TCRP
REPORT 98

TRANSIT COOPERATIVE RESEARCH PROGRAM

Sponsored by the Federal Transit Administration

Resource Requirements for Demand-Responsive Transportation Services

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Resource Requirements for Demand-Responsive Transportation Services

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, The National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

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The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

To save time and money in disseminating the research findings, the report is essentially the original text as submitted by the research agency. This report has not been edited by TRB.

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The authors of the report are Professors Schofer and Nelson; Ronald Eash, Visiting Scholar at the Transportation Center; Mark Daskin, Professor of Industrial Engineering and Management Sciences at Northwestern University; and Ying Yang, Hong Wan, Jingfeng Yan, and Laszlo Medgyesy, Research Assistants at Northwestern University. Richard Brazda and Daniel Dembinski of Pace, the northeastern Illinois suburban bus operator, monitored all aspects of this work, contributed perspectives on contemporary demand-responsive transportation operations, and tested the software product.

FOREWORD

By Gwen Chisholm
Staff Officer
Transportation Research Board

TCRP Report 98: Resource Requirements for Demand-Responsive Transportation Services documents a methodology for determining the resources required (i.e., vehicles and vehicle service hours) to provide demand-responsive transportation (DRT) for different levels of demand and different levels of service in a given service area. For the purposes of this research, DRT was understood to include point-to-point services and not point-deviation and route-deviation services. This report is accompanied by a software tool on CD-ROM (*CRP-CD-40*) that can provide a preliminary estimate of the number of vehicles required for a new or modified DRT service. An instruction manual for software use is also included on the referenced CD-ROM. This report may be used by transportation planners and human service transportation providers in assisting with estimation of vehicle resource requirements.

DRT, which is currently provided throughout the United States as specialized transportation for older persons and persons with disabilities, is also provided to the general public, particularly in areas with lower population densities or lower levels of demand. Despite the widespread availability of these services, there is no generally accepted procedure for determining the resources required to serve different levels of demand or to provide different levels of service in a specific service area. Resource requirements for fixed-route, fixed-schedule public transportation service are determined either by demand (e.g., peak-load-point volumes) or by policy (e.g., 30-minute headways in midday hours). Once the route and service frequency are established, it is relatively easy to compute the resources required to operate fixed-route, fixed-schedule service (i.e., driver pay hours, vehicle-miles, vehicle-hours, and number of buses). However, for DRT, the problem of estimating resource requirements is far more complex.

This report documents the supporting research and development of a model for roughly estimating the number of vehicles needed to operate a DRT service. The accompanying software can be used for the initial planning of new DRT services or for the expansion of existing services.

For this report, researchers at Northwestern University described and assessed current methods used to determine resource requirements for DRT. The research team also investigated the parameters and methodologies used by other industries for determining their resource requirements by service area and assessed the applicability of these methodologies for determining resource requirements for DRT. After developing a methodology for estimating resource requirements for DRT, the research team tested and validated the methodology.

CONTENTS

RESOURCE REQUIREMENTS FOR DEMAND-RESPONSIVE TRANSPORTATION SERVICES

SUMMARY

A review of approaches for estimating the number of vehicles needed to provide demand-responsive transit (DRT) service found no consistently used formal tools or models. The general strategy for fleet planning for spatially distributed on-demand services—including public transit, emergency services, and private services such as express package delivery—is to divide estimated demand for service by estimated service rate. For example, trips per day would be divided by the number of trips one service unit—a vehicle, in this case—can complete in a day. The challenge is to develop good estimates of both demand for service and service rate, a difficult task because of the variety of factors affecting both of these variables.

Statistical analyses of public-transit and human-service-agency DRT services in the United States, as well as a survey of these DRT providers, show the anticipated strong positive correlation between trips demanded and fleet size. Other factors of importance are service area size and trip duration, which tend to increase fleet requirements as they increase (positive correlation). Two more important factors are population (trip) density and vehicle productivity (related to many factors including types of riders carried), which tend to reduce the size of the fleet needed as they increase (negatively correlated).

