sit Authority; Des Moines Metropolitan Transit Authority; Orange County Transit District; Regional Transportation District, Denver; Regional Transit Authority, New Orleans; Salem Area Mass Transit District; Seattle Metro; Southeastern Pennsylvania Transit Authority; Southern California Rapid Transit District; Tri-County Metropolitan Transportation District, Oregon; Utah Transit Authority; and Washington Metropolitan Area Transit Authority.

REFERENCE

1. Public Transit Bus Maintenance Manpower Planning. NCTRP Report 10. TRB, National Research Council, Washington, D.C., Oct. 1984.

Publication of this paper sponsored by Committee on Transit Bus Maintenance.

Space Allocation in Bus Maintenance Facilities

STEPHEN J. ANDRLE and BRIAN McCOLLOM

ABSTRACT

A summary is given of the findings of a research effort sponsored by UMTA to identify the space guidelines used in the transit industry to plan bus maintenance facilities. Data from 30 maintenance facilities built within the last 15 years were analyzed by examining the statistical relationships between the space allocations within the facilities and variables such as annual vehicle miles operated, fleet size, and employees on site. Although the relationships derived from this research reflect as-built and not necessarily desired conditions, they can be used as guidelines for the initial feasibility phases of facility planning.

UMTA initiated a project in 1982 to develop a handbook on the planning of bus maintenance facilities. Although close to 100 new bus maintenance facilities have been constructed in the United States in the last 15 years, most with financial assistance from UMTA, only limited information is available on the major parameters and guidelines that should be used in the planning of such facilities. The last major work in this area was a 1975 report prepared for UMTA by the Mitre Corporation (1). The guidelines in that report were developed from a survey of existing maintenance facilities, a number of which were designed for streetcar, not bus, use. The purpose of the current UMTA study is to update this report and develop guidelines based on current practice in bus facility planning.

This paper is a summary of the first phase of the UMTA study--the inventory of space guidelines being used to size bus maintenance facilities. An unsuccessful attempt was made to contact transit systems where facilities had been recently constructed. Unfortunately, most of the systems had not documented the guidelines that were used in their facility planning. Therefore, an alternative approach was used in which the guidelines were derived from data on recently constructed facilities.

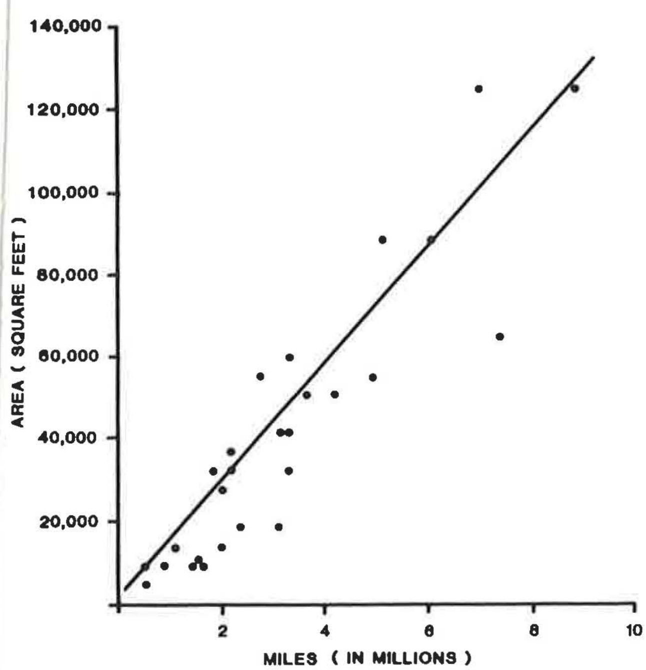
The data were assembled for more than 30 facilities built within the last 15 years. Planning and design documents were requested for each facility; however, in most cases, the amount of space that was provided for the various maintenance functions was obtained by scaling drawings of as-built facilities. These data were analyzed by examining the statistical relationships between the provided space and the operating characteristics of each facility such as annual vehicle miles operated, fleet size, and employees on site. The analyses were controlled for system type (i.e., single or multiple maintenance facility system) because of the different kinds of facilities that are built in these systems.

