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Transit Project Planning Guidance
Estimation of Transit Supply Parameters

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Transportation Systems Center

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TRANSIT PROJECT PLANNING GUIDANCE

ESTIMATION OF TRANSIT SUPPLY PARAMETERS

Michael Jacobs, Robert E. Skinner, and Andrew C. Lemer

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16. Abstract

This report discusses techniques applicable to the estimation of transit vehicle fleet requirements, vehicle-hours, vehicle-miles, and other transit supply parameters. These parameters are used for estimating operating and maintenance costs as well as certain capital costs such as rolling stock. These costs, in turn, are critical factors in evaluating public transportation investment proposals.

General considerations in estimating supply parameters are discussed. These include the relationship of supply parameter estimation to the overall project development process, typical data requirements for system planning and project planning, the assessment of operational feasibility, and the sensitivity of the supply parameter estimates to input assumptions and procedures. The use of empirical data to assess the reasonableness of these estimates is emphasized, and selected empirical data are provided.

The following topics also are covered: the definition and description of alternatives; the estimation of transit vehicle and line capacities; the preparation of ridership forecasts and the analysis of the compatibility among these forecasts and the underlying capacity and level of service assumptions; the estimation of fleet requirements and service parameters; and the estimation of the numbers of employees required to operate proposed transit services.

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PREFACE

This is the first in a series of reports intended to assist State and local agencies in the conduct of urban transportation planning, with particular emphasis on major mass transportation investments. Subsequent reports will be published and updated periodically under the overall title of "Transit Project Planning Guidance," and will address such subjects as capital and operating cost estimation, financial planning, travel forecasting, evaluation of alternatives, energy and air quality impact analysis, economic and development impact analysis, and noise and vibration impact analysis.

The guidance strives primarily to provide information which will be useful to agencies undertaking transit project planning, including those agencies seeking to fulfill the requirements described in UMTA's "Major Capital Investment Policy of 1984." Discussions will encompass the definition of the physical and operational characteristics of alternative transit projects, plus the estimation and assessment of expected fiscal and other impacts.

Where agencies are contemplating applying to the Federal government for financial assistance, the guidance also will convey general expectations regarding basic analysis principles (e.g., uniformity of assumptions among alternatives, and compatibility of forecasts with available empirical data). While specific analysis techniques are not mandated, these principles will help assure consistency in the evaluation criteria used for Federal decision-making related to the granting of discretionary capital assistance.

ABSTRACT

This report discusses techniques applicable to the estimation of transit vehicle fleet requirements, vehicle-hours, vehicle-miles, and other transit supply parameters. These parameters are used for estimating operating and maintenance costs as well as certain capital costs such as rolling stock. These costs, in turn, are critical factors in evaluating public transportation investment proposals.

General considerations in estimating supply parameters are discussed first. These include the relationship of supply parameter estimation to the overall project development process, typical data requirements for system planning and project planning, the assessment of operational feasibility, and the sensitivity of the supply parameter estimates to input assumptions and procedures. The use of empirical data to assess the reasonableness of these estimates is emphasized, and selected empirical data are provided throughout the text and in appendices.

Other chapters deal in somewhat greater detail with the following aspects of supply parameter estimation: the definition and description of alternatives; the estimation of transit vehicle and line capacities; the preparation of ridership forecasts and the analysis of the compatibility among these forecasts and the underlying capacity and level of service assumptions; the estimation of fleet requirements and service parameters; and the estimation of the numbers of employees required to operate proposed transit services.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

1. INTRODUCTION

Transit supply parameters are measures which describe and quantify either the amount of transit service provided by an existing or proposed mass transportation system, or the non-monetary resources such as vehicles and employees needed to maintain this level of service. Key supply parameters include:

- o peak period, daily, and annual vehicle-hours or train-hours, by vehicle type;
- o peak period, daily, and annual vehicle-miles or train-miles, by vehicle type;
- o peak period, daily, and annual seat-hours or place-hours, by transit mode;
- o peak period, daily, and annual seat-miles or place-miles, by transit mode;
- o average system operating speed, by transit mode;
- o fleet size, by vehicle type; and
- o number of employees, by category.

These types of supply parameters are essential inputs for estimating operating costs and certain capital costs such as rolling stock, which in turn are critical factors in evaluating public transportation investment proposals. Careful estimation of supply parameters is especially important inasmuch as large transit systems in the U.S. currently typically recover less than half of their operating costs from the farebox. The financial condition of these systems, therefore, and their need for operating assistance (e.g., from various taxes), depends greatly on operating costs as well as on ridership and fare revenues.

The estimation of transit supply parameters is an integral part of the planning process, related to: the definition of alternatives and description of services to be provided; the estimation of ridership; and the reconciliation of supply and demand. Performance characteristics of particular interest include routings and stops, speeds, headways, and vehicle and line or guideway capacities. In developing and analyzing alternatives, these characteristics should be examined carefully--along with such factors as loading standards and reliability expectations--to ensure that proposed services are operationally feasible, and that comparisons among alternatives are unbiased.

Despite its importance, transit supply parameter estimation has received relatively little attention in the literature, and there are few standardized procedures or technical guidelines for carrying out this process. Partly as a consequence, supply-related assumptions and procedures sometimes are developed which impart biases to the analysis of alternatives, which fail to reflect adequately certain constraints related to operational feasibility, and/or which do not provide sufficiently accurate inputs to the estimation of fleet requirements and operating costs. For example, bus and rail transit vehicle capacities are sometimes estimated which imply significantly different passenger loading standards.

This report provides guidance in estimating key transit supply parameters and requirements. Available analytical procedures and data sources are identified and described. Reasonableness checks are discussed, and some representative value ranges are provided.

Although the report has general applicability to public transportation planning, the primary focus is on major investment planning, including system planning and, especially, detailed alternatives analyses, corridor studies, and other types of project planning. Since bus and rail transit systems are the technologies typically examined in these studies, the emphasis is on procedures and data sources pertinent to these modes.

The report is intended primarily for those individuals involved in performing, directing, or monitoring those activities in system planning or project planning concerned with the estimation of transit supply parameters. Other study participants also may benefit from this report through improved understanding of the procedures, assumptions, and sensitivities involved in this process. Toward this end, efforts have been made to avoid excessive use of jargon, and a glossary has been provided in Appendix A.

The remainder of the report is organized as follows.

- Chapter 2 -- General Considerations. Provides an overview of the role of supply parameter estimation in the transit project development process, including a description and discussion of the major analysis steps, principal inputs and outputs, and important analysis issues and constraints.

- Chapter 3 -- Definition of Alternatives. Identifies and discusses key inputs and assumptions for supply parameter estimation embodied in the design and definition of alternatives.

- Chapter 4 -- Estimation of Capacities. Identifies and discusses procedures and issues to be addressed when estimating transit vehicle and line capacities.

- Chapter 5 -- Demand Estimates and Supply-Demand Checks. Reviews the general types of travel demand estimates generally prepared and used for supply parameter estimation, and the necessary checks which should be undertaken to ensure the compatibility of demand and supply estimates.

- Chapter 6 -- Estimation of Fleet Requirements and Service Parameters. Discusses procedures for estimating required fleet size and service parameters such as vehicle-miles and vehicle-hours.

- Chapter 7 -- Estimation of Employee Requirements. Discusses alternative approaches to estimating numbers of employees required to operate specified transit services.

- Chapter 8 -- Reasonableness Checks. Discusses compatibility of estimated supply parameters with comparable empirical information, and references and summarizes some of these data.

2. GENERAL CONSIDERATIONS

This chapter provides an overview of transit supply parameter estimation and its relationship to the overall project planning and development process. Critical issues and general considerations relating to the estimation process are discussed.

2.1 AN OVERVIEW OF THE SUPPLY PARAMETER ESTIMATION PROCESS

Figure 1 illustrates the typical study phases leading to implementation of urban public transportation projects. Also indicated are the basic responsibilities of State and local agencies contemplating such projects, and, where Federal financial assistance is being sought, the major Federal decisions to be made at the end of each study phase.

Estimation of transit supply parameters usually occurs in each of these phases, although the greatest effort generally is expended during detailed project planning, or alternatives analysis. By comparison, system planning encompasses a less detailed analysis, with less information on transit supply parameters, less precision, and less accuracy. Subsequent to project planning--e.g., during preliminary engineering--certain supply parameter estimates may need to be refined if the design of the system is altered, but this usually will not be a major activity.

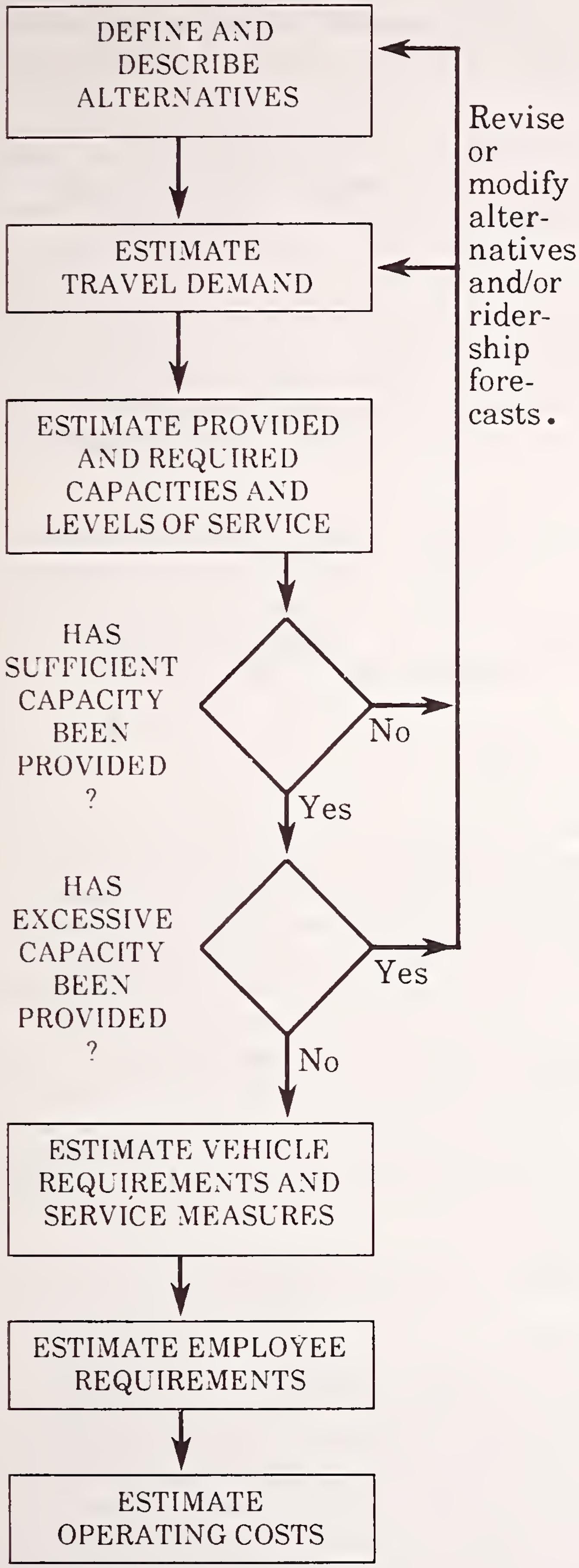
Schematically illustrated in Figure 2 is an overview of transit supply parameter estimation and its relationship to the flow of activities during project planning. Estimates of supply parameters are prepared throughout the process, from definition of alternatives through ridership forecasts to cost estimation.

The definition of alternatives includes an initial specification of the level of service (LOS) to be provided by each alternative, encompassing types of service, locations (routes and stops), quantities (e.g., headways during the various service periods), and qualities (such as speeds). This initial LOS specification attempts to anticipate demand, and to match supply with demand in ways that tend to minimize capital and operating costs, subject to policy constraints (e.g., maximum headways) and technological constraints (e.g., minimum headways).

The initial LOS specification is used as an input to the estimation of travel demand. This is followed by the determination of demanded and initially specified capacities and LOS, and by any modifications and iteration through previous steps which may be necessary to reconcile any significant discrepancies. If, after the initial demand estimates have been prepared, it is determined that insufficient capacity has been provided to accommodate this

STUDY PHASE	RESPONSIBILTIES OF SPONSORING STATE AND LOCAL AGENCIES	MAJOR DECISIONS OF THE LEAD FEDERAL AGENCIES
SYSTEM PLANNING	• Identify corridor(s) warranting major investment consideration, if any.	
	• Identify alternatives appropriate for study in detailed alternatives analysis/project planning.	
	• Provide conclusive evidence that such further study is warranted.	• Provide funding for detailed alternatives analysis?
ALTERNATIVES ANALYSIS/ PROJECT PLANNING	• Prepare Draft Environmental Impact Statement (DEIS).	
	• Prepare preferred alternative(s) report.	• Provide funding for engineering?
PRELIMINARY ENGINEERING	• Engineer preferred alternative(s).	
	• Make final selection and confirm cost-effectiveness and financial feasibility of preferred alternative.	
	• Prepare Final Environmental Impact Statement (FEIS).	• Provide funding for final design plus letter of intent for construction funding?
FINAL DESIGN	• Prepare construction management program and contracts.	• Provide full funding contract for construction?
CONSTRUCTION	• Manage project construction contracts.	

Figure 1.
OVERVIEW OF THE TRANSIT PROJECT DEVELOPMENT PROCESS



Includes specification of routes, stops, vehicle and guideway types, and initial level of service (e.g., nominal & policy headways, service hours, run times, loading standards).

Includes estimation of link and station volumes, maximum load point volumes, time-of-day distribution, and sub-hourly peaking.

Includes determination of service headways by route and time period to meet projected demand, accounting for loading standards, anticipated reliability, and policy and technology contraints.

For example, are service headways significantly higher or lower than nominal headways such that headways and/or ridership forecasts should be revised?

- Vehicle fleet size.
- Vehicle-hours or train-hours.
- Vehicle-miles or train-miles.

- Employees by category.

(Transit supply parameter estimates are key inputs to estimating operating costs.)

Figure 2.
ESTIMATION OF KEY TRANSIT SUPPLY PARAMETERS

demand, either: the demand should be constrained (reduced and/or reallocated to other modes and routings); and/or additional capacity should be provided (e.g., by reducing headways, by running longer trains).

Similarly, capacity should be reduced if demand does not appear to warrant that quantity of service. If capacity changes entail significant changes in headways or other LOS measures, the demand estimates should be modified accordingly.

The service characteristics (e.g., headways and run times) resulting from a satisfactory equilibration of the supply and demand estimates are then used to compute overall service measures (e.g., vehicle-miles, vehicle-hours) and vehicle requirements, and to estimate the numbers of employees required to maintain and operate these services. In turn, these transit supply parameters are key inputs to the estimation of operating costs.

A continuous activity during the supply estimation process is the application of "reasonableness" checks. These checks should be made of the LOS measures and supply parameter estimates to ensure their reasonableness, which is assessed largely in terms of consistency with transit experience observed locally and elsewhere which involves similar technologies and operating conditions.

2.2 SUPPLY-DEMAND EQUILIBRIUM

An imbalance between supply assumptions and demand forecasts in a transportation analysis can lead to unrealistic and erroneous conclusions. Consequently, as noted above, there is a need during project planning to address supply-demand equilibrium explicitly. This should be done routinely as part of the ridership forecasting process--i.e., steps should be taken routinely to ensure that reported ridership estimates are compatible with capacities and levels of service assumed for each respective alternative. Frequently, however, this issue is not given sufficient attention.

Two basic interrelated comparisons are necessitated for each alternative:

- capacity provided vs. capacity required; and
- LOS assumed vs. LOS implied by the travel demand estimates.

The capacity check is necessary to determine whether, given the physical, technological, and policy constraints associated with a particular alternative, sufficient capacity is being provided to accommodate fully the estimated travel demand. If not, these constraints should be modified by revising the definition of the alternative. In an extreme case, since certain technological constraints cannot be modified, this may mean abandoning a particular technology.

Conversely, the comparison may indicate that excessive capacity is being provided; i.e., that estimated demand is significantly less than that which can be accommodated, so that the alternative as initially defined is unlikely to prove cost-effective. In this case, too, the alternative should be modified.

The LOS check should be performed to ensure that the results of the ridership forecasting process are consistent with the LOS assumptions input to that process. Some revisions made to an alternative as a result of the capacity check (for example, the use of larger or smaller buses at the same assumed headways, or larger or smaller rail transit consists) may not alter the LOS significantly. Other changes, however, such as changes to headways, routings, or speeds/run times, will result in levels of service different from those initially input to the demand forecasting process. Reduced headways and/or increased speeds, for example, generally will result in increased ridership, while increased headways or lowered speeds normally will lead to reduced demand levels.

Such differences often will not be so great as to require revised or modified demand estimates. Significant differences should be reconciled, however, and such checks are always necessary to ensure supply-demand equilibrium.

2.3 ITERATIVE NATURE OF SUPPLY PARAMETER ESTIMATION

The estimation of transit supply parameters generally is an iterative process within each of the project development phases. Supply parameter estimation occurs initially during system planning, and continues through project planning, engineering, and beyond into detailed operational planning. As the estimation of supply parameters proceeds along this course, the input assumptions should be examined more rigorously, the alternatives should be specified in greater detail, and the estimation procedures should be increasingly precise and accurate. The process itself, however, remains essentially similar.

Initially, supply parameter estimation is directed at providing information in sufficient detail to distinguish among broadly defined alternatives. Later, it provides information needed to assess the worthiness of a limited number of alternatives. And finally, it is concerned with the design and optimal operation of a single alternative.

In addition, at any given analysis stage, there may be need for iterative or multiple estimates of supply parameters. There are two primary purposes for such iterations:

- o to explore capital cost and operating cost tradeoffs; and
- o to conduct sensitivity analyses with respect to analysis assumptions and procedures.

Illustrations of such iterative applications are provided below in the following sections of this chapter.

2.4 SENSITIVITY TO INPUT ASSUMPTIONS AND PROCEDURES

An example is presented to illustrate the sensitivity of supply parameter estimates to input assumptions and analysis procedures. Table 1 summarizes the assumptions and procedures used to estimate, for a hypothetical rail line, three key supply parameters: annual train-hours; annual car-hours; and annual car-miles. Table 2 reports the baseline estimates for these parameters and their sensitivity to various changes in assumptions or procedures. (Sample calculations are provided in Appendix E).

Because additional passenger capacity can be added only in discrete units, as indicated schematically by the "lumpy" supply curve in Figure 3, excess capacity usually is provided in order to meet a pre-specified demand level. The amount of this excess capacity influences the degree of change in supply parameters which may occur in response to a change in an input assumption. (Table 2 also indicates the amount of peak and off-peak excess capacity provided by each sensitivity test).

Based on this example, several observations can be made about the estimation of supply parameters:

- The sheer number of input assumptions alone illustrates the complexity of supply parameter estimation. Furthermore, the need for decision rules, such as minimizing train-hours, suggests that the procedures are not as straightforward as many have supposed.

- Because of the "lumpiness" in the supply curve, a minor change in a particular input parameter (such as cruise speed) sometimes may be just enough to significantly reduce or increase equipment requirements. In other situations, however, a more substantial change in an input parameter may have a negligible impact. The net change depends in part on site specific circumstances. (Thus, it is not possible to generalize based on the results of this example.)

- None of the sensitivity tests in the example revealed dramatic changes in supply parameters resulting from a single change in an input assumption over the ranges tested. They do illustrate, however, that results can be constrained or partially predetermined by seemingly minor assumptions (e.g., load peaking factors, station dwell times, annualization factors, and off-peak policy headways).

- The impact upon supply parameters of multiple changes in input assumptions sometimes can be additive. For example, the combination of change No. 6 (which decreases train-hours by 20 percent) and change No. 10 (which results in a 15 percent reduction) decreases train-hours by 35 percent. In general, two different sets or packages of assumptions could yield significant differences in supply parameter estimates.

Table 1. EXAMPLE TO ILLUSTRATE SENSITIVITY OF SUPPLY PARAMETERS TO INPUT ASSUMPTIONS AND PROCEDURES (BASELINE DESCRIPTION)

Definition of Alternative

- 10 mile rail line with 7 stations
- Average station spacing: 1.67 miles
- Vehicle characteristics
  - 630 gross square feet per car
  - Maximum train consist contains 3 cars
  - Loading standard of 5.4 square feet per passenger
  - Cruise speed of 60 miles per hour
  - Service acceleration & deceleration of 3.0 mph per second
- Policy headways
  - 5 minutes for 4 peak hours
  - 10 minutes for 12 off-peak hours
- Weekend and holiday service such that the annualization factor is 310
- Station dwell time of 40 seconds
- Minimum headway: 2.5 minutes

Demand Levels

- Maximum load point volume: 32,000 daily riders (two-way).
- Peak hour maximum load point volume in peak direction: 4,800 riders (15% of total daily ridership).
- Off-peak maximum hourly peak load point volume in peak direction: 1,200 riders (3.75% of total daily ridership).

Supply Parameter Estimation Procedures

- Average speed estimated using formula applicable for sufficient station spacing to reach cruise speed:

$$V = \frac{D}{T + D/C + C(1/2a + 1/2d)}$$

where V = average transit vehicle velocity or speed;
D = average distance or spacing between stations;
T = stop (dwell) time at stations or stops;
C = cruising speed;
a = rate of acceleration;
d = rate of deceleration.

- Train-hours minimized (headways maximized) subject to policy headway and demand constraints.
- Adequate capacity provided in 12 off-peak hours to meet peak load point, peak direction demand (1,200 riders/hour).
- Adequate capacity provided in 4 peak hours to meet peak-load point, peak-direction demand (4,800 riders/hour).

Table 2. SENSITIVITY OF SUPPLY PARAMETERS TO CHANGES IN ANALYSIS ASSUMPTIONS AND PROCEDURES

(BASED ON EXAMPLE DESCRIBED BY TABLE 1)

Sensitivity Test	Cars Required**	Annual Supply Parameters* Train-Hours (x100)	Car-Hours (x100)	Car-Miles (x1000)	Excess Passenger Places Peak	Off-Peak
1. Baseline estimates	24	248	595	2232	465	555
2. Decrease loading standard by 10% to 4.9 sq. ft. per passenger	21 (-12.5%)	235 (-5%)	557 (-6%)	2091 (-6%)	309	555
3. Increase cruise speed by 10% to 66 mph (increases average speed by 4%)	21 (-12.5%)	235 (-5%)	556 (-6%)	2184 (-2%)	9	632
4. Increase maximum train consist to 4 cars	24	248 (0)	595 (0)	2232 (0)	465	555
5. Decrease annualization factor by 10% to 279	24	223 (-10%)	535 (-10%)	2009 (-10%)	465	555
6. Remove one station, increase average station spacing to 2 miles (+20%) (increases average speed by 18%)	21 (-12.5%)	198 (-20%)	483 (-18%)	2146 (-4%)	641	361
7. Decrease station dwell time to 30 seconds (-25%) (increase average speed by 7%)	21 (-12.5%)	198 (-20%)	483 (-18%)	1936 (-13%)	114	206
8. Decrease maximum train consist to two cars	22 (-8%)	285 (+15%)	569 (-4%)	2138 (-4%)	25	555
9. Decrease peak-hour, peak-load point one-way volume from 15% to 14% of daily max. load point 2-way volume (4800 pass./hour to 4400 pass./hour)	21 (-12.5%)	235 (-5%)	557 (-6%)	2091 (-6%)	118	555
10. Increase off-peak policy headways from 10 minutes to 15 minutes	21 (-12.5%)	210 (-15%)	520 (-13%)	1952 (-13%)	465	116
11. Minimize car-miles rather than train-hours subject to demand and policy constraints	22 (-8%)	359 (+45%)	495 (-17%)	1859 (-17%)	25	116
12. (Numbers 6 and 10)	21 (-12.5%)	161 (-35%)	483 (-19%)	2144 (-4%)	641	358
13. (Numbers 6, 9, and 10)	18 (-25%)	148 (-40%)	445 (-25%)	1981 (-11%)	200	360

*Revenue service only. **Excludes spares.
( )Percentage change compared with baseline estimate.

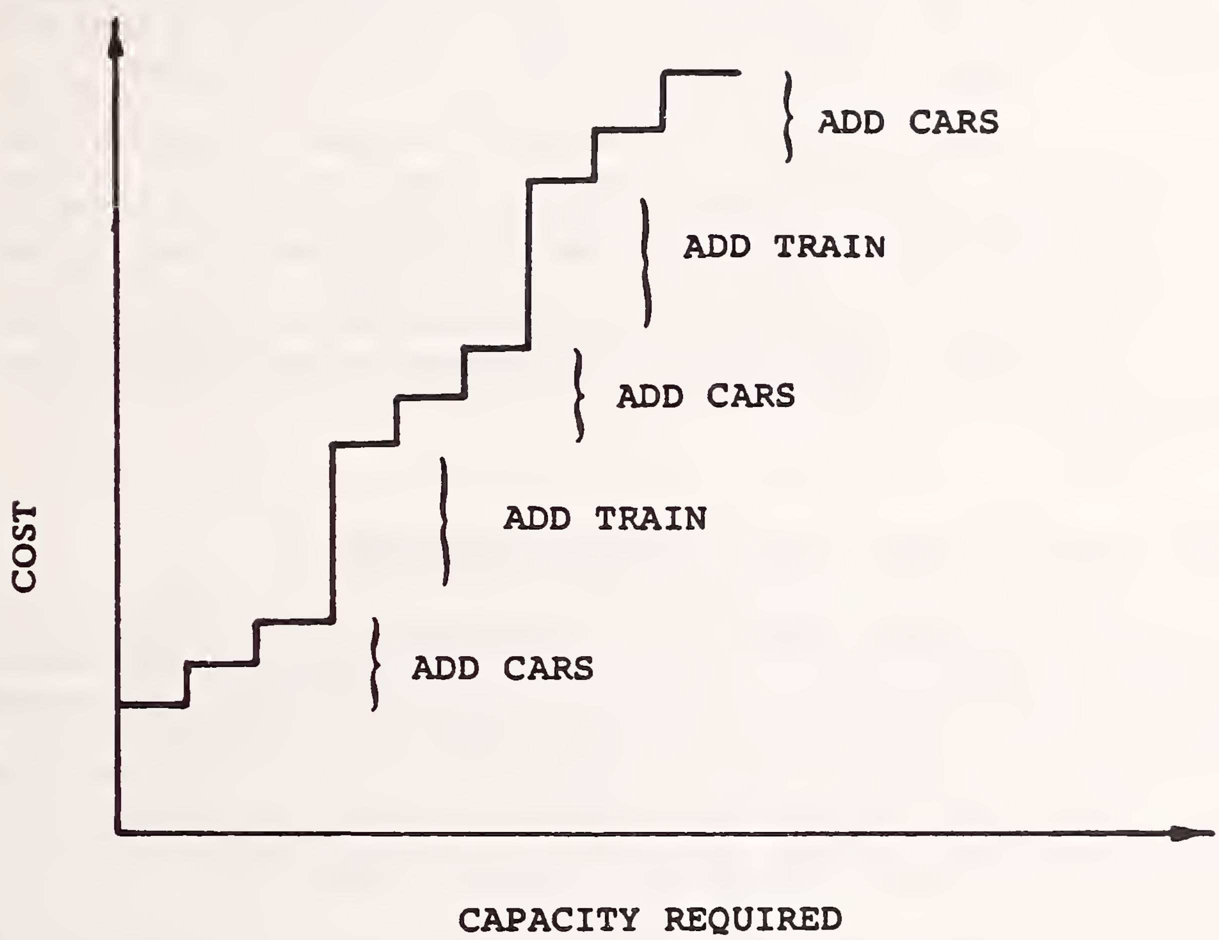


Figure 3.
SCHEMATIC SUPPLY CURVE -- RAIL TRANSIT

- Train-hours, probably one of the most significant parameters from an operating cost standpoint, tended in this example to be more sensitive to changes in input assumptions than either car-miles or car-hours.

- Changing the objective function from minimizing train-hours to minimizing car-miles can result in significant changes in supply parameters.

This example illustrates the potential need for iteration to explore capital-operating cost tradeoffs. For example, compared with three-car station platforms, a two-car platform alternative would result in lower capital costs due to the shorter platforms and a small reduction in the required fleet. However, the operating costs for the two-car station alternative would be greater, with more train-hours of service operated.

Similarly, the example also demonstrates that changes in input assumptions, particularly in combination, can have a significant impact on the resulting supply parameter estimates. Analyses may be needed to reveal the extent of such sensitivities and to explore alternative operating strategies and capital-operating cost tradeoffs such as cited above. The results of sensitivity analyses may spur changes in input assumptions so that further iterations are required. These changes may affect the levels of service provided, which in turn potentially could necessitate revising the travel demand projections.

2.5 SYSTEM PLANNING VERSUS PROJECT PLANNING REQUIREMENTS

The distinction between supply parameter requirements of system planning and of project planning cannot be drawn clearly and unequivocally because of the variability in site-specific circumstances and the range of alternatives considered. Clearly, for example, studies examining alternatives which include additions to extensive rail systems will involve greater operational complexity than studies considering a single rail line in an area with no existing rail services. Greater operational complexity generally requires more sophisticated procedures to estimate supply parameters.

While firm guidelines cannot be prescribed, however, it is possible to characterize in an approximate sense the procedural and level of detail differences between system planning and project planning. Supply parameter estimation during system planning generally will:

- be geared for simplified operating cost estimation;

- include vehicle-miles, vehicle-hours, and fleet size, but not necessarily employees by category;

- focus on peak-period weekday services;

- utilize relatively simple manual estimation procedures;

- include only limited iteration and sensitivity analyses; and
- include only limited reasonableness checks, possibly not independent of the estimation procedures.

By contrast, supply parameter estimation during project planning generally should:

- be geared for comprehensive operating cost estimation procedures, usually incorporating explicit analysis of labor, materials, and service requirements;
- include a fairly extensive and complete set of supply parameters;
- include consideration of both peak and off-peak weekday service, and possibly weekend service as well;
- employ more complex estimation procedures, including, typically, a greater reliance on computer-assisted procedures;
- include more extensive iteration and sensitivity analyses (e.g., examining potential effects of alternative fleet mix, wage rate, and/or productivity assumptions); and
- include extensive reasonableness checks independent of estimation procedures.

Because supply parameter requirements and appropriate procedures for either system planning or project planning will vary from location to location, project participants should reach agreement in advance with regard to supply parameter requirements, input assumptions, and estimation procedures. While such agreements may require modification during the course of the analysis, they will serve as a basic guide for the conduct of the study.

2.6 OPERATING FEASIBILITY

As the analysis of transit alternatives proceeds, the definition of alternatives is continually refined and increasingly detailed. As this occurs, it becomes increasingly important that the alternatives being examined are feasible from engineering and operational viewpoints. Operating or operational feasibility is concerned with whether or not a system or technology can actually perform as specified, and this issue is thus of considerable relevance to supply parameter estimation and system evaluation.

Furthermore, the fact that a system may be operationally feasible does not mean necessarily that it is operationally efficient--i.e., that the best service is provided at lowest possible unit costs consistent with service policies, safety, and other constraints. Thus, feasibility should not be viewed simply as a "yes or no" question. Relative operational efficiency should be determined by exploring different operating strategies through the use of iterative planning approaches. Examination of operating feasibility issues generally can indicate not only operating strategies which are totally infeasible, but also those which may be marginally feasible; i.e., those operating strategies more likely to lead to operating problems and/or lower operating efficiencies.

There are several major prerequisites for operational feasibility. First, the relationships among level of service descriptors, other descriptors of alternatives, vehicle performance specifications, estimated demand levels, and supply parameter estimates should be internally consistent. Examples of characteristics which should be checked for consistency include the following.

- Average speed and: vehicle performance; route characteristics; station/stop spacing; station dwell times.
- Vehicle passenger capacity and: loading standards; vehicle dimensions.
- Station dwell times and: boarding/alighting volumes; vehicle/train characteristics.
- Vehicle requirements and: route characteristics; demand levels; vehicle characteristics; minimum/maximum headways.
- Guideway capacity and: minimum headways; maximum train consist; vehicle passenger capacities.
- Travel demand and: headways; route characteristics; average speeds; maximum vehicle/train passenger capacities.

Another prerequisite is that the specification of the various performance characteristics should be within the capability of available technologies, and that these technologies should be specified in the capital cost estimates. Performance characteristics of particular concern with regard to operational feasibility include vehicle performance and, for rail technologies, signal control.

For more complex alternatives, frequently involving additions and/or modifications to existing systems, additional feasibility issues may be raised regarding such operational features as skip-stop service, branching, partial turnbacks, and shared route segments of express and local services. While branching, for example, can provide increased geographic coverage and bring line-haul transit service closer to greater numbers of people, the impact on the quality of those services, as measured by headways, should be examined carefully.

For example, high demand on two or more branches of a rail line may strain peak period capacity of the common (e.g., downtown) portions of the line, and increase the difficulties of schedule maintenance. Or, peak period capacity limitations downtown may preclude the complete accommodation of peak demand on one or more branches. And, in relatively low demand situations, moderate headways on shared portions of a branched line may, particularly during off-peak periods, imply unacceptably large headways on the branches or, if policy headways prevail, unacceptably low vehicle loadings.

In general, all operating proposals involving partial sharing of route segments, such as branching and partial turnbacks, should be examined carefully with regard to demand distributions and their likely impacts on vehicle/train loading patterns. An imbalanced demand distribution relative to service patterns can make schedule adherence difficult or impossible.

To illustrate, consider an example of two middle or outer suburban branches of a rail transit line, each operating during the a.m. peak period at five minute headways, joining together in the inner suburbs (at two-and-a-half minute headways) before entering the downtown area. If demand on one of these branches is significantly higher than on the other branch, and if there are significant alightings at the (shared) inner suburban stations, the alternate trains from the high-demand branch will experience higher station dwell times.

This, in turn, will unbalance the headways at subsequent stations, lengthening the elapsed time prior to arrival of the high-demand branch trains, and reducing the headways following these alternate trains. Assuming random arrival patterns, greater portions of the boardings at these stations will occur on these alternate (high-demand branch) trains, further lengthening their dwell times, further unbalancing the headways, etc. As trains go farther along the shared route segment, the problem thus can become magnified and, if of significant magnitude, can lead to poor schedule reliability and "bunching" of trains and all that this entails--e.g., poor utilization of vehicle capacity, potentially increased fleet requirements, overcrowding, increased wait times, and/or demand for some trains in excess of train capacity.

2.7 RELATIONSHIP BETWEEN PREDICTIVE TECHNIQUES AND REASONABLENESS CHECKS

Estimates of transit supply parameters should be verified by comparison with empirical evidence in the study region or elsewhere. These "reasonableness" checks may utilize data from separate sources or, less desirably, from data sources used also for the estimation procedures.

For example, data describing average transit speeds by mode, perhaps broken down by average stop or station spacing, might be used in an early cycle of system planning to estimate supply parameters. The same data, however, also might be incorporated in a reasonableness check of estimated service speeds.

Reasonableness checks, thus, are not necessarily independent of the estimation procedures, and care should be exercised in selecting and using data for these activities. When reasonableness checks are not fully independent of estimation procedures, their limited value should be recognized. Non-independent checks sometimes may be satisfactory during system planning, but such checks generally should be independent of estimation procedures for detailed corridor studies or other types of project planning.

3. DEFINITION OF ALTERNATIVES

Various inputs and assumptions necessary for estimating transit supply parameters are embodied in the definition of alternatives. This chapter reviews the most critical of these, including:

- alignment and stations;
- line-haul travel times;
- service characteristics; and
- background bus services.

These characteristics define to a great extent the level and quality of transportation services provided by a proposed alternative, and are used as well in the estimation of travel demand.

