	10
Roller, Trench	10
Roller, Vibratory	10
Rooter or Ripper, Heavy	8
Scarifier, Rotary	5
Scraper, Drawn	7
Scraper, Self-Propelled	7
Screen, Vibrating	8
Screening and Loading Plant	8
Seed-Gathering Machine	4
Shovel, Crawler	10
Shovel, Truck Mounted	10

Type of Equipment	Depreciation Period (years)
Snowplow, One-way	10
Snowplow, Rotary	10
Snowplow, V	10
Spraying Machine, Insect	5
Spreader, Drawn or Attached	6
Spreader, Self-Propelled	5
Sprinkler, Water, Truck-Mounted	7
Stump Cutter	7
Subgrade Finisher	4
Sweeper, Rotary	5
Tank, Bitumen Storage	10
Tank, Bitumen, Wheel-Mounted	10
Tank, Water, Skid-Mounted	10
Tractor, Crawler	7
Tractor, Wheel	6
Traffic Line Marker	7
Trailer, House	7
Trailer, Platform	7
Tree Mover, Truck Mounted	8
Truck Tractor, with Semitrailer	7
Trucks, Multiuse	5
Trucks, Snow Use Only	10
Vibrator, Pneumatic	5
Wagon, Semi, with Tractor	7
Washing and Screening Plant	8
Welding Outfit, Electric	5

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