The functional areas of a maintenance facility were grouped into four categories: maintenance, bus servicing, transportation (e.g., drivers' dayroom, dispatching), and office space. Regression analysis was used to examine the amount of space provided both for each category and for each function within the category. For example, relationships were tested for the amounts of space provided for the total maintenance category and the subareas within the maintenance category such as maintenance bays, parts and storage areas, and the tire shop. The results of these tests are presented in the following sections.

MAINTENANCE

Maintenance services include all maintenance bay areas and shops but exclude service lanes and vehicle storage. The amount of maintenance space required to properly service a fleet is dependent primarily on the amount of revenue service operated from the facility and secondarily on the number of ehicles in the fleet. Because vehicles in most ystems cannot be operated more than 12 to 16 hr per lay, annual vehicle miles tends to reflect both the ize and utilization of the fleet. Accordingly, annual vehicle miles should be a better indicator than fleet size of maintenance space needs.

This expectation was confirmed in the analysis. The best statistical relationship was 1,400 ft^2 of maintenance service area per 100,000 annual vehicle miles plus 564 ft^2 (Figure 1). This includes all maintenance bay areas, shops, and service lanes but excludes vehicle storage.



TOTAL MAINTENANCE AREA REGRESSION EQUATION

y = 1389x + 564
(129) (4763) STANDARD ERROR OF REGRESSION COEFFICIENT
(10.81) (0.12) T-VALUE
(0.00) (0.45) SIGNIFICANCE OF T-VALUE
r^2 = 0.82 NUMBER OF CASES = 27
x = ANNUAL VEHICLE MILES IN 100,000'S
y = TOTAL MAINTENANCE AREA IN SQUARE FEET

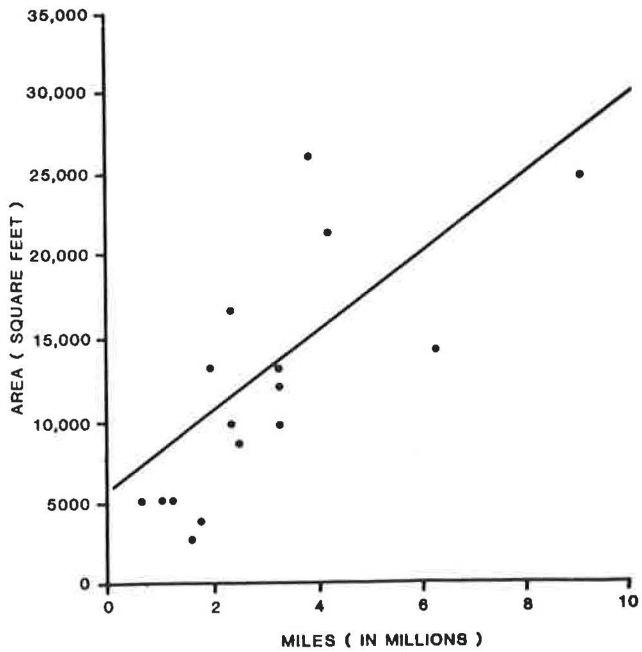
FIGURE 1 Total maintenance area analysis.

Maintenance Bays

The maintenance bay is the area that is provided to work directly on the bus. It includes space for all maintenance functions with the exception of servicing and work conducted in shops.

A statistical relationship for the maintenance bay area was only found for single-facility systems. The best relationship for single-facility systems was 5,600 ft^2 plus 250 ft^2 per 100,000 annual vehicle miles (Figure 2). A similar relationship was observed for multiple-facility systems; however, its coefficient of determination was poor (R^2 = 28).

The poor relationship for multiple-facility systems may be attributed to the small number of cases in which data were available and to differences in the maintenance programs among the systems. Data were only available on eight multiple systems. Strong relationships are often difficult to identify with such a small number of observations. The maintenance programs also tended to vary more among multiple-facility systems. Unlike single-facility systems, space is not provided for all maintenance functions in multiple-facility garages; painting, body work, and overhaul work are often concentrated in a heavy-maintenance garage. However, the degree to which these maintenance functions are centralized varies among systems and thus produces less stable space relationships.