3.1 ALIGNMENT AND STATIONS

3.1(a) Guideway Alignment

For alternatives which include fixed guideway components, the extent and characteristics of the guideway will have significant effects on the supply parameter estimates. Degree of exclusivity, horizontal alignment, and vertical alignment influence system performance which, in turn, affects both the vehicle-hours and vehicle-miles operated as well as the numbers of vehicles required to provide a given level of service. Guideway characteristics, coupled with vehicle technologies, also affect the determination of maximum system and line capacities.

During system planning, horizontal guideway alignments sometimes are specified only in general terms--e.g., within a fairly broad band perhaps several hundred yards wide. Vertical alignments also may not be fully defined, although because of the wide variations in construction costs and neighborhood impacts, they generally need to be identified as elevated (aerial), at-grade, open cut, or subway (cut-and-cover or tunnel). This lack of specificity should not impede the estimation of supply parameters for system planning, commensurate with the levels of precision and accuracy needed for this phase of analysis.

Detailed project planning demands more precise specification of alignments than does system planning, both for cost estimation and for assessment of local environmental and neighborhood impacts. Such specification should permit relatively accurate estimates to be made of guideway-related supply parameters.

3.1(b) Stations

The number and spacing of stations or stops on transit lines directly affect not only travel demand, but also average service speed (or scheduled speed) which, in turn, affects supply parameters. Station locations for each fixed guideway alternative normally should be indicated in fairly specific terms during project planning, but this need not always be the case during system planning, where an expected average station spacing may suffice for supply parameter estimation purposes.

For fixed guideway systems, station design characteristics influence capital costs, station capacity, access/egress times, and, to a certain extent, supply parameters such as vehicle hours. The principal design characteristics of interest are construction type and platform layout. As with vertical guideway alignment, the construction-type alternatives for stations are aerial, at-grade, and below-grade (open-cut, cut-and-cover, or tunnel). The costs of these alternatives vary widely, and the selection of a particular type is greatly dependent on the vertical alignment of the guideway section on which a station is located.

There are two basic platform layout options: center platform and side platforms. A principal advantage of center platform layouts is that they tend to minimize the duplication of facilities such as stairways, escalators, elevators, and fare collection equipment. Since the same platform is used for both directions, stairways, escalators, etc. can be used by entering and exiting passengers regardless of direction. If passenger flows are significantly unbalanced by direction during peak perids, a center platform station potentially requires only half as many of these facilities as a side platform station.

Similarly, the total platform area of center platform stations typically is less than that of side platform stations because the same platform is used to accommodate morning and evening peak-period passengers. The principal disadvantage of a center platform station is that it often requires an extensive system of passageways to provide access to both sides of a street. Side platforms usually are more conducive to direct sidewalk access.

Generally, adequate station capacity can be provided with all types of station designs, and the major impacts of alternative designs likely will be on construction costs and neighborhood impacts. Station design also affects passenger convenience, with design problems potentially contributing to, for example, increased walking distances for access/egress and transfers, platform congestion, and crowding at doors, stairways, and turnstiles.

Station design affects supply parameters to a lesser extent, although it can influence passenger boarding and alighting rates which, in turn, affect station dwell times and average speeds. Also, inadequate design can result in inefficient utilization of train capacity, in turn causing unnecessary overcrowding and, potentially, increased fleet requirements.

Station entryways at the rear of several high volume stations on a line, for example, can cause overcrowding in the rear cars of the train while seats in front cars remain unoccupied. The location of stairs and escalators in stations thus should attempt to distribute passengers evenly among cars in the train, with an appropriate balance achieved among stations on a single line.

3.2 LINE-HAUL TRAVEL TIMES

Line-haul travel times, or average service speeds, are dependent partly on route and guideway characteristics and partly on other characteristics such as station spacing, vehicle performance characteristics, and station dwell times.

3.2(a) Station Spacing

As noted earlier, the spacing of stations or stops on transit services directly affects average service speed (or scheduled speed), which in turn affects supply parameters. For rail transit, Figure 4 illustrates the impact of station spacing on average speed. As average station spacing is reduced, acceleration and deceleration characteristics become increasingly more important in determining average operating speed, while top cruise speed becomes progressively less important.

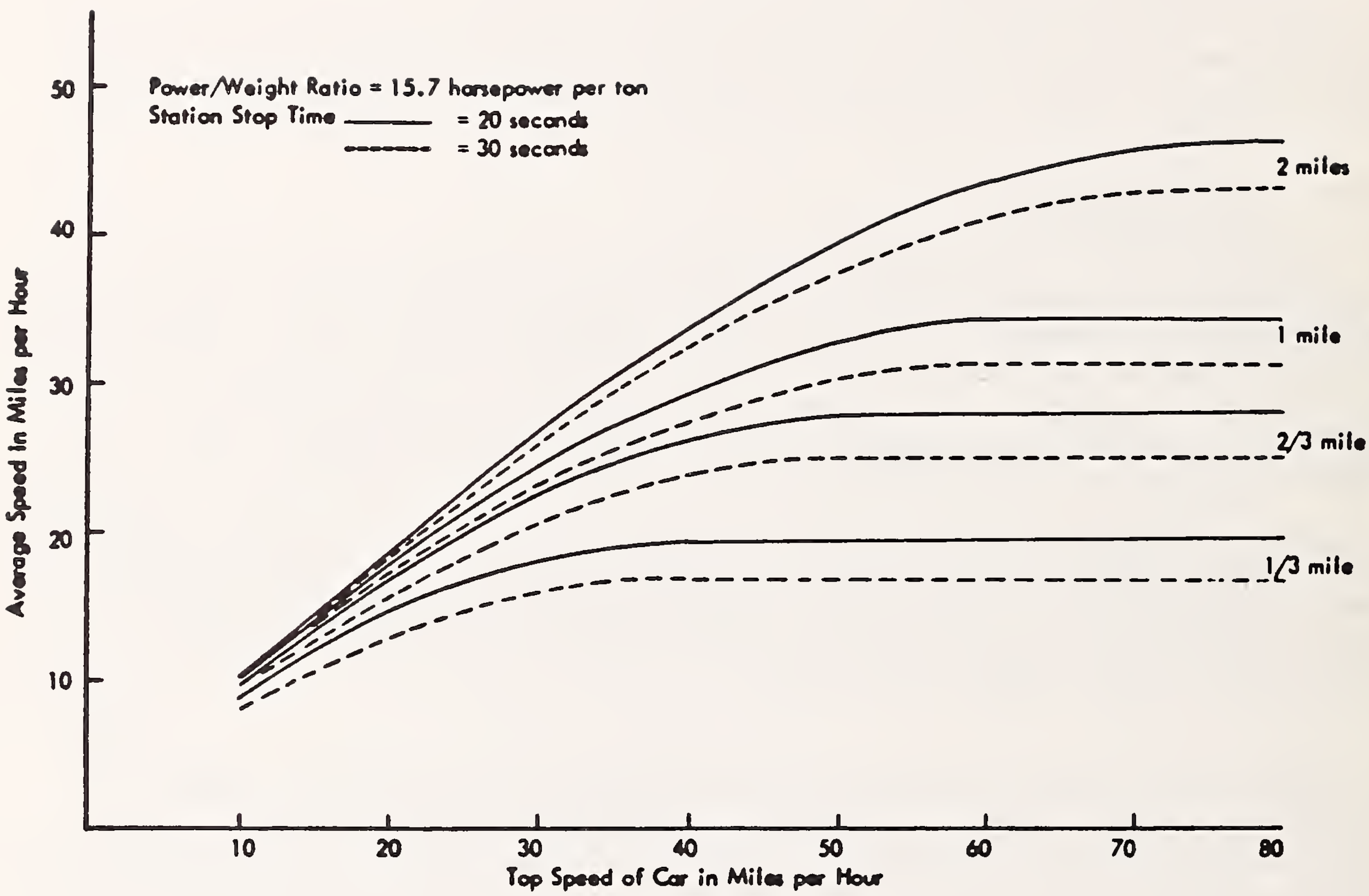
While average service speed is critical to supply parameter estimation, door-to-door travel time is critical to demand estimation. Increasing the number of stations on a fixed guideway service will decrease the average service speed, but because accessibility to the service is improved, improved door-to-door travel times may result.

Typical station or stop spacings for various transit modes are summarized by Table 3, with spacings for specific North American rail rapid transit systems and European light rail systems presented in Tables 4 and 5, respectively. These data can be used early during system planning to select station spacings or stop spacings which are typical of the transit technologies under consideration.

For project planning, in contrast, the spacing for fixed guideway services should be based upon specific station locations. Determining the number and location of stations involves tradeoffs among a number of factors including demand, capital cost, operating cost, community impacts, and joint development opportunities.

3.2(b) Vehicle Performance

Average service speed is influenced by the performance capabilities of the transit vehicle itself, including top cruise speed, acceleration and deceleration rates, and jerk rate (rate of change of acceleration/deceleration).



Source: Lang and Soberman (1964).

Figure 4.

RELATIONSHIP BETWEEN TOP SPEED, STATION SPACING, AND AVERAGE SPEED FOR RAIL TRANSIT

Table 3. STOP SPACINGS FOR VARIOUS TRANSIT MODES

Transit Vehicle and Service Type	Linear Spacing [ft(m)]		
		Non-CBD	
	CBD	Typical Traditional Practice in North America and Elsewhere	Typical Contemporary Practice with Longer Stop Spacings
Local bus, urban	400-800 (122-243)	500-800 (152-243)	1000-1500 (304-456)
Limited-stop bus, urban	400-800 (122-243)	1200-3000 (365-912)	2000-5000 (608-1520)
Express bus, urban	500-1000 (152-304)	4000-30000 (1216-9120)	1-30 mi (2-50 km)
Intercity bus	*	**	**
Local tram, urban	400-800 (122-243)	500-800 (152-243)	1000-1500 (304-456)
Express tram, urban	600-1500 (182-457)	--- ---	2000-5000 (608-1520)
Rapid transit, urban	1000-2500 (304-608)	1700-3500 (517-1064)	3500-8000 (1064-2432)
Rapid transit, regional	2000-3000 (608-912)	--- ---	6000-30000 (1824-9120)
Commuter railroad	*	4000-15000 (1216-4560)	8000-30000 (2432-9120)
Rapid transit, super-regional			
Super-express	*	---	50-150 mi (80-240 km)
Limited-express	*	---	10-50 mi (16-80 km)

*Usually stop at only one or two CBD terminal points.
**Widely variable, depending on route characteristics.

Source: Quinby (1976).

Table 4. AVERAGE DISTANCE BETWEEN STOPS FOR EXISTING RAIL RAPID TRANSIT SYSTEMS

System	Average Distance Miles	Average Distance Km
TTC	0.54	0.87
CTA	0.81	1.30
BART	2.30	3.70
MUCTC	0.54	0.87
MBTA	0.78	1.26
PATH	1.07	1.72
WMATA	0.94	1.51
PATCO	1.18	1.90
GCRTA	1.13	1.82
SIRT	0.65	1.05
MARTA	0.98	1.58

Note: Average between train stops. Does not equal average distance between stations when there is express or skip stop operation.

Source: Pushkarev and Zupan (1980).

Table 5. TYPICAL LIGHT RAIL STATION SPACINGS

City	Average Station Spacing Miles	Average Station Spacing Km
Cologne	0.41	0.66
Hannover	0.37	0.60
Frankfurt	0.34	0.54
Nuremberg	0.32	0.51
Stuttgart	0.32	0.51
Bochum	0.31	0.49
Dortmund	0.31	0.49
Brussels	0.30	0.48
Bremen	0.29	0.47
Kassel	0.26	0.42
Basel, Brunswick, Heidelberg	0.25	0.40
Bern, Gothenburg	0.22	0.35
Antwerp	0.20	0.32
Ghent	0.18	0.29

Source: DeLeuw, Cather & Company (1977).

These performance characteristics may be constrained in some instances by service limits based on passenger comfort. Upper limits for acceleration and deceleration of 3.0 to 3.5 miles per hour per second usually are considered appropriate for standing passengers not using stationary handhold. Similarly, a maximum allowable jerk rate typically is about 3.0 mi/hr/sec per second. (A broad range of selected vehicle characteristics is presented in Appendix F).

The extent to which top cruise speed affects average service speed depends in general upon the station or stop spacing and the degree of guideway exclusivity. Approximate ranges of typical top cruise speeds for various transit modes are summarized below. (Bus speeds for operations in mixed traffic, however, will be constrained by legal highway speed limits).

o Urban rail transit	50-70 mph
o Light rail transit	45-55 mph
o Commuter rail	45-70 mph
o Conventional transit bus	50-70 mph
o Double-deck transit bus	45-60 mph
o Articulated transit bus	40-60 mph
o Intercity bus	70-80 mph

3.2(c) Station Dwell Times

Transit vehicle dwell times at stations/stops must be of sufficient duration to permit the opening and closing of doors and the boarding and alighting of passengers. Sometimes additional time must be provided for vehicle maneuvering (at bus stops and stations) or for waiting for the vehicles to start after the doors close (e.g, signal delays).

The opening and closing of doors for a given vehicle will be relatively constant, generally requiring 1 to 4 seconds for each step. The most variable component of dwell time is passenger boarding and alighting time. Boarding and alighting rates are affected by a variety of factors including:

- number of doors per vehicle;
- effective door width;
- number of steps (high or low platform);
- presence of handrails with steps;
- location and type of fare collection;

- presence of directional aids or personnel to supervise boarding;
- number of in-vehicle standees;
- special provisions for handicapped users; and
- consistency in the side(s) of vehicles used for exiting.

Typical bus boarding and alighting service times are summarized by Tables 6 and 7. For boarding handicapped riders in wheelchairs, the service times are considerably longer. The cycle times for wheelchair lifts are approximately 45 seconds, but the dwell time also must include time for the passengers to board and exit the lift and to secure a position on the vehicle. In total, the dwell time for loading or unloading a single wheelchair passenger by a lift requires about 1.5 to 3 minutes, depending on the specific equipment used and the familiarity of the passenger with the process.

For rail rapid transit systems with high platform boarding, typical boarding and alighting service times are each about 1.5 to 2.0 seconds per passenger in each separate door lane. Low platform rail boarding and alighting service times generally approach bus times, particularly with on-board fare collection. In peak periods, an additional time allowance of 5 to 15 percent might be made to account for passenger loading imbalance (i.e., uneven passenger distribution at vehicle doorways).

For rail transit systems, station dwell times generally range from 15 to 30 seconds. A minimum dwell time usually is set as a matter of policy.

Rigorous calculation of dwell times at individual stations probably is unwarranted for either system planning or project planning. However, assumptions about dwell times should be supportable and generally consistent with anticipated passenger loadings.

3.2(d) Average Speed Estimates

Transit (in-vehicle) travel times are a function of distances traveled and average speeds attained by transit vehicles. Estimation of average speeds should consider not only cruise speeds, but also acceleration, deceleration, and station dwell times.

Three basic options exist for estimating average speeds of transit services:

- transferring experience and data from other locations with similar transit services;
- calculating average speed based on vehicle performance and site-specific conditions; and

Table 6. BUS BOARDING AND ALIGHTING INTERVALS

Operation	Conditions	Time per Separate Door-Lane per Passenger (Seconds)
Loading	Single coin or token farebox.	2.0-3.0
	Multiple-coin cash fares.	3.0-4.0
	Multiple-zone fares; prepurchased tickets and registration on bus.	4.0-6.0
	Multiple-zone fares; cash, including registration on bus.	6.0-8.0
Unloading	Very little hand baggage and parcels; few transfers.	1.5-2.5
	Moderate amount of hand baggage or many transfers.	2.5-4.0
	Considerable baggage from racks (intercity runs).	4.0-6.0

Source: Quinby (1976).

Table 7. TYPICAL BUS PASSENGER BOARDING AND ALIGHTING SERVICE TIMES FOR SELECTED BUS TYPES AND DOOR CONFIGURATIONS

Bus Type	Available Doors or Channels Number	Available Doors or Channels Location[2]	Typical Boarding Service Times (sec)[1] Pre-payment[3]	Typical Boarding Service Times (sec)[1] Single Coin Fare[4]	Typical Alighting Service Times (sec)
Conventional	1	F	2.0	2.6-3.0	1.7
	1	R	2.0	na[4]	1.7
	2	F	1.2	1.8	1.0-1.2
	2	R	1.2	na[4]	1.0-1.2
	2	F,R[5]	1.2	na[4]	0.9
	4	F,R[7]	0.7	na[4]	0.6
Articulated	3	F,R,C	0.9[7]	na[4]	0.8
	2	R	1.2[8]	na[8]	---
	2	F,C[5]	---	---	0.6[8]
	6	F,R,C[6]	0.5	na[4]	0.4
Special Single Unit[9]	6	3 double doors	0.5	na[4]	0.4

[1] Typical interval in seconds between successive boarding or alighting passengers. Does not allow for clearance times between successive buses, or dead time at stops.
[2] F=front; R=rear; C=center.
[3] Also applies to pay-on-leave or free transfer situations.
[4] Not applicable with rear-door boarding.
[5] One each.
[6] Two double doors each position.
[7] Less use of separate doors for simultaneous loading and unloading.
[8] Double-door rear loading with single exits, typical European design. Provides one-way flow within vehicle, reducing internal congestion. Desirable for line-haul, especially if 2-person operation is feasible. May not be best configuration for busway operation.
[9] Examples: Neoplan TR-40 Mobile Lounge designed by Tripal Systems, Inc., for airport apron use.

Source: Levinson (January 1978)

o (for buses in mixed traffic) developing average transit speed estimates based on estimated highway travel speeds.

The first option, transferring experience and data from other locations, includes the use of "typical" speeds by mode, a method appropriate for system planning. Figure 5 illustrates the ranges of average speed for various transit modes, and indicates considerable variability. More extensive data on typical transit speeds are found in other sources, notably the UMTA-FHWA sponsored Characteristics of Urban Transportation Systems (CUTS). The CUTS handbook presents typical average speed ranges for different transit modes, stratified by such factors as station spacing, type of roadway, degree of right-of-way exclusivity, and time of day.

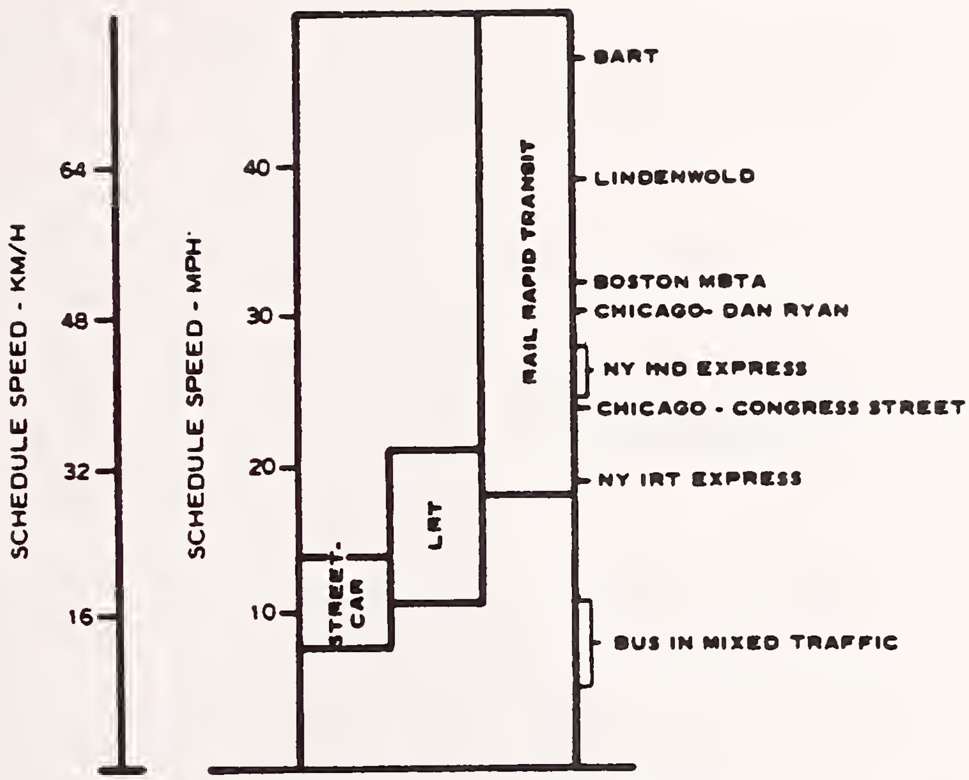
Generally, the use of typical values based on nationwide experience is not sufficiently accuracate for detailed project planning, where it is critical that average speeds specified be supportable for site-specific conditions. However, estimating average speeds based upon local experience or experience elsewhere still may be an appropriate estimation method if the services are nearly identical and the operating conditions are very similar.

This approach is particularly applicable for bus transit services which operate with varying degrees of preferential treatment. Speeds from similar applications may be used directly, adjusted to reflect different operating conditions (e.g., frequency of bus stops), or used to estimate the anticipated percentage improvement in existing service speeds which may be expected from various priority treatments. Data for this purpose should be highly specific in terms of service characteristics and operating conditions, but there is a variety of possible sources available, including project evaluation reports from UMTA's Service and Management Demonstration Program, and research studies such as NCHRP Report No. 143, Bus Use of Highways.

A variation on this option is to use actual scheduled service speeds for existing transit services that are included in the future network. A substantial portion of a background bus network may be made up of such services, and this method is frequently used. A disadvantage of this approach is that it is not sensitive to increased congestion on the highway network, which may cause bus transit speeds to decrease over time.

The second option for determining average speed is direct calculation based on vehicle performance and route characteristics. This option is particularly appropriate for transit systems which operate on exclusive rights-of-way, such as rail transit systems, where other modes do not affect the performance of the transit vehicle. Using the equations illustrated in Figure 6, the average speed and travel time between two stations, without intervening stops, can be determined if the acceleration, deceleration, and cruise speed characteristics are known. To determine total trip time, total station dwell time must be added.

Direct calculation is appropriate during project planning studies for line haul transit services when there is consistency in vehicle performance characteristics. It is particularly applicable to rail transit, where exclusive rights-of-way permit such consistency.



Source: DeLeuw, Cather & Co. (1977).

Figure 5.
<u>REPRESENTATIVE AVERAGE SPEEDS OF U.S. TRANSIT SERVICES</u>

Case 1: Station Spacing Sufficient to Reach Cruise Speed

$$V = \frac{3600D}{T + \frac{3600D}{C} + \frac{C}{2a} + \frac{C}{2d}}$$

where: $D \geq \frac{C^2}{7200a} + \frac{C^2}{7200d}$

Case 2: Station Spacing Not Sufficient to Reach Cruise Speed

$$V = \frac{3600}{(7200(a+d)/adD)^{1/2} + T/D}$$

where: $D \leq \frac{C^2}{7200a} + \frac{C^2}{7200d}$

and:

V = average velocity or speed (mph)

T = stop (dwell) time at stations or stops (seconds)

C = cruising (maximum) speed (mph)

a = acceleration rate (constant) (mph/sec)

d = deceleration rate (constant) (mph/sec)

D = average distance or spacing between stations (miles)

Figure 6.
THEORETICAL EQUATIONS FOR ESTIMATING AVERAGE RAIL SPEEDS

Furthermore, average speed and travel time need not always be calculated on a link-by-link basis. Simplified formulas may be used, such as the ones in Table 1 and in the CUTS handbook. Computerized procedures also are available in multistep analysis packages, as discussed in Appendix B.

The third option for estimating average speed is applicable to bus transit services operating in mixed (automobile-transit) traffic. The approach consists of estimating bus transit speeds based on estimated speeds for the highway network. In this situation, it is assumed that general traffic flow conditions on the highway network influence the average travel speed of a bus more than the actual performance capabilities of the vehicle. As highway facilities become more congested, this becomes increasingly the case.

Although this approach has appeal from a theoretical viewpoint, it was used infrequently until fairly recently because of limited availability of pertinent software to handle large transit networks. This problem was remedied largely by the release of the UTPS program INET, which uses highway network speeds as a basis for computing transit speeds. (See Appendix B for further discussion of this program).

The INET auto-transit cruise speed transformation function is depicted schematically in Figure 7. The conversion factors are determined by the speed function's inflection points, which can be user-specified or defaulted to values stored in INET. The program also calculates dwell times based on specific stop locations or stop density functions, and computes acceleration and deceleration times. Thus, it combines direct calculation of travel times with network performance characteristics.

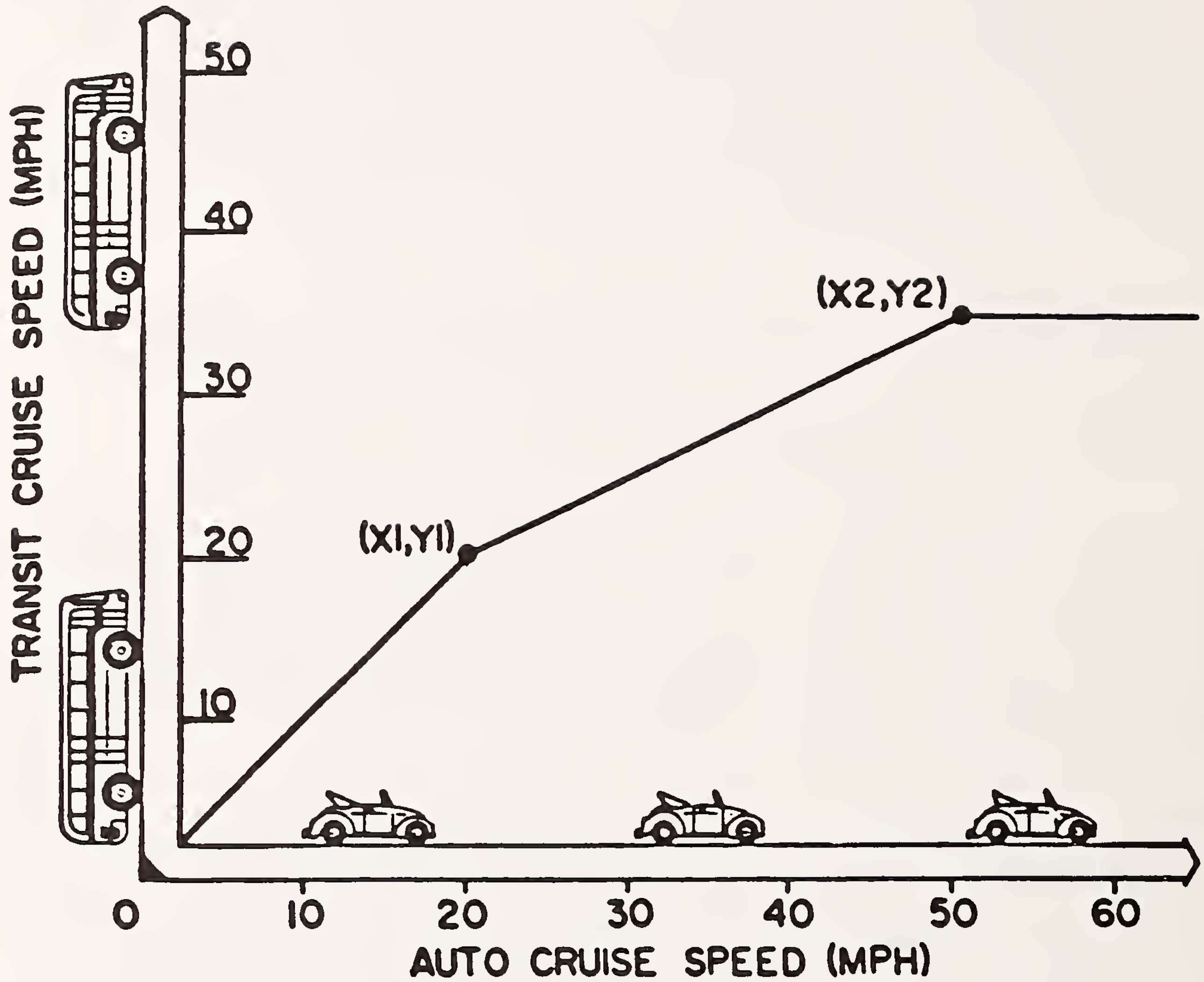
Generally, in addition to its theoretical appeal, use of INET can result in significant labor savings during preparation of transit networks. Too, with careful calibration of the transformation function, most transit travel times produced in this manner should be able to replicate actual travel times within reasonable tolerances. However, there also usually will be some facilities with relatively unique bus speed-auto speed relationships. Therefore, it is advisable to compare travel times derived from INET with those obtained from transit schedules and available empirical data, and to make adjustments wherever necessary.

3.3 SERVICE CHARACTERISTICS

3.3(a) Routings

Routes or routings of transit vehicles are a major determinant of transit supply parameters. In conjunction with average speeds/travel times and service frequency (headways), routings are major factors influencing vehicle-hours, vehicle-miles, and required fleet size.

Transit routes may be located entirely on exclusive fixed-guideway facilities, on partially exclusive rights-of-way (e.g., with grade crossings), on surface streets in mixed traffic, or on some combination of these (e.g., with a portion of a route on surface streets and another portion on an



NOTE: This graph shows the nature of the assumed relationship between auto and transit cruise speeds. The (X1,Y1) and (X2,Y2) are the speed function's inflection points and determine the conversion factors. These points can be user-specified or defaulted to ones stored in INET.

Source: Dial et al. (1979).

Figure 7.
INET AUTO/TRANSIT SPEED CONVERSION FUNCTION

exclusive fixed-guideway). The degree of exclusiveness of the transit route will significantly affect transit speeds.

Route lengths should be distinguished from lengths of fixed-guideway or other rights-of-way. Multiple transit routes can be operated over the same fixed-guideway facilities, for example, such that different alternatives can incorporate all or portions of the same fixed-guideway facilities (i.e., differing only in the extent and location of individual routes). In general, the length of guideway or right-of-way over which a given number of route-miles of service are operated is a major influence on capital and maintenance costs.

3.3(b) Service Frequency (Headways)

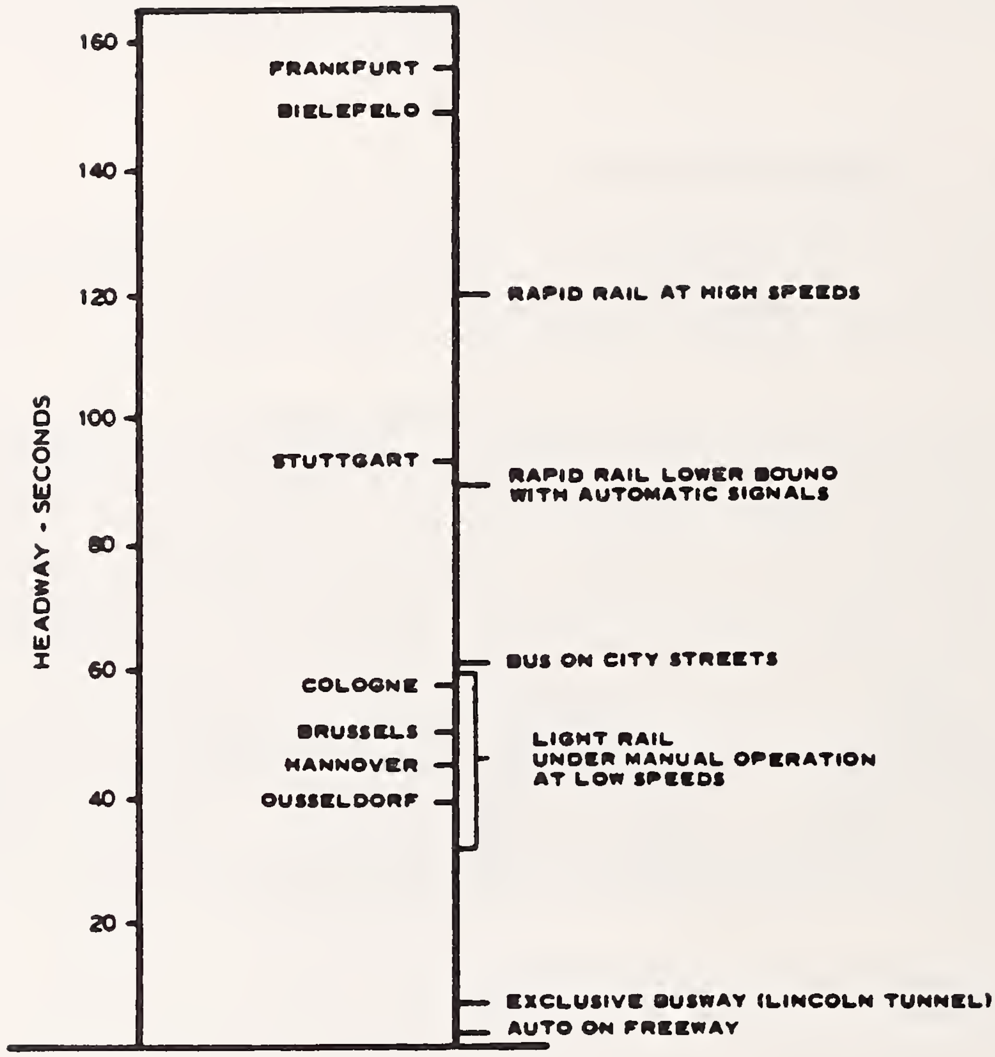
Frequency of service commonly is expressed in terms of headways, or time separation between transit vehicles or trains on a given route. When defining alternatives, "nominal" headways are initially specified which reflect both anticipated demand and minimally acceptable service levels.

In periods of low demand, transit services generally will operate at or near specified maximum or "policy" headways, which represent minimum service standards. Policy headways generally trade off some cost-effectiveness in favor of a perceived need to provide a level of service felt to be minimally acceptable. Typically, the rationale behind the establishment of policy headways is that headways lower than these would result in unacceptably increased operating deficits, while higher headways would translate into an unsatisfactory lowering of service quality and traveler mobility.

In periods of high demand, service frequency (headways) generally will be designed specifically to accommodate demand, although "demand" headways at times may be constrained by capacity limitations; i.e., by the minimum headways safely achievable by the pertinent transit technologies. Observed minimum headways on various transit modes are summarized in Figure 8.

For rail systems, the minimum permissable headways are influenced by a variety of factors:

- maximum train speed;
- train length;
- deceleration or brake rate, adjusted for grade;
- type of signal control;
- train control delay (delays in interpreting, processing, and transmitting data and commands by and between wayside and vehicle-borne train control equipment);



Source: DeLeuw, Cather & Co. (1977).

Figure 8.
OBSERVED MINIMUM HEADWAYS ON DIFFERENT TRANSIT SYSTEMS AND MODES

- block length (in essence, that minimum length of track which can be occupied at any one time by only one train or part thereof); and

- station dwell time.

For automatic block segments, minimum headways typically are 90 to 120 seconds or longer. At lower speeds under manual control (e.g., for low-speed light rail operations), however, headways sometimes can be as low as 40 seconds.

3.3(c) Service Hours and Service Days

For system planning and project planning, headways are needed initially for travel demand analysis. Thus, the precise service periods for which nominal headways are initially defined usually are largely conditional on the requirements of the specific travel demand models being utilized. Typically, demand analyses emphasize the average weekday a.m. peak period, with some lesser consideration given frequently to weekday non-peak periods. (Many such analyses, for example, do incorporate consideration of off-peak headways, which typically may reflect average midday service or an average of midday and evening services).

The various off-peak, weekend, and holiday services can significantly affect supply parameters and operating cost estimates, and therefore need careful examination. Frequently, assumptions regarding such services are treated implicitly in the factors used to expand supply parameters from peak periods to weekday totals, and then from weekday to annual totals.

The use of such expansion factors, without detailed consideration of off-peak and weekend service levels, can be appropriate for system planning, provided the factors are reasonable in light of local and national experience, and provided it is recognized that, since experience is widely varying, results will be only of a very approximate nature.