Private-sector for-profit services use similar strategies for fleet sizing, and the same factors are important. However, private firms tend to view vehicles as profit centers, and thus they are less constrained by budgets and a desire to minimize fleet size. Furthermore, they tend to develop very reliable estimates of vehicle service rates, which help ensure the accuracy of their fleet planning process. Finally, private operators have considerable flexibility to adjust fleet size (e.g., by leasing, reallocating, or borrowing vehicles in response to short-term demand fluctuations).

For all operators of demand-responsive service, the tradeoff between quality and cost, when cost is largely driven by fleet size, represents a key decision variable. There is no optimal fleet size, and spending more resources to increase the fleet size will either serve a larger fraction of the market or serve the same market at a better service quality.

Based on these findings, a software tool (NU DRT) was developed to produce a rough estimate of the fleet requirements for DRT services (NU DRT and the User's Manual for this software are available on *CRP-CD-40*, which accompanies this report). This tool was designed to show the tradeoff between fleet size and share of the market

served at a user-defined service quality level. It requires minimal user inputs, including a definition of the service area using Census 2000 geographic units, the type of riders to be carried, the capacity of the vehicle to be used, the hours of service, the size of the pick-up and drop-off time window, the expected number of trips to be requested each day, and other readily supplied parameters. The software is packaged with all necessary U.S. demographic and employment data to apply it anywhere in the 50 states and the District of Columbia.

Using data specific to the DRT service area, a simulation model synthesizes the characteristics of trip requests that are then assigned to vehicles. The number of vehicles is increased until all trips are served, producing the tradeoff between vehicle fleet size and trips carried. It is easy and efficient for the user to vary design parameters (e.g., hours of service, vehicle size, types of riders served, and use of computerized vehicle scheduling) to explore alternative service designs in support of planning decisions. The tool produces both numerical and graphical results to illustrate tradeoffs between service and fleet size, as well as vehicle and wheelchair tie-down utilization. Summary statistics (vehicle-miles, vehicle-hours, and so forth) are also calculated, allowing the costs of alternative service designs to be estimated.

Sensitivity analyses were conducted to test various applications of the NU DRT estimation tool and to demonstrate its operation. Validation tests were conducted with data from nine different DRT services operated in the northeastern Illinois metropolitan area. Comparisons were quite good, and logical explanations could readily be found for the few major differences between model estimated fleet sizes and the number of vehicles currently in daily use.

NU DRT can be used for diagnosing existing DRT operations and for DRT fleet planning for new services, when the replacement of fixed route service by DRT is under consideration. It can analyze areawide or “many-to-one” DRT services. The flexibility of the software, the user interface, and the limited data requirements will enable DRT planners and managers in transit agencies and human service organizations to apply NU DRT in a wide variety of DRT planning applications.

CHAPTER **1**

INTRODUCTION AND RESEARCH APPROACH

The objective of this project is to provide a tool to assist planners of demand-responsive transit (DRT) services in developing a preliminary estimate of the number of vehicles required for a new or modified DRT service. The estimated number of vehicles is important for determining the approximate cost of a service, for evaluating its feasibility, and for developing a preliminary design of the service.

PROBLEM STATEMENT

The dominant type of passenger DRT services in the United States are paratransit operations designed to meet the travel needs of persons whose mobility is limited. Much of this service is mandated by federal regulations that implement the transportation provisions of the Americans with Disabilities Act (ADA) of 1990 (*1*). This type of DRT service is termed ADA-complementary service, and it is provided by transit operators to complement conventional fixed route transit service that is not accessible to individuals who are disabled. DRT is also offered in some communities as a travel option for senior citizens, and it is increasingly provided to the general public in low-density areas where fixed route transit cannot deliver service of acceptable quality or cost.