MAINTENANCE BAY AREA REGRESSION EQUATION: SINGLE FACILITY SYSTEMS

y = 246x + 5628
(62) (2137) STANDARD ERROR OF REGRESSION COEFFICIENT
(3.95) (2.64) T-VALUE
(0.00) (0.01) SIGNIFICANCE OF T-VALUE
r^2 = 0.53 NUMBER OF CASES = 16
x = ANNUAL VEHICLE MILES IN 100,000'S
y = TOTAL MAINTENANCE BAY AREA IN SQUARE FEET

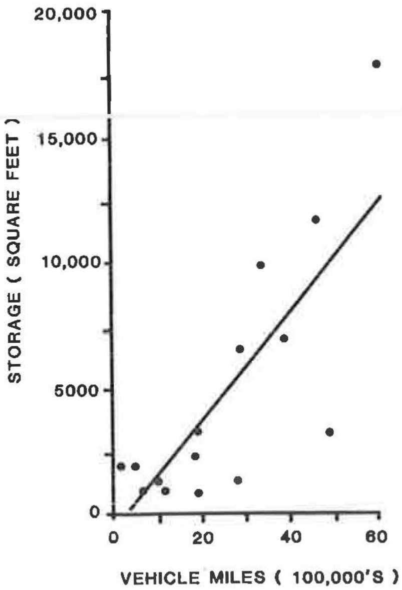
FIGURE 2 Maintenance bay area analysis: single-facility systems.

Parts and Other Storage

Lack of parts storage is a problem in some older facilities. Many transit systems are operating a greater variety of vehicles than in the past--smaller buses, standard buses, and articulated buses. A larger parts inventory must be maintained to accommodate this variety.

Different parts storage relationships were found for single- and multiple-facility systems. Over 230 ft^2 per 100,000 annual vehicle miles is provided in single-facility systems (Figure 3), whereas a little more than half of that amount (126 ft^2) is provided in multiple-facility systems (Figure 4). Again this difference may be attributed to the more limited maintenance activities that are typically conducted at operating garages in multiple-facility systems.

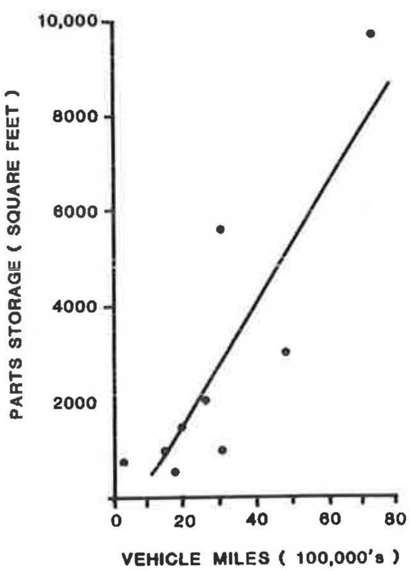
In addition to the parts room, space must be allocated for other storage--grease, fluids, detergent, body parts, and spare engine and transmission units. A relationship of approximately 50 ft^2 per 100,000 annual vehicle miles was found for single-facility systems (Figure 5). No significant relationship was identified for multiple-facility systems; the variability among these systems in the maintenance activities conducted may be an explanation.



PARTS STORAGE REGRESSION EQUATION:
SINGLE FACILITY SYSTEMS

```
y = 233x  -  1923
    (56)     (1668)    STANDARD ERROR OF
                       REGRESSION COEFFICIENT
    (4.18)   (1.15)    T-VALUE
    (0.00)   (0.14)    SIGNIFICANCE OF T-VALUE
r2 = 0.59              NUMBER OF CASES = 14
x = ANNUAL VEHICLE MILES IN 100,000'S
y = PARTS STORAGE AREA IN SQUARE FEET
```

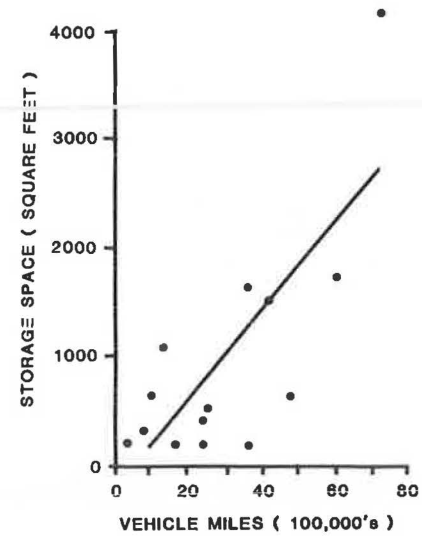
FIGURE 3 Parts storage area analysis: single-facility systems.