For project planning, however, transit supply parameters should be based on explicit assumptions regarding weekday off-peak, weekend, and holiday service levels. In developing weekday supply parameter estimates, service levels generally can be specified in three to five time periods during which it is assumed that these service levels (e.g., headways) are relatively constant. For example:

o	peak	6 hours (7-10 am; 3-6 pm)
o	midday or "base"	5 hours (10 am - 3 pm)
o	evening	4 hours (6-10 pm)
o	"owl"	6 hours (5-7 am; 10 pm - 2 am)
		21 hours of weekday service

It should be recognized that dividing a weekday into a limited number of constant service time periods is a simplification, albeit a necessary one. Transitions between time periods, special "tripper" (short) runs, and other scheduling considerations typically produce hourly variations with no two hours being exactly the same in larger transit systems. Thus, the reasonableness of any simplified service assumption for weekday service should be verified against current local experience.

To develop annualization factors--i.e., factors which are used to expand weekday supply parameters to annual supply parameter estimates--explicit assumptions regarding weekend and holiday service are necessary for project planning. The sensitivity of annualization factors to weekend and holiday service assumptions is illustrated by Table 8.

Note that annualization factors for different supply parameters may differ from one another, depending on how service is measured (e.g., vehicle-hours, vehicle-miles, seat-miles). Similarly, annualization factors for supply parameters often will differ from those used to annualize demand, depending in large part on variations in load factors (passenger-to-capacity ratios) during the various service days and service periods.

Another important consideration in developing annualization factors is seasonality. Often, bus transit systems provide special revenue school runs when schools are in session. Fares are charged, and anyone may use the services, but they are oriented toward school children. Such services may represent a sizable proportion of background bus services, and should be taken into account when developing annualization factors. Some transit systems also have seasonal service variations related to recreational travel and climatic conditions, although these tend to be minor in most areas.

3.4 SPECIAL SERVICES

The definition of service characteristics should recognize the potential for various "special" services--i.e., services other than those which operate along a single fixed-route with periodic stops. Special services often require unique or specialized consideration when assessing operational feasibility and/or when estimating supply parameters.

Examples of such services, some of which are schematically diagrammed in Figure 9, include the following: express services; skip-stop operations; branch line operations; partial turnbacks; school services; and paratransit services.

3.4(a) Express Services

Express transit services decrease line-haul travel times by reducing the frequency of stops. Improved travel times, in turn, can lead to reductions in equipment requirements and vehicle hours.

Table 8. ILLUSTRATIVE SUPPLY ANNUALIZATION FACTORS: SENSITIVITY TO WEEKEND AND HOLIDAY SERVICE

SERVICE AS PERCENT OF WEEKDAY				
WEEKDAY	SATURDAY	SUNDAY	HOLIDAYS	ANNUALIZATION FACTOR
100	--	--	--	251
100	50	--	--	277
100	70	--	--	287
100	70	40	40	311
100	50	50	50	308

NOTE: Assumes 9 holidays per year and no seasonal variation in transit services.

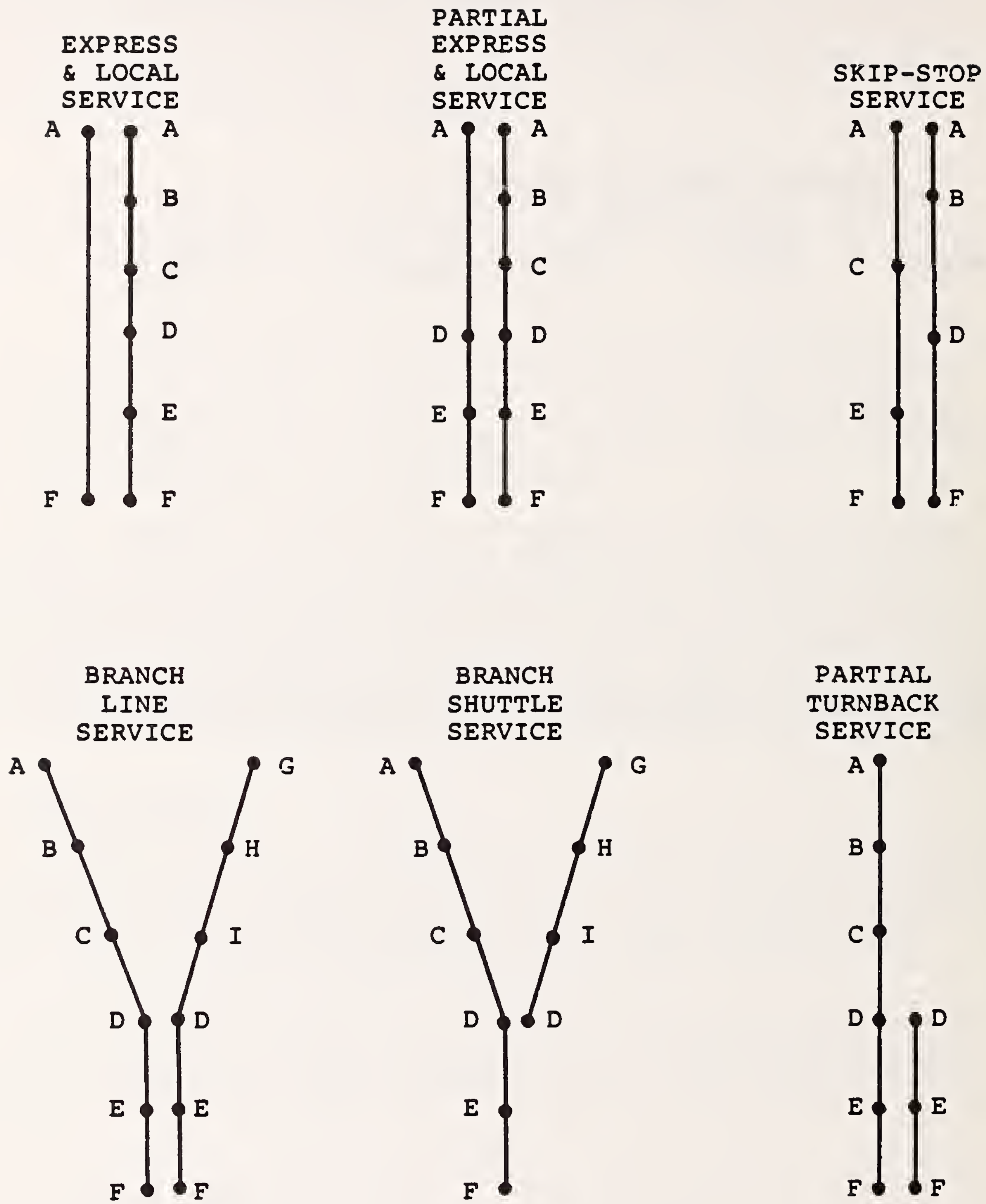


Figure 9.
ILLUSTRATIVE SPECIAL TRANSIT SERVICES

Express services can be operated in a variety of ways, on or off exclusive guideways. Considerable latitude is available, particularly, in the design of express bus services, both in reserved rights-of-way and in mixed traffic. Not all vehicles need make every stop, for example, and feeder services can be provided by the same vehicles providing line haul services (thus eliminating the need to transfer).

These advantages are obtained at the expense of decreased frequency of service for some passengers, and are representative of the many tradeoffs entailed in designing express bus services. To help ensure the cost-effectiveness of these services, therefore, such tradeoffs should be examined explicitly.

While express bus services are common, the New York City Transit Authority is the only U.S. rail transit system currently operating express rail services on exclusive tracks (i.e., on tracks separate from those used for local rail services). There are, however, variations on express rail services, including part express-part local services, and express services on shared (local) track. The former might entail express operation for part of a route on exclusive track, merging onto the local track for the remaining portion of the route (e.g., express in the suburbs, local through downtown). Potential problems with this service relate to proper balancing of passenger loads and maintenance of schedules.

Running express services on local tracks--in essence, running "closed door" through most stations--is done usually only on lines with relatively high headways. Some commuter rail systems operate some services of this type. For safety, it often is necessary to reduce train speed when approaching and passing station platforms.

3.4(b) Skip-Stop Operations

Another variation of express service is skip-stop operation, whereby not all trains or buses stop at all stations. The Chicago Transit Authority, for example, makes extensive use of skip-stop operation on dual-track lines. In general, "A" and "B" trains alternate their respective station stops, with both trains stopping at major stations.

Skip-stop operation, like express services generally, improves travel times and can reduce equipment requirements and vehicle hours. However, it does create situations where passengers must transfer in order to travel between certain stations on the same line. Also, it potentially can lead to poor allocation of capacity.

3.4(c) Branch Line Operations

Branch line rail operations, where two or more branches feed the same trunk line, provide greater geographic coverage and bring line-haul transit service closer to greater numbers of people. However, such operations need to be carefully designed with regard to passenger load balancing and schedule maintenance. They also introduce special capacity and headway concerns.

Consider, for example, the services diagrammed schematically in Figure 9. If the minimum achievable headway on the trunk (combined) portion of the line (DEF) is 2 minutes, then the maximum capacity on branch lines ABCD and GHID will be governed by minimum 4 minute headways. Similarly, if demand justifies a headway on the trunk portion DEF of only, say, 7 minutes, the headways on branch lines ABCD and GHID will be only 14 minutes each. This might be viewed as relatively poor quality service, but the provision of more frequent service on all portions of the line would require additional costs probably not warranted by the demand.

In situations where headways are sufficiently large such that passengers schedule their arrivals at stations (typically, headways larger than about 12-15 minutes), branch lines can be operated with uneven frequencies; i.e., with more trains run on one branch than on another. Such services are operated by some commuter rail systems, for example.

Where closer headways more typical of rail rapid transit systems are operated, however, such that passenger arrivals tend to be random, unequal service on different branches of a single line generally is difficult or infeasible. This is due to resulting disparate passenger loadings, leading in turn to inefficient utilization of capacity and problems in maintaining schedules.

Another operational alternative is to operate one branch as a shuttle. This permits minimum headway operation throughout the system, but requires a passenger transfer at the junction to or from the shuttle.

3.4(d) Partial Turnbacks

An efficient transit system attempts to match supply to demand as closely as possible. Where demand along the outer portion of a transit line comprises only a relatively modest portion of the demand at the maximum load point, it is conceivable that cost savings could be realized by "turning back" alternate buses or trains at a carefully selected intermediate point.

In practice, as with other special services discussed above, this can be most readily implemented where service is infrequent and passengers schedule their arrivals at stations (e.g., commuter rail services). In low headway situations typical of rail rapid transit, however, passenger load balancing and schedule maintenance problems may preclude implementation of partial turnbacks.

3.4(e) School Services

As noted previously, special revenue "tripper" services oriented to serving school children, commonly are provided by bus transit systems. These should be considered when formulating background bus services.

Another consideration is contract school services. In some urban areas, transit authorities operate school bus services on a contract basis for school districts. These charge no fares to the user and are essentially equivalent to "yellow" school bus services. These services, like charter services, generally should be treated separately from regular revenue transit services during detailed project planning.

3.4(f) Paratransit Services

A variety of paratransit services may be included in the background transit system, or may be a featured component of a particular alternative--e.g., an alternative that features transportation system management (TSM) measures. The services of greatest concern in supply parameter estimation are those which require paid drivers and which would be publicly operated, such as demand-responsive transit and special services for elderly and/or handicapped persons.

The estimation of supply parameters for fixed-route paratransit services requires the same types of service characteristics specification as for other fixed-route transit services. For other forms of paratransit service, such as demand-responsive transit, other characteristics need to be specified such as service area, degree of pre-arrangement required, desired minimum service level, and numbers and configurations of origins and destinations (e.g., many-to-one).

3.5 BACKGROUND BUS NETWORKS

During both system planning and project planning, proposed capital-intensive line-haul transit services and facilities are superimposed over existing and/or proposed local and feeder ("background") bus systems. The design, extent, and cost-effectiveness of these background bus systems are important, particularly for project planning, because they greatly influence the utilization of the proposed line-haul services, and because the evaluation of alternatives must consider the ridership, revenues, and costs of all transit services in the study corridor(s).

At a minimum, an existing background bus system should be modified: to interface with the capital-intensive line-haul system under consideration; and to reduce or eliminate service duplication. In addition, the background bus system may be modified to provide additional feeder/distribution service for the line-haul service, and/or expanded (for future years) to include new services warranted by anticipated growth. In the latter case, the background bus system often is based on an improved "all bus" alternative for the study corridor(s).

In developing background bus systems for corridor or other project planning studies, a number of questions should be addressed, including the following.

- o Should all capital-intensive alternatives be superimposed over the same background bus network, with only interface changes and route truncations and/or eliminations to reduce service duplication?

- o Should the background bus network be based on an "existing" network or on an improved network?

- o Should there be an attempt to "optimize" the background bus network for individual capital-intensive alternatives?

- o Can individual bus lines be aggregated to simplify the analysis?

- o How should the treatment of background bus systems vary between system planning and project planning?

In project planning studies completed to date, capital intensive alternatives frequently have been superimposed over essentially the same background bus network, with the basis for this network often being an "improved" all-bus alternative. While the background networks usually have been modified to provide feeder and distribution services, formalized attempts to determine "optimal" bus networks generally have not been made. At least for project planning, bus networks usually have been analyzed at the level of detail required for a comprehensive computerized transit network, with all background bus transit services coded into the network.

In developing background bus networks for future project planning studies, no radical departures from past practice appear necessary, but local preferences will dictate the specific approach adopted in each study. Generally, the following observations can be made.

- o Essentially the same background bus network may be readily used for all capital-intensive alternatives. Different background networks potentially could be individually tailored to each alternative, but the additional efforts entailed by this approach likely will not be warranted in most instances.

- o A useful basis for the background bus network is an improved bus network reflecting TSM improvements and service increases warranted by projected growth.

- o The background bus network should be modified for each line-haul alternative to provide appropriate interfaces and to eliminate service duplications. Service duplications should be eliminated only to the extent feasible, however. Experience with BART and Washington's METRO indicates that substantial community opposition may arise to the elimination of bus routes which largely duplicate rail service but which also provide local services not offered by the rail lines.

- While no formalized attempt should be made during project planning to "optimize" background bus networks, modifications should be made to provide adequate feeder and distribution services. After the analysis, the supply-demand equilibrium of the background network, especially feeder services, should be checked to insure that the capacity being provided is adequate without being excessive.

- Furthermore, reasonableness checks of riders per bus-mile and riders per bus-hour should be made during corridor or other project planning studies to determine the relative productivity of the background bus network for different capital-intensive line-haul alternatives. These checks may indicate the need for refining the specification of the background bus network for a particular line-haul alternative. Such refinements usually can be made manually without changing computer networks and repeating the travel demand forecasts.

- For project planning, supply parameter estimation and travel demand estimation require significant detail, such that the background bus networks generally should be at the level of individual routes or lines within the corridor(s) under study. For system planning, aggregation of individual routes and other schematic representations likely will be an appropriate option. Another potentially useful approach, depending on the travel demand models being utilized, is to develop a background bus network intended for eventual use in project planning, and to use this background network as well for system planning, with appropriate modifications such as fewer (larger) analysis zones.

4. ESTIMATION OF CAPACITIES

Some of the most significant assumptions necessary for estimating transit supply requirements relate to system capacities and associated loading standards. Despite the significance of these assumptions, there is considerable variability in the manner in which they are developed and in the resulting capacity estimates and implied comfort levels.

Of particular concern is the tendency to bias the evaluation of alternatives by using different loading standards for different transit modes in the same analysis. For example, if both busway and light rail alternatives are being considered, the respective assumed vehicle capacities should reflect comparable loading or comfort standards; e.g., comparable percentages of passengers seated, and comparable amounts of space per standee.

In general, to avoid imparting bias to the analysis, capacity estimates should be estimated very carefully during both system planning and project planning, and factors affecting these estimates should be examined explicitly.

4.1 VEHICLE CAPACITIES AND LOADING STANDARDS

In order to estimate vehicle capacities, policy decisions need to be made with regard to:

- the percentage of passengers to be seated in the peak design period (total/seated ratio);
- the minimum amount of space to be allocated to each seated passenger; and
- the minimum amount of space to be allocated to each standing passenger.

These decisions should take into account the nature of the transit services being analyzed and the cost implications of different loading standards. For services with long average trip lengths, for example, such as commuter rail operations, the ratio of total to seated passengers for design volumes is usually low, approaching 1.0 (i.e., where a seat is planned for every passenger). Furthermore, the seating may use a relatively large amount of space per seat to increase passenger comfort. As passenger trip lengths decrease, on the other hand, and as passengers board and alight more frequently, the total/seated passenger ratio typically increases, and smaller seats are utilized.

There is a tradeoff between total capacity and the amount of seating provided, since standing passengers consume less space per person than seated passengers. Table 9 indicates typical space requirements for seated and standing passengers. To increase available space for standees, seats can be either eliminated or reduced in size, and/or different seating configurations (e.g., longitudinal instead of transverse seating) can be employed. Reducing the number of seats, of course, increases the frequency of conditions where all seats are occupied and some passengers must stand.

Figure 10 illustrates the sensitivity of vehicle capacity to the total/seated passenger ratio for a hypothetical rail car. The implications of such changes in vehicle capacity on supply parameters (and, therefore, on operating costs) and on vehicle requirements were illustrated in the example in Chapter 2.

4.1(a) Use of Gross Loading Standards

For each transit mode, there is a variety of vehicles available, with varying dimensions and other characteristics (e.g., articulation, doors, single- or double-endedness). For any particular vehicle design, too, there usually are options for seating configurations, and different transit systems using the same vehicles may estimate different total vehicle capacities due to different assumptions regarding usable space and loading standards. Thus, while it is possible for planning purposes to select a figure from the range of reported capacities for a given mode, explicit or implied loading standards should be addressed directly in order to achieve consistency among alternatives.

One technique for estimating capacities entails the use of a constant loading standard expressed in gross square feet (or square meters) per passenger, where gross area is measured by exterior dimensions. Gross vehicle area is convenient to use since it generally is easier to determine than the amount of usable interior space.

The Regional Plan Association (RPA, 1978), for example, proposed a standard for rail transit vehicles of 5.4 square feet of gross vehicle area per passenger. For peak hour urban rail transit operations, the RPA found that, of 58 lines examined, 31 met or exceeded (provided more space than) this standard, with the majority of those below the standard being in New York City. Many transit vehicles, loaded to this standard, will provide seats for about half the riders.

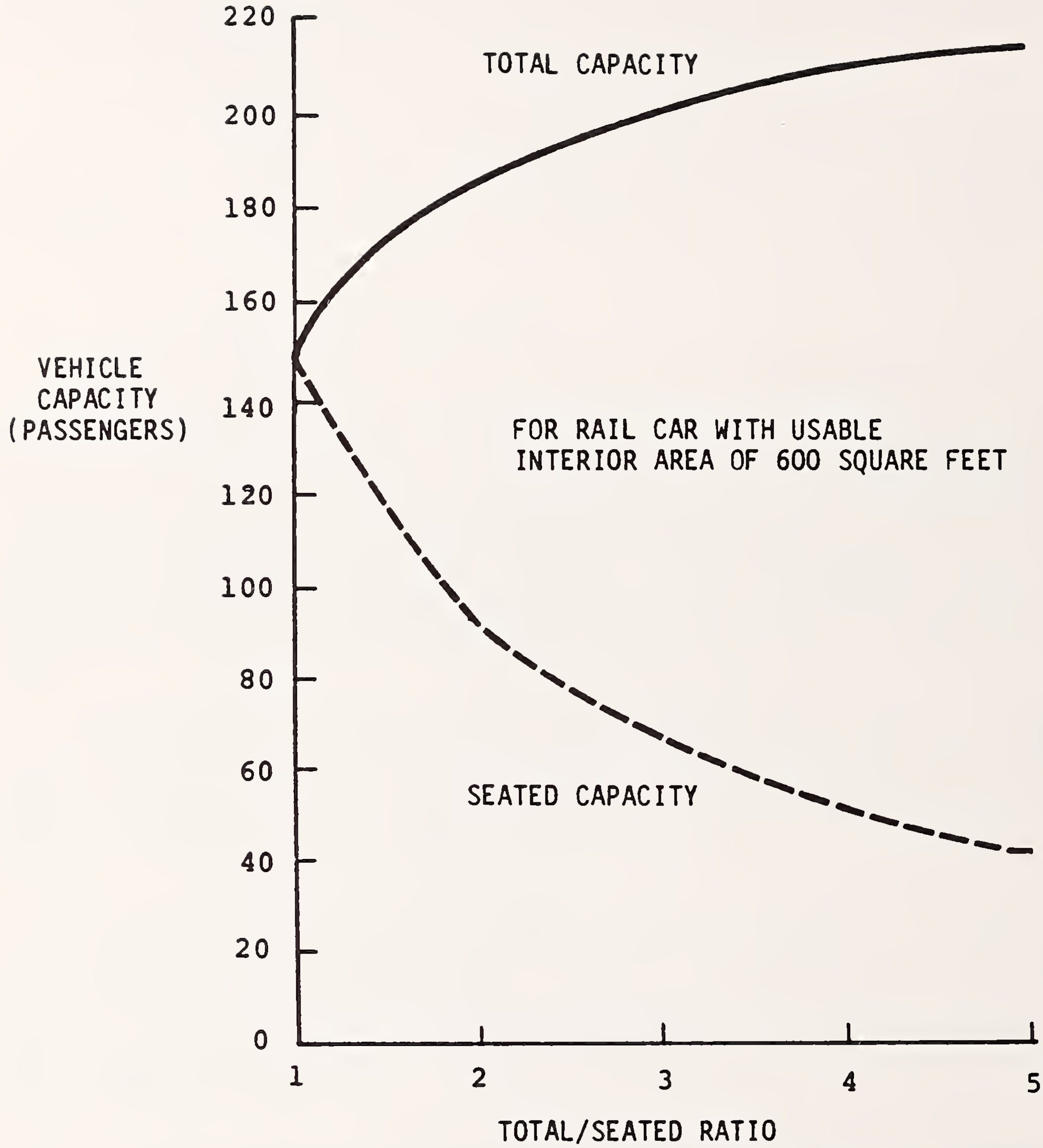
Other sources (N.D. Lea Corporation, 1975, 1976-1977; APTA, 1980) suggest that somewhat lower standards currently are prevalent. Representative capacities and implied gross loading standards derived from these sources for a range of buses and rail transit vehicles are provided in Appendix F and summarized in Table 10. The computed average gross loading standard for the heavy and light rail vehicles tabulated, for example, is only 4.2 and 3.3 square feet per passenger, respectively, although the newer systems tend usually to be higher than these averages.

Table 9. SPACE REQUIREMENTS FOR SEATED AND STANDING PASSENGERS

	Square Feet Per Passenger (Net)*
Seated Passenger	
Typical Commuter Rail	4-6
Typical Urban Rail Transit	3-5
Typical Urban Bus Transit	3-4
Standing Passenger	
Spacing of persons in unconstrained condition	4-9
Minimum space requirement to avoid contact	2.4-2.8
DuWag standard--commonly used in German LRT systems	2.7
NYCTA space for maximum "practical" capacity	1.8
Moscow Metro minimum standard	1.3

*Exclusive of non-usable space. For seated passengers, includes space consumed by seat plus space between seats for legs. For standing passengers, based on clear floor area per standee.

Sources: Pushkarev and Zupan (1975), Quinby (1976), Diamant et al. (1976).



(Based on 4.0 square feet per seated passenger and 2.5 square feet per standee)

Figure 10.
ILLUSTRATIVE SENSITIVITY OF VEHICLE CAPACITY TO TOTAL/SEATED PASSENGER RATIO

Table 10. TYPICAL TRANSIT VEHICLE CAPACITIES AND GROSS LOADING STANDARDS

	Heavy Rail	Light Rail	Small & Medium Buses	Stndard Size Buses	Articu-lated Buses	Double-Deck Buses	Trolley Buses
Number of vehicles/ models	28-38*	11-16	5-8	14-18	9	5	2-5
Design Capacity							
Seats							
range	35-83	16-84	14-35	37-53	49-77	75-106	24-51
average	62	48	23	48	61	89	33
Standees							
range	18-204	69-188	0-35	21-75	32-135	8-54#	19-70
average	103	113	10	39	87	22	53
Total							
range	90-280	87-272	17-70	63-112	97-186	96-129#	70-99
average	165	162	34	86	148	111	86
% Seated							
range	21-80	18-41	50-100	33-69	27-64	57-92	29-73
average	44	30	76	57	45	81	40
Gross Sq Ft Per Psnger							
range	2.7-7.7	2.7-4.6	3.5-8.5	2.6-4.7	2.5-4.9	5.0-6.4	3.0-4.9
average	4.2	3.3	6.0	3.7	3.4	5.8	3.7
Crush Capacity							
Seats							
range	35-83	16-84	14-35	37-53	49-77	75-106	24-51
average	62	48	23	48	61	89	33
Standees							
range	99-280	81-246	5-25	na	na	na	33-83
average	175	161	13	na	na	na	58
Total							
range	155-350	97-330	22-54	na	na	na	84-107
average	237	209	36	na	na	na	96
% Seated							
range	15-44	15-30	50-76	na	na	na	22-61
average	27	23	66	na	na	na	42
Gross Sq Ft Per Psnger							
range	2.0-4.1	1.9-3.7	4.0-6.5	na	na	na	2.9-4.1
average	2.8	2.7	5.2	na	na	na	3.5

*12-13 North American transit systems.
#All vehicles assume no standees on upper deck.
na = data not available.

Source: (Abstracted from data in Appendix F).

Another advantage of using a loading standard expressed in square feet per passenger is that the seating configuration need not be treated explicitly. Inherent in the technique is the assumption that seating patterns could be developed for different transit vehicles which would have the same total/seated passenger ratio, the same space per seated passenger, and the same space per standee, thus offering equivalent levels of passenger comfort. While the interior layout of vehicles may constrain this assumption somewhat, it generally should be possible to meet or at least closely approximate these conditions.

On the other hand, a loading standard expressed in square feet per passenger is not independent of space standards for seated and standing passengers and the total/seated passenger ratio. Thus, the loading standard should be selected based on the type of service being planned and its cost implications. This implies that an appropriate universal standard for all transit loading does not exist, and that in selecting a standard for a specific set of circumstances, consideration should be given to its implications for seated passenger and standee space and for the total/seated passenger ratio.

Another consideration in using loading standards based on gross area is that different transit vehicles may have different percentages of usable interior area as compared with gross floor area. The RPA found considerable similarity in this regard among various rail transit cars, but this percentage will be affected by such factors as whether single- or double-ended cars are being considered. Also, the fraction of usable space appears generally lower for light rail vehicles and transit buses. Thus, using the same loading standard based on exterior dimensions may not be appropriate for some inter-modal (e.g., bus versus rail) comparisons.

4.1(b) Use of Prototypical Seating Configurations

In many instances it may be simpler to compute vehicle capacities based directly on prototypical seating patterns and standee space standards, rather than to adjust loading standards based on gross floor area. Based on production vehicle specifications and data, on trip characteristics and industry experience, and on policies governing comfort levels to be provided for passengers, the following standards initially would be defined:

- usable floor area;
- floor space per seated passenger;
- floor space per standee (minimum); and
- total/seated passenger ratio in peak conditions.

The vehicle capacity then could be calculated as follows:

$$\text{Seated Capacity} = \frac{UFA}{AX + (R-1)(AY)}$$

$$\text{Standee Capacity} = \text{Seated Capacity} \times (R-1)$$

$$\text{Total Capacity} = \text{Seated Capacity} + \text{Standee Capacity}$$

where:

AX = area per seated passenger;
AY = area per standee;
R = ratio of total to seated passengers; and
UFA = usable floor area per vehicle.

Note that, in using these formulas, the exact seating pattern specified may not be strictly possible. Door locations, passageway requirements, wheelchair tie-down requirements, and other considerations are constraints on the interior layout of a transit vehicle. Nonetheless, the loading plan developed using these formulas should be feasible in at least an approximate sense, and should ensure consistency in the estimation of vehicle capacities.

4.1(c) Upper Bounds on Standee Space Standards

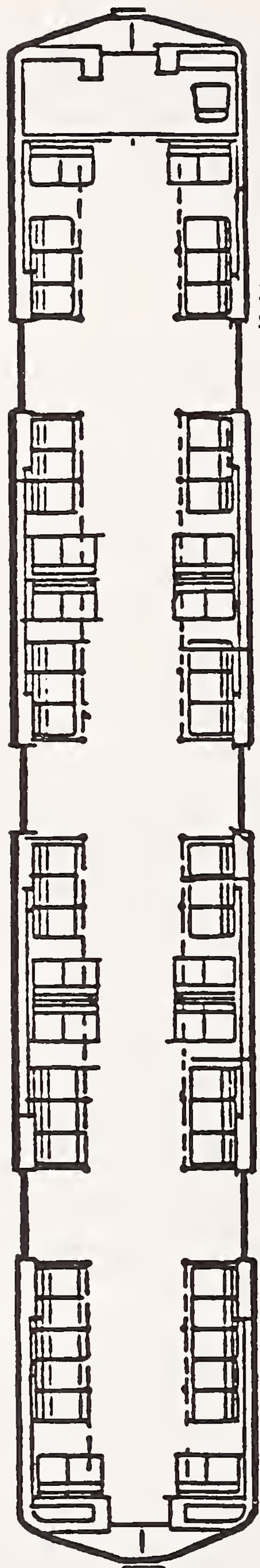
Whatever technique is used for estimating vehicle capacities, there is flexibility in defining a standard for minimum space per standee. Vehicle requirements and operating costs may be increased if a generous standard is utilized, but such a standard should be readily and routinely achievable, and should result in relatively high levels of passenger comfort.

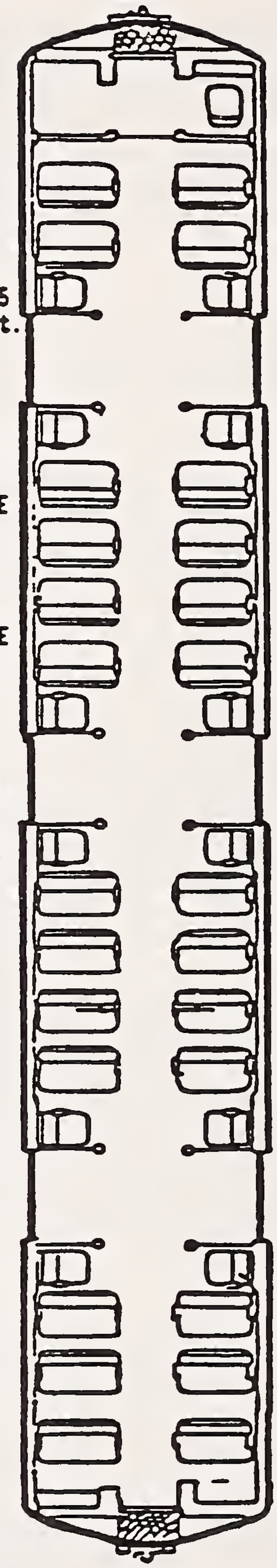
If, however, in the interest of minimizing costs and vehicle requirements, a relatively low standard (i.e., relatively little space per standee) is sought, care should be taken to ensure that the standard is realistic in light of actual operating conditions. Standees typically do not load evenly throughout a transit vehicle, because passengers commonly crowd more closely together near doors than in other areas of the vehicle. If the loading standard for standees reflects this tighter spacing near doors, therefore, it may overstate the number of passengers which normally will be accommodated by the vehicle.

For example, Figure 11 contains a diagram used by the Massachusetts Bay Transportation Authority to publicize and explain the reconfiguration of seats on some South Shore (Red Line) rail rapid transit cars. The new design did not change the number of seats provided, but does provide less space per seated passenger and thereby more space for standees.

The basic objective--to provide increased capacity to accommodate peak period demand--was accomplished, but both new and old capacities appear overstated because they are based on a "crush" load standard of only 1.5 square feet per standee. While this loading standard is perhaps theoretically achievable, it seems to exceed what can be observed on North American systems. Some informal counts by the MBTA of crush loads on rail transit vehicles

NEW		OLD
64	SEATED	64
308.3 sq. ft.	STANDING	262.5 sq. ft.
	HANDRAILS:	
30	VERTICAL	12
98 ft.	OVERHEAD	NONE
1	WHEELCHAIR TIEDOWN	NONE
	CAPACITY:	
64	SEATED	64
205	STANDING	175
269	TOTAL	239





Source: Massachusetts Bay Transportation Authority.

Figure 11.
SAMPLE RECONFIGURATION OF SEATING IN RAIL TRANSIT VEHICLES

appear to confirm this--i.e., that even under these conditions there generally are some gaps and uneven loadings inside vehicles such that actual vehicle loadings are regularly less than nominal crush load capacities.

4.2 TRAIN CAPACITIES

For rail transit, the unit of capacity provided is not an individual rail car but, rather, a consist or train of cars. The maximum capacity of a train is determined by the capacity of an individual car and the maximum number of cars which can be coupled together into a train.

While train capacity usually is computed simply by multiplying car capacity by the number of cars in the consist, full utilization of this (maximum) capacity is contingent on appropriate station designs which encourage passengers to load relatively uniformly into the various cars in the train. This often is difficult to accomplish at a single station due to the specific cost and geometric constraints (e.g., limited numbers of stairways or escalators favoring use of some cars in the consist over others). However, balanced loading generally should be achievable on a line (multi-station) basis, taking into account relative boarding volumes and points of passenger access at each station.

The maximum number of rail transit vehicles that can be coupled together into a train is dependent on the length of each car and on platform length. As indicated in Appendix F, rail transit platforms in the U.S. range from only about 230 feet on some Boston stations to about 700 feet.

Rail rapid transit system and platform design also should recognize constraints imposed by vehicle design. Trains in many systems, for example, are usually composed of even numbers of cars (e.g., 6 or 8, but not 7). This to reflects the high proportion of "married pairs" in many rail transit fleets: pairs of cars which share needed control and communications equipment in order to reduce capital costs, with some of this equipment housed in one car and the complementary equipment in the other.

Other arrangements also are possible, such as the use of "trailer" cars which lack motive power and must be pulled or pushed by other (powered) cars. The rail rapid transit system in Montreal, for example, operates 3-car units (a trailer car between two powered cars), in 3-car, 6-car, and 9-car trains.

Such constraints are not normally a factor for light rail transit. Most light rail vehicles can be operated as single units, and such vehicles commonly are run singly, or in short trains of two or three cars.

The ability to provide longer trains in peak periods can reduce operating costs, but longer platforms increase capital costs. Thus, there is a tradeoff between capital cost and operating cost with respect to platform and maximum train length. This tradeoff should be acknowledged when defining a rail transit alternative, and sensitivity analyses may be required to make a final specification during project planning. In the Chapter 2 illustration, for example, decreasing the maximum consist from 3 to 2 cars increased train-hours by 15 percent.

This tradeoff also may be affected by work rules resulting from labor negotiations. While some systems do run shorter trains during off-peak hours, many others do not. In these latter instances, the increased energy and maintenance costs of the longer trains generally are regarded as being more than offset by the increased labor costs required for breaking down and reassembling consists. Too, this activity can occur only at certain points on the system, where such facilities as crossover tracks, sidings, and/or car storage areas are available, and where such activity will not interfere with scheduled service.

4.3 LINE CAPACITIES

The capacity of a transit line is a function of the capacity of individual vehicles or trains and of headways on the line. Normally, the computation is simple. For example, for a line which is operated at a 5 minute headway (12 trains per hour), and which uses consists of 6 rail rapid transit cars each with a capacity of 200 passengers, the peak hour line capacity is simply 12x6x200 = 14,400 passengers per hour.