The basic resources needed to provide any kind of transit service are labor and vehicles. For services based on buses or vans, a driver is needed for each vehicle; therefore, costs will be roughly proportional to the fleet size. For fixed route services—typical bus or rail transit services—estimating the number of vehicles is reasonably straightforward. Under peak conditions, vehicle capacity and the number of passengers flowing past the maximum load point on the route establish the frequency of service (or headways between vehicles, the inverse of service frequency). The number of vehicles required on the route can then be readily determined from vehicle frequency, the length of the route, and average vehicle operating speed.

In concept, the required fleet size for a DRT service is simply the number of trips requested during a time period divided by the service rate, the number of trips a single vehicle can serve in that time period. However, it is difficult to estimate the service rate for DRT because passenger origins and destinations are spread out over a broad area, not clustered along a fixed route. As a result, the distances traveled by DRT vehicles and the passengers assigned to DRT vehicles are not easily determined. To deal with this complexity, a simulation software tool has been developed that first reproduces the dispersed and variable pattern of trip origins and destinations in a DRT market and then assigns enough vehicles to carry those passengers at an acceptable level of service.

OVERVIEW OF THE SOFTWARE PRODUCT

This report presents a software tool that produces a rough estimate of the number of vehicles required to operate a DRT service. The software tool, NU DRT, can be used in the initial DRT service planning stages to provide an approximation of vehicle requirements to support feasibility analysis and rough service design. By quickly providing an estimate of the number of vehicles needed to serve a particular market, this tool can support decisions about the costs and feasibility of implementing a new DRT service, expanding an existing service, or replacing a fixed route service with DRT.

Given very basic descriptions of the DRT service area and markets, NU DRT performs a stochastic simulation of weekday trips for multiple days to reflect variability in trip making. Trip characteristics for DRT riders are derived from travel data in the 1995 National Personal Transportation Survey (NPTS) (*2*), 1990 and 2000 census data (*3,4*), a 1978 survey of the “transportation handicapped” (*5*), and published paratransit plans *(6,7,8*). Service area origins and destinations of DRT trips are based on demographic information from the “Census 2000 Summary File 1” (*9*) and the employment data in “ZIP Code Business Patterns: 1998” (*10*), which are packaged with the software.

These trips are then assigned to DRT vehicles using vehicle scheduling algorithms that mimic those used in practice to serve the trip demand with the smallest number of vehicles. After scheduling vehicles, the operations of the DRT service are stochastically simulated for the multiple days of service. The results of this service simulation are presented in the form of tradeoffs between the number of vehicles operated and the fraction of total demand served. Data on maximum vehicle loadings during an average day of service are also presented. Summary statistics are also calculated over the simulated days of service to enable the DRT planner to estimate operating costs and evaluate alternative service configurations.

NU DRT runs on personal computers utilizing current Microsoft Windows operating systems. It does not demand advanced computer skills or extensive data input. Because the tool is readily accessible to users, it supports interactive, exploratory analyses of a variety of markets and service concepts. Inputs required of the user are quite simple, including the following:

- Definition of the area to be served, in terms of census-designated places, county subdivisions, or tribal areas (service areas must be within the 50 states and the District of Columbia);
- Definition of the types of riders (e.g., senior citizens, individuals whose mobility is limited, or the general public);
- Capacity of the DRT vehicle to be used;
- Daily hours of service;
- Service quality requirements; and
- Daily trips to be carried.

The NU DRT software relies on the user to supply estimates of demand expressed as weekday trips carried. Although DRT demand estimation can be a challenge, particularly for a new service, the software allows users to rapidly test a range of demand estimates, giving planners a clear understanding of the relationship between the number of trips carried and the associated vehicle requirements.

Transit planners, consultants, and social service agency managers are the intended users of NU DRT. They would utilize the software tool when considering expansions of existing DRT services or the implementation of DRT services in new areas. NU DRT can also be used to estimate the number of vehicles needed to replace a fixed route service with DRT. The package itself has modest resource requirements in terms of computing capability, user computer skills, and input data. The computer time required to conduct an analysis is usually quite short, measured in minutes rather than hours, except for the very largest service areas. Simulating computer assisted vehicle scheduling (in contrast to manual scheduling) requires more computing time, and the increased time can be substantial for large services. Estimating the vehicle requirements for a large metropolitan area DRT service with computer assisted vehicle scheduling can take several hours or more.