PARTS STORAGE REGRESSION EQUATION:
MULTIPLE FACILITY SYSTEMS

```
y = 126x  -  821
    (29)     (1010)    STANDARD ERROR OF
                       REGRESSION COEFFICIENT
    (4.41)   (0.81)    T-VALUE
    (0.00)   (0.22)    SIGNIFICANCE OF T-VALUE
r2 = 0.74              NUMBER OF CASES = 9
x = ANNUAL VEHICLE MILES IN 100,000'S
y = PARTS STORAGE AREA IN SQUARE FEET
```

FIGURE 4 Parts storage area analysis: multiple-facility systems.



MAINTENANCE STORAGE SPACE REGRESSION
EQUATION: SINGLE FACILITY SYSTEMS

```
y = 52x  -  402
    (12)    (451)     STANDARD ERROR OF
                      REGRESSION COEFFICIENT
    (4.10)  (0.90)    T-VALUE
    (0.00)  (0.20)    SIGNIFICANCE OF T-VALUE
r2 = 0.58             NUMBER OF CASES = 14
x = ANNUAL VEHICLE MILES IN 100,000'S
y = MAINTENANCE STORAGE SPACE IN
    SQUARE FEET
```

FIGURE 5 Maintenance storage space analysis: single-facility systems.

Tire Shop

Two types of tire shop arrangements are found. In one case a work bay is dedicated to tire work and storage is included in the bay area. This bay is often walled off from the rest of the facility. The other common arrangement is a dedicated room that does not include a work bay.

The size of the tire shop was relatively uniform and did not appear to be related to any measure of system size or use. The average size of a tire shop without a dedicated work bay was 517 ft^2, whereas the average size of a tire shop with a dedicated work bay was 2,141 ft^2. There was greater variation in size among tire shops with a dedicated work bay (standard deviation = 1,021 ft^2) than among those without a dedicated work bay (standard deviation = 135 ft^2). This may be attributable to the dedication of more than one work bay in some tire shops.

Brake Shop

Only 20 percent of the facilities examined had separate areas dedicated to brake repair. Like tire shops, a dedicated room and a dedicated work bay are the two types of brake shops that were found. In facilities without brake shops one or more bays are used for brake work but are not exclusively assigned to brakes. Brake lathes are placed reasonably close to the bays in these cases and the brake drums are wheeled to the lathes on dollies.

The limited number of facilities with dedicated brake shops made it impossible to examine any statistical relationships. The size of the brake shops without dedicated bays ranged in size from 140 to 608 ft^2, whereas the brake shops with dedicated bays ranged in size from 1,250 to 2,300 ft^2.

TABLE 1 Other Maintenance Support Areas

	Space (ft^2)				
Functional Area	No. of Cases	Mean Value	Low Value	High Value	Standard Deviation
Battery room	21	235	80	720	150
Body shop	16	2,835	264	9,550	2,452
Dynamometer bay	4	1,719	1,229	2,200	
Electrical shop	4	291	140	510	
Injection repair shop	5	187	104	423	
Overhaul shop	12	2,324	163	7,100	1,780
Paint shop	12	2,037	810	5,575	1,365
Parts cleaning area	6	500	169	825	
Steam cleaning area	18	1,148	220	1,950	411

Other Support Areas

There were a number of maintenance support areas for which no relationships were found. No systematic relationships to annual vehicle miles, fleet size, or any other measures of system operations were identified. Likewise, as shown in Table 1, the size of these areas was not uniform and appeared to vary almost randomly.

There are a number of reasons that may partly explain the apparent absence of statistical relationships. One is the way in which these areas are considered in the design process. Interviews with a number of systems suggested that the initial space may be allocated for the entire support area and not for individual activities. The breaking up of this space for individual activities is influenced not only by the nature of the activity but also by location of load-supporting walls, column placements, and the physical shape of the facility.