However, several factors may affect this calculation. Demand during the peak hour is not normally evenly distributed, sub-hourly peaks often do not occur uniformly from day to day, and it generally is not feasible to vary headways within the peak hour to match demand variations precisely. Thus, for example, to accommodate adequately the peak 15 minute demand, it usually is necessary to provide peak hour capacity somewhat in excess of peak hour demand.

Also, demand estimates are at best approximate, and to account for contingencies (demand in excess of the estimates) and/or for future growth in demand, it is desirable to allow for a potential, reasonably cost-effective, expansion of capacity after initial operations. Since lengthening of station platforms implies major capital investments, this usually is most easily accomplished by the lowering of headways; i.e., it usually is prudent to design an alternative such that transit services are operated somewhat less frequently than is implied by the minimum headways permitted by the pertinent technologies.

Another issue which may take on greater importance at low headways is the impact of schedule reliability on line capacities. Schedules incorporating close spacing of transit vehicles or trains often are more difficult to maintain, and departure from schedule of a single vehicle or train likely will impact subsequent vehicles/trains. When "bunching" occurs, capacities often are not utilized effectively, and greater numbers of vehicles (greater capacity) must be provided. This is particularly a problem with bus lines operating with low headways in mixed traffic on congested streets. It also can be a problem on rail lines operating at or near minimum headways.

5. TRANSIT DEMAND ESTIMATES AND CAPACITY/LEVEL OF SERVICE CHECKS

Transit demand estimates, along with the definition of alternatives, are the primary inputs to the estimation of transit supply parameters. Demand forecasting is itself a very complex subject, and will be discussed in companion reports on predicting travel impacts. From a supply estimation standpoint, nonetheless, it is important to review here the general types of travel demand data typically required for system planning and project planning, as well as the various procedures and checks necessary to ensure the compatibility of demand and supply estimates.

5.1 PREPARATION OF TRANSIT RIDERSHIP ESTIMATES

Transit demand estimates play a key role in the determination of supply parameters, since anticipated demand largely governs the minimum capacity requirements for a particular transit service. However, neither total daily ridership nor daily maximum load point volumes--the most common ridership measures--are useful directly for supply parameter estimation. Instead, from a supply and capacity viewpoint, the more important demand measures are maximum load point volumes in the prevailing direction for various time periods during an average weekday.

Although ridership forecasts are needed for both peak and off-peak time periods, particularly for estimating revenues and user benefits, the peak period generally receives the most attention since peak demand usually dictates fleet requirements and the maximum service to be provided. During off-peak periods, on the other hand, service characteristics are likely to be governed less by demand and more by minimum service policies (policy headways).

The travel demand forecasting process used for project planning should produce estimates both on a daily basis and for one or more component time periods (e.g., morning peak period). To accomplish this, there are available a great variety of approaches encompassing both the determination of specific needed outputs (time periods) and the design and sequencing of procedures for estimating these data. Figure 12, for example, illustrates schematically a few basic alternative approaches which may be adopted, with each approach having considerable flexibility as regards how many and which time periods should be explicitly analyzed.

Other approaches and combinations of these approaches also are feasible--for example, assigning separately both daily (average weekday) transit trips and morning peak period transit trips. Selection of a specific approach entails detailed consideration of a variety of factors such as specific data

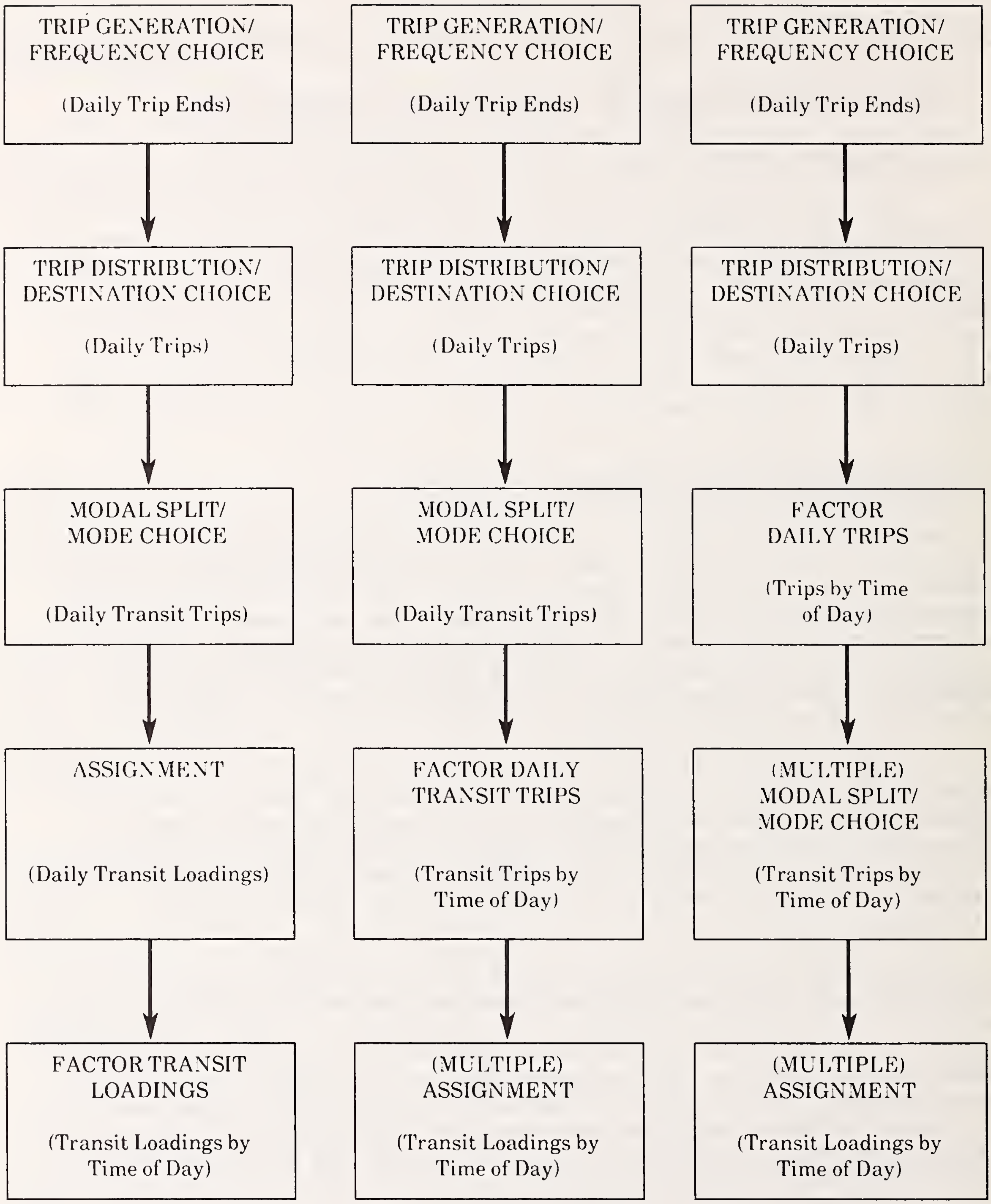


Figure 12.
SOME ALTERNATIVE APPROACHES TO ESTIMATING TRANSIT RIDERSHIP BY TIME OF DAY

needs, network characteristics, software capabilities, data availability, data processing and analysis costs, perceived travel patterns, etc.

A common thread among all of these approaches is that somewhere in the process, some estimated measures of average daily weekday travel (trips, transit trips, and/or transit loadings or use of specific transit facilities and services) will need to be broken down at least partially to one or more peak periods and, possibly, to one or more off-peak periods. Possibly, the adopted procedures also may entail the expansion of travel estimates, such as the scaling up of peak period transit loadings to daily transit patronage estimates.

It is possible to "model" this temporal disaggregation or expansion--i.e., to develop and apply quantified relationships based on various transportation system, land use, and/or travel demand characteristics. Generally, however, this is adequately accomplished in a less costly manner using relatively simple factors derived largely from available relevant empirical data for the study region or elsewhere. For example, factors may be developed for translating daily station boardings or maximum load point volumes into hourly boardings or volumes in the prevailing direction.

Development and use of such "peaking" and/or expansion factors should be undertaken very carefully, however. There tends to be considerable variation in such time-of-day relationships, depending on various site-specific conditions such as parking availability and mix of trip purposes. Furthermore, none of these factoring procedures captures adequately the demand elasticity between time periods.

For example, considerably greater proportions of transit travel generally occur during peak periods at locations where ridership is highly work trip-oriented and heavily dependent on automobile access. There usually is considerably less peaking, for instance, where "walk-ins" constitute a high percentage of transit ridership, or where a greater proportion of transit usage is for non-work purposes. In some instances, there can be considerable sensitivity of supply parameter estimates to seemingly minor changes in some of these factors or assumptions, as indicated by the example in Chapter 2.

5.1(a) Empirical Data for "All-Mode" Trips and Transit Trips

There is not a great deal of published data available which can be used readily for the various needed peaking and expansion factors. However, valuable data often can be obtained from unpublished transit counts and surveys taken locally and elsewhere.

Factors of total (all-mode) trips, designed for use following trip distribution, generally can be derived from the same home interview or other survey data used for calibration of the travel demand models. Care should be taken, however, when using these data, to distinguish between complete trips and segments of multi-modal trips (e.g., a trip from home to work utilizing both automobile and transit, or a trip utilizing two transit modes such as bus and train).

Care also should be taken in interpreting the times of travel. Trips may be assigned to specified time periods on the basis of the start time of the journey, the arrival time, or the mid-point time. There is no single best approach, and the decision should be made on the basis of factors specific to the analysis. Regardless of the approach taken, consistency should be maintained.

The selection of time periods for separate analysis also should recognize that peak flows occur at different times on different parts of the transit network. For example, morning peak periods often occur earlier in suburban areas than in areas closer to downtown.

The development of factors to be applied following mode choice analysis requires similar data (i.e., travel volumes disaggregated by time of day), but only for those trips which utilize transit. Additional potential sources of these data include counts or surveys of transit riders, but problems may arise due to the availability of only incomplete data. For example, a survey of rail rapid transit usage may indicate peaking characteristics and other time-of-day relationships specific to that mode, but may not adequately reflect the peaking or mid-day usage patterns of bus routes used to access the rail rapid transit system. Thus, home interview surveys also commonly serve as the primary data source for these factors.

5.1(b) Empirical Data on Transit Loadings/Use of Specific Transit Facilities and Services

Transit count or survey data are needed to develop factors for disaggregating or expanding the results of transit assignments. Some published data are available which describe the patronage of various transit systems or lines on a limited time-of-day basis, usually incorporating daily and peak hour ridership.

For example, Table 11 indicates for several U.S. and Canadian rail rapid transit systems and lines the peak hour maximum load point volumes in the prevailing direction as a percent of daily two-way maximum load point volumes. These percentages range from about 12 to 20 percent, excepting two lines with peaking of 9 and 24 percent, respectively; the average value for the lines shown is 15.3 percent, with a standard deviation of only 3.5.

Similarly, Table 12 indicates, for a number of rail rapid and light rail transit systems, peak hour inbound boardings as a percent of daily inbound boardings. If symmetrical volumes by direction are assumed, peak hour inbound volumes would be, on average, 13.9 percent of total daily boardings, comparing closely with the 15.3 percent factor cited above. However, the range of observed values is considerably wider.

Such data likely may not be sufficiently detailed for a particular analysis. Variations in ridership during the course of a day will depend greatly on the nature of the demand in the study corridor (e.g., whether it is comprised predominantly of peak period commuting or whether there is extensive mid-day travel) and on the capacities and levels of service provided during

Table 11. RELATIONSHIP OF PEAK LOAD TO DAILY PATRONAGE ON RAPID TRANSIT LINES

City and Facility	Estimated Daily Patronage at Maximum Load Point (Two-Way) (x1000)	Peak Hour Load Past Maximum Load Point (One-Way) (x1000)	Percent of Daily Patronage
NEW YORK CITY (1976)			
59th Street Cordon	1305.6	170.5	13.0
Queens Cordon	791.2	130.6	16.5
Brooklyn Cordon	1109.9	179.5	16.1
PATH - Lower Manhattan	82.5	29.0	24.2
PATH - Midtown	51.4	10.0	19.5
CHICAGO (1973)			
North-South (Northside)	120.	14.0	11.7
North-South (Southside)	80.	11.0	13.7
West-Northwest (NW side)	72.	14.0	19.4
West-Northwest (SW side) (Douglas-Congress)	78.	8.5	12.0
Lake-Ryan (Westside)	43.	5.8	15.8
Lake-Ryan (Southside)	87.	14.0	16.1
Ravenswood*	45.	6.6	14.7
Evanston*	20.**	3.7	18.5
Skokie Swift*	7.	1.3	18.5
PHILADELPHIA (1974-1975)			
Broad Street (N. of Market)	96.	8.5	8.9
Market-Frankford (E. of Broad)	103.	12.8	12.4
Market-Frankford (W. of Broad)	103.	11.7	11.3
Camden-Lindenwold Line - PATCO	41.	8.0	19.5
CLEVELAND (1974-1975)			
East-West Rapid (Eastside)	10.	1.9	19.0
East-West Rapid (Westside)	34.	5.1	15.0
TORONTO (1974-1975)			
Yonge Street (N. of Bloor)	234.	28.	12.0
Yonge Street (S. of Bloor)	265.	36.	13.6
Bloor Street (W. of University)	193.	23.	12.0
Bloor Street (E. of Yonge)	184.	22.	12.0
University (S. of Bloor)	70.	15.	12.0
SAN FRANCISCO (1974-1975)			
BART (Concord Line)	32.	6.2	19.4
BART (Daly City Line)	36.	6.3	17.5

*Stub End Operations.
**Peak Service Only.

Source: Levinson (April 1978).

Table 12. AM PEAK HOUR BOARDINGS AS PERCENT OF TOTAL DAILY BOARDINGS FOR RAIL RAPID AND LIGHT RAIL SYSTEMS (DIRECTIONAL)

System	Rail Rapid (RR) or Light Rail Transit (LRT)	8-9 AM Passenger Boardings As Percent of Total Daily System Passengers (Inbound Direction Only)
NYCTA	RR	29.5
TTC	RR	23.4
CTA	RR	20.5
BART	RR	30.4
MUCTC	RR	22.5
SEPTA	RR	18.2
MBTA	RR	28.7
PATH	RR	43.1
WMATA	RR	25.5
MARTA	RR	21.3
PATCO	RR	38.5
GCRTA	RR	24.0
SIRT	RR	52.9
MBTA	LRT	19.9
MUNI	LRT	9.5
SEPTA	LRT (5 routes)	24.8
PAT	LRT	30.7
GCRTA	LRT	30.7
NJT	LRT	25.7
Range		9.5-52.9
Average		27.8
Standard Deviation		9.8

Source: Pushkarev and Zupan (1980).

the various hours. Notably, off-peak service usually is determined by minimum service policies, and these may vary considerably among different areas.

Better quality data to develop necessary factors more sensitive to these issues within a local context generally must be derived from relatively detailed transit counts or surveys. Not all rail systems have such data, and relatively small amounts of these data are in published form. However, relevant information should be obtainable from several cities, which should suffice for other areas if interpreted and utilized carefully. For bus transit services, local data from on-board surveys or passenger counts are more frequently available for estimating needed time-of-day factors.

Regardless of whether local or non-local data are used, consideration should be given to the similarity of the services analyzed to those for which the data were gathered, and to the sensitivity of supply parameters to these assumptions. In determining the similarity of transit services, the following characteristics should be observed.

- Directional orientation of the service -- Radial services tend usually to be more peaked by time period and direction than non-radial services.

- Transit mode -- Line-haul busway services and rail services serving longer trips tend usually to be more peaked than local bus services.

- Trip purpose mix -- A higher percentage of non-work travel usually will flatten the peaks.

- Origin-destination patterns -- The number and locations of major trip generators relative to the service will affect the directional splits by time period.

- Supply constraints -- Constraints in the supplied transit services in either peak or off-peak time periods may distort the data for application to other services.

5.1(c) Sub-Hourly Peaking

Estimates of peak hour transit demand may not be sufficient for estimating certain supply parameters. Demand levels within the peak hour normally vary, and the use of factors may be necessary to take into account peaks within the peak hours. A service designed on peak hour demand thus may be insufficient to accommodate these sub-hourly peaks without exceeding the specified minimum loading standards or leaving waiting passengers on the platform. Exceeding these standards for short periods may be a legitimate policy option, but this policy should be applied consistently to all alternatives. Alternatively, additional capacity can be provided.

Table 13 presents peak flow data from local bus services, express bus services, and rail rapid transit services. These data compare peak hour

Table 13. OBSERVED PEAK HOUR PASSENGER VOLUMES ON URBAN TRANSIT ROUTES (PREVAILING DIRECTION ONLY)

City	Facility	Buses/ Trains per Hour	Passenger Movement: Actual Peak Hour	Passenger Movement: Hourly Rate for 15-20 Min	Ratio
Local Buses/City streets, parking prohibited					
New York	Hillside Ave.	150	10,251	10,824	1.06
San Francisco	Market St.	130	7,553	8,500	1.13
Cleveland	Euclid Ave.	90	4,316	5,600	1.30
Chicago	Michigan Ave.	75	4,240	4,770	1.13
Baltimore	Baltimore St.	76	4,387	4,758	1.08
Local Buses/City streets, reserved transit lane					
Chicago	Washington Blvd.	66	3,235	3,600	1.11
Atlanta	Peachtree St.	67	2,807	3,504	1.25
Dallas	Commerce St.	67	3,069	3,444	1.12
Birmingham	2nd Ave., North	44	2,301	2,712	1.18
Express Buses/City streets, parking prohibited					
St. Louis	Gravois St.	66	2,918	4,185	1.43
Cleveland	Clifton Blvd.	32	1,872	2,700	1.44
Chicago	Archer Ave.	29	1,896	2,500	1.32
San Francisco	Van Ness Ave.	17	1,234	1,784	1.45
New Orleans	Earhart Blvd.	25	1,267	1,620	1.28
Express Buses/Freeways					
Chicago	Lake Shore Dr.	99	5,595	6,350	1.13
Cleveland	Shoreway West	32	1,872	2,700	1.44
San Francisco	Bayshore Freeway	35	2,270	2,700	1.19
Los Angeles	Hollywood Freeway	41	2,268	2,640	1.16
St. Louis	Mark Twain Highway	52	1,767	2,295	1.30
Atlanta	North Expressway	19	803	1,892	2.36
Express Buses/Terminal ramps, tunnel approaches, tunnels, bridges					
New York	Port Authority Bus Terminal	511	23,187	28,556	1.23
Union City,NJ	Route 3	397	17,800	23,000	1.29
New York	Lincoln Tunnel	480	21,600	22,860	1.06
San Francisco	Oakland Bay Bridge	216	7,812	10,945	1.40
New York	George Washington Bridge	136	6,939	9,468	1.36
Rail Rapid Transit					
New York	IND 6th & 8th Ave Exp/10 car	32	61,400	71,790	1.17
New York	IND 8th Ave. Express/10 car	30	62,030	69,570	1.12
New York	IRT Lexington Ave. Exp/9 car	31	44,510	50,700	1.14
Toronto	Yonge St. Subway/6 car	28	35,166	39,850	1.13
New York	IRT 7th Ave. Express/9 car	24	36,770	38,520	1.05
Chicago	Eisenhower Expwy./6 car	25	10,376	14,542	1.40
Cleveland	Private R/W & Subway/6 car	20	6,211	8,349	1.34

Source: Quinby (1976).

volumes with equivalent hourly rates derived from the peak 15- or 20-minute peak periods. These equivalent hourly rates range from 5 to 40 percent higher than the respective peak hour volumes, with lower-volume services tending to have more pronounced sub-hourly peaks. Such sub-hourly peaking can affect estimates of fleet requirements and other supply parameters, and should be examined explicitly during project planning.

5.2 CAPACITY AND LEVEL OF SERVICE CHECKS

As part of the travel demand analysis process, initial ridership forecasts should be subjected to various checks and, possibly, iterative analysis to achieve supply-demand equilibrium and determine final or service headways and consists (numbers of cars per train). Additionally, park-and-ride demand estimates should be compared with assumptions regarding parking availability, in order to ensure compatibility between these.

5.2(a) Parking Capacities and Park-and-Ride Demand

Travel demand forecasting processes normally do not directly constrain estimates of park-and-ride demand so as not to exceed the parking capacities assumed in the definition of alternatives. Rather, demand-capacity relationships should be examined subsequent to the initial demand forecasts, and any inconsistencies should be resolved by revising the demand estimates and/or the assumed parking capacities. For system planning, this sometimes can be accomplished on the basis of a total transit line, but project planning requires that each station be examined explicitly.

Assumptions regarding the demand for and supply of parking often are made in a simplified manner, but there are a number of issues which should be given explicit consideration.

- On-street parking -- The number of parking spaces available at a transit station may include some on-street parking, depending on proximity to the station, parking regulations and enforcement thereof, competing demand for parking, local public attitudes towards such parking, etc. It is difficult to determine the number of on-street spaces which will be available for vehicles of persons accessing transit, but an estimate can be made based on the above factors and on observed experience in similar areas. Alternatively, it may be decided conservatively that no on-street parking should be assumed if such parking seems incompatible with local land use and neighborhood sentiment.

- Non-transit demand for parking -- Off-street parking facilities (garages and lots) at transit stations often are used by persons other than those boarding transit; i.e., by persons destined for other activities in the vicinity of the station. In the absence of explicit parking management policies (i.e., other than "first-come, first-served"), estimates should be made of the proportion of spaces which will be available to transit users.

In making these estimates, anticipated ranges of arrival times will be an important factor. For example, if most would-be park-and-riders are commuters going to work, other drivers who work in the station vicinity likely would compete directly for parking spaces during commuting periods, but persons wishing to shop in the area, arriving later in the day, may not be a major factor (i.e., may generally find all spaces already occupied).

- Parking management policies -- In some instances where both transit and non-transit parking demand is anticipated, it may be desirable to consider explicit parking management policies designed to ensure some availability of spaces to all classes of users; e.g., implementing pricing policies designed to discourage all-day parking, delaying opening of some spaces until after the commuting period, or reserving some spaces for shoppers who must present parking tickets validated by a local merchant. These policies should be reflected in the estimated numbers of parking spaces assumed available for park-and-riders.

- Parking turnover rates -- Some parking spaces are likely to be occupied and vacated more than once during the course of a day, so that a parking facility with, for example, 300 spaces, can on a daily basis accommodate more than 300 vehicles. This turnover rate is highly related to the nature of the parking at the facility; i.e., to the trip purposes of the patrons.

  Typically, most park-and-ride lots and garages are heavily patronized by commuters who park for the complete work day. Thus, turnover rates tend to be very low, and daily usage is at best only marginally higher than capacity. However, there are exceptions to this pattern, and higher effective capacities might be assumed in some locations if short-term demand is appropriately distributed over the course of the day.

- Automobile occupancies -- Generally, travel demand models estimate the numbers of persons park-and-riding at a particular transit station. For analysis of traffic and parking impacts, this person-trip demand must be translated into vehicular demand by estimating average automobile occupancies. As with parking turnover rates, this is very much a function of trip purpose. Because most park-and-ride facilities are patronized by commuters (work trips), average vehicle occupancies usually tend to be relatively low.

In instances where park-and-ride demand exceeds the assumed supply of parking spaces at a station, several options are available:

- increase the planned parking space availability;
- reallocate (forecast) excess park-and-ride demand to other stations and park-and-ride facilities;
- reallocate (forecast) excess demand to other transit modes and/or access modes;
- reallocate (forecast) excess demand to automobiles or other non-transit trips; and/or
- reduce the estimated numbers of trips (assume some trips will not be made).

From a strictly procedural viewpoint, other options conceivably might include increasing the assumed parking turnover rate and/or the average vehicle occupancy. However, these assumptions, based initially on best estimates of relevant travel characteristics, should not be altered simply to force a match between supply and demand; i.e., any changes which are made should reflect realistic expectations of probable traveler behavior.

The above techniques are not mutually exclusive, and the resolution of excess parking demand frequently entails more than one type of adjustment. The design and application of such procedures should be performed very carefully on a site-specific basis. While increasing the assumed parking supply may be technically an easy solution, for example, political considerations (e.g., opposition to additional parking) may preclude such an approach.

Reallocation of excess park-and-ride demand to other stations is probably the most realistic and simplest solution from an analytical viewpoint, if there are other stations with available parking capacity which are conveniently located with respect to traveler origins and destinations. Where such alternatives do not exist, excess demand probably should be reallocated (either by hand or by re-running pertinent demand models) both to automobiles and to other transit modes. While hand techniques generally will suffice, assumptions and techniques should be stated explicitly, should be compatible with existing mode splits and trip/traveler characteristics, and should be applied consistently.

5.2(b) Service Headways, Line Capacities, and Maximum Load Point Volumes

The initial definition of alternatives normally includes tentative specification of (nominal) headways and, for rail transit, size of consist (cars per train). These assumptions are input to the initial ridership projections. The resultant demand estimates should be reviewed in light of the implied line capacities in order to finalize service headways and consists consistent with demand.

For a particular transit route and service period, this determination will be made using a variety of inputs:

- maximum load point volume in the peak direction;
- minimum headway;
- policy (maximum) headway;
- maximum consist (maximum numbers of cars per train); and
- minimum loading standards (percent of passengers seated, space per seated passenger, and space per standee).

The objective is to establish a service headway and consist subject to various constraints. The service headway should be:

- greater than or equal to the minimum headway;
- less than or equal to the policy headway; and
- approximately equal to the headway assumption reflected by the demand estimate.

Within these constraints and subject to the limits of the maximum consist, line capacity can be adjusted by altering the headway, consist, or both. If the derived service headway differs significantly from the headway reflected by the demand estimate, the demand estimate should be modified. Such modification can be accomplished by re-running selected demand models, but systematic manual adjustments often will suffice.

The line capacity resulting from the establishment of service headway and consist should equal or exceed the demand--i.e., the maximum load point volume in the peak direction--without being excessive. Where capacity far exceeds anticipated demand, it is highly probable that the cost-effectiveness of the proposed service will be poor. In such a case, service (capacity) probably should be reduced.

The relationship between line capacity and peak load point volumes also reflects loading or comfort standards, and this relationship should be examined explicitly to ensure consistency among alternatives. It may be possible, for example, to reduce the consist (and thus reduce fleet requirements and other supply measures) without violating minimum specified loading standards.

The development of service headways and consists, in accord with the above considerations, may be accomplished in a variety of ways, with great flexibility in the definition and sequencing of specific procedures. An example of a process which might be followed is illustrated schematically in Figure 13.

- The vehicle and, if applicable, train capacity is estimated based on the assumed vehicle characteristics and dimensions, minimum loading standards, and maximum consist.

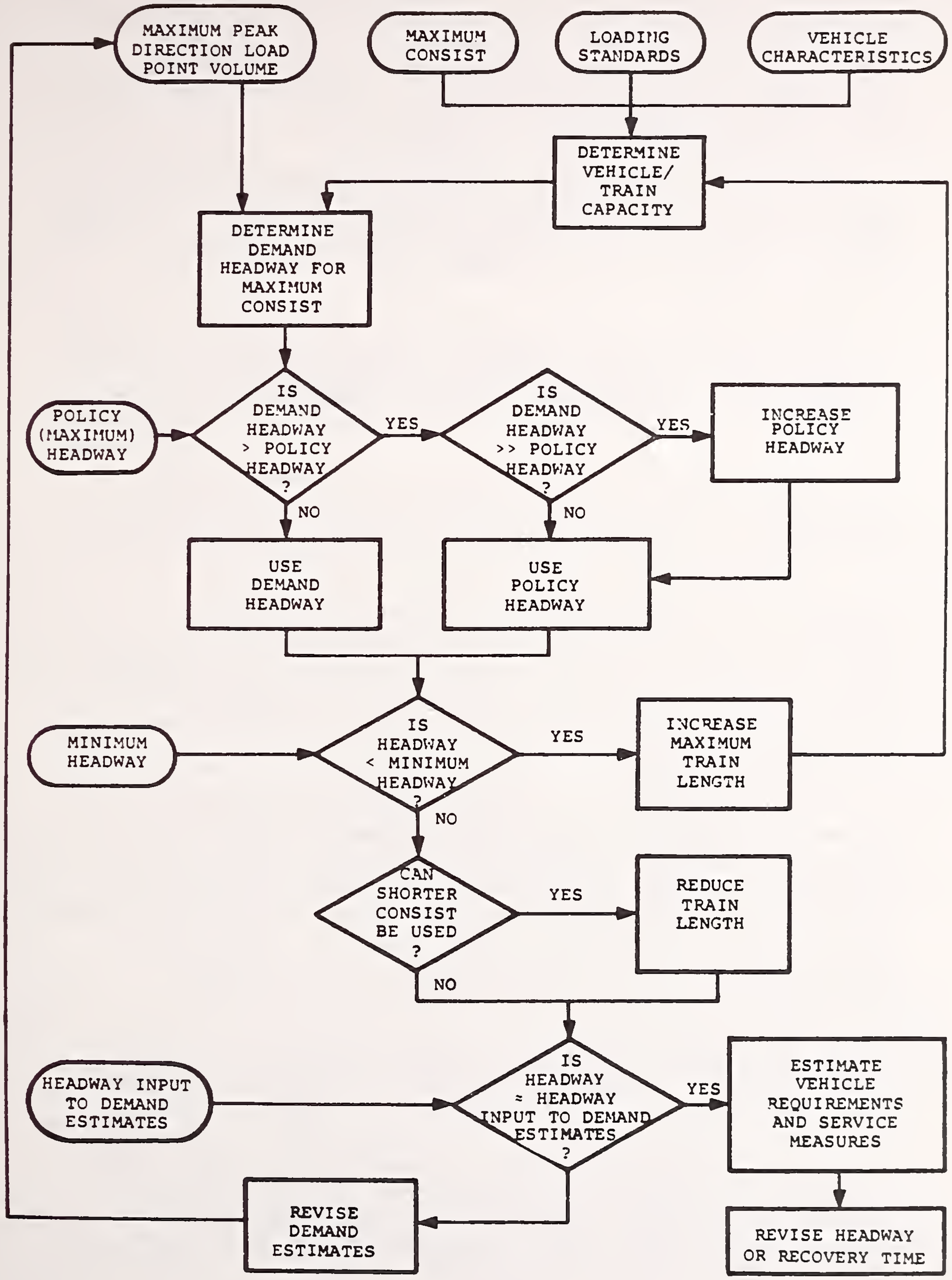


Figure 13.
ILLUSTRATIVE FLOW OF ACTIVITIES TO ESTABLISH SERVICE HEADWAY AND CONSIST

- The demanded minimum frequency of service (trains per hour) for the maximum consist is computed by dividing the estimated train capacity into the maximum load point volume (or effective volume based on sub-hourly peaking) in the peak direction. Sixty minutes per hour divided by this frequency of service will yield the demand headway (in minutes).

- An initial service headway is determined by comparing this demand headway with the policy or maximum headway. The demand headway is used if it is less than the policy headway--i.e., if the policy headway does not provide sufficient capacity to accommodate demand.

  Alternatively, the policy headway is used if it provides ample capacity--i.e., if it is less than the demand headway. Consideration also should be given to increasing the policy headway if it is significantly lower than the demand headway.

- If the demand headway is less than the minimum attainable headway, then the size of the maximum consist will have to be increased. If for cost or other reasons this cannot be done, the alternative as defined will not be feasible.

- Headways and capacities should be examined as above to determine if a shorter consist can be used. If a shorter consist operating at the same service frequency can provide adequate capacity (this may be the case, for example, where the policy headway is being utilized), a more cost-effective service will result.

  It also may be possible to provide sufficient capacity with shorter consists operating at lower headways. Due to shorter wait times, this would provide better service from a user perspective, as long as uneven arrival patterns do not result in excessive demand for some trains. However, operating costs likely would be increased thereby. Selection of a service headway thus reflects a policy tradeoff among competing objectives.

- The resultant service headway is compared with the nominal headway input to the demand forecasts. If there is a significant difference--i.e., if service is to be operated significantly less or more frequently than was assumed for purposes of the ridership projections--then the demand projections should be modified or revised. Changes in the demand estimates in turn may affect required capacities, and possibly will necessitate iterating through the above procedures to check the service headway and size of consist.

- Service headways may be modified further after vehicle requirements are estimated. The required number of vehicles or trains is calculated by dividing the headway into the total round trip travel time, including line haul-time, turnaround time in both directions, and recovery time.

For rail systems, the resulting train requirement usually is rounded upward to a whole number. By doing this, service headways can be reduced slightly, and/or planned recovery times can be increased. Alternatively, if the computed number of required trains is only slightly higher than a whole number, this number can be rounded downward (e.g., from 6.1 trains per hour to 6 trains rather than 7), thereby sacrificing some capacity in order to reduce vehicle requirements.

Vehicle requirements for bus routes generally are similarly adjusted, although the typically greater possiblities for interlining can make these computations somewhat more complex. (The estimation of fleet requirements and the need for turnaround and recovery time are discussed in greater detail in Chapter 6).

It is possible to utilize more elaborate techniques to refine supply-demand equilibrated service headways and consists. Fairly complex mathematical procedures, for example, can be used to optimize explicitly some objective function such as minimization of train-hours (i.e., as opposed to the more implicit objective functions generally underlying simpler procedures). Detailed manual procedures also can be used to try to account for the impacts on headways and consists of storage yard locations, turnback or turnaround and recovery times, and coordination of various routes which share equipment.

For example, a singly operated route with a service headway of 8 minutes and a total round trip time (including turnaround and recovery) of 42 minutes would imply a need for 6 vehicles (or trains); each vehicle or train would return to the starting location two minutes after the departure of the fifth subsequent vehicle or train, necessitating an additional six minutes of recovery time. (Alternatively, this recovery time may be distributed between the outbound and the return legs, or service headway may be reduced to 7 minutes).

Capacity and service policy permitting, it may be preferable in such an instance to increase the headway slightly to 8-1/2 minutes, such that each vehicle or train would return one-half minute before the fifth subsequent departure, thus reducing added recovery time to 30 seconds and reducing fleet requirements and operating costs by obviating the need for a sixth vehicle or train (and operator).

Similarly, additional complexity is added by services involving the merging of multiple lines (e.g., branch and trunk lines) and by the common practice of scheduling buses and drivers on "runs" which entail successive operation of several different routes ("interlining"). Efficient scheduling and run-cutting can produce significant operating cost savings, and these are thus important issues to be considered in depth during detailed operational planning.

During project planning, detailed examination of all such operational factors is generally neither warranted nor feasible, and slight service modifications to achieve cost savings would be unlikely to affect significantly the demand estimates. Estimation of fleet requirements and service parameters, however, as discussed in the next section, does require some consideration of these issues, inasmuch as these requirements and measures must incorporate non-revenue services (e.g., deadheading) and can be more sensitive to small changes in service characteristics.

6. ESTIMATION OF FLEET REQUIREMENTS AND SERVICE PARAMETERS

The estimation of fleet requirements and service parameters, including vehicle-miles and vehicle-hours, is based largely on estimated transit line-haul times, distances, and headways input to the travel demand analysis, modified as necessary by the supply-demand equilibrium checks. Allowances also should be made for turnaround and for deadheading, such as to and from storage facilities.

Typically, these supply or service parameters are determined initially for an average weekday, and then annualized using assumptions regarding weekend and holiday service. Weekday peak period service is translated into vehicle requirements for operating this service, and estimates of needed spare vehicles are made to determine the total required fleet size.

Analysis steps can be summarized as follows:

- estimation of non-revenue vehicle-miles and vehicle-hours;
- estimation of weekday service measures;
- estimation of annual service measures; and
- estimation of fleet size.