RESEARCH APPROACH

The first step in the research approach was to carry out background studies of current methods for estimating DRT resource requirements and for planning implementation of DRT services in passenger transportation and other industries. This was followed by a statistical analysis of existing demand-responsive passenger transportation services to identify key factors associated with DRT fleet size. These background studies and factors guided the development of the stochastic simulation model (NU DRT) that is the primary product of this research.

This simulation model is designed to perform a preliminary analysis of the required vehicle resources. This rough estimate of vehicle requirements helps determine the feasibility of a service prior to investing time and resources in a detailed implementation plan or setting up a protocol to manage the day-to-day operations. This determination is critical because the time and resources required to produce a detailed plan and assemble staff to implement DRT services is considerable and should not be invested in a DRT operating scheme unless it is capable of delivering the desired performance for the available budget. Preliminary analyses produce results that are accurate enough to make a "go" or "no-go" decision without expending substantial time and resources on detailed data collection and analysis. The key to successful preliminary analysis is matching the level of detail of the model to the level of the decision to be made.

Chapter 2 summarizes background research that guided the development of NU DRT. Additional, more detailed, descriptions of these investigations are included in the Background Document and Appendixes A, B, C, and D, available in the Supplementary Documents folder on *CRP-CD-40*, which accompanies this report. Chapter 3 presents an overview of the NU DRT software, and sample applications are shown in Chapter 4. The examples in Chapter 4 illustrate some of the advanced features of NU DRT. Chapter 5 reports the results of validation testing and illustrates the sensitivity of the model to variations in input data. Chapter 6 reviews some of the limitations of NU DRT and presents an agenda for future research. In addition to the appendixes mentioned above, *CRP-CD-40* contains the NU DRT software itself, a User's Manual, and all supplied data and default inputs.

CHAPTER **2**

BACKGROUND RESEARCH

DRT passenger services have been used frequently in the United States to serve the needs of people whose mobility is limited and, in lower-density areas, the general public. In addition, there are many other kinds of demand-responsive services for passengers (e.g., taxis and airport shuttles) as well as goods (e.g., express parcel delivery services, electronic commerce retailers of products delivered to businesses and households, and various repair and installation services). Although there is a need to estimate fleet requirements for planning all of these services, no routine method for solving this problem has evolved.

In the simplest terms, fleet size is a function of the demand per time period and the service rate (time to serve a demand) per time period that can be expressed as follows:

$$\textit{initial fleet size} = \frac{\textit{demand per unit time}}{\textit{vehicle service rate per time period}}$$

The challenge is to estimate the demand for service and service rates, which vary across markets (types of passengers or commodities carried) and geographic settings and are affected by vehicle size, operating strategies, and service quality. There is also day-to-day variation in demand for service and in operating conditions that makes the problem even more complex. Furthermore, the demand experienced will be a function of actual service quality, and thus there is an ongoing equilibrium process that defines the required fleet size. Stated differently, fleet size can be expected to evolve as service is delivered and experienced and as demand responds to that service.

To understand how fleet size is determined and what factors influence it, the research team reviewed published literature, analyzed published DRT fleet size data, conducted a special survey to probe a broader range of DRT providers, and interviewed private-sector and nontransportation demand-responsive service providers. The results of these efforts are presented in detail in the Background Document included in the Supplementary Documents folder on *CRP-CD-40* and are summarized briefly in the following sections.

STATISTICAL ANALYSES OF EXISTING DRT OPERATIONS

Multivariate regression analyses of DRT characteristics and variables associated with fleet size were carried out using a data set taken from the 1998 National Transit Database (NTD) (*11*) and additional data on rural and smaller-city providers from the Community Transportation Association of America (CTAA) (*12*). These analyses were designed to accomplish the following objectives:

1. Identify key local parameters that affect DRT service characteristics to reduce the number of such parameters to be supplied by users of the simulation tool (NU DRT) to a manageable level.
2. Determine parameter default values for application of the simulation when local data are unavailable, such as when DRT operations are to be expanded into new service areas.
3. Investigate the effect of the size of DRT operations and other operational characteristics on vehicle utilization.