Another reason is the small number of facilities in the sample that contained some of these other support areas. As shown in Table 1, four of the nine functional areas had less than seven cases. Even when there is an underlying relationship, it is difficult to identify it statistically when the number of cases is this small.

A final reason may be that the space required for a number of the areas is small and can be significantly changed by the addition of a few feet in a dimension. For example, the size of a 20 x 25-ft battery room can be increased 25 percent from 550 to 625 ft^2 by simplying increasing the first dimension by 5 ft. When the dimensions are small, small absolute changes in dimensions can produce large percentage changes in area.

BUS SERVICING

This category consists of three bus activities that are performed on a routine basis: daily servicing, vehicle inspection, and parking. These activities are usually performed by employees from the maintenance department, although in some instances transportation department employees are involved. The number of buses in the fleet was found in the analysis to provide the best statistical relationship for daily servicing and parking areas, whereas annual vehicle miles provided the best relationship for inspection area. No statistical analysis was performed for the category as a whole because of the disparate nature of the activities within the category.

Daily Servicing

Bus servicing is a daily function for most of the active fleet. Farebox vault pulling, refueling, fluid checking, and interior and exterior cleaning are activities that are often done as part of daily servicing.

The most common servicing arrangement is an in-line pattern. At the first station, vault pulling is performed; at the second, combined refueling, fluid checking, and interior cleaning; and at the third, drive-through exterior washing. Typically, one or two service lanes are provided that bypass the exterior wash station to accommodate servicing when washing is unnecessary.

There are variations on this basic arrangement. One variation that is popular for reasons of security is to pull the farebox vaults at the front gate so no buses on the property have cash aboard. Some systems believe that this is very important and others find it sufficient to pull farebox vaults in the service lanes. If farebox vaults are pulled at the front gate, a driveway long enough to prevent bus queuing on the street is provided.

Another variation is to segregate washing entirely from other servicing activities. The long service lanes act as a wind tunnel. The spray from the exterior washers blows back through the servicing area making an unpleasant working environment, especially in the winter. One facility that has adopted this strategy designed a free-standing building for servicing and interior cleaning and constructed two wash bays at the end of the main building. The site circulation plan featured counterclockwise movement from the vaulting station at the front gate to the service building to the washer. Because the washer is at the end of the building, the washer bypass route is simply around the end. This facility is in the South, so the exterior circulation is not a problem.

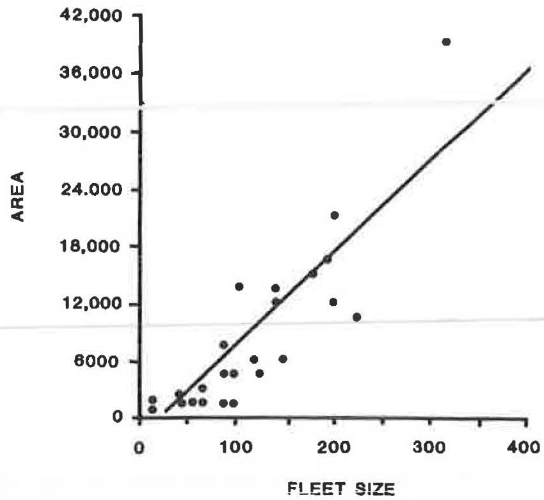
The best statistical relationship for service area was approximately 100 ft^2 per bus in the active fleet (Figure 6). This relationship appears reasonable because every bus that operates during the day is generally serviced regardless of the miles that it travels.

Vehicle Inspection

Like daily servicing, vehicle inspection is a frequent activity. Almost all transit systems perform thorough inspections at fixed mileage intervals that range from 3,000 to 6,000 miles. In addition, daily safety inspections or brake adjustments or both are performed in the inspection area at some transit systems.

Most transit systems prefer pits for inspection because a bus can be moved over a pit more quickly than it can be raised on a hoist. Whether pits or hoists are used, inspection areas are generally designed as drive-through lanes to minimize the time that is required to maneuver the vehicles.