6.1 NON-REVENUE VEHICLE-MILES AND VEHICLE-HOURS

Operating costs and fleet requirements can be influenced significantly by non-revenue vehicle-hours and vehicle-miles, including deadheading (moving vehicles between locations without passengers on board), turnaround, and recovery (time spent by a vehicle waiting to begin a scheduled run). Failure to consider adequately these non-revenue service requirements can lead to underprediction of supply parameters and resultant fleet requirements and operating costs.

6.1(a) Maintenance and Storage Facilities

Most deadheading entails the moving of transit vehicles between storage or maintenance facilities and revenue service routes. For bus transit, maintenance and storage facilities usually already exist, although their capacity and location may not be adequate for new services specified in future alternatives. Particularly for project planning, the adequacy of existing facilities should be assessed, and needed new facilities (or expansion of existing facilities) should be included in the definition of alternatives.

Although it may not be necessary to locate specifically these new facilities, it is important that the assumed proximity of the facilities to transit revenue services be realistic. The location of bus maintenance and storage facilities often involves capital cost and operating cost tradeoffs. Remote facilities sometimes are less expensive to construct due to lower land costs, but later lead to increased operating costs.

Compared to bus garages, there is considerably less flexibility in the location of rail maintenance and storage facilities, since these facilities must be connected by guideway to the revenue service guideways. Thus, the close proximity of storage and maintenance facilities to revenue service guideways for rail alternatives is critical to minimizing both operating and capital costs.

Often, the scarcity of suitable sites for maintenance and storage facilities plays a major role in the development of rail transit alternatives. Incremental development of a rail system may be influenced by the locations of sites suitable for maintenance and storage yards.

6.1(b) Turnaround and Recovery

For rail transit lines, facilities must be provided at terminal stations for trains to turn around. Alternative methods for accomplishing this turnback or turnaround include the following.

- Loop -- The simplest type of turnaround facility is a simple loop arrangement beyond the last station. No switching is required, and operators do not have to move to the opposite end of the train.

- Tail track switching -- In this method, mainline tracks extend beyond the station and are connected to a fanlike arrangement of tail tracks, with each mainline track connected to each tail track. Switching is required, and train operators must move to the opposite end of the train. Of the three methods cited, this is the one most commonly used.

- Cross-over tracks -- This method utilizes "cross-over" tracks on the approaches to the terminal station. A train crosses over to the opposite track either as it approaches the station or just after it departs the station on the return trip. This method minimizes right-of-way requirements but requires special signaling and restricts operational flexibility.

During project planning, the types of turnaround facilities to be employed should be considered in developing supply parameter estimates. From an operating standpoint, low turnaround times are preferred. If the turnaround cannot be accomplished within the minimum operating headway, then an arriving train cannot be the next departing train unless the headway is increased. Otherwise, to maintain this minimum headway, an arriving train must be held over on tail tracks and be the second train to depart after it arrives.

Performing the turnaround in less than the minimum headway is desirable since it provides "recovery" time which can be used to improve schedule adherance. If there are 20 seconds of recovery time available, for example, a train arriving 45 seconds late can depart just 25 seconds late. Some systems utilize an extra train waiting on tail tracks, which can be inserted into service to maintain scheduled headways when an arriving train is late.

Recovery time can be significant for services with large headways (e.g., commuter rail services and lightly traveled bus routes). A service operated on an hourly basis which requires a 52-minute run, for example, requires an eight minute recovery, for which an operator usually has to be paid.

6.2 ESTIMATION OF WEEKDAY SERVICE MEASURES

Weekday service measures are determined by summing the appropriate measures estimated for each of the constant service time periods comprising the service day. For peak periods, estimates of train- or vehicle-miles, train- or vehicle-hours, place-miles, and place-hours in revenue service can be computed directly from validated service characteristics derived from the demand analysis--i.e., run times, distances, service frequencies, vehicle capacities, size of consists.

Comparable measures for the various off-peak periods similarly can be computed using explicit assumptions concerning run times, headways, and vehicle and/or train characteristics during these periods. Or, these measures can be estimated by making assumptions regarding relative quantities of service provided in these hours as compared to peak hours.

For each constant service time period, measures of train- or vehicle-miles and train- or vehicle-hours should include components for non-revenue as well as revenue services, as illustrated in Table 14. The estimates for non-revenue service can be developed either for individual routes or on a system-wide basis using prior experience. The former procedure is particularly appropriate for new exclusive guideway services, while the latter generally would be appropriate for background bus services.

6.3 ESTIMATION OF ANNUAL SERVICE MEASURES

To obtain annual estimates of train- or vehicle-miles, train- or vehicle-hours, place-miles, and place-hours, the entire process described above for an average weekday could be repeated for Saturdays, Sundays, and holidays. Annual totals then could be computed on the basis of the numbers of each of these types of days occurring in a year.

More commonly, however, annualization factors are used to expand average weekday estimates to annual estimates. As noted in Chapter 3, annualization factors should be based on policy assumptions regarding weekend and holiday transit service and on demand-capacity considerations. Annualization factors for supply measures usually will be higher than annualization factors for weekday ridership or revenue estimates, since for policy reasons weekend and

Table 14. SERVICE PARAMETER ESTIMATION FOR A GIVEN INDIVIDUAL ROUTE AND CONSTANT SERVICE TIME PERIOD

Revenue train-miles	=	no. round trips x round trip distance
Revenue vehicle-miles	=	revenue train miles x vehicles per train
Revenue train-hours	=	no. round trips x (round trip time - recovery time for return trip)
Revenue vehicle-hours	=	revenue train-hours x vehicles per train
Total train-miles	=	revenue train miles
		+ added distance for turnaround per round trip (if any) x no. round trips
		+ allocated miles traveled while deadheading (distances to/from yards and garages + half the deadhead distance between revenue routes, if any, for each appropriate train)
Total vehicle-miles	=	total train-miles x vehicles per train
Total train-hours	=	revenue train-hours
		+ turnaround and recovery time per round trip x no. round trips
		+ allocated deadhead time (to/from yards/garages + half the deadhead time between revenue routes, if any, for each appropriate train)
Total vehicle-hours	=	total train-hours x vehicles per train
Place-miles of revenue service	=	revenue vehicle-miles x passenger places per vehicle
Place-hours of revenue service	=	revenue vehicle-hours x passenger places per vehicle

holiday service reductions usually are less than the corresponding reductions in ridership.

Furthermore, annualization factors are not necessarily the same for different supply parameters. For example, in the case of a rail line, trains are likely to be shorter on weekends, so that compared with weekday service the reduction in vehicle-miles will be greater than the reduction in train-hours. Strictly, such differences imply that different annualization factors should be used for vehicle-miles and train-hours. For system planning, however, the use of a constant annualization factor for supply parameter estimation is a reasonable approximation. During project planning, annualization factors should be developed with greater care, and, where appropriate, different annualization factors should be employed for different supply parameters.

Annualization factors can be developed by two general methods. The first is to construct them based upon specific service assumptions for weekend and holiday service relative to weekend service. This method and its sensitivity to different weekend and holiday service assumptions were illustrated earlier in Table 8. Special consideration should be given to seasonal variations which may occur, as well as to differences in service characteristics (e.g. average travel speeds, train lengths, non-revenue operations) between weekend/holiday and weekday services.

The second method relies on historical data as a basis for developing annualization factors. For example, existing weekday and annual bus-miles might be used to develop a vehicle-mile annualization factor. The use of historical data implicitly takes into account seasonal variations and differences between weekend and weekday service. When using this method, it is important that the historical data be selected from a period of relatively constant service levels (except for recurring seasonal variations). Also, the underlying service policy assumptions should be consistent with those assumed for the future.

The first method of developing annualization factors--i.e., building up the factors based on policy assumptions--is particularly appropriate for new fixed guideway transit modes, where the operating policies and service characteristics may differ from existing transit services. The other method, using historical data, usually is most appropriate for background bus transit services.

6.4 ESTIMATION OF FLEET SIZE

The required fleet size for a given transit mode is determined by first estimating the number of vehicles required to operate the peak period service, and then adding to that an estimate of the number of spare vehicles required such that this service can be maintained while vehicles are in the shop for needed maintenance and repairs.

6.4(a) Vehicles Needed for Peak Period Service

Vehicle requirements for a particular transit route can be calculated as follows:

$$\text{Number of Vehicles or Trains} = \frac{\text{Total Round Trip Travel Time}}{\text{Headway}}$$

The round trip travel time includes line haul and turnaround times in both directions. Usually, too, there are recovery times which must be included, such as: where headways are rounded up to whole minutes; where allowance is made for varying levels of traffic congestion encountered by bus services operating in mixed traffic; and where infrequent transit service is scheduled at convenient easy-to-remember intervals such as 30 minutes or 60 minutes even though slightly closer headways would be feasible.

In a simple, single-line case, total round trip travel time, including line-haul, turnaround, and recovery times, would be an even multiple of the headway, this multiple representing the number of trains or singly operated transit vehicles required to operate the route. For the total system (of a given transit mode):

$$\text{Vehicles Required}_p = \sum_{i=1}^{n} \text{Vehicles Required}_{ip}$$

where:

$\text{Vehicles Required}_p$ = the total number of vehicles of a given transit mode required to operate in peak period p;

$\text{Vehicles Required}_{ip}$ = the number of vehicles required to operate route i in peak period p; and

n = the number of individual routes of a given transit mode.

The peak time period selected for the calculation is the one for which the vehicle requirement will be the greatest. In order to ascertain which is the appropriate period, several trial calculations for multiple time periods may be necessary. The period defining the greatest vehicle requirement may be an a.m. or p.m. peak hour or subcomponent of a peak hour. For exclusive guideway systems with a limited number of high-volume lines, the use of a peak 15- or 20-minute period may be appropriate, while the use of a peak hour usually will suffice for background bus systems.

Additional complexity is added by the merger of multiple lines and by the consolidation of multiple routes into single runs (interlining). In such instances, occurring frequently in large systems, caution should be exercised in applying the above formula. Because the possibility of interlining is not explicitly considered, there is a tendency to overestimate the fleet requirements, particularly for bus systems. In such a case, historical data can be used to develop adjustment factors that relate the actual fleet required to operate a given schedule to the hypothetical fleet requirement built up by aggregating the fleet requirements of individual routes.

This tendency to overestimate fleet requirements may be traced in part to the "rounding up" of the vehicle requirement for an individual route. For large bus systems, another approach to avoiding over-estimation is to aggregate the vehicle requirements of individual routes without rounding, thus assuming that interlining opportunities will permit vehicles effectively to be split between two or more routes.

6.4(b) Requirements for Spare Vehicles

Transit equipment reliability and maintenance policies are complex subjects which have significant long-term cost and operational implications. Within the context of supply parameter estimation, they are of significance because they determine the number of spare vehicles required in a fleet to maintain normal operations. The spare vehicle requirement usually is expressed as a percentage of the vehicles required to provide service in peak conditions.

The determination of the appropriate spare percentage for a particular transit vehicle fleet operating in particular conditions should be based largely on judgment and available empirical data. Table 15 summarizes the availability of spare vehicles for a number of different North American transit systems, by mode, for 1975. It reveals considerable variability in spare percentages, with the numbers often exceeding the spare percentages of 10-15 percent commonly used in planning. However, many established transit systems tend to retain older vehicles for reserve rather than selling them or having them scrapped. This tends to increase the number of active vehicles in relation to service vehicle requirements.

During project planning, a spare percentage must be selected for each transit mode under consideration. This selection should be based on relevant local experience and on the experience of other systems with similar operating conditions and equipment. Commonly, it will fall within a range of 10-20 percent.

The values selected in this step should be regarded as initial values, subject to modification when the various reasonableness checks are made. Of particular relevance is the check of the number of annual vehicle-miles per vehicle. If this figure is substantially above experience with similar equipment elsewhere, it could indicate that the selected spare vehicle percentage is too low.

Table 15. REPRESENTATIVE VEHICLE SPARE RATIOS

Percent of Fleet Requirement for Peak Service,
Based on Active Fleet (1975)

Rapid Rail	
CTA	21%
GCRTA	35%
NYCTA	18%
PATH	25%
PATCO	9%
BART	90%
SEPTA	31%
MUCTC	27%
TTC	19%

Light Rail	
GCRTA	30%
New Orleans	59%
SEPTA/ Red Arrow	40%
SEPTA/ City	22%
TNJ	62%
TTC	42%

Trolley Coach	
MVRTA	25%
SEMTA	35%
TTC	50%

Commuter Rail	
Burlington Northern	0%
Milwaukee Road	3%
SEPTA--total	18%
SEPTA--Reading	18%
SEPTA--Penn Central	16%
SIRT	86%

Bus	
AC Transit	15%
Austin	30%
Columbus	20%
Dallas	30%
MARTA	12%
NYCTA	14%
Sacramento	16%
Norfolk	26%
Portland	10%
Winston-Salem	10%
Ottawa	12%

Source: American Public Transit Association (1977).

7. ESTIMATION OF EMPLOYEE REQUIREMENTS

Labor costs represent the major portion of transit operating costs, as illustrated in Table 16. Accounting for all forms of public transportation, this fraction averages nearly 75 percent. Since labor costs are highly correlated with numbers of employees, employee requirements are thus a key supply parameter critical to the financial assessment of a proposed transit system. Furthermore, the number of jobs which will be provided by a proposed transit system is itself an issue which often is of concern during project planning.

Until recently, there have been few consistent data sources available upon which to base analyses of labor required to operate and maintain transit systems. Differences in accounting and record keeping systems among transit properties made the development of basic structural relationships for use in planning very difficult. Partly as a result, there presently are no widely accepted procedures for predicting employee requirements.

The situation has been improved by the development of the Uniform System of Accounts and Records and Reporting System required by Section 15 of the Urban Mass Transportation Act of 1964, as amended. Employee data in the Section 15 data base currently suffer to some extent from inconsistent accounting, interpretation, and reporting. However, as more transit systems adapt their accounting systems and procedures to Section 15 definitions, and as these definitions are clarified and expanded over time, the Section 15 Annual Reports will become an increasingly valuable source of data on transit labor requirements.

Another relevant source--albeit one that will not be updated on a regular basis--has been assembled by the Regional Plan Association (Pushkarev and Zupan, 1980). Starting with data available in the APTA Transit Operating Report, RPA staff conducted extensive discussions with transit properties to try to make the data set complete and consistent. The resulting data base contains employment in five categories for thirteen North American rail rapid transit systems, nine light rail systems, and five peoplemover systems:

- vehicle operation;
- vehicle maintenance;
- way, power, and signals (rail systems only);
- station (rail systems only); and
- administration.

Table 16. LABOR EXPENSE AS A FRACTION OF TOTAL OPERATING EXPENSE - BUS, RAIL RAPID, AND LIGHT RAIL/STREETCAR SYSTEMS

		Percent of Total Expense			
Mode	Transit System	Operators' Salaries and Wages	Other Salaries and Wages	Fringe Benefits	Total Labor Costs
Bus	NYCTA	29.8	22.7	31.7	84.2
Bus	CTA	38.5	16.1	26.0	80.6
Bus	SCRTD	27.5	23.0	22.0	72.5
Bus	SEPTA	37.4	15.4	23.4	76.2
Bus	WMATA	32.3	17.8	27.3	77.4
Bus	MBTA	30.4	23.2	29.8	83.4
Bus	MTC-St. Paul	31.2	19.4	25.7	76.3
Bus	Dallas Transit	29.4	18.5	20.8	68.7
Bus	San Diego Transit	34.0	18.0	26.3	78.3
Bus	Tacoma Transit	34.3	20.1	19.2	73.6
Bus	Weighted avg./311 systems	31.5	18.7	23.1	73.3
RR	NYCTA	9.9	41.6	31.1	82.6
RR	CTA	14.9	40.5	26.2	81.6
RR	SEPTA	8.3	47.7	24.8	80.8
RR	WMATA	4.0	38.9	24.1	67.0
RR	MBTA	12.5	36.3	26.8	75.6
RR	GCRTA	18.3	33.2	20.4	71.9
RR	MARTA	7.8	47.1	20.1	75.0
RR	BART	4.4	39.2	27.0	70.6
RR	PATCO	6.0	35.7	18.4	60.1
RR	Weighted avg./9 systems	9.8	41.0	29.3	80.1
LRT	NJTC	21.4	28.3	19.1	68.8
LRT	SEPTA	24.8	30.8	24.6	80.2
LRT	MBTA	9.3	33.7	25.2	68.2
LRT	GCRTA	15.7	34.8	20.0	70.5
LRT	MUNI	34.9	33.2	16.5	84.6
LRT	PAT	17.7	42.8	26.6	87.1
LRT	NOPS	22.6	32.9	20.9	76.4
LRT	Weighted avg./8 systems	21.9	34.0	21.7	77.6

Source: Jacobs et al. (1983).

Employment in three categories also is given for selected bus systems, and typical train crew sizes are given for the rail rapid transit and light rail systems. These data are summarized in Tables 17 and 18.

A smaller data set, describing European systems, has been assembled by the Tri-County Metropolitan Transportation District of Oregon (Tri-Met). This data set has been used to summarize comparative European experience. (See Table 19).

The measures in Tables 17-19, which relate numbers of employees to selected supply parameters such as vehicle-miles, can be used for estimating or checking the reasonableness of labor requirements. Since, however, there is substantial variability in the underlying data, these measures are of value only as indicators of general levels of employee requirements, and not as precise prediction tools.

In general, there are two basic approaches to projecting employee requirements. The first, which might be termed a "structural" approach, is to build up employee requirements from detailed consideration of operating characteristics of the system under study. Past labor practices and policy assumptions on station manning and system maintenance are used to estimate crew sizes, maintenance force requirements, etc. These estimates then are aggregated to yield total employee estimates.

Alternatively, a "statistical" approach can be used. Previously estimated supply measures such as number of vehicles in service or total vehicle-miles are used with multipliers (developed from sources such as the Section 15 and/or RPA data) to estimate total system employment, possibly by category. At the most aggregated level, total employment would be estimated in this way, and then disaggregated using statistically estimated percentages of employment by category, to permit estimation of payroll costs.

7.1 FACTORS AFFECTING EMPLOYEE REQUIREMENTS

While available statistics are inadequate to support definitive analyses, a number of factors may be identified which will affect employee requirements of a proposed alternative. In any particular planning situation, it may be possible to improve confidence in projections by comparing the alternative to systems in operation which are analogous in terms of these factors:

- system scale and service level;
- maintenance policy and reliability; and
- labor and work rules.

7.1(a) System Scale and Service Levels

This set of factors logically is the most important for projecting labor requirements. For a given hardware configuration, labor requirements will be

Table 17. REPRESENTATIVE TRANSIT LABOR RATE STATISTICS - RAIL SYSTEMS

	Min.	Max.	Mean	Std Dev
RAIL RAPID (13 systems)				
Operating Employees per:				
. Peak-Hour Train	3.65	13.04	7.97	3.05
. Peak-Hour Vehicle	0.80	3.15	1.38	0.67
. Vehicle in Service	0.53	2.06	1.04	0.45
. Million Vehicle-Miles	9.49	59.35	23.91	15.15
. Million Place-Miles	0.04	0.48	0.19	0.14
Vehicle Maintenance Employees per Vehicle	0.43	2.00	1.00	0.49
Maint. of Way & Power Empl. per Line Mile	3.31	30.24	13.13	9.58
Station Employees per Station	0.64	11.20	5.43	3.42
Total Employees per:				
. Vehicle in Service	2.74	7.70	4.45	1.35
. Million Vehicle-Miles	61.56	192.71	95.76	35.89
. Million Place-Miles	0.46	1.96	0.88	0.40
LIGHT RAIL (9 systems)				
Operating Employees per:				
. Peak-Hour Train	1.31	6.30	2.78	1.65
. Peak-Hour Vehicle	1.31	2.51	1.99	0.38
. Vehicle in Service	0.88	2.00	1.40	0.35
. Million Vehicle-Miles	36.94	76.71	54.62	15.14
. Million Place-Miles	0.30	1.14	0.74	0.29
Vehicle Maintenance Employees per Vehicle	0.17	1.20	0.71	0.35
Maint. of Way & Power Empl. per Line Mile	1.63	14.46	4.48	4.10
Station Employees per Station (5 systems)	1.00	8.91	4.78	3.39
Total Employees per:				
. Vehicle in Service	1.83	8.00	3.73	1.84
. Million Vehicle-Miles	80.73	245.28	139.98	54.02
. Million Place-Miles	1.10	3.63	1.87	0.92

Source: Pushkarev and Zupan (1980).

Table 18. REPRESENTATIVE TRANSIT LABOR RATE STATISTICS - BUS SYSTEMS AND PEOPLEMOVERS

	Min.	Max.	Mean	Std Dev
BUS SYSTEMS IN CITIES WITH RAIL OPERATIONS (11 systems)				
Operating Employees per:				
. Vehicle in Service (10 systems)	1.38	2.50	1.79	0.37
. Million Vehicle-Miles (10 systems)	8.31	111.33	54.86	25.92
. Million Place-Miles (10 systems)	0.63	1.73	1.01	0.31
. Thousand Vehicle-Hours (10 systems)	0.07	0.83	0.60	0.21
Vehicle Maint. Employees/Vehicle (7 systems)	0.43	0.67	0.56	0.09
Total Employees per:				
. Vehicle in Service	2.20	3.50	2.62	0.40
. Million Vehicle-Miles	11.89	154.08	82.41	34.07
. Million Place-Miles	1.06	2.40	1.50	0.38
. Thousand Vehicle-Hours	0.10	1.15	0.90	0.28
BUS SYSTEMS IN CITIES WITHOUT RAIL OPERATIONS (16 systems)				
Operating Employees per:				
. Vehicle in Service (15 systems)	1.13	2.11	1.52	0.28
. Million Vehicle-Miles (15 systems)	37.08	61.87	47.49	7.16
. Million Place-Miles (15 systems)	0.59	1.05	0.79	0.13
. Thousand Vehicle-Hours (15 systems)	0.55	0.82	0.63	0.06
Vehicle Maintenance Employees per Vehicle	(data not available)			
Total Employees per:				
. Vehicle in Service	1.60	3.10	2.24	0.39
. Million Vehicle-Miles	50.09	99.92	72.53	13.09
. Million Place-Miles	0.80	1.64	1.20	0.22
. Thousand Vehicle-Hours	0.81	1.06	0.93	0.07
PEOPLEMOVERS (5 systems)				
Operating Employees per:				
. Vehicle in Service (4 systems)	0.20	0.62	0.37	0.19
. Million Vehicle-Miles (4 systems)	2.67	20.71	11.64	9.16
. Million Place-Miles (4 systems)	0.08	1.08	0.38	0.47
. Thousand Vehicle-Hours (4 systems)	0.03	0.20	0.10	0.09
Vehicle Maint. Employees/Vehicle (3 systems)	1.13	1.47	1.32	0.18
Total Employees per:				
. Vehicle in Service	1.80	5.00	2.78	1.34
. Million Vehicle-Miles	29.51	165.84	78.90	52.25
. Million Place-Miles	0.63	5.42	2.60	2.23
. Thousand Vehicle-Hours	0.27	1.61	0.73	0.54

Source: Pushkarev and Zupan (1980).

Table 19. COMPARISON OF U.S. AND EUROPEAN LABOR RATES FOR LIGHT RAIL AND BUS TRANSIT SYSTEMS

	Drivers per Vehicle		Drivers per Million Vehicle-Miles		Vehicle Maint'nce Employees per Vehicle		Total Employees per Vehicle		Total Employees per Million Vehicle-Miles	
	US	Eur	US	Eur	US	Eur	US	Eur	US	Eur
LIGHT RAIL										
Minimum	0.9	1.2	36.9	40.9	0.2	0.6	1.8	2.8	80.7	117.8
Maximum	2.0	3.1	76.7	109.3	1.2	1.6	8.0	6.6	245.3	312.5
Mean Value	1.4	2.0	54.6	70.3	0.7	1.1	3.7	4.8	140.0	193.9
Std. Deviation	0.4	0.6	15.1	18.4	0.4	0.3	1.8	1.4	54.0	68.5
Sample Size	9	12	9	12	9	8	9	7	9	7
BUS OPERATIONS										
Minimum	1.1	1.2	8.3	41.3	0.4	0.2	1.6	2.4	11.9	76.4
Maximum	2.5	3.4	111.3	100.0	0.7	0.7	3.5	4.5	154.1	179.5
Mean Value	1.6	2.2	58.6	70.9	0.6	0.6	2.3	3.3	77.6	112.3
Std. Deviation	0.3	0.6	18.5	16.2	0.1	0.1	0.4	0.6	23.2	28.7
Sample Size	27	15	26	15	7	10	27	10	27	10

Source: Tri-County Metropolitan Transportation District of Oregon.

expected to increase as service frequency increases, as more lines and stops are added, and (for fixed guideway systems) as stations are enlarged.

Average system speed also is an important indicator of labor productivity, with higher speeds tending to produce greater numbers of vehicle-miles (output) per labor-hour (input). Rapid transit systems, thus, generally show a higher output of transit service per employee than do bus or light rail systems. Since there are considerable fluctuations among systems, however, development of statistical prediction models is difficult.

Furthermore, care should be taken to distinguish among local bus operations, express bus operations in mixed traffic, and bus operations in reserved or exclusive rights-of-way. Unit operating costs and employee requirements would be expected usually to differ significantly among these types of services.

7.1(b) Maintenance Policy and Reliability

As noted earlier, many established transit systems retain older vehicles for reserve, thereby increasing fleet size beyond the 10-15 percent spares level commonly used in planning. This approach tends also to increase the average age of the fleet, such that greater maintenance (and more maintenance employees) often are required.

In general, policies designed to increase system reliability may be expected to require increased labor input. However, there is a tradeoff between labor required for vehicle operation and that required for vehicle and right-of-way maintenance. Greater hardware sophistication, for example, frequently requires increased maintenance labor but saves operating labor. Because administrative and certain maintenance labor requirements are less directly dependent upon quantities of service than are operating labor needs, there may be relatively distinct thresholds of volume at which rail rapid transit shows net labor savings compared to more operating-labor-intensive conventional or express bus systems.

7.1(c) Labor and Work Rules

Labor requirements are not easily related to level of service, in large part because of greatly varying collective bargaining agreements and work rules having considerable impact on manning practices. Furthermore, these contracts and work rules often exhibit limited relationship to current system configuration. When planning extensions to an existing system, it usually is reasonable to assume that existing work rules also will be extended. When considering a new system, an attempt should be made to infer the impact of previous labor practices on the new system.

In general, based on assumed system technology and manning practices, expected minimum labor requirements are estimated as a function of supply measures such as annual vehicle-miles or place-miles of service. This minimum level of labor then should be increased by the degree to which work practices reduce the net effective working time of the individual employee. Such factors as the fraction of a workday spent reporting and for breaks, limitations on split shifts, and the extent to which overtime and part-time work is permitted will determine how much the work force will need to be increased above the theoretically feasible minimum for that operating technology.

7.2 USE OF STATISTICAL VERSUS STRUCTURAL APPROACH TO ESTIMATING EMPLOYEE REQUIREMENTS

As noted above, estimation of employee requirements may be approached from a structural or a statistical viewpoint. As illustrated in Figure 14, the structural approach develops estimates of total employee requirements by building up individual categories. Each category of employment, in turn, depends upon pertinent transit system characteristics and local labor practices, and upon policies which may be partially established during planning.

Where a totally new system is being planned, previous local labor practices will have less direct influence than where a new line is being added to an existing system. In the latter case, employee requirements per unit of service or per facility may be established almost totally by current work rules.

Because of non-uniform accounting practices, work rules, and other factors not directly related to transit supply measures, there tends to be considerably more variation in the empirical data on individual categories of employment than in the data on total employment (as illustrated earlier in Table 16). For this reason, it may at times be preferable to use a simpler, less costly statistical approach relating required total employees to a service measure such as vehicle-miles. On the other hand, the structural approach, by requiring more explicit assumptions regarding the operational characteristics of the alternatives being studied, does allow for closer examination of the factors underlying the employee estimates (and, thus, for easier modification to reflect differing assumptions).

The two approaches are not mutually exclusive. Labor estimates can be developed structurally, for example, and then checked using a statistical approach. Or some component(s) of the required labor force (e.g., vehicle operating employees) can be developed structurally, with remaining components estimated on a broader statistical basis.

The choice of a specific approach to estimating labor requirements will depend on a number of factors, such as the nature of the alternatives being studied, the nature of existing transit services and systems in the study region, the quality and extent of relevant available empirical data, and the levels of detail and accuracy required by the analysis. A structural approach, for example, probably would be excessively detailed and precise for system planning, while a statistical approach during project planning may be hindered by wide variations in the pertinent empirical data on total employment rates.

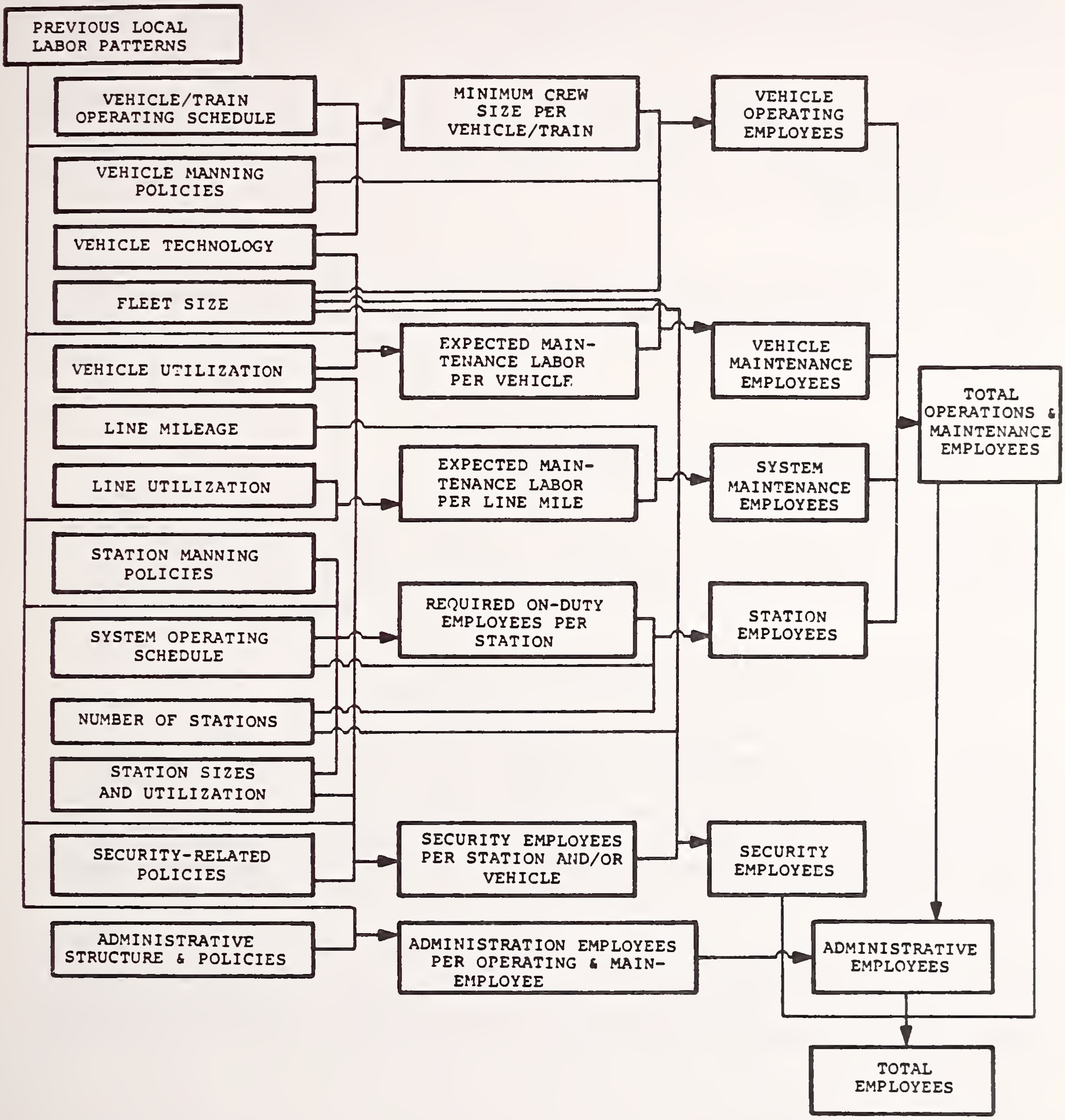


Figure 14.
STRUCTURAL APPROACH TO ESTIMATING REQUIRED NUMBERS OF EMPLOYEES

As illustrated in Tables 15-17, such variations can be significant, and these statistics should be used with care. In particular, space loading standards and vehicle designs must be assumed in order to permit inferences of place-miles or place-hours from vehicle-miles or vehicle-hours of service, and, as noted earlier, there are substantial uncertainties inherent in this conversion.

Employment rates for bus systems in cities with rail systems appear from the RPA data to be consistently higher than in those cities without rail. This relationship may be a result of accounting practices related to allocations of labor, however, rather than to systematic variations in labor practices or system efficiency.

Some of the variations in employment rates also may be explainable as the systematic influence of some functionable variable. Operating speed, for example, as illustrated in Figure 15, may be a significant factor influencing labor productivity, although wide variations are still evident in the empirical data.

7.3 ESTIMATION OF COMPONENT LABOR CATEGORIES

If an estimate is made of total labor force requirements, labor force composition then might be assumed to enhance the estimation of the payroll component of operating cost. Generally, component labor categories are estimated individually during project planning. Each of these categories presents some unique issues and suggests certain estimation techniques.

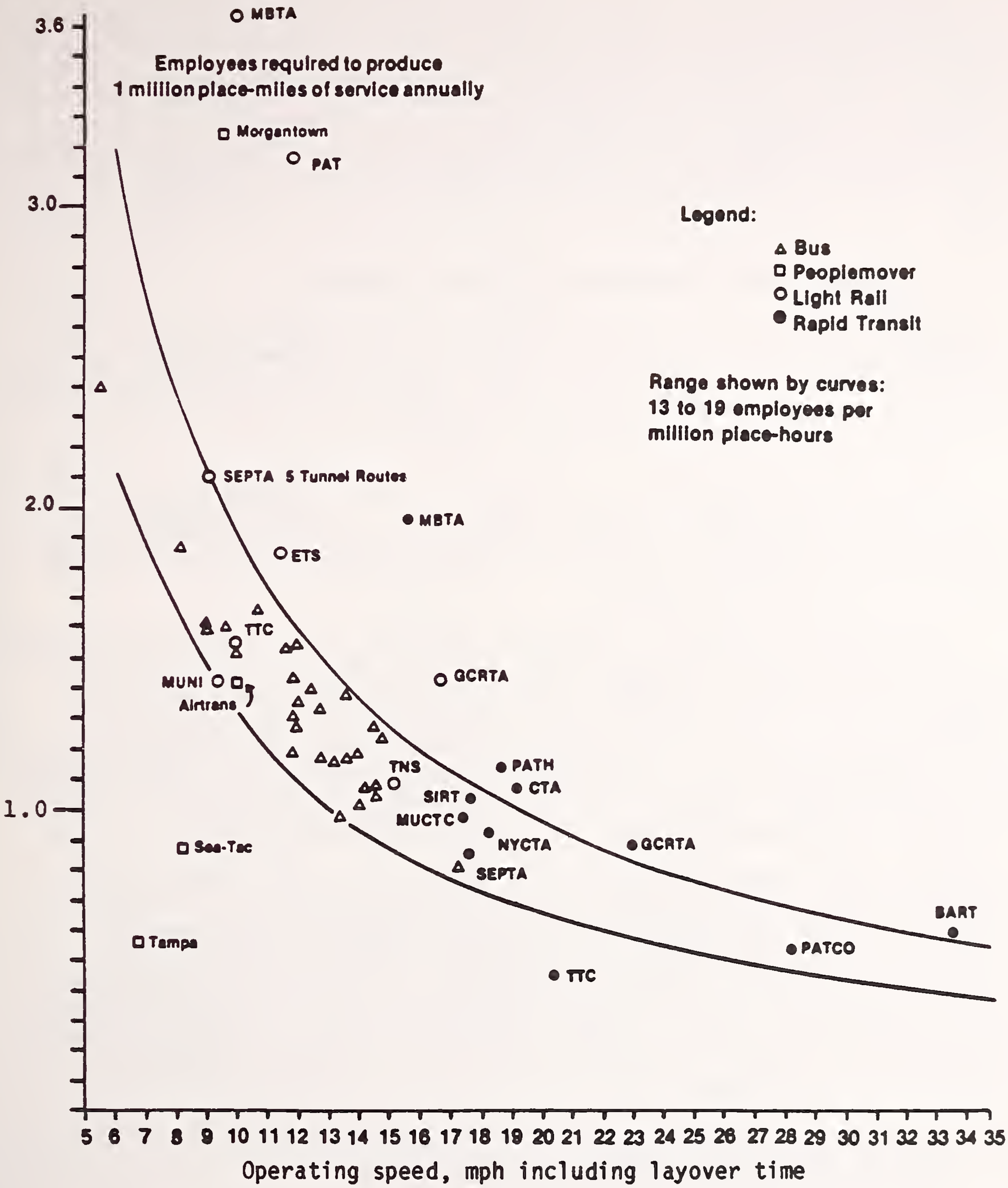
7.3(a) Vehicle Operating Employees

Vehicle operating employees, in principle, should be the most easily estimated category of employee requirements. Crew sizes range generally between one person per train or vehicle to perhaps two persons per vehicle, and can be developed from the basic system technology and from peak and off-peak operating schedules, as modified by information on expected work rules. Given a system's crew requirements, total operating employment then may be derived from estimates of the vehicle fleet and usage thereof.

When viewed on a statistical basis, peak/off-peak operations and labor practices will contribute to the variance shown in Tables 17 and 18. However, it still may be reasonable to use vehicles in service or peak-hour vehicles as single-number supply measures for statistical estimation of operating employee requirements.

7.3(b) Maintenance Employees

Maintenance employee rates generally should be related to the size, utilization, age, and condition of the vehicle fleet, and, for rail systems, to the size and utilization of the guideway network. As shown in Tables 17 and 18, however, there is considerable variance in these rates.



Source: Pushkarev and Zupan (1980).

Figure 15.
TOTAL EMPLOYMENT REQUIREMENT RELATED TO OPERATING SPEED

Maintenance of way and power employee rates for fixed guideway systems do seem to exhibit correlation with service volume, as illustrated in Figure 16. This exhibit also indicates that maintenance employee requirements usually are lower for newer systems. As equipment and plants age, maintenance requirements may be expected to increase, assuming that system reliability is maintained at a constant level. There thus may be some justification for viewing the two curves in Figure 16 as "limits" between new and old systems. Over time, a new system would move vertically from the lower curve toward the upper curve.

7.3(c) Station, Administrative, and Security Employees

Station employee rates would be expected to be largely a matter of policy, although systems with extensive automation might have somewhat lower rates, and systems with larger stations, slightly higher rates. The RPA data, which exclude security forces, indicate little difference in average requirements for existing rail rapid and light rail systems.

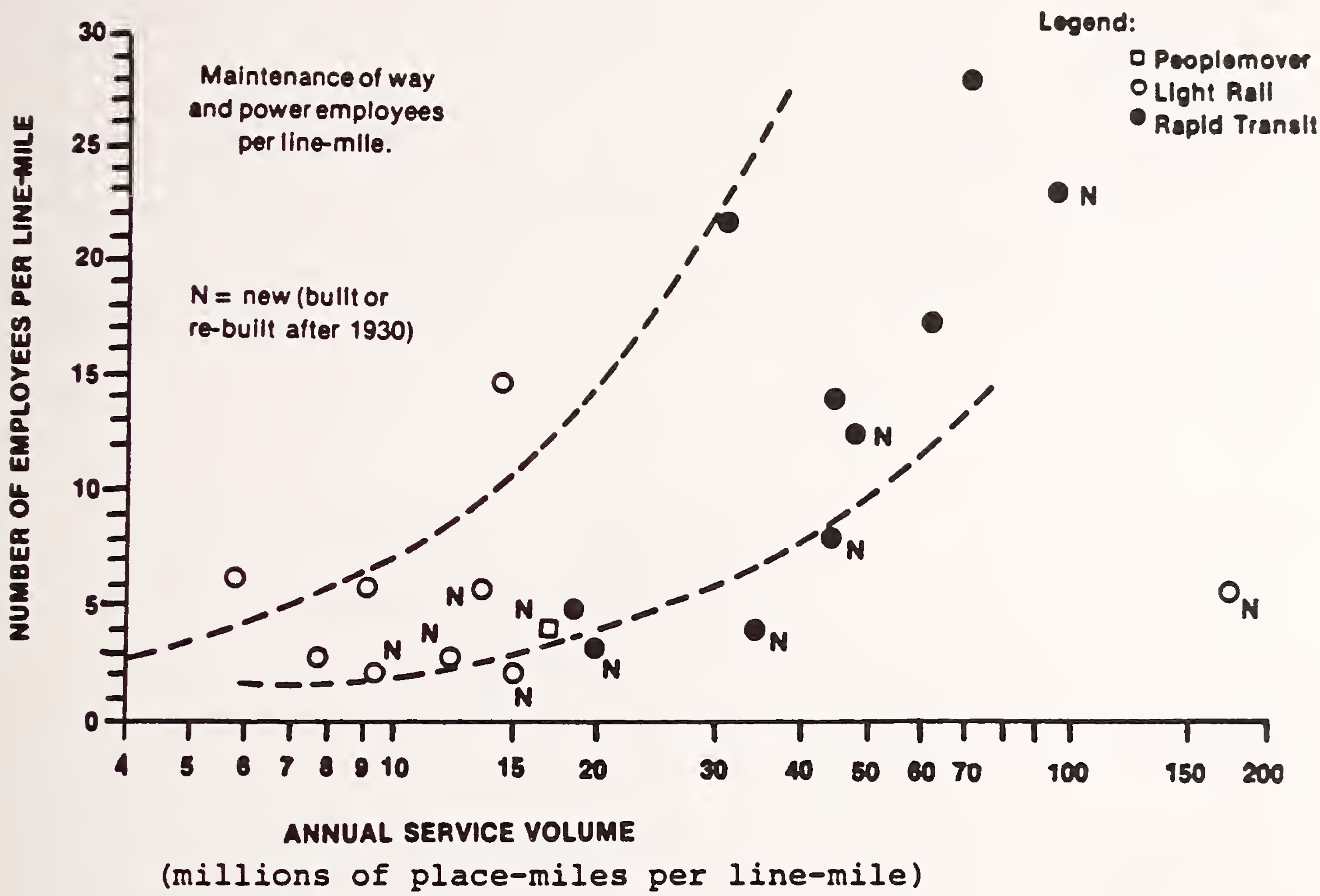
Administrative employment as a fraction of total employment, as shown in Table 20, can vary widely, although some of the variation undoubtedly is attributable to allocation problems or accounting techniques in multi-modal systems. For estimation or checking purposes, a figure of about 10 percent may be a reasonable approximation.

One important component of employment which is not well identified in most data sources is security forces. Some systems justify, on the basis of improved security, manning levels which to some degree exceed the minimum necessary levels--i.e., which exceed the numbers of station employees absolutely needed to sell tokens, service fare machines, provide information, etc. Although security is either formally or informally understood to be part of these employees' responsibilities, it generally is not their main function, and they are counted with other operating or station employees.

Other systems employ persons specifically for security purposes (e.g., transit police), and the numbers of these personnel can be a significant fraction of total employment. Unfortunately, they are not enumerated explicitly in many data sources, but combined, instead, with such other categories as "administrative." The presence or absence of such employees thus is not always clear, and this uncertainty probably contributes to the variance observed in data on transit employment rates. For project planning purposes, it is useful to address explicitly the presence or absence of special security personnel.

7.4 EMPLOYEE REQUIREMENTS AND TOTAL OPERATING COST

Direct estimation of system operating costs, using either statistical/econometric methods or a structural approach, represents another level of complexity and uncertainty beyond that of estimating employee requirements. Consideration should be given to wage rates, benefits packages, overtime policies, and other factors which will affect labor costs per employee.



Source: Pushkarev and Zupan (1980).

Figure 16.

RELATIONSHIP OF MAINTENANCE OF WAY AND POWER EMPLOYEE REQUIREMENT RATE TO SERVICE OUTPUT

Table 20. PERCENTAGE COMPOSITION OF LABOR FORCE FOR TRANSIT OPERATIONS

<table>
<tr><th></th><th colspan="3">U.S. Rapid Rail Systems (13)</th><th colspan="3">U.S. Light Rail Systems (9)</th><th colspan="3">U.S. Bus Systems* (15)</th><th colspan="3">U.S. People-Movers (4)</th></tr>
<tr><th></th><th>Min</th><th>Max</th><th>Avg</th><th>Min</th><th>Max</th><th>Avg</th><th>Min</th><th>Max</th><th>Avg</th><th>Min</th><th>Max</th><th>Avg</th></tr>
<tr><td>Vehicle operations</td><td>5</td><td>40</td><td>26</td><td>25</td><td>64</td><td>43</td><td>61</td><td>90</td><td>67</td><td>6</td><td>33</td><td>13</td></tr>
<tr><td>Vehicle maintenance</td><td>13</td><td>45</td><td>20</td><td>6</td><td>29</td><td>23</td><td>na</td><td>na</td><td>na</td><td rowspan="2">58</td><td rowspan="2">71</td><td rowspan="2">62</td></tr>
<tr><td>Way and power</td><td>6</td><td>45</td><td>27</td><td>8</td><td>35</td><td>22</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>Station</td><td>3</td><td>28</td><td>18</td><td rowspan="2">8</td><td rowspan="2">45</td><td rowspan="2">12</td><td>na</td><td>na</td><td>na</td><td rowspan="2">8</td><td rowspan="2">30</td><td rowspan="2">25</td></tr>
<tr><td>Administrative</td><td>6</td><td>25</td><td>9</td><td>na</td><td>na</td><td>na</td></tr>
<tr><td>Total</td><td>--</td><td>--</td><td>100</td><td>--</td><td>--</td><td>100</td><td>--</td><td>--</td><td>100</td><td>--</td><td>--</td><td>100</td></tr>
</table>

<table>
<tr><th></th><th colspan="3">European Light Rail Systems (6)</th><th colspan="3">European Bus Systems (10)</th></tr>
<tr><th></th><th>Min</th><th>Max</th><th>Avg</th><th>Min</th><th>Max</th><th>Avg</th></tr>
<tr><td>Vehicle operations</td><td>22</td><td>53</td><td>40</td><td>38</td><td>78</td><td>63</td></tr>
<tr><td>Vehicle maintenance</td><td>18</td><td>43</td><td>23</td><td rowspan="2">14</td><td rowspan="2">26</td><td rowspan="2">19</td></tr>
<tr><td>ROW maintenance</td><td>9</td><td>20</td><td>17</td></tr>
<tr><td>Administrative</td><td>8</td><td>40</td><td>20</td><td>7</td><td>40</td><td>18</td></tr>
<tr><td>Total</td><td>--</td><td>--</td><td>100</td><td>--</td><td>--</td><td>100</td></tr>
</table>

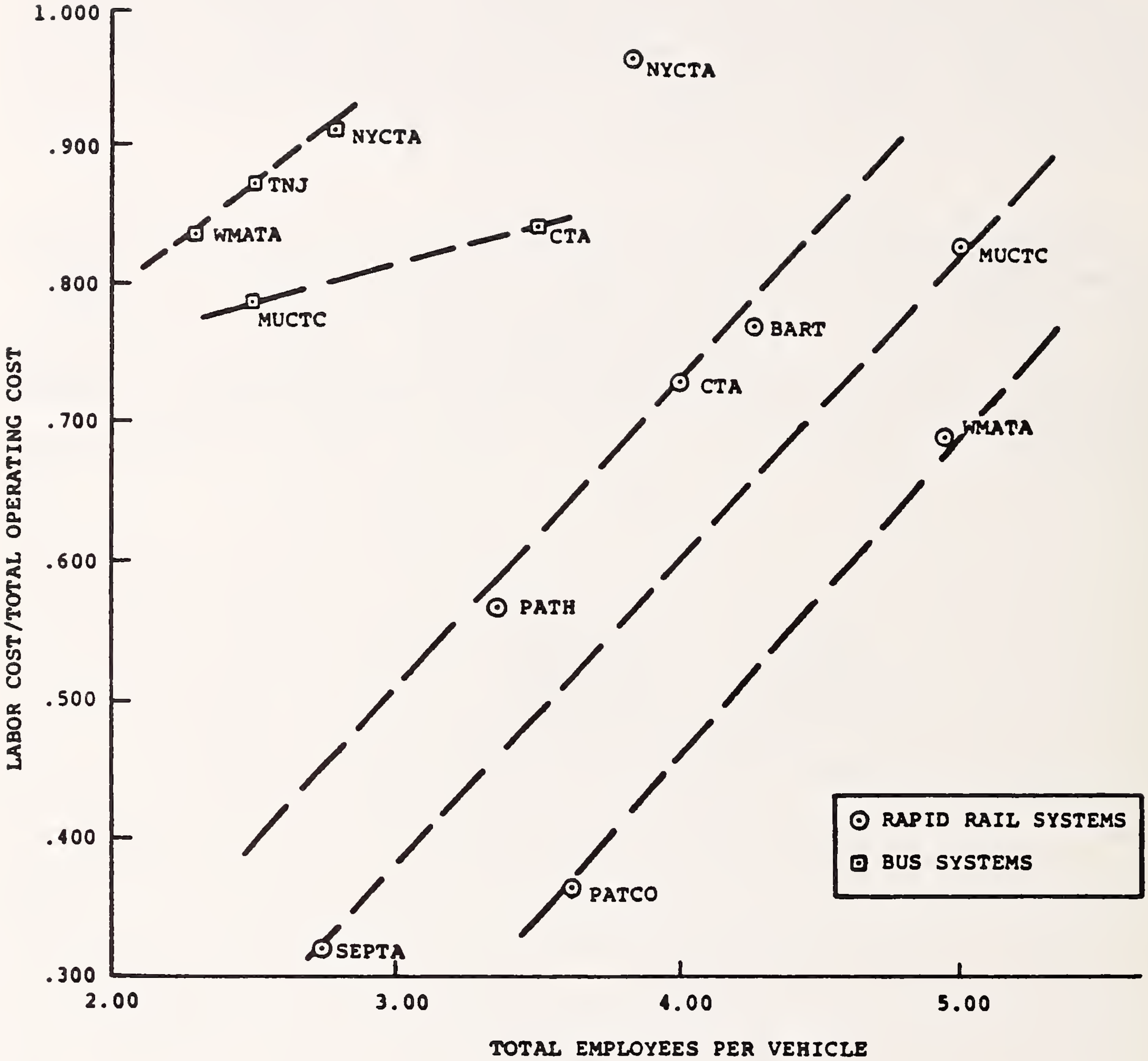
*Systems without rail operations.
na = data not available.

Source: Tri-County Metropolitan Transportation District of Oregon.

Consideration also should be given to such non-labor operating costs as fuel and other supplies and materials.

Detailed examination of these factors probably is beyond what is needed for project planning, but studies have indicated a high correlation between total system output (e.g., vehicle-miles) and operating costs for several bus systems, without regard for wage rates. Although such a relationship can be rationalized, it probably is not sufficiently documented to be used confidently for prediction. Use for prediction also is hindered by the difficulty of predicting the labor fraction of operating costs.

However, as Figure 17 illustrates, there may be a strong systematic relationship between the labor cost/total operating cost ratio and the total system employment per vehicle, by vehicle system type. Again, this relationship is logical, but not defined precisely by explicit cost data. Nonetheless, given estimates of total employee requirements and total fleet requirements, the labor cost ratio can be estimated using relationships such as those suggested in Figure 17, with the estimated ratio then compared with independently derived cost estimates to test the reasonableness of these cost estimates.



Sources: American Public Transit Association (1976); Pushkarev and Zupan (1980).

Figure 17.
LABOR COST RATIOS AND MANNING LEVELS

8. REASONABLENESS CHECKS

After supply parameters are estimated, they should be checked for reasonableness with respect to relevant empirical data. The use of reasonableness checks may lead to revisions in input data and assumptions and/or in the selection and use of revised estimation procedures. This chapter identifies some reasonableness checks for transit supply parameter estimates which should be performed during system planning and project planning. Where possible, representative value ranges are provided, or appropriate data sources are referenced.

In using value ranges for reasonableness checks, two important points should be emphasized. First, these checks should be based on similar technologies operating under similar conditions. While available data usually can be disaggregated by technology type, it often is difficult to disaggregate data on the basis of operating conditions. Hence, average values, drawn from transit systems with different conditions and policies, should be used with caution. It often may be more appropriate in checking the reasonableness of estimates to use data from a single system or service with closely matching operating conditions, than to use aggregated data from a variety of systems with differing operating characteristics.

Second, as noted earlier, prediction techniques and reasonableness checks are not necessarily independent. The data used for a reasonableness check also may be the basis for a supply parameter estimate, particularly during system planning. Obviously, the value of conducting a reasonableness check is diminished if it is not independent of the prediction procedures employed, and the analyst should strive to maintain such independence, particularly during project planning. However, for some parameters, such as employee productivity, very limited data are available, and complete independence of estimation procedures and reasonableness checks may not be possible.

In the area of transit supply parameter estimation, reasonableness checks may be grouped into three categories:

- o level of service checks;
- o quantities of service checks; and
- o employee productivity checks.

Generally, these checks comprise ratios which relate two supply measures (e.g., employees and vehicle-hours). Thus, the checks determine reasonableness by examining internal consistency as well as consistency with experience elswhere.

8.1 LEVEL OF SERVICE CHECKS

These checks involve verifying the reasonableness of the overall level of service specified by a given alternative.

8.1(a) Average Speed by Transit Mode

This check is necessary to determine if the estimated or assumed average operating speed used for supply parameter estimation is reasonable given the technology and operating conditions specified. Critical operating conditions include frequency of stops and degree of right-of-way exclusiveness. Reasonableness checks should be made with data from existing applications similar in this respect to the planned service.

Data sources for typical transit operating speeds were discussed earlier for use with preliminary estimation procedures. The most complete and accessible data probably are available in the "CUTS" handbook (DeLeuw, Cather & Co. et al., 1977). This handbook presents typical average speed ranges for different transit modes, stratified by factors such as station spacing, type of roadway, degree of right-of-way exclusivity, and time of day.

8.1(b) Maximum Vehicle or Train Frequency

Maximum vehicle or train frequency (i.e., minimum headway) should be checked to determine if it is consistent with the transit technology specified, with the average operating speed specified, and (for rail) with the type of control system assumed. Typical minimum headways for different transit modes and operating conditions were shown earlier in Figure 8. The CUTS handbook has theoretical bus and rail volumes for different operating conditions and performance assumptions.

8.1(c) Maximum Seats or Places Per Hour

Maximum seats or passenger places per hour is, like the preceding check, a measure of the capacity provided on a single line or route in a single direction. It should be checked to determine if the maximum passenger capacity provided is within the capability of the technology and operating plans specified. Once typical values for maximum train frequency are known, maximum seats or places per hour can be calculated directly using vehicle or train capacity. For typical bus and rail seating capacities, tables in the CUTS handbook report maximum seats per hour for different operating conditions and performance assumptions.

8.1(d) Peak-to-Base Ratio

This ratio represents the number of peak period transit vehicles required, divided by the number of vehicles required in the midday base period. Checking this ratio in relation to existing systems can be useful in assessing the reasonableness of the proposed operating plan upon which supply parameters are based. Peak-to-base ratios are summarized by Table 21 for a number of U.S. and Canadian systems. While the ratios vary in response to different temporal demand distributions and operating policies, they do provide a basis for order-of-magnitude reasonableness checks.

8.2 QUANTITIES OF SERVICE CHECKS

These checks are made of the aggregated amount of service provided by a given alternative.

8.2(a) Annual Miles Per Vehicle

Comparing planned or estimated annual vehicle-miles per vehicle with experience from existing transit systems serves as a check on estimated fleet size and anticipated vehicle utilization. Some experience with respect to annual miles per vehicle of rapid rail, light rail, and bus systems is summarized in Table 22. The range and variance are large, especially for rail rapid transit, reflecting underlying differences in the degree of off-peak and weekend services as well as different maintenance and vehicle utilization policies.

Furthermore, these represent average utilization rates for each system, and there commonly is a wide range of usage within any given fleet. For example, many systems retain older vehicles for extra spares, which are used infrequently. Too, while most vehicles may be in use during peak periods, many fewer vehicles are in use during off-peak periods, and the newer, more comfortable vehicles usually tend to be selected for the off-peak runs (often, to the exclusion of the older vehicles). This creates a significant disparity in vehicle usage in many systems, such that the more heavily used vehicles are operated for considerably more annual vehicle-miles than are shown in the average system data in Table 22.

Thus, these ranges and mean values should be used only for gross order-of-magnitude reasonableness checks. For more detailed checks needed during project planning, data from selected systems with comparable conditions should be used, adjusted as necessary to reflect differences in operating conditions.

8.2(b) Place-Miles Per Line-Mile

Place-miles (or seat-miles) per line-mile theoretically can be used to check the systemwide capacity of a transit system by mode for reasonableness. Unfortunately, data for this measure, as shown in Table 22, reveal considerable variation, due probably to different levels of demand, schedules, operating speeds, and maximum train lengths, as well as to different vehicle designs, seating configurations, and standee space assumptions. Except as a rough, order-of-magnitude check, therefore, the place-miles per line-mile ratio probably has limited usefulness.

Table 21. REPRESENTATIVE PEAK-TO-BASE VEHICLE RATIOS*

Rapid Rail		Light Rail		Trolley Coach	
CTA	3.39	GCRTA	7.33	MVRTA	1.67
GCRTA	5.40	New Orleans	1.22	TTC	2.59
NYCTA	1.00	SEPTA/ Red Arrow	3.33	PATH	3.27
PATCO	4.31	SEPTA/ City	na		
BART	1.90	TNJ	2.67		
SEPTA	2.79	TTC	2.13		
MUCTC	2.20				
TTC	1.80				

Commuter Rail		Bus	
Burlington Northern	1.00	AC Transit	2.50
Milwaukee Road	1.00	Austin	1.20
SEPTA/ Reading	6.67	Columbus	2.39
SEPTA/ Penn Central	8.58	Dallas	3.08
SIRT	1.56	MARTA	3.95
		NYCTA	1.09
		Sacramento	1.61
		Norfolk	4.72
		Portland	2.05
		Winston-Salem	1.61
		Ottawa	2.61

*Number of peak period transit vehicles required, divided by the number of vehicles required in the midday base period.

Source: American Public Transit Association (1977).

Table 22. ADDITIONAL DATA FOR REASONABLENESS CHECKS

	Minimum	Maximum	Mean Value	Standard Deviation	Coefficient of Variation*
RAIL RAPID (13 systems)					
Annual Vehicle-Miles per Vehicle	30,951	99,945	50,384	20,365	0.40
Annual Vehicle-Hours per Vehicle	1,365	4,079	2,408	859	0.36
Annual Place-Miles per Line-Mile	17,574	173,139	65,338	44,617	0.68
LIGHT RAIL (9 systems)					
Annual Vehicle-Miles per Vehicle	19,898	54,142	27,100	10,989	0.40
Annual Vehicle-Hours per Vehicle	1,397	3,008	2,099	685	0.33
Annual Place-Miles per Line-Mile	4,313	20,550	10,889	5,069	0.46
BUS SYSTEMS WITHOUT RAIL OPERATIONS (16 systems)					
Annual Vehicle-Miles per Vehicle	19,433	43,024	31,969	6,816	0.21
Annual Vehicle-Hours per Vehicle	1,799	3,004	2,431	388	0.16
Annual Place-Miles per Line-Mile	729	2,561	1,528	558	0.37

*Standard deviation divided by mean value.

Source: Pushkarev and Zupan (1980).

8.3 EMPLOYEE PRODUCTIVITY CHECKS

These checks examine the reasonableness of transit employee estimates and underlying productivity rates. Generally, such estimates account for overtime and part-time work through the use of full-time-equivalent employees, although this may not be stated explicitly.

8.3(a) Employees Per Million Annual Place-Miles

This ratio can be checked to assess the reasonableness of the employee estimates and the assumed level of productivity, but it is a relatively crude measure. Some data for operating and total employees per million annual place-miles were presented earlier in Tables 17 and 18, and, as with other measures involving place-miles, these ratios vary considerably among systems of the same transit mode.

8.3(b) Employees Per Million Annual Place-Hours

Employees per million annual place-hours can be estimated simply by multiplying employees per million place-miles by the average operating speed for each system. As such, this measure takes into account different operating speeds, but still reflects much of the same variation among systems as that expressed by the ratio of employees per million annual place-miles. Similarly, it can be used as a crude measure of operating and total employee estimates and assumed productivity.

8.3(c) Employees Per Thousand Annual Vehicle-Hours

Employees per thousand annual vehicle-hours or train-hours is another reasonableness check of (operating and total) employee estimates and underlying employee productivity. The use of vehicle-hours (or train-hours for rail systems) avoids some of the variation among systems evident with vehicle-mile, place-mile, or place-hour measures, since it usually is not significantly affected by system speed differences, vehicle capacity differences, or (for rail systems) differences in train length.

Some relevant data were presented earlier in Tables 17-19. For rail systems, it appears preferable to develop such checks using data for individual systems with similar operating conditions, rather than through the use of average values derived from multiple systems with widely varying characteristics.

8.3(d) Station Employees Per Station

This measure may be used to help determine if the station employee estimate is compatible with experience elsewhere. Data for this measure were presented earlier in Tables 17 and 18, and indicate considerable variability largely due to differences in station manning policies. Thus, the data in aggregated form are useful only for order-of-magnitude checks, and more detailed checks should be made using data from selected systems with similar station manning policies to the proposed line or system under study.

8.3(e) Maintenance of Way and Power Employees Per Line-Mile

Data for this measure also were summarized in Tables 17 and 18, and also exhibit considerable variability among systems. Thus, the aggregated data should be used only for order-of-magnitude checks of maintenance of way and power employee estimates, with more detailed checks based on data from selected systems with similar operating conditions.

8.3(f) Employees Per Vehicle

Total employees per vehicle is another reasonableness check of total employee estimates. Pertinent data or this measure were summarized in Tables 17-19. The data do exhibit considerable variability, but will support order-of-magnitude reasonableness checks.

APPENDIX A. GLOSSARY

Annualization Factor -- A factor or set of factors with which to expand average weekday supply parameter estimates to annual supply parameter estimates. Annualization factors also are used to expand demand (ridership) estimates; these tend to be slightly lower than the equivalent supply factors because service on weekends and holidays usually is not cut back fully proportionately to ridership.

Assignment; Trip Assignment -- Techniques whereby estimated trips for specific modes, time periods, and origin-destination pairs are "assigned" to specific transportation routes, facilities, and services.

Average Speed -- (See "Speed").

Block -- The sequence of all trips, including deadheading, made by a bus between leaving and returning to the garage ("pull-out" and "pull-in"). A block may consist of many driver "runs".

Block Segment; Block -- A length of track of defined limits on which the movement of trains is governed by block signals, cab signals, or both.

Bunching -- Departure from schedule characterized by the arrival of several transit vehicles or trains (bunched) closely together, with long periods before and after during which no vehicles arrive. This can be a serious problem for buses operating in heavy mixed traffic, and can compound as buses go farther along the route, since long wait periods preceding the "bunch" create unduly high demand for these vehicles and consequent lengthy dwell times, further increasing the gap preceding the bunch, etc.

Commuter Rail -- (See "Mode of Travel").

Consist -- Rail vehicles connected together to form a train.

Constant Service Time Period -- A time period, usually a portion of a day, during which the headway or frequency of service on a given route can be assumed to be constant.

Cruise Speed -- (See "Speed").

Crush Load -- Maximum loading of passengers into transit vehicles during periods when demand exceeds available capacity. These loadings exceed design capacities, and imply very uncomfortable loading (space) standards.

Deadheading -- Movement of a transit vehicle with passengers excluded, such as to and from a garage or yard or from the end of one revenue trip to the beginning of another.

Demand; Travel Demand -- The number of trips made by persons or automobiles under specified conditions (travel times, costs, etc.). Current ridership is a measure of transit demand under existing conditions.

Demand Headway -- (See "Headway").

Demand-Responsive Transit -- (See "Mode of Travel").

Dwell Time -- The time spent by transit vehicles at stops or stations to permit the opening and closing of doors and the boarding and alighting of passengers.

Express Buses -- (See "Mode of Travel").

Express Service -- (See "Service").

Feeder Service -- (See "Service").

Floor Area

Gross Floor Area -- The floor area of a transit vehicle calculated using exterior dimensions.

Usable Floor Area -- The interior floor area of a transit vehicle which is actually available to accommodate passengers, either seated or standing.

Frequency of Service; Service Frequency -- (See "Headway").

Gross Floor Area -- (See "Floor Area").

Guideway -- The surface or track and its supporting structure on or in which transit vehicles travel.

Headway -- The elapsed time between the arrival of transit vehicles (or trains) traveling in the same direction on a given route; usually expressed in minutes (e.g., a 10-minute headway). The frequency of a transit service sometimes is expressed in terms of headways, and sometimes in terms of vehicles or trains within a given time period (usually, number of vehicles or trains per hour).

Demand Headway -- Headway needed to provide adequate capacity to serve anticipated demand.

Minimum Headway -- Lowest headway or highest frequency of service which can be operated safely for a given technology and system design.

Policy Headway -- Maximum headway on a given route, specified as a matter of policy (i.e., minimum acceptable frequency of service).

Nominal Headway -- Headway estimate used initially as input to demand estimation; equal to or less than the policy headway.

Service Headway -- Headway actually operated (or to be operated); dependent on demand and policy headways and other operational considerations.

Interlining -- A common scheduling practice in which a given driver and vehicle may provide trips on different routes in succession to increase overall operating efficiency.

Jerk Rate -- The rate of change of acceleration or deceleration. The maximum allowable jerk rate for rail transit vehicles typically is about 3.0 mph/sec/sec.

Jitneys -- (See "Mode of Travel").

Kiss-and-Ride -- Travel encompassing an individual's being driven in an automobile to a transit stop or station, and then transfering to the transit system while the auto is driven home or to another destination; so-called because of the stereotypical situation in which a man is driven to a transit station by his wife, who kisses him good-bye and then drives away. (See "Park-and-Ride").

Level of Service -- The quantity and quality of transportation service provided.

Light Rail Transit -- (See "Mode of Travel").

Line-Haul Service -- (See "Service").

Loading Standards -- Measures of passenger comfort, such as the ratio of total design capacity to the number of seats provided on a transit vehicle, and the amount of floor space provided per passenger, seated and/or standing.

Local Buses -- (See "Mode of Travel").

Local Service -- (See "Service").

Maximum Load Point -- The point on a transit route at which the maximum volume or passenger loading occurs over a given time period. Usually, it is expressed with respect only to the peak direction.

Maximum Load Point Volume -- The number of passengers crossing the maximum load point during the appropriate time period, usually in the peak direction only.

Minimum Headway -- (See "Headway").

Mode of Travel; Travel Mode -- A basic transportation technology, having certain typical operating or service characteristics.

Commuter Rail -- Train service between downtown terminals and suburban areas, usually operating primarily during peak commuting hours over intercity railroad tracks shared with freight and sometimes intercity passenger service.

Demand-Responsive Transit; Demand-Actuated Transit; Dial-a-Bus -- Flexibly routed, door-to-door service provided on demand, generally utilizing a van or mini-bus. Although designed to provide service nearly comparable with that of a taxicab but at a cost near that of a bus, many experimental demand-responsive services have resulted in the reverse experience--service near that of a bus with costs near those of taxicabs.

Express Buses -- Bus service which serves only selected origins and destinations with nonstop runs on local streets, on freeways in mixed traffic, and/or on reserved bus lanes.

Jitneys -- Transit service generally following a relatively fixed route but with no fixed schedule or stops, and hailed by passengers who wait for it in the street. The density of demand must be very high for this type of service to be economically efficient. Because they can provide erratic passenger service, and because they compete with conventional transit routes, jitney services are prohibited in many areas of the U.S.

Light Rail Transit -- Vehicles operating singly or in short trains on tracks in a variety of rights-of-way: with mixed traffic on streets; in reserved lanes with grade crossings; on fully grade-separated facilities. Of the more than 300 cities which today have light rail systems, about a third are in the Soviet Union, and over a half are in the remainder of Europe.

Local Buses -- The dominant form of public transportation in the U.S., operating along fixed routes in mixed traffic (i.e., sharing roads with automobiles and trucks) with either frequent or infrequent (scheduled) service.

Rail Rapid Transit; "Heavy" Rail -- Intra-urban train service on exclusive rights-of-way (elevated, at-grade, and/or below-grade in open cuts or tunnels), with high-platform boarding and with fare collection at stations. Station spacing can be relatively close (e.g., one-half mile or less) in downtown areas, where rapid transit provides a distribution system for travelers, ranging to a several mile separation between stations in suburban areas which "feed" passengers to these stations via automobiles and buses.

Streetcars -- An older name for light rail transit vehicles, generally operating singly in mixed traffic. Also called trams or tramways. Of the nearly 50,000 miles of streetcar track existing in the U.S. in 1920, less than 2 percent remains, most streetcars having been replaced by the more operationally flexible gasoline- or diesel-powered transit bus.

Trolley Buses; Trackless Trolleys -- Buses powered by electricity drawn from overhead wires. Most American trolley bus systems were replaced during the 1950's by diesel or gasoline buses, primarily because of the ready availability of inexpensive fuel and the limited mobility of trolley buses in mixed traffic. While the number of trolley bus systems in the U.S. declined by 1970 to only 5, there has been recent interest in this mode in several other cities, due to its independence from petroleum-based fuels, the absence of fumes and pollutants emitted from vehicles, and its quietness of operation.

Minimum Headway -- (See "Headway").

Models -- Analytical relationships or tools to aid in estimating demographic and economic activity and resultant travel patterns and use of transportation facilities and services.

Nominal Headway -- (See "Headway").

Operating Feasibility; Operational Feasibility -- The ability of a proposed transit system or service to perform as specified from an operational standpoint.

Owl Service -- (See "Service").

Paratransit -- Forms of public transportation services that are more flexible and personalized than conventional fixed-route, fixed-schedule services; often defined to exclude charter buses and exclusive-ride taxis, and usually available to the public on demand, by subscription, and/or on a shared-ride basis.

Park-and-Ride -- Travel encompassing the driving of an automobile to a transit stop or station, the parking of the auto nearby, and the transfering to the transit system for travel to the individual's destination. (See "Kiss-and-Ride").

Peak; Peak Period -- The hours, usually in the morning or afternoon, when use of transportation facilities and services is at its highest. Other hours are referred to as off-peak.

Policy Headway -- (See "Headway").

Rail Rapid Transit -- (See "Mode of Travel").

Reasonableness Check -- An assessment of the consistency of supply parameter estimates with transit experience locally and elsewhere involving similar technologies and operating conditions.