The best statistical relationship was 0.045 lane



SERVICE AREA SPACE REGRESSION EQUATION

$y = 99x - 2771$
(12) (1727) STANDARD ERROR OF REGRESSION COEFFICIENT
(8.21) (1.60) T-VALUE
(0.00) (0.06) SIGNIFICANCE OF T-VALUE
$r^2 = 0.75$ NUMBER OF CASES = 25
x = ANNUAL VEHICLE MILES IN 100,000'S
y = SERVICE AREA IN SQUARE FEET

FIGURE 6 Service lane area analysis.

per 100,000 annual vehicle miles plus 0.667 lane (Figure 7). The use of service area as a dependent variable did not produce a significant relationship, probably because most of the facilities used the drive-through design. When this design is used, the placement of exterior doors and internal circulation lanes can greatly influence the size of the inspection area.

As shown in Figure 7, the relationship between the number of inspection lanes and annual vehicle miles has a relatively low coefficient of determination ($R^2 = 0.51$). This occurs in part because the number of inspection lanes is a discontinuous variable. The plot in Figure 7 suggests that a step function may exist where an additional inspection lane is added every 1.5 million to 2.0 million annual vehicle miles.

Parking

The most significant new development in bus parking is the provision of indoor parking in areas with inclement weather. The pattern in the sample transit systems was to provide indoor parking where the temperature drops below 32° F more than 100 nights per year.

Where indoor parking is provided, it is usually in-line parking. This is the most space-efficient parking pattern. Where outdoor parking is provided, in-line stacking is used only in the most restrictive cases, because buses are not easily accessible. Angle parking or double-angle parking is preferred because each individual bus is always accessible. These patterns require more space than in-line parking, but they are preferred when the acreage is available. Double-angled parking requires almost twice as much space per bus as conventional in-line stacking because of the additional circulation lanes. Single-angled parking requires almost three times the space of in-line stacking (2):

Parking Type	Required Space per Bus (ft^2)
In-line	504
Double, 30-degree angle	920
Single, 30-degree angle	1,450
Single, 60-degree angle	1,325
Single, 45-degree angle	1,465

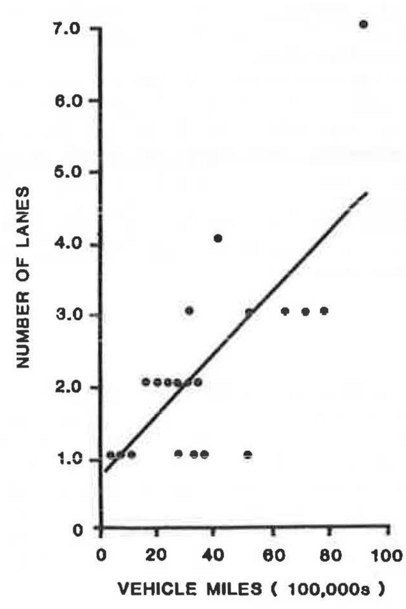
In some climates transit agencies have opted for total internal circulation and storage. Where winters are severe, internal circulation insulates the maintenance operation from the effects of weather. Buses do not have to "drip dry" before maintenance work is conducted, and shuttling buses to the shop from the parking area is never impaired by snow on the lot. Systems that have internal storage and circulation claim that the quality of maintenance improves.

The cost trade-offs for the benefit of improved maintenance are a larger building and a more elaborate ventilating system. It is necessary to have heat exchangers and a high rate of air turnover in the parking area when internal circulation is used. Because there are fewer doors, the old system of opening the storage garage doors for ventilation during pull-outs and pull-ins cannot be used.

The best statistical relationship for indoor parking was approximately 500 ft^2 per bus in the active fleet plus 2,665 ft^2 (Figure 8). This finding is consistent with the space recommendations that were cited for in-line parking earlier in this section. No data were available to analyze the provision of external parking space.