Recovery Time -- Vehicle waiting time scheduled at terminals which is in excess of that required for turnaround. This time can be used, for example, to coordinate schedules of connecting routes, or to allow a late-arriving vehicle to depart closer to schedule.

Revenue Service -- (See "Service").

Rolling Stock -- Transit vehicles.

Route -- The geographical path followed by a transit vehicle in revenue service; on buses, passengers may ride from start to finish of a route, paying their fares (or displaying their passes) when boarding and/or alighting. Several transit routes may traverse a single portion of road or track, and a single run may encompass more than one route (see "interlining").

Run (Driver) -- A transit driver's assignment of trips for a day of operation.

Run (Vehicle) -- The trip of a transit vehicle in one direction from the beginning of a route to the end of it.

Run Cutting -- The process of organizing all scheduled trips operated by a transit system into runs.

Schedule Speed -- (See "Speed").

Service; Transportation Service -- Facilities, equipment, and labor which are provided to enable persons to travel between origins and destinations.

> Express Service -- Services providing higher speeds and fewer stops than generally are found on other portions of the system or on the same route in local service.
>
> Feeder Service -- A service that transports passengers to a station or transfer point for express bus, commuter rail, or rail rapid transit service.
>
> Line-Haul Service -- Transit operations, usually express service, along a single corridor or variety of corridors.
>
> Local Service -- Service involving frequent stops and consequent low speeds, the purpose of which is to pick up and deliver passengers close to their origins and destinations.
>
> Owl Service -- Transit service provided during the late night and early morning hours.
>
> Revenue Service -- Normal service during which (paying) passengers are permitted on-board, as opposed to deadheading.
>
> Skip-Stop Service -- Transit service in which not all trains or vehicles stop at all stations or stops along a route; usually, "A" and "B" trains or vehicles alternate their respective stops, with both stopping at major stops or stations.

Service Headway -- (See "Headway").

Skip-Stop Service -- (See "Service").

Software; Computer Software -- "Programs," or sets of instructions for computers to perform desired functions or computations.

Spare Percentage; Spares -- The number of additional vehicles provided in a fleet to accommodate vehicles being out of service for maintenance; usually expressed as a percentage of the maximum number of vehicles required for service during peak periods.

Speed -- Velocity; rate of travel.

Average Speed -- The actual distance traversed by a given transit route, divided by the total elapsed time, including all station or stop dwell time.

Cruise Speed -- Speed which a transit vehicle will accelerate to and maintain on a given route, provided there is sufficient distance between stops to reach this speed before deceleration.

Schedule Speed -- The distance traversed by a given transit route, divided by the scheduled run time.

Streetcars -- (See "Mode of Travel").

Supply Parameter -- A descriptor of transit service to be supplied and/or the non-monetary resources such as vehicles or employees required to provide this transit service.

Switching -- A means of changing the route of a vehicle or train from one track or guideway to another.

Trackless Trolleys -- (See "Mode of Travel").

Transportation System Management (TSM) -- Non-capital-intensive actions designed to improve a region's transportation system.

Travel Mode -- (See "Mode of Travel").

Trip -- A one-way movement of a person or vehicle between two points for a specific purpose.

Tripper -- A short piece of work for a driver which cannot be incorporated into a full day's run. Typically, a tripper begins and ends in the garage.

Trolley Buses -- (See "Mode of Travel").

Turnaround Time; Turnback Time -- The time required to turn transit vehicles or trains around at terminal stations so that they can begin service in the reverse direction.

Usable Floor Area -- (See "Floor Area").

APPENDIX B. AVAILABLE SOFTWARE

There is a variety of computer software available which can be used to assist in transit supply parameter estimation. Some of this software is well established and has been in use for a number of years on mainframe computers. Much of it, however, has been developed recently for mini- and microcomputers: the availability of much of this software is not widely known: many programs have had relatively little use, and some may not be fully debugged; and much of this software is relatively specialized and more limited in scope than the large transportation planning packages which run mostly on mainframes. In addition, new software is being written for microcomputers at a very rapid pace, and users should try to keep abreast of developments through software clearinghouses and other sources.

For example, periodically updated software summaries are published by DOT (UMTA, 1983). Also, there currently are Federally-sponsored user groups and support centers for transit operations and for transportation planning--Transit Industry Microcomputer Exchange (TIME) and Microcomputers in Transportation Planning (MTP), respectively. These groups provide opportunities for professionals in these fields to share microcomputer information; in addition, newsletters are published, and public-domain software is distributed on request.

Persons interested in joining these user groups should contact:

TIME Support Center
Rensselear Polytechnic Institute
Civil Engineering Department
Troy, NY 12181
(518) 266-6227

MTP Support Center
DOT/Transportation Systems Center
DTS-62
Kendall Square
Cambridge, MA 02142
(617) 494-2247

A brief summary is provided below of some available software and relevance to transit supply parameter estimation.

B.1 TRANSPORTATION PLANNING SOFTWARE

There are several proprietary software packages available designed to assist in the convention transportation planning and travel demand forecasting processes. By far the most widely used package, however, is the public-domain Urban Transportation Planning System (UTPS), a battery of computer programs developed and maintained by UMTA and FHWA, and intended for use in planning multimodal transportation systems. UTPS currently runs on IBM mainframes, although smaller versions are being planned and developed to run on microcomputers.

Two UTPS programs are especially relevant to supply parameter estimation:

- o UNET, the initially developed UTPS transit network analysis program; and
- o INET, an improved transit network analysis program released in 1979.

Using UNET, a separate transit network is coded without explicit reference to underlying highway networks. Although it is oriented toward demand estimation, the program does produce estimates of vehicle-miles, vehicle-hours, and the numbers of vehicles required to operate the specified transit services. These estimates often require manual adjustment for a variety of reasons, however.

- o While the program permits a day to be divided into a maximum of four service periods, service headways usually are specified for only one or two of these periods.
- o Policy or nominal headways are used exclusively, and demand-capacity checks are not made within the program.
- o Transit speeds are not necessarily consistent with highway conditions, particularly for future years during which increased congestion may be encountered.
- o The possibility of interlining transit vehicles is not considered.
- o Standing time is always increased to maintain headways in even minutes.

INET (Integrated Transit Network) was designed, in part, to address some of the deficiencies of UNET. Unlike UNET, INET is coded with specific reference to an existing computer-coded highway network. This is intended to simplify the coding process while at the same time insuring consistency between highway and transit networks (i.e., maintaining consistent relationships between the speeds of buses and automobiles operating on the same streets). Significant program features from a supply parameter estimation standpoint include the following.

- o Bus transit speeds for services in mixed traffic are based on the highway speeds from a "loaded" highway network. Bus cruise speed on a given link is calculated from the highway speed with a transformation relationship. (See Figure 7).

- Stop or station dwell times are calculated based either on the number of nodes coded or on a stop-density function.

- Acceleration and deceleration times are estimated based upon the number of stops made.

- Initially specified or nominal headways are adjusted, subject to maximum (policy) headways and minimum turnaround times, to reduce the number of vehicles required, if possible. If the number of vehicles cannot be reduced, the headway is reduced to provide more frequent service, if that is possible.

While INET represents a considerable advance over UNET, manual adjustments of resulting vehicle, vehicle-mile, and vehicle-hour estimates still are necessary in most cases. Demand headways are not calculated, and neither demand-capacity checks nor headway adjustments are made. Moreover, since interlining still is not considered, there will be a tendency to overestimate the numbers of vehicles and vehicle-hours required.

B.2 TRANSIT OPERATIONS SOFTWARE

An example of a relevant transit operations software package is TRANS-ADE, a proprietary package developed by BRH Mobility Services Company and now available from Brown & Root. Among the programs in TRANS-ADE which can be used for supply parameter estimation are the following.

- Vehicle/Train Performance Analysis -- This program determines average speed and round-trip time, and estimates energy requirements for rail operations. Inputs include vehicle characteristics (acceleration and deceleration, cruise speed, jerk rate, weight, frontal area, and resistance and loss coefficients), and route characteristics (grades, station spacing, and dwell times). Outputs of this program are used as input to the Vehicle/Train Operations Simulation program.

- Bus Performance Analysis -- This program performs an analysis similar to the Vehicle/Train Performance Analysis for bus transit service. Energy and power requirements are expressed in different units.

- Vehicle/Train Operations Simulation -- For rail systems of one to ten lines, this program estimates fleet and service parameters (e.g., vehicle-miles), excepting place-miles and place-hours. Inputs may be on an hourly basis, and include results from the Vehicle Train Performance Analysis, plus policy (maximum) headways, minimum headways, vehicle capacity, maximum train consist, maximum load point volumes, train routings, and yard location. Outputs may include up to four reports.

  - The Operating Schedule Output report produces for each route/day-of-week/simulation-year combination the following measures: hourly schedule of trains; cars per train and total operational cars; car load factors; headway; and maximum link passenger-volumes and passenger-miles.

- The Route Operating Summary report includes annual train-hours, train-miles, car-hours, car-miles, and required fleet inventory.
- The Yard Operating Statistics report includes annual car-hours in storage, yard car-miles, yard car-hours, yard train-miles, and yard train-hours.
- The final report is a composite of the Route Operational Summary and the Yard Operating Statistics report.

o Bus Operations Simulation -- This program performs a bus operations simulation similar to the one performed for rail in the Vehicle/Train Operations Simulation.

The use of a package like TRANS-ADE is unnecessary for system planning, but can be useful for project planning and preliminary engineering, especially for complex networks. The programs virtually automate the entire process of service and fleet supply parameter estimation.

B.3 FINANCIAL PLANNING AND ANALYSIS SOFTWARE

Increasing emphasis is being placed in the transit industry on financial planning and management, and relevant software and software applications are being developed--largely on microcomputers--which may have some use for transit supply parameter estimation. Many of these developments entail use of the many electronic spreadsheets and data base management systems currently being marketed. These products offer increased flexibility and efficiency for manipulating data and testing alternative input assumptions.

In addition, some special-purpose software is being developed, such as UBUCKS, a financial forecasting tool for transit operations being developed at Tri-Met (Portland, Oregon). For example, UBUCKS can estimate driver requirements based on an (input) daily profile of service hours.

APPENDIX C. BIBLIOGRAPHY

Allen, Geoffrey A. (ed.), Jane's World Railways, 1982-83, 24th edition, London, England: Jane's Publishing Company Ltd., 1982.

This is part of a series of volumes on different international transportation systems and modes. Listings are provided on manufacturers, international railway associations and agencies, and consultants. Data also are provided on railway systems and on rapid transit and underground railways in the various cities throughout the world.

American Public Transit Association, Transit Operating Report for Calendar/Fiscal Year 1975, Washington, DC, March 1977.

American Public Transit Association, Roster of North American Rapid Transit Cars, 1945-1980, 2nd edition, Washington, DC, July 1980.

This report contains a very complete and detailed description of the heavy rail cars comprising the fleets of North American rapid transit systems, including some vehicles ordered but not yet delivered. Data include cost, performance, dimensions, weights, electrical equipment, heating and ventilation systems, traction motors, propulsion equipment, lighting systems, and trucks and suspensions.

American Public Transit Association, 1983 Operating Report - Volume I: Transit System Revenues and Expenses for Calendar/Fiscal Year 1982, Washington, DC, September 1983.

American Public Transit Association, 1983 Operating Report - Volume II: Transit System Operating Statistics for Calendar/Fiscal Year 1982, Washington, DC, October 1982 (sic).

Anderson, J.E., Transit Systems Theory, Lexington, MA: Lexington Books, 1978.

Bodin, L., et al., "UCOST: A Micro Approach to a Transportation Planning Problem," Urban Analysis, Vol. 5, 1978, pp. 47-69.

Brumberger, N.A., "Bay Area Rapid Transit District, System Performance Study," Oakland, CA: BART, June 1980.

This paper analyzes major technical and safety problems that have prevented BART from achieving its goals for system operations. It discusses recent and proposed remedial actions, and the tradeoffs that must be made among capacity, service consistency, safety, and cost.

Carter, M.M., et al., Transit Corridor Analysis--A Manual Sketch Planning Technique, prepared for the U.S. Department of Transportation, April 1979.

Chomitz, Kenneth and Charles Lave, Labor Work Rules and Transit Operating Costs, (Draft), University of California/Irvine, August 1980.

This report contains a detailed analysis of the impacts on transit operating costs of certain labor work rules, including the use of part-time labor. The report describes the run-cutting process, and discusses operator (driver) requirements and labor costs for various sets of work rules and peak-to-base ratios.

Creighton, R.L., Urban Transportation Planning, Urbana, Illinois: University of Illinois Press, 1970.

DeLeuw, Cather & Co. and Rock Creek Associates, Characteristics of Urban Transportation Systems: A Handbook for Transportation Planners, prepared for the U.S. Department of Transportation, July 1977.

This [CUTS] handbook reports data from a variety of sources which can be used to develop or check supply parameter estimates for rail transit, local bus and bus rapid transit, and highway systems. More specifically, data are reported for each of these modes regarding speed, capacity, operating cost, energy consumption, pollutant emissions, capital costs, and accident frequency. An updated version of CUTS currently is being prepared under UMTA's sponsorship and should be available soon.

Dial, R.B., et al., Transit Network Analysis: INET, prepared for the U.S. Department of Transportation, DOT-OST-78-048, July 1979.

Diamant, E.S., et al., Light Rail Transit: State of the Art Review, prepared for the U.S. Department of Transportation, DOT-UT-50009, 1976.

This report deals exclusively with light rail transit (LRT) technology. It reviews contemporary planning concepts of LRT and describes LRT guideways, stations, hardware, operations, and costs. Drawing upon Western European and North American experience, it presents data and information concerning a group of twelve representative systems.

Howell, J.K., Brief Description of TRANS-ADE Programs, 1975.

Jacobs, Michael, Robert O'Connor, Suzanne Chen, et al., "National Urban Mass Transportation Statistics, 1982 Section 15 Annual Report," prepared by the Transportation Systems Center for the Urban Mass Transportation Administration, November 1983.

This is the fourth and most recent Annual Report derived from the "Section 15" data base. The report summarizes the financial and operating data submitted annually by the nation's public transit operators, pursuant to Section 15 of the Urban Mass Transportation (UMT) Act of 1964, as amended. The report provides aggregate industry statistics as well as statistics for the individual transit systems. Many of these statisics are relevant to transit supply parameter estimation.

Lang, A.S., and Soberman, R.M., Urban Rail Transit: Its Economics and Technology, Cambridge, MA: MIT Press, 1964.

This book is one of the relatively few resources available focusing on urban rail transit. Although some of the data contained in it are out of date, notably the cost data, much of the information is still applicable to current planning. Of particular value to supply parameter estimation are its discussions of vehicle performance and capacity.

N.D. Lea Transportation Research Corporation, Lea Transit Compendium, Multiple Issue Series, including "Light Rail Transit" (No. 5), "Heavy Rail Transit" (No. 6), and "Roadway Transit Vehicles" (No. 9); Vol. II, 1975; and Vol. III, 1976-1977.

A multi-issue series which is designed to be updated periodically, the Lea Transit Compendium reports technical data pertaining to transit equipment and systems. The reports in the series are primarily organized by transit mode, but there also are special issues dealing with other subjects such as "Passenger Admission Processing Systems." For vehicles, the Compendium summarizes their specifications and performance capabilities, and usually presents engineering drawings of the vehicles depicting exterior dimensions and interior layout. For transit systems, it summarizes the demographic characteristics of the urbanized area, as well as service and operating characteristics of the system. Another update has been started, but the 1976-1977 series is the most recent currently available.

Levinson, H.S., et al., Bus Use of Highways: State of the Art, NCHRP Report 143, 1973.

Levinson, H.S., "Bus Transit Capacity," presented at the Transportation Research Board Annual Meeting, Washington, DC, January 1978.

Levinson, H.S., Characteristics of Transportation Demand--A Handbook for Transportation Planners, prepared for the U.S. Department of Transportation, UMTA-IT-06-0049-78-1, April 1978.

Drawing upon a wide variety of sources, this [CUTD] handbook presents data which describe urban travel demands with respect to factors such as travel mode, spatial distribution, temporal distribution, trips per household, trip purpose, and facility loadings. Of particular usefulness to supply parameter estimation are the data for different transit modes which relate observed peak-hour demands to daily demands.

Niagara Frontier Transportation Authority, unpublished comparison of light rail vehicles, May 1979.

O'Neil, R.S., et al., Study of Subway Station Design and Construction, prepared for the U.S. Department of Transportation, DOT-TSC-UMTA-77-9, March 1977.

This document develops a set of seven recommended prototypical subway station designs, selected to be responsive to a range of different geotechnical and urban conditions. These designs are compared with respect to their implications on capital costs, operating costs, and user convenience.

Pushkarev, B.S., and Zupan, J.M., Urban Space for Pedestrians, Cambridge, MA: MIT Press, 1975.

Pushkarev, B.S., and Zupan, J.M., Public Transportation and Land Use Policy, Bloomington, Indiana: Indiana University Press, 1977.

Pushkarev, B.S., and Zupan, J.M., "Urban Rail in America: An Exploration of Criteria for Fixed-Guideway Transit," November 1980.

This report explores the range of travel volumes which may be sufficient to warrant various types of fixed-guideway investments, including rail rapid transit, light rail, and automated downtown people movers. Appendices provide, for existing rail systems, various physical and operating statistics useful for transit supply parameter estimatation.

Quinby, H.D., "Mass Transportation Characteristics," Transportation and Traffic Engineering Handbook, Institute of Traffic Engineers, 1976, pp. 207-257.

"Mass Transportation Characteristics" provides an overview of public transportation system characteristics plus hard-to-find data on operational aspects of transit that are useful in supply parameter estimation. For example, it includes data on seating dimensions and patterns, and information on passenger loading rates. Additionally, it reviews vehicle performance, fare systems, and observed peak period passenger volumes.

Spear, Bruce D. et al., "Service and Methods Demonstrations Program Report," prepared by the Transportation Systems Center for the Urban Mass Transportation Administration, December 1981.

Urban Mass Transportation Administration, "Microcomputers in Transportation, Software and Source Book," September 1983.

Weiers, B., and M. Rossetti, "Transit Bus Manufacturer Profiles," Cambridge, MA: US DOT, Transportation Systems Center, March 1982.

APPENDIX D. TRANSIT AGENCY ABBREVIATIONS

Abbreviation	Area	Metropolitan Operating Agency or Authority
AC Transit	San Francisco-Oakland	Alameda-Contra Costa Transit District
BART	San Francisco-Oakland	San Francisco Bay Area Rapid Transit District
BRRTS	Baltimore	Baltimore Regional Rapid Transit Authority
CTA	Chicago	Chicago Transit Authority
GCRTA	Cleveland	Greater Cleveland Regional Transit Authority
MARTA	Atlanta	Metropolitan Atlanta Rapid Transit Authority
MBTA	Boston	Massachusetts Bay Transportation Authority
MDCTA	Miami	Metropolitan Dade County Transportation Administration
MTA	Baltimore	Maryland Mass Transit Administration
MUCTC	Montreal	Montreal Urban Community Transit Commission
MUNI	San Francisco	San Francisco Municipal Railway
MVRTA	Dayton	Miami Valley Regional Transit Authority
NOPS	New Orleans	New Orleans Public Service
NJTC	New Jersey	New Jersey Transit Corporation
NYCTA	New York	New York City Transit Authority
PAT	Pittsburgh	Port Authority of Allegheny County
PATCO	Philadelphia	Port Authority Transit Corporation of Pennsylvania and New Jersey
PATH	New York-NE N.J.	Port Authority Trans-Hudson Corporation
SEMTA	Detroit	Southeastern Michigan Transportation Authority
SEPTA	Philadelphia	Southeastern Pennsylvania Transportation Authority
SIRT	New York	Staten Island Rapid Transit Operating Authority
TNJ	New York-NE N.J.	Transport of New Jersey
Tri-Met	Portland, OR	Tri-County Metropolitan Transportation District of Oregon
TTC	Toronto	Toronto Transit Commission
WMATA	Washington	Washington Metropolitan Area Transit Authority

APPENDIX E. SAMPLE CALCULATIONS FOR CHAPTER 2 SENSITIVITY EXAMPLE

This appendix presents sample calculations to illustrate how the baseline results of the Chapter 2 sensitivity example were developed. Those results are summarized by Table 2.

E.1 BASELINE INPUT ASSUMPTIONS AND PROCEDURES

Described below are the specific baseline assumptions and procedures upon which the example is predicated.

E.1(a) Definition of Alternative

- 10-mile rail line with 7 stations.
- Average station spacing: 1.67 miles.
- Vehicle characteristics:
  - 630 gross square feet per car;
  - maximum train consist of 3 cars;
  - loading standard of 5.4 square feet per passenger;
  - cruise speed of 60 mph;
  - service acceleration and deceleration of 3.0 mph per second.
- Policy headways:
  - 5 minutes during 4 peak hours;
  - 10 minutes during 12 off-peak hours.
- Weekend and holiday service levels which yield a supply annualization factor of 310.
- Station dwell time of 40 seconds.
- Minimum headway: 2.5 minutes.

E.1(b) Demand Levels

- Maximum load point volume: 32,000 daily riders (two ways).
- Peak-hour maximum load point volume in peak direction: 4,800 riders (15 percent of total daily ridership).
- Off-peak maximum hourly peak-load point volume in peak direction: 1,200 riders (3.75 percent of total daily ridership).

E.1(c) Supply Parameter Estimation Procedures

- Average speed estimated using formula that is applicable when there is sufficient station spacing to reach cruise speed (Creighton, 1970).

$$V = \frac{D}{T + D/C + C(1/2a + 1/2d)}$$

where: V = average transit vehicle velocity or speed;
D = average distance or spacing between stations;
T = stop (dwell) time at stations or stops;
C = cruising speed;
a = rate of acceleration;
d = rate of deceleration.

- Train-hours minimized (headways maximized) subject to policy headway and demand constraints.

- Adequate capacity provided in 12 off-peak hours to meet peak-load point, peak-direction demand (1,200 riders per hour).

- Adequate capacity provided in 4 peak hours to meet peak-load point, peak-direction demand (4,800 riders per hour).

- Vehicle requirements rounded upward and headways recalculated.

- Example assumes no schedule recovery time and no turnaround time at terminal stations in excess of normal dwell time.

E.2 CALCULATION OF AVERAGE SPEED AND ROUND TRIP TIME

Use formula above with following inputs:

D = 10/6 = 1.67
C = 60 mph = 1 mpm [miles per minute]
a = 3 mph/second = 3 mpm/minute
d = 3 mph/second = 3 mpm/minute
T = 40 seconds = 0.67 minute

$$V = \frac{D}{T + D/C + C(1/2a + 1/2d)}$$

$$= \frac{1.67 \text{ mi}}{0.67 \text{ min} + \frac{1.67 \text{ mi}}{1 \text{ mpm}} + 1 \text{ mpm}\left(\frac{1}{2(3 \text{ mpm/min})} + \frac{1}{2(3 \text{ mpm/min})}\right)}$$

$$= \frac{1.67 \text{ mi}}{0.67 \text{ min} + 1.67 \text{ min} + 0.33 \text{ min}}$$

= 1.67 miles/2.67 minutes

V = 0.625 mpm = 37.5 mph

Round trip travel time = 20 miles/0.625 mpm = 32 minutes = 0.533 hour.

E.3 CAR/TRAIN CAPACITY

Car capacity	= 630 gross sq. ft./5.4 sq. ft. per passenger = 117 passengers/car
Maximum train capacity	= (3 cars/train)(117 passengers/car) = 351 passengers/train

E.4 PEAK-PERIOD CALCULATIONS

Required demand headway at maximum consist	= (60 min/hour)(maximum train capacity)/ maximum load point volume per hour = 60(351)/480 = 4.39 minutes

Since the demand headway (4.39 minutes) is less than the policy headway (5 minutes), the demand headway governs with the maximum train consist.

Trains required	= total round trip travel time/headway = 32 minutes/4.39 minutes = 7.29 (Use 8 trains)

Recalculate minimum headway for 8 trains:

Final headway	= total round trip travel time/trains required = 32 minutes/8 = 4 minutes (60/4 = 15 trains/hour)
Daily peak-period train hours	= (hours in peak period)(trains/hour)(round trip travel time) = 4 hours(15 trips/hour)(0.533 hour/round trip) = 32.0
Daily peak-period car-hours	= (cars/train)(train-hours) = (3 cars/train)(32 train-hours) = 96
Daily peak-period car-miles	= (hours in peak period)(trains/hour) = round trip distance)(cars/train) = (4 hours)(15 trains/hour)(20 miles)(3 cars/train) = 3600

Peak-period car requirement = (trains required)(cars/train)
= (8 trains)(3 cars/train)
= 24

Excess passenger capacity (hourly in peak direction at maximum load point) = passenger capacity - (maximum load point volume)
= (15 trains)(351 places/train) - 4800
= 5265 - 4800
= 465 passenger places

E.5 OFF-PEAK CALCULATIONS

Required demand headway at maximum consist = (60 minutes/hour)(maximum train capacity)/maximum load point volume per hour
= 60(351)/1200
= 19.1 minutes

Since policy headway (10 minutes) is less than demand headway (19.1 minutes), the policy headway governs. Try shorter train.

Required demand headway for 2-car trains = 60(2)(117)/1200
= 11.7 minutes

2-car train is sufficient, since it will provide excess capacity at policy headway of ten minutes. Try single car train.

Required demand headway for 1-car trains = 60(1)(117)/1200 = 5.85 minutes

To minimize train-hours, reject single-car train and use 2-car train at policy headway.

Trains required = total round trip travel time/headway
= 32 minutes/10 minutes
= 3.2 trains (Use 4 trains)

Calculate final service headway:

Final headway = total round trip travel time/trains required
= 32 minutes/4
= 8 minutes (60/8 = 7.5 trains/hour)

Daily off-peak train-hours = (12 hours)(7.5 trains/hour)(0.533 hour/trip
= 48.0

Daily off-peak car-hours	= (2 cars/train)(48.0 train-hours)
	= 96.0
Daily off-peak car-miles	= (12 hours)(7.5 trains/hour)(20 miles)(2 cars/train)
	= 3600
Off-peak car requirements	= 4 trains(2 cars/train)
	= 8
Excess passenger capacity (hourly in peak direction at maximum load point)	= (passenger capacity) - (maximum load point volume)
	= (7.5 trains)(234 places/train) - 1200
	= 1755 - 1200
	= 555

E.6 DAILY AND ANNUAL SUPPLY PARAMETERS

Daily train-hours	= peak train-hours + off-peak train hours
	= 32.0 + 48.0
	= 80.0
Annual train-hours	= annualization factor(daily train-hours)
	= 310(80.0)
	= 24,800
Daily car-hours	= peak car-hours + off-peak car-hours
	= 96 + 96
	= 192
Annual car-hours	= annualization factor(daily car-hours)
	= 310(192)
	= 59,520
Daily car-miles	= peak car-miles + off-peak car-miles
	= 3600 + 3600
	= 7200
Annual car-miles	= annualization factor(daily car-miles)
	= 310(7200)
	= 2,232,000

APPENDIX F. SELECTED TRANSIT SYSTEM AND VEHICLE CHARACTERISTICS

This appendix contains selected performance, capacity, and other information on rail rapid ("heavy rail"), light rail, and bus transit systems and vehicles. Emphasis is on North American systems and equipment, although data on selected European vehicles also are included where insufficient American data are available and/or where foreign designs and/or manufacturers seem likely to capture significant shares of the American market.

Care should be taken in using these data. Sources include the American Public Transit Association's (APTA's) Roster of North American Rapid Transit Cars, 1945-1980 (for heavy rail vehicles), and (for all other tables) the multi-volume Lea Transit Compendium series prepared by N.D. Lea Transportation Research Corporation (LTRC). In turn, the data in these documents are derived from a large variety of sources and methods, such as: manufacturers' claims; published reports or articles; independent unpublished technical studies; private correspondence from developers, manufacturers, and suppliers; observations and estimates made by LTRC staff, etc.

Thus, while these are detailed, carefully prepared documents, such large quantities of data, derived from such a large variety of primary sources, are most unlikely to be completely consistent or error-free. For example, estimates of design and crush capacities require that estimates be made of the specific seating configuration and the amount of usable interior space available for standees, and that standards for average space per standee be selected. These assumptions generally are not all stated explicitly, and they generally will differ with the specific organization and individual preparing a given estimate. Such data, therefore, should be viewed as approximate rather than as precise.

Table F-1. SELECTED HEAVY RAIL TRANSIT SYSTEM CHARACTERISTICS

	Atlanta	Baltimore	Boston	Chicago	Cleveland
Operator	MARTA	MTA	MBTA	CTA	GCRTA
Year system inaugurated	1978	1982	1908	1893	1955
No. of lines	4+3 branch (planned)	2 (planned)	3	6	1
No. of stations:					
At-grade	19	3	15	35	3
Below grade	13	9	20	20	9
Above grade	7	9	7	87	6
Average station spacing, mi(km)	1.5 (2.4)	1.4 (2.3)	0.7 (1.1)	0.63 (1.02)	1.0 (1.6)
Typical platform:					
Length, ft(m)	600 (183)	450 (137)	187-343 (57-105)	420 (128)	300 (91)
Width, ft(m)	10 (3.0)	22 (6.7)	na	16 (4.9)	13.2 (4.0)
Cruise speed, mi/hr(km/hr)	up to 70 (113)	40-75 (64-120)	38-50 (61-80)	45-55 (72-89)	up to 55 (89)
Operators per train	1	1	2 or 3	2	2; 1 for single car
Cars per train:					
Peak	8	up to 6	2 or 4	6 or 8	3-6
Off-peak	1	2 or more	2 or 4	1 or 2	1
Trains per hour:					
Peak	10-18	15	24-30	13-21	17
Off-peak	6	12	na	4-17	10
Maximum hourly one-way line capacity:					
No. of cars	144	90	120	168	102
Passengers/car*	140	166	na	100	120
No. of passengers	20160	14940	na	16800	12240

*Maximum design capacity (seated plus standees); from Table F-4.
na = data not available.

(Continued on next page).

Table F-1. (Continued).

	Montreal	N.Y./N.J.	San Francisco	Toronto	Washington
Operator	MUCTC	PATH	BART	TTC	WMATA
Year system inaugurated	1966	1908	1972	1954	1975
No. of lines	3	4	4	2	5 (planned)
No. of stations:					
At-grade	0	3	8	0	28
Below grade	26	10	14	43	53
Above grade	0	0	12	6	5
Average station spacing, mi(km)	0.55 (0.89)	1.2 (1.9)	2.2 (3.5)	0.55 (0.89)	1.14 (1.83)
Typical platform:		(center)		(side/cntr)	
Length, ft(m)	500 (152)	350-525 (107-160)	700 (213)	500 (152)	600 (182)
Width, ft(m)	14 (4.3)	na	26-36 (8-11)	12 (3.7)	13.5/30 (4.1/9.1)
Schedule or cruise speed, mi/hr(km/hr)	30-45 (48-72) (sched.)	to 55(89) avg 21(34) (sched.)	25-80 (40-129) (sched.)	19-23 (31-37) (sched.)	to 75(120) avg 35(56) (cruise)
Operators per train	1	2	1	2	1
Cars per train:					
Peak	6-9	4-7	5-10	6-8	4-8
Off-peak	3-9	3-4	2-4	4-6	2-4
Trains per hour:					
Peak	13-26	14-27	5-10	20-30	15-30
Off-peak	10-11	4	5-10	12-13	6-12
Maximum hourly one-way line capacity:					
No. of cars	234	189	100	240	240
Passengers/car*	158	165	120	235	187
No. of passengers	36972	31185	12000	56400	44880

*Maximum design capacity (seated plus standees); from Table F-4.
na = data not available.

Source: Compiled from N.D. Lea Transportation Research Corporation (1975, 1976-1977).

Table F-2. SELECTED NORTH AMERICAN HEAVY RAIL VEHICLES

Operator	Car Nos.	Type*	Length over Couplers, ft-in	Maximum Width ft-in	Manufacturer**	Year Purchased	Year Placed in Service	Bid Price (x $1000)
MARTA	101-200	mp	75-0	10-6	SFB	1976	1979	563.0
	501-520	su	75-4	"	"	"	"	(avg)
MTA	100-171	mp	75-0	10-3	Budd Co.	1979	c.1982	616.1
MBTA	1600-1651	mp	69-10	10-0	Pull-Std	1968	1969,70	161.1
	1500-1523	su	"	"	"	"	"	175.3
	0600-0669	mp	48-10	9-3	Hawk-Sid	1976	1979	446.9***
	1200-1319	mp	65-4	9-3	Hawk-Sid	1976	1980,81	459.5***
CTA	2201-2350	mp	48-3	9-4	Budd Co.	1967	1969,70	125.0
	2401-2600	mp	48-3	9-4	Boeing-V	1974	1976-78	300.0
	2601-2900	mp	48-3	9-4	Budd Co.	1978	not yet	444.3
GCRTA	171-180	su	70-3	10-5	Pull-Std	1970	1970	252.0
MUCTC	79/501-782	mc	56-5	8-3	Bombardr	1973	1976	334.0
	78/001-141	tc	53-11	"	"	"	"	199.2
NYCTA	R-42	mp	60-6	10-0	St.L.Car	1968	1969,70	130.8
	R-44	4-c	75-0	10-0	St.L.Car	1970	1972-74	206.6
	R-44/SIRT	4-c	75-0	10-0	St.L.Car	1970	1973	215.0
	R-46	4-c	75-0	10-0	Pull-Std	1972	1975-77	275.4
PATH	PA2/710-723	mc	51-3	9-3	St.L.Car	1966	1967	128.9
	PA2/152-181	tc	"	"	"	"	"	116.9
	PA3/724-769	mc	51-3	9-3	Hawk-Sid	1970	1972	182.0
SEPTA	701-929	mp	55-4	9-1	Budd Co.	1959	1960,61	88.9
	601-646	su	"	"	"	"	"	97.6
PATCO	201-250	mp	67-10	10-2	Budd Co.	1966	1969	178.0
	101-125	su	"	"	"	"	"	191.0
	251-296	mp	67-10	10-2	Vickers	1977	1980	800.0
BART	501-774	mp	70-0	10-6	Rohr	1969-73	1972-75	266.8-
	101-276	su	75-5	"	"	"	"	390.0
TTC	H2/5506-5575	mp	74-9	10-4	Hawk-Sid	1970	1971,72	154.6
	H4/5576-5663	mp	74-9	10-4	Hawk-Sid	1973	1974,75	226.3
	H5/5670-5807	mp	74-9	10-4	Hawk-Sid	1975	1977-80	389.2
WMATA	1000-1299	mp	75-0	10-2	Rohr	1972	1976	298.0
	2000-2093	mp	75-0	10-2	Breda	1979	1981	740.1-791.9

(Continued on next page).

Table F-2. (Continued).

Footnotes

*Vehicle type codes:
mp = married pair;
su = single unit;
mc = motor car;
tc = trailer car (run as 3-car unit, mc-tc-mc, in Montreal);
4-c = 4-car unit.

**Manufacturer codes:
SFB = Societe Franco-Belge de Materiel de Chemins de Fer;
Budd Co. = Budd Company;
Pull-Std = Pullman Standard;
Hawk-Sid = Hawker-Siddeley Canada, Ltd.;
Boeing-V = Boeing Vertol;
Bombardr = Bombardier, Ltd.;
St.L.Car = St. Louis Car Company;
Vickers = Vickers Canada;
Rohr = Rohr Industries;
Breda = Breda Costruzioni Ferroviarie.

***excluding escalation.

Source: Compiled from American Public Transit Association (1980).

Table F-3. HEAVY RAIL VEHICLE PERFORMANCE CHARACTERISTICS

Operator	Car Nos.	Minimum Horiz. Turn Radius, feet	Track Gauge, ft-in	Maximum Operating Speed, mph	Maximum Service Acceleration, mph/sec	Maximum Service Deceleration, mph/sec	Emergency Deceleration, mph/sec
MARTA	101-200	350	4-8.5	75	3.0	3.0	3.5
	501-520	"	"	"	"	"	"
MTA	100-171	250	4-8.25	70	3.0	3.0	3.2
MBTA	1600-1651	125	4-8.5	70	2.5	2.75	3.25
	1500-1523	"	"	"	"	"	"
	0600-0669	75	4-8.5	49	2.5	2.75	3.25
	1200-1319	120	4-8.5	65	2.5	2.75	3.25
CTA	2201-2350	85	4-8.5	55	3.2	3.2	6.5
	2401-2600	85	4-8.5	55	3.2	3.2	6.5
	2601-2900	90	4-8.5	55	3.2	3.2	6.5
GCRTA	171-180	120	4-8.5	55	2.75	3.0	3.5
MUCTC	79/501-782	90	4-8.5	50	3.0	2.0	3.8
	78/001-141	"	"	"	"	"	"
NYCTA	R-42	125	4-8.5	45	2.5	3.0	3.0
	R-44	145	4-8.5	45	2.5	3.0	3.0
	R-44/SIRT	145	4-8.5	45	2.5	3.0	3.0
	R-46	145	4-8.5	45	2.5	3.0	3.0
PATH	PA2/710-723	90	4-8.5	55	2.5	3.0	3.0
	PA2/152-181	"	"	"	"	"	"
	PA3/724-769	80	4-8.5	55	2.5	3.0	3.0
SEPTA	701-929	140	5-2.25	55	3.0	2.75	2.75
	601-646	"	"	"	"	"	"
PATCO	201-250	125	4-8.5	75	3.0	3.0	>3.0
	101-125	"	"	"	"	"	"
	251-296	125	4-8.5	75	3.0	3.0	>3.0
BART	501-774	400	5-6.0	80	3.0	3.0	3.0
	101-276	"	"	"	"	"	"
TTC	H2/5506-5575	230	4-10.875	55	2.5	2.8	3.0
	H4/5576-5663	230	4-10.875	55	2.5	2.8	3.0
	H5/5670-5807	230	4-10.875	55	2.5	2.8	3.0
WMATA	1000-1299	225	4-8.25	75	3.0	3.0	3.2
	2000-2093	225	4-8.25	75	3.0	3.0	3.2

Source: Compiled from American Public Transit Association (1980).

Table F-4. SELECTED HEAVY RAIL VEHICLE PASSENGER CAPACITIES

Operator	Car Nos.	Gross Area, sq ft	Number of Seats	Estimated or Reported Standees ("A"car;"B"car) Design	Crush	Avg.Gross Sq. Ft. Per Passenger ("A";"B"car) Design	Crush	Percent Seated @ Capacity Design	Crush
MARTA	101-200	788	68	72	182	5.63	3.15	49	27
	501-520	791	62	78	173	5.65	3.37	44	26
MTA	100-171	769	76	90	199	4.63	2.80	46	28
MBTA	1600-1651	698	64	na	205	na	2.59	na	24
	1500-1523	"	60	na	198	na	2.71	na	23
	0600-0669	452	42	na	113	na	2.92	na	27
	1200-1319	604	58	na	162	na	2.75	na	26
CTA	2201-2350	450	47;51	53;49	103;99	4.50	3.00	49	33
	2401-2600	450	45;49	55;51	105;101	4.50	3.00	47	31
	2601-2900	450	43;49	57;51	107;101	4.50	3.00	46	31
GCRTA	171-180	732	80	40	100	6.10	4.07	67	44
MUCTC	79/501-782	465	40	118	169	2.94	2.22	25	19
	78/001-141	445	40	118	169	2.84	2.13	25	19
NYCTA	R-42	605	46	174	254	2.75	2.02	21	15
	R-44	750	72;76	200;204	278;274	2.8;2.7	2.14	27	21
	R-44/SIRT	750	72;76	200;204	278;274	2.8;2.7	2.14	27	21
	R-46	750	70;76	202;204	280;274	2.8;2.7	2.14	26	21
PATH	PA2/710-723	474	41	99	156	3.39	2.41	29	21
	PA2/152-181	"	42	98	156	3.39	2.39	30	21
	PA3/724-769	474	35	130	187	2.87	2.14	21	16
SEPTA	701-929	503	56	59	146	4.37	2.49	49	28
	601-646	"	54	61	146	4.37	2.52	47	27
PATCO	201-250	690	80	20	120	6.90	3.45	80	40
	101-125	"	72	18	118	7.67	3.63	80	38
	251-296	690	80	20	120	6.90	3.45	80	40
BART	501-774	750	72	48	144	6.25	3.47	60	33
	101-276	792	72	48	144	6.60	3.67	60	33
TTC	H2/5506-5575	772	83	147	226	3.36	2.50	36	27
	H2/5576-5663	772	77	158	242	3.29	2.42	33	24
	H3/5670-5807	772	76	159	242	3.29	2.43	32	24
WMATA	1000-1299	762	80	95	140	4.35	3.46	46	36
	2000-2093	762	68	119	164	4.07	3.28	36	29

Source: Compiled from American Public Transit Association (1980).

Table F-5. SELECTED LIGHT RAIL TRANSIT SYSTEM CHARACTERISTICS

	Newark	New Orleans	Phila-delphia	Phila-delphia
Operator	TNJ	NOPS	SEPTA/City Division	SEPTA/Red Arrow Div.
Year system inaugurated	1935	1833	1831	1907
Number of lines	1	1	12	3
Length of single track, mi(km):	9.1 (14.6)	13.1 (21.2)	142.9 (230.1)	101.2 (162.9)
In street, mixed traffic	0	na	130.7 (210.4)	3.2 (5.2)
In street, separated	0	(most)	6.4 (10.3)	0
Exclusive right-of-way	9.1 (14.6)	na	5.8 (9.4)	98.0 (157.7)
Length of lines, one-way, mi(km):	4.2 (6.7)	6.6 (10.6)	82.0 (131.9)	54.6 (87.9)
At-grade	2.9 (4.7)	6.6 (10.6)	69.0 (111.)	54.6 (87.9)
Below grade	1.3 (2.0)	0	13.0 (20.9)	0
Number of stations:	11	104	na	72
Full platform	11	0	na	na
Simple platform	0	0	na	na
On-street	0	104	na	na
Average station spacing, mi(km)	0.38 (0.61)	0.15 (0.24)	na	0.76 (1.22)
Platform length, ft(m)	160.0 (48.8)	none	200.0 (61.0)	na
Platform width, ft(m)	13.0 (4.0)	none	12.0 (3.7)	na
Speed, mi/hr(km/hr)	22-50 (35-81) (cruise)	3-27 (5-44) (cruise)	5-35;10 avg (8-56;16 avg) (schedule)	na
Cars/train--peak	1	1	1	1 or more
Cars/train--off-peak	1	1	1	1
One-way trains/hr/line:				
Peak	8	25	20 avg.	12 or more
Off-peak	3	20	15 avg.	2-4

na = data not available.

(Continued on next page).

Table F-5. (Continued).

	Pittsburgh	San Francisco	Shaker Heights, OH	Toronto
Operator	PAT	MUNI (Pre-Metro)	City DOT	TTC
Year system inaugurated	na	1976	1920	1892
Number of lines	5	5	2(branches)	11
Length of single track, mi(km):	69.2 (112.)	45.4 (73.1)	26.1 (42.0)	120. (193.)
In street, mixed traffic	na	29.3 (47.2)	14.3 (23.1)	116. (187.)
In street, separated	na	2.3 (3.7)	0	4.0 (6.4)
Exclusive right-of-way	1.5 (2.4)	13.8 (22.2)	11.8 (18.9)	0
Length of lines, one-way, mi(km)	24.9 (40.0)	36.1 (58.1)	13.1 (21.3)	68.5 (110.)
At-grade	24.1 (38.8)	30.0 (48.3)	7.2 (11.5)	68.5 (110.)
Below grade	0.8 (1.2)	6.1 (9.8)	5.9 (9.8)	0
Number of stations:	na	na	29	805
Full platform	na	9	0	0
Simple platform	na	na	29	50
On-street	na	na	0	755
Average station spacing, mi(km)	na	0.33-2.00 (0.53-3.22)	0.33-1.00 (0.53-1.6)	0.167 (0.268)
Platform length, ft(m)	na	300-450 (91-137)	200 (61)	na
Platform width, ft(m)	na	8.0-10.0 (2.4-3.1)	5.0 (1.5)	na
Speed, mi/hr(km/hr)	11 avg (18 avg) (schedule)	up to 50 (up to 81) (cruise)	20-45 (32-72) (cruise)	20-40;10 avg (32-64;16) (cruise;sched)
Cars/train--peak	1	3-4	2 avg	1-2
Cars/train--off-peak	1	1-4	1	1
One-way trains/hr/line:				
Peak	16 avg	15	45	9-45
Off-peak	3 avg	6-15	5	6-15

na = data not available.

Source: Compiled from N.D. Lea Transp. Research Corp. (1975, 1976-1977).

Table F-6. SELECTED NORTH AMERICAN AND EUROPEAN LIGHT RAIL VEHICLES

Manufact'r*	Articulation	Number of Axles	Direction	City(ies)	Approx. Deliv. Dates	Vehicle Length, ft(m)	Vehicle Width, ft(m)
Pulm;St.L. [PCC Car]	none	4	single & dual	various, US,Canada	1936-mid-50s	47.0 (14.33)	8.33 (2.54)
UTDC et al.	none	4	single	Toronto, Canada	1977-79 (sched)	50.67 (15.44)	8.33 (2.54)
BN	none	4	dual	Ghent, Belgium	?-1974	46.59 (14.20)	7.22 (2.20)
BN	none	4	dual	Marseille, France	1969	46.58 (14.20)	6.63 (2.02)
MAN-powered -trailer	none none	4 4	single single	Nurnberg, W.Germany	1955-?	46.26 (14.10)	7.68 (2.34)
Wegmann	single	4	single	Bremen, W.Germany	1971-?	54.78 (16.70)	7.55 (2.30)
Boeing-V	single	6	dual	Boston,San Fran., US	1976-?	71.0 (21.64)	8.86 (2.70)
Metro-Cam	single	6	dual	Newcastle, England	1977-79 (sched)	91.20 (27.80)	8.69 (2.65)
BN	single	6	single & dual	Brussels, Belgium	1973	68.57 (20.90)	7.22 (2.20)
DuWAG	single	6	dual	Hannover, W.Germany	1961-?	63.97 (19.50)	8.20 (2.50)
MAN	single	6	single	Nurnberg, W.Germany	1962-66	65.95 (20.10)	7.68 (2.34)
MAN et al.	dual	8	single	Augsberg, W.Germany	1976-?	83.16 (25.35)	7.22 (2.20)
DuWAG	dual	8	dual	Hannover, W.Germany	1974-77	88.58 (27.00)	7.88 (2.40)
DuWAG	dual	8	dual	Frankfort, W.Germany	1972-74	90.00 (27.43)	7.71 (2.35)
BN	dual	8	dual	Brussels, Belgium	1977-?	90.54 (27.60)	7.22 (2.20)

(Continued on next page).

Table F-6. (Continued).

Footnotes

*Manufacturer codes:
- Pulm = Pullman-Standard Car Manufacturing;
- St.L. = St. Louis Car Division, General Steel Industries;
- UTDC = Urban Transportation Development Corporation;
- BN = S.A. La Brugeoise et Nivelles;
- MAN = Maschinenfabrik Augsburg-Nurnberg Aktiengesellschaft;
- Wegmann = Waggonfabrik Wegmann & Co.;
- Boeing-V = Boeing Vertol Company;
- Metro-Cam = Metro-Cammell Limited;
- DuWAG = Waggonfabrik Uerdingen A.G.

na = data not available.

Source: Compiled from N.D. Lea Transportation Research Corporation (1975, 1976-1977).

Table F-7. LIGHT RAIL VEHICLE PERFORMANCE CHARACTERISTICS

Vehicle Description (See Table F-6)	Maximum Operating Speed, mph(kph)	Service Acceleration, fps/s (mps/s)	Service Deceleration, fps/s (mps/s)	Emergency Decel. fps/s (mps/s)	Maximum Jerk, ft/s^3 (m/s^3)
PCC Car/non-artic	40 (64)	4.6 (1.4)	4.6 (1.4)	9.5 (2.9)	7.0 (2.2)
UTDC/Toronto non-artic	50-70 (80-113)	4.8 (1.5)	5.1 (1.6)	10.3 (3.1)	3.7* (1.1)
BN/Ghent non-artic	40 (65)	6.2 (1.9)	4.8 (1.4)	9.8 (3.0)	3.3 (1.0)
BN/Marseille non-artic	40 (65)	6.2 (1.9)	4.8 (1.4)	9.8 (3.0)	3.3 (1.0)
MAN/Nurnberg non-artic	37 (60)	2.6 (0.8)	4.3 (1.3)	9.8 (3.0)	na
Wegmann/Bremen artic	44 (70)	2.9 (0.9)	3.3 (1.0)	na	na
Boeing/US std artic LRV	50 (80)	4.6 (1.4)	5.1 (1.6)	8.8 (2.7)	3.7 (1.1)
Met-Cam/Newcastle artic	50 (80)	3.3 (1.0)	4.3 (1.3)	7.6 (2.3)	na
BN/Brussels artic	40 (65)	6.2 (1.9)	5.2 (1.6)	9.8 (3.0)	3.3 (1.0)
DuWAG/Hannover artic	50 (80)	3.9 (1.2)	3.9 (1.2)	9.8 (3.0)	na
MAN/Nurnberg artic	37 (60)	2.6 (0.8)	3.3 (1.0)	9.8 (3.0)	na
MAN/Augsberg dual-artic	44 (70)	3.3 (1.0)	3.3 (1.0)	9.2 (2.8)	na
DuWAG/Hannover dual-artic	49 (80)	3.6 (1.1)	5.2 (1.6)	9.8 (3.0)	na
DuWAG/Frankfort dual-artic	44 (70)	3.3 (1.0)	3.9 (1.2)	9.8 (3.0)	na
BN/Brussels dual-artic	40 (65)	6.2 (1.9)	5.2 (1.6)	9.8 (3.0)	3.3 (1.0)

*Emergency jerk: 8.8 fps/s/s (2.7 mps/s/s). (Continued on next page).

Table F-7. (Continued).

Vehicle Description (See Table F-6)	Track Gauge, ft(m)	Maximum Grade (percent)	Minimum Horiz. Turn Radius ft(m)		Minimum Vertical Turn Radius, ft (m) [crest;dip]	
			Single Veh.	Coupled Vehs.	Single Vehicle	Coupled Vehicles
PCC Car/non-artic	4.708 (1.435)	6.5	varies		varies	
UTDC/Toronto non-artic	4.906 (1.495)	8	30 (9)	36 (11)	122;800 (37;244)	122;800 (37;244)
BN/Ghent non-artic	3.281 (1.000)	6	56 (17)	na	984 (300)	na
BN/Marseille non-artic	4.708 (1.435)	6	66 (20)	na	1312 (400)	na
MAN/Nurnberg non-artic	4.708 (1.435)	7	59 (18)	59 (18)	1640 (500)	1640 (500)
Wegmann/Bremen non-artic	4.708 (1.435)	na	53 (16)	53 (16)	1640 (500)	1640 (500)
Boeing/US std artic LRV	4.708 (1.435)	9	42 (10)	42 (10)	310;460 (94;140)	310;460 (94;140)
Met-Cam/Newcastle artic	4.708 (1.435)	na	492 (150)	492 (150)	na	na
BN/Brussels artic	4.708 (1.435)	6.5	48 (15)	na	984 (300)	na
DuWAG/Hannover artic	4.708 (1.435)	5	59 (18)	59 (18)	492 (150)	820 (250)
MAN/Nurnberg artic	4.708 (1.435)	7	59 (18)	59 (18)	1640 (500)	1640 (500)
MAN/Augsberg dual-artic	3.281 (1.000)	10.4	69 (21)	69 (21)	1641 (500)	1641 (500)
DuWAG/Hannover dual-artic	4.708 (1.435)	5	59 (18)	59 (18)	492 (150)	820 (250)
DuWAG/Frankfort dual-artic	4.708 (1.435)	4.4	56 (17)	56 (17)	820 (250)	820 (250)
BN/Brussels dual-artic	4.708 (1.435)	6.5-8	48 (15)	na	984 (300)	na

Source: Compiled from N.D. Lea Transp. Research Corporation (1975, 1976-1977).

Table F-8. SELECTED LIGHT RAIL VEHICLE PASSENGER CAPACITIES

Vehicle Description (See Table F-6)	Area, sq ft (sq m)	Gross No. of Seats	Number of Standees		Avg. Gross Sq Ft (Sq M) Per Passnger		Percent Seated @ Capacity	
			Design	Crush	Design	Crush	sign	Crush
PCC Car/non-artic [MBTA]	391.5 (36.4)	49	69	na	3.32 (0.31)	na	42	na
UTDC/Toronto non-artc	422.1 (39.2)	51 (max)	≤90	na	2.99 (0.28)	na	36	na
BN/Ghent non-artic	336.4 (31.2)	34	69	80	3.27 (0.30)	2.95 (0.27)	33	30
BN/Marseille non-artic	308.8 (26.7)	16	71	81	3.55 (0.33)	3.18 (0.30)	18	16
MAN/Nurnberg non-artic (powered unit)	355.3 (33.0)	29	100	na	2.75 (0.26)	na	21	na
Wegmann/Bremen artic	413.6 (38.4)	48	101	118	2.78 (0.26)	2.49 (0.23)	32	29
Boeing/US std artic LRV {San Fran},[Boston]	629.1 (58.4)	{68} [52]	{151} [167]	na	2.87 (0.27)	na	{31} [24]	na
Met-Cam/Newcastle artic	792.5 (73.7)	84	188	246	2.91 (0.27)	2.40 (0.22)	31	25
BN/Brussels artic	495.1 (46.0)	43 (max)	115	138	3.13 (0.29)	2.74 (0.25)	27	24
DuWAG/Hannover artic	524.6 (48.8)	44	134	160	2.95 (0.27)	2.57 (0.24)	25	22
MAN/Nurnberg artic	506.5 (47.0)	41	145	227	2.72 (0.25)	1.89 (0.18)	22	15
MAN/Augsberg dual-artic	600.4 (55.8)	61	87	174	4.06 (0.38)	2.55 (0.24)	41	26
DuWAG/Han'ver dual-artic	698.0 (64.8)	46	104	208	4.65 (0.43)	2.75 (0.26)	31	18
DuWAG/F'kfort dual-artic	693.9 (64.5)	62	108	216	4.08 (0.40)	2.50 (0.23)	36	22
BN/Brussels dual-artic	653.7 (60.7)	48	110	128	4.14 (0.38)	3.71 (0.35)	30	27

Source: Compiled from N.D. Lea Transportation Research Corporation (1975, 1976-1977).

Table F-9. SELECTED SMALL AND MEDIUM-SIZE BUS CHARACTERISTICS

Mfger*	Model or Type	Length, ft(m)	Width, ft(m)	Weight, x1,000 lb (x1,000 kg) Empty	Weight, x1,000 lb (x1,000 kg) Gross	Maximum Velocity mph (kph)	Type of Fuel
Wayne	Transette	17.5 (5.33)	7.85 (2.39)	na	10.0 (4.5)	55 (88.5)	gasoline
Steyr; Ep-Bux	city bus	19.1 (5.80)	6.66 (2.03)	5.3 (2.4)	9.7 (4.4)	43.5 70	diesel
M-Benz	0 309 D	19.68 (6.00)	6.95 (2.12)	7.7 (3.5)	11.0 (5.0)	58 (93)	diesel
W'bago	Series 19	22.25 (6.78)	7.25 (2.21)	8.1 (3.7)	11.7 (5.3)	na	gasoline
ARGOSY	CB 24	24.0 (7.32)	8.0 (2.44)	8.4 (3.8)	12.5 (5.7)	70 (113)	gasoline
		"	"	9.2 (4.2)	14.0 (6.3)	"	diesel
Chance	RT-50	25.17 (7.67)	8.00 (2.44)	13.5 (6.1)	20.0 (9.1)	55 (88.5)	diesel
TwCoach	TC-HD-31-C	28.2 (8.60)	8.0 (2.44)	12.4 (5.6)	19.9 (9.0)	60 (97)	gasoline
		"	"	13.2 (6.0)	20.7 (9.4)	"	diesel
Flxible	31-foot	30.88 (9.41)	8.0 (2.44)	20.7 (9.4)	31.5 (14.3)	varies	diesel

(Continued on next page).

Table F-9. (Continued).

Mfger*	Model or Type	Minimum Turning Radius, ft(m)	Gross Area, sq ft (sq m)	Number of Seats	Number of Standees: Design	Number of Standees: Crush	@ Design Cap: Gross Sq Ft (Sq M) /Psngr	@ Design Cap: Per-cent, Seated
Wayne	Transette	50.5 (15.4)	137.4 (12.7)	17	0	5	8.08 (0.75)	100
Steyr; Ep-Bux	city bus	45.0 (13.7)	127.2 (11.8)	14	14	na	4.54 (0.42)	50
M-Benz	0 309 D	40. (12.2)	136.8 (12.7)	19	0	8	7.20 (0.67)	100
W'bago	Series 19	28.1 (8.6)	161.3 (15.0)	19	0	6	8.49 (0.79)	100
ARGOSY	CB 24[gas]	24.8 (7.6)	192.0 (17.9)	25	na	na	na	na
	[diesel]	29.8 (9.1)	"	"	na	na	na	na
Chance	RT-50	28.5 (8.7)	201.4 (18.7)	25	15	25	5.03 (0.47)	63
TwCoach	TC-HD-31-C	29.9 (9.1)	225.6 (21.0)	31	16	23	4.80 (0.45)	66
Flxible	31-foot	31. (10.)	247.0 (23.0)	35	35	na	3.53 (0.33)	50

(Continued on next page).

Table F-9. (Continued).

Manufacturer Codes

AMGenl	= AM General Corporation (US)
ARGOSY	= ARGOSY Manufacturing Co. (US)
Berliet	= Automobiles M. Berliet (France)
Chance	= Chance Manufacturing Co. (US)
D-Benz	= Daimler-Benz AG (W.Germany)
Ep-Bux	= Epple-Buxbaum (Austria)
Falken.	= Fahrzeugwerkstatten Falkenreid GmbH (W.Germany)
Flxible	= The Flxible Company (US)
Flyer	= Flyer Industries, Ltd. (Canada)
Gillig	= Gillig Corp. of Hayward (US)
GMC	= GMC Truck & Coach Division of General Motors Corp. (US)
Hess	= Karosseriefabrik Hess AG (Switzerland)
Kass.	= Karl Kassbohrer Fahrzeugwerke GmbH (W.Germany)
Kiepe	= Kiepe Electric GmbH (Austria)
Leyland	= Bus Manufacturers, Ltd., Leyland National Workington (England)
M-A-N	= Maschinenfabrik Augsburg-Nurnberg AG (W.Germany)
M-Benz	= Mercedes-Benz AG (W.Germany)
NEOPLAN	= NEOPLAN Gottlob Auwarter KG (W.Germany)
O-G&S	= Osterreichische Automobilfabrik OAF-GRAF & STIFT (O-G&S) AG (Austria)
O&K	= Orenstein & Koppel (O&K) Altiengesellschaft (W.Germany)
Steyr	= Steyr-Daimler-Puch AG (Austria)
TwCoach	= Highway Products, Inc., Twin Coach Division (US)
Volvo	= AB Volvo, Bus Division (Sweden)
Wayne	= Wayne Corporation, Wayne Transportation Division (US)
W'bago	= Winnebago Industries, Inc.

Source: Compiled from N.D. Lea Transportation Research Corporation (1975, 1976-1977).

Table F-10. SELECTED DIESEL-POWERED STANDARD SIZE TRANSIT BUS CHARACTERISTICS

Mfger*	Model or Type	Length, ft(m)	Width, ft(m)	Weight, x1,000 lb (x1,000 kg) Empty	Gross	Maximum Velocity, mph (kph)
AMGenl	9635	35.0 (10.70)	7.92 (2.41)	22.5 (10.2)	28.9 (13.1)	57 (92)
	9640	40.00 (12.19)	7.92 (2.41)	23.8 (10.8)	31.6 (14.3)	"
	10235	35.0 (10.70)	8.49 (2.59)	23.1 (10.5)	29.5 (13.4)	"
	10240	40.00 (12.19)	7.92 (2.41)	24.2 (11.0)	32.0 (14.5)	52 (84)
Flxible	35-foot [new-look]	35.0 (10.70)	8.0 (2.44)	23.2 (10.5)	37.0 (16.8)	varies
	"	35.0 (10.70)	8.50 (2.59)	23.5 (10.7)	37.5 (17.0)	"
	40-foot [new-look]	40.0 (12.2)	8.0 (2.44)	na	39.5 (17.9)	"
	"	40.0 (12.2)	8.5 (2.59)	na	39.9 (18.1)	"
Flxible	870 [ADB]	35. (10.67)	8.5 (2.59)	{approx. 24.0 (10.9)	approx. 37.5 (17.0)	70 (113)
	"	40. (12.19)	8.5 (2.59)	{		"
GMC	45 series [new-look]	35. (10.70)	7.98 (2.43)	18.2-19.3 (8.3-8.8)	na	50 (80)
	53 series [new-look]	40.0 (12.20)	7.98 (2.43)	20.3 (9.2)	na	45-54 (72-87)
		40.0 (12.20)	8.5 (2.59)	21.1 (9.6)	na	"
GMC	RTS-II/TH-8203 [ADB]	40.0 (12.19)	8.50 (2.59)	na	na	na
D-Benz	0 307	38.75 (11.81)	8.20 (2.50)	19.4 (8.8)	35.3 (16.0)	59 (94)
Leyland	11.3 m	37.2 (11.3)	8.20 (2.50)	19.9 (9.0)	30.5 (13.8)	67 (107.5)
M-A-N	SL-200	36.09 (11.00)	8.20 (2.50)	na	35.3 (16.0)	varies

*See legend on Table F-9.

(Continued on next page).

Table F-10. (Continued).

Mfger*	Model or Type	Minimum Turning Radius, ft(m)	Gross Area, sq ft (sq m)	Design Capacity Seated	Stan-dees	Total	Gross Sq Ft (Sq M) /Psngr	Percent Seated
AMGenl	9635	34.6 (10.6)	277.2 (25.8)	42	21	63	4.40 (0.41)	67
	9640	41.7 (12.7)	316.8 (29.4)	51	26	77	4.11 (0.38)	66
	10235	34.8 (10.6)	297.2 (27.7)	42	21	63	4.72 (0.44)	67
	10240	42.0 (12.8)	316.8 (29.4)	51	26	77	4.11 (0.38)	66
Flxible	35-ft/8'	34.5 (10.5)	280.0 (26.1)	45	45	90	3.11 (0.29)	50
	/8.5'	"	297.5 (27.7)	45	45	90	3.31 (0.31)	50
	40-ft/8'	41.0 (12.5)	320.0 (29.8)	53	53	106	3.02 (0.28)	50
	/8.5'	"	340.0 (31.6)	53	53	106	3.21 (0.30)	50
Flxible	870/35'	na	297.5 (27.6)	48	24	72	4.13 (0.38)	67
	/40'	42. (12.8)	340.0 (31.6)	48	24	72	4.72 (0.44)	67
GMC	45 series	32.2 (9.8)	279.3 (26.0)	45	na	na	na	na
	53 ser/8'	37.3 (11.4)	319.2 (29.6)	53	na	na	na	na
	/8.5'	"	340.0 (31.6)	53	na	na	na	na
	RTS-II	44. (13.4)	340.0 (31.6)	47	na	na	na	na
D-Benz	0 307	74. (22.5)	317.8 (29.6)	53	46	99	3.21 (0.30)	54
Leyland	11.3 m	35.4 (10.8)	305.0 (28.3)	52	23	75	4.07 (0.38)	69
M-A-N	SL-200	34.8 (10.6)	295.9 (27.5)	44	59	103	2.87 (0.27)	43
	"	"	"	37	75	112	2.64 (0.25)	33

*See legend on Table F-9.

Source: Compiled from N.D. Lea Transp. Research Corp. (1975, 1976-1977).

Table F-11. SELECTED DIESEL-POWERED ARTICULATED TRANSIT BUS CHARACTERISTICS

Mfger*	Model or Type	Length, ft(m)	Width, ft(m)	Weight, x1,000 lb (x1,000 kg) Empty	Gross	Maximum Velocity, mph (kph)
AMGenl & M-A-N	SG-220-16.5-2A	55.0 (16.77)	8.5 (2.59)	35.1 (15.9)	49.6 (22.5)	na
	SG-220-18-2A	59.7 (18.20)	8.5 (2.59)	35.5 (16.1)	50.9 (23.1)	na
D-Benz	0 303 G**	56.30 (17.15)	8.20 (2.50)	28.4 (12.9)	57.3 (26.0)	na
Falken. & M-Benz	**	55.77 (17.00)	8.20 (2.50)	25.9 (11.7)	52.8 (23.9)	44 (71)
Kass.	SG 180S	55.37 (16.88)	8.20 (2.50)	26.5 (12.0)	53.4 (24.2)	na
	SG 180SL	58.65 (17.88)	8.20 (2.50)	27.6 (12.5)	54.5 (24.7)	na
M-A-N	SG 192	54.10 (16.49)	8.20 (2.50)	26.5 (12.0)	49.8 (22.6)	varies
NEOPLAN	N220	60.00 (18.29)	8.20 (2.50)	31.5 (14.3)	54.0 (25.0)	68 (110)
Volvo & Hess	B58	58.57 (17.85)	8.20 (2.50)	33.1 (15.0)	57.3 (26.0)	50 (80)

*See legend on Table F-9.
**Prototype vehicle.

(Continued on next page).

Table F-11. (Continued).

Mfger*	Model or Type	Minimum Turning Radius, ft(m)	Gross Area, sq ft (sq m)	Design Capacity			Gross Sq Ft (Sq M) /Psngr	Percent Seated
				Seated	Stan-dees	Total		
AMGenl & M-A-N	SG-220-16.5-2A	33.8 (10.3)	467.5 (43.4)	65	32	97	4.82 (0.45)	67
	SG-220-18-2A	33.8 (10.3)	507.5 (47.1)	69	34	103	4.93 (0.46)	67
D-Benz	0 303 G**	69.79 (21.24)	461.7 (42.9)	49	135	184	2.51 (0.23)	27
Falken. & M-Benz	** (11.5)	37.5 (42.5)	457.3	57	116	173 (0.25)	2.64	33
Kass.	SG 180S	36.7 (11.2)	454.0 (42.2)	55	130	185	2.45 (0.23)	30
	SG 180SL	38.4 (11.7)	480.9 (44.7)	59	127	186	2.59 (0.24)	32
M-A-N	SG 192	77.4 (23.6)	443.6 (41.2)	50	110	160	2.77 (0.26)	31
NEOPLAN	N220	36.9 (11.3)	492.0 (45.7)	77	43	120	4.10 (0.38)	64
Volvo	B58	37. (11.3)	480.3 (44.6)	65	57	122	3.94 (0.37)	53

*See legend on Table F-9.
**Prototype vehicle.

Source: Compiled from N.D. Lea Transportation Research Corporation (1975, 1976-1977).

Table F-12. SELECTED DOUBLE-DECK TRANSIT BUS CHARACTERISTICS

	Manufacturer*				
	M-A-N,O&K	NEOPLAN	NEOPLAN	O-G&S	O&K
Model	na	N 122	N 426/3	**	SD 200
Length, ft(m)	37.70 (11.49)	40.00 (12.19)	39.4 (12.00)	39.4 (12.00)	37.7 (11.49)
Width, ft(m)	8.17 (2.48)	≤8.50 (2.59)	8.2 (2.50)	8.2 (2.50)	8.1 (2.48)
Height, ft(m)	13.12 (4.00)	≤14.00 (4.27)	13.1 (4.00)	13.5 (4.10)	13.1 (4.00)
Empty weight, x1,000 lb (x1,000 kg)	22.5 (10.2)	38.0 (17.2)	28.2 (12.8)	28.0 (12.7)	21.4 (9.7)
Gross weight, x1,000 lb (x1,000 kg)	na	52.0 (24.0)	48.5 (22.0)	48.5 (22.0)	37.4 (17.0)
Type of fuel	diesel	diesel	diesel	propane	diesel
Maximum velocity, mph(kph)	53 (85)	65 (105)	na	39 (63)	46 (74)
Minimum turning radius, ft(m)	na	38.5 (11.7)	74. (24.)	38.4 (11.7)	na
Gross area, single deck, sq ft(sq m)	308.0 (28.5)	340.0 (31.6)	323.1 (30.0)	323.1 (30.0)	305.4 (28.5)
Lower deck design capacity					
Seated	na	na	45	29	35
Standees	na	na	20	54	8
Total	na	na	65	83	43
Percent seated	na	na	69	35	81
Gross sq ft(sq m) per passenger	na	na	4.97 (0.46)	3.89 (0.36)	7.10 (0.66)
Upper deck design capacity					
Seated	na	na	61	46	53
Standees	na	na	0	0	0
Gross sq ft(sq m) per passenger	na	na	5.30 (0.49)	7.02 (0.65)	5.76 (0.54)
Total vehicle design capacity					
Seated	91	84	106	75	88
Standees	8	22	20	54	8
Total	99	106	126	129	96
Percent seated	92	79	84	57	92
Gross sq ft(sq m) per passenger	6.22 (0.58)	6.42 (0.60)	5.13 (0.48)	5.01 (0.47)	6.36 (0.59)

*See legend on Table F-9. **Prototype vehicle.

Source: Compiled from N.D. Lea Transp. Research Corp. (1975, 1976-1977).

Table F-13. SELECTED TROLLEY BUS CHARACTERISTICS

	Manufacturer*				
	O-G&S & Kiepe	Berliet			Flyer
Model	OE-110/ 54/A	ER 100			E 700
Length, ft(m)	37.9 (11.53)	36.84 (11.23)			40.25 (12.27)
Width, ft(m)	8.2 (2.50)	8.20 (2.50)			8.50 (2.60)
Empty weight, x1,000 lb (x1,000 kg)	21.6 (9.8)	20.0 (9.1)			20.0 (9.1)
Gross weight, x1,000 lb (x1,000 kg)	35.6 (17.5)	35.3 (16.0)			33.4 (15.2)
Maximum velocity, mph(kph)	60 (97)	37 (60)			na
Minimum turning radius, ft(m)	65.6 (20.)	34.4 (10.5)			34.1 (10.4)
Gross area, sq ft(sq m)	310.8 (28.8)	302.1 (28.1)			342.1 (31.9)
Design capacity					
Seated	24	29	35	28	51
Standees	50	70	58	66	19
Total	74	99	93	94	70
Percent seated	32	29	38	30	73
Gross sq ft(sq m) per passenger	4.20 (0.39)	3.05 (0.28)	3.25 (0.30)	3.21 (0.30)	4.89 (0.46)
Crush capacity					
Seated	24	29	35	28	51
Standees	83	na	na	na	33
Total	107	na	na	na	84
Percent seated	22	na	na	na	61
Gross sq ft(sq m) per passenger	2.90 (0.27)	na	na	na	4.07 (0.38)

* See legend on Table F-9.

Source: Compiled from N.D. Lea Transp. Research Corp. (1975, 1976-1977).

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