TRANSPORTATION

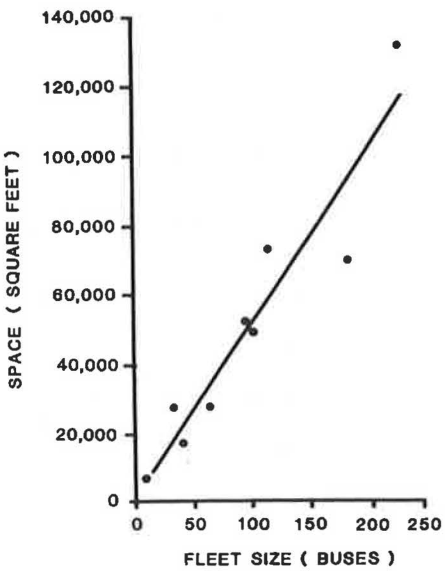
Transportation space includes the drivers' dayroom and locker room and dispatching offices. Fleet size



INSPECTION LANE REGRESSION EQUATION

$y = 0.045x + 0.667$
(0.010) (0.393) STANDARD ERROR OF REGRESSION COEFFICIENT
(4.64) (1.70) T-VALUE
(0.00) (0.05) SIGNIFICANCE OF T-VALUE
$r^2 = 0.51$ NUMBER OF CASES = 23
x = ANNUAL VEHICLE MILES IN 100,000'S
y = NUMBER OF INSPECTION LANES

FIGURE 7 Inspection lane area analysis.



INTERIOR PARKING SPACE REGRESSION EQUATION

y = 496x + 2665
(59) (1160) STANDARD ERROR OF REGRESSION COEFFICIENT
(8.35) (2.30) T-VALUE
(0.00) (0.03) SIGNIFICANCE OF T-VALUE
r^2 = 0.91 NUMBER OF CASES = 9
x = ANNUAL VEHICLE MILES IN 100,000'S
y = INTERIOR PARKING SPACE IN SQUARE FEET

FIGURE 8 Indoor vehicle storage analysis.

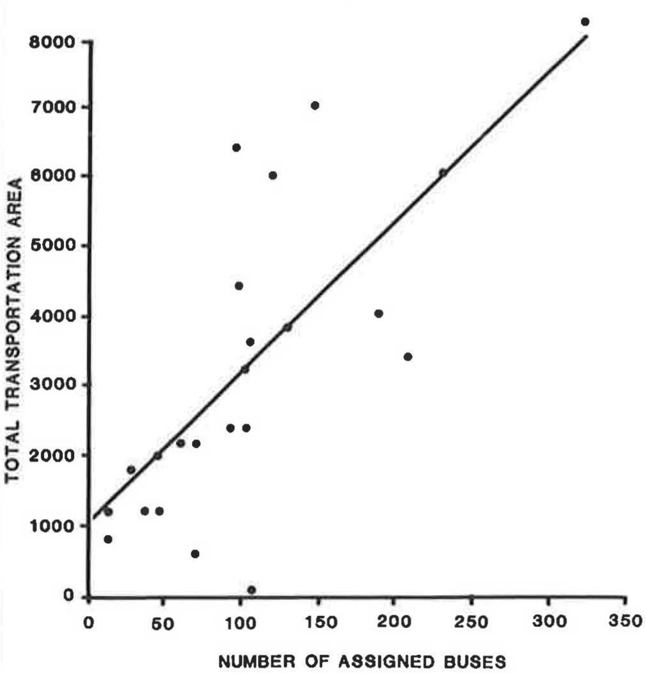
was found to be a good estimator of transportation space allocation (Figure 9). The regression equation calculated from the data suggests a minimum of 900 ft^2 plus 22 ft^2 additional per bus in the active fleet.

As shown in Figure 9, there is variation from the regression line on both the high and the low sides. This may be the result of differences in driver amenity policies. Some transit systems have relatively austere facilities for drivers, whereas others provide exercise rooms, large dayrooms, snack rooms, and so on.

OFFICE SPACE

More office space for administrative functions is provided in transit systems with only a single maintenance facility than in systems with multiple facilities. An average of 7,100 ft^2 of administrative space was provided in single-facility systems, whereas only 1,900 ft^2 was provided in multiple-facility systems. The reason for this difference is that multiple-facility systems are more likely than single-facility systems to maintain separate administrative offices away from the maintenance facility.

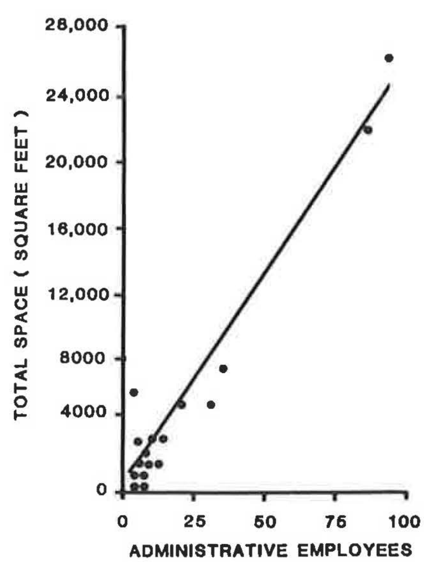
Although the gross amount of administrative space differed between the two system types, there was no difference in the amount of space that was provided per administrative employee. Approximately 260 ft^2 per administrative employee was provided in both single- and multiple-facility systems. The use of administrative employees as the independent variable was found to provide the best statistical relationship for administrative space (Figure 10).



TRANSPORTATION SPACE REGRESSION EQUATION

y = 22x + 938
(4) (553) STANDARD ERROR OF REGRESSION COEFFICIENT
(5.18) (1.70) T-VALUE
(0.00) (0.05) SIGNIFICANCE OF T-VALUE
r^2 = 0.56 NUMBER OF CASES = 23
x = ANNUAL VEHICLE MILES IN 100,000'S
y = TRANSPORTATION SPACE IN SQUARE FEET

FIGURE 9 Transportation space analysis.



TOTAL ADMINISTRATIVE SPACE REGRESSION EQUATION

y = 258x + 752
(15) (460) STANDARD ERROR OF REGRESSION COEFFICIENT
(17.15) (1.64) T-VALUE
(0.00) (0.06) SIGNIFICANCE OF T-VALUE
r^2 = 0.94 NUMBER OF CASES = 20
x = ANNUAL VEHICLE MILES IN 100,000'S
y = TOTAL ADMINISTRATIVE SPACE IN SQUARE FEET

FIGURE 10 Administrative space analysis: all facilities.

TABLE 2 Summary of Space Guidelines for Transit Maintenance Facilities

Functional Area	Space Allocation (ft^2) Single-Facility Systems	Multiple-Facility Systems	All Systems
Maintenance			
Maintenance bays			250 x VMT
Parts storage	233 x VMT	126 x VMT	
Other storage	52 x VMT		
Tire shop			
With bay			2,141[a]
Without bay			517[a]
Brake shop			
With bay			1,600[a]
Without bay			330[a]
Battery room			235
Body shop			2,835
Dynamometer bay			1,719
Electrical shop			291
Injector repair shop			187
Overhaul shop			2,324
Paint shop			2,037
Parts cleaning area			500
Steam cleaning area			1,148
Bus servicing			
Daily servicing			99 x bus
Vehicle inspection			0.667 lane per VMT
Interior parking			496 x bus + 2,665
Transportation			22 x bus + 938
Administration			258 x ADEMP

Note: VMT = annual vehicle miles (100,000s); BUS = number of buses in the active fleet; ADEMP = number of administrative employees.

[a]Some shops include a bus bay; others do not.

CONCLUSION

The state-of-the-practice data presented in this paper reflect the design decisions of many architects and bus maintenance engineers that have bee incorporated into facility designs. It was not pos sible to totally reconstruct the planning proces for the facilities in the sample, because the per sonnel responsible are often no longer with th system or the details of planning are forgotten. Th approach of this research effort was to construct composite planning guideline by observing what wa actually built and relating that to the condition of operation. Table 2 summarizes the key space-allocation findings.

These space-allocation guidelines are not intended to replace the planning and design role o architects and local maintenance managers. Rathe the guidelines provide both a starting point fo space-allocation planning, to be refined accordin to local conditions, and a final check to see whether a new design is more or less in line with what other systems have done.

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2. Prototypical Design Criteria for a Satellite Bus Maintenance Facility. Fleet Maintenance Consultants, Inc., Houston, Tex., April 1980.

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