Larger Urban Area Transit Agencies

Table 27 of the 1998 NTD includes all directly operated and purchased demand-responsive services for larger urban area transit agencies. These demand-responsive data records were first summed by agency, combining the operating statistics for directly operated and purchased service, as well as any additional records in Table 27 for service purchased from private operators of 100 or more vehicles. After removal of records with missing or questionable values, 357 NTD observations were used in the regression analyses.

The analyses were repeated for five roughly equal groupings of similarly sized agencies based on vehicles operated in maximum service (see Table 1). This grouping of agencies reveals the effect of fleet size on regression results.

The relationship between the number of trips carried and the number of vehicles operated was investigated using linear equations, with vehicles operated in maximum service as the dependent variable and annual unlinked passenger trips as the independent variable. The results are summarized in Table 2. This regression model implies that the DRT vehicles operated by a provider are some minimum number (the intercept values in Table 2) plus an additional vehicle for fixed increments in the number of trips carried (the coefficients in Table 2 estimate the number of vehicles added per 1000 additional annual passenger trips).

TABLE 1 NTD transit agency categories

Quintile	Vehicles Operated in Maximum Service From	To	Observations
1	1	5	75
2	6	10	63
3	11	20	72
4	21	50	76
5	> 50		71

The coefficient for trips carried is also interpreted in Table 2 as the approximate additional daily trips needed to justify adding another vehicle. This restatement of the annual passenger trips coefficient is simply the inverse of the regression coefficient factored to daily trips, assuming 270 typical service days annually. The relationships between vehicles operated and trips carried are reasonably significant, and the *t* statistics indicate that both the intercepts and coefficients are statistically different from zero.

Both the r^2 and *t* statistics show that the relationship between vehicles operated and passenger trips is strongest for transit agencies with the largest fleets. The large number of trips required to justify another vehicle for smaller agencies indicates that the number of vehicles operated is less dependent on trips carried than it is for the larger agencies. The intercept values for smaller agencies are generally more significant than the trips coefficients, whereas the opposite is true for agencies with larger fleets. This suggests that DRT service area and operating characteristics are relatively more important in determining fleet size for smaller operators.

Analyses of Transit Agency DRT Service Area and Operations Variables

To begin these analyses, a set of variables expected to influence the number of DRT vehicles in service was constructed from NTD variables. These variables are the following:

1. **Service Area Variables.** Three service area variables were investigated:
   - Size of the DRT service area as reported in the transit profiles section of the NTD;
   - Population density, determined from 1990 Census data on population and service area size; and
   - Daily trip density, which was obtained by factoring the annual unlinked passenger trips to daily trips and dividing by the service area.
2. **Daily Hours per Vehicle.** This variable was calculated using annual vehicle revenue hours factored to daily revenue hours and divided by the vehicles operated in maximum service.
3. **Average Trip Duration.** Average trip distance was calculated by dividing annual passenger miles by unlinked passenger trips. Average speed was determined by dividing annual vehicle revenue miles by revenue hours; then, the average speed was used to convert average trip distance to average trip duration. This measure reflects user behavior, service area size, and the distribution of trip origins and destinations in the service area.
4. **Average Vehicle-Hours per Trip.** To determine average vehicle-hours per trip, annual revenue vehicle-hours were divided by annual unlinked passenger trips. This variable reflects average trip duration, vehicle deadhead time without a passenger onboard, and the average vehicle load factor (the average number of passengers onboard a vehicle).
5. **Passenger Miles per Vehicle-Mile.** This variable reflects the vehicle load factor and the relative amount of time spent by a vehicle with and without passengers.

These variables were used in regression analyses to evaluate their effect on DRT fleet-sizing decisions. They were first tested individually to determine their relationship with DRT fleet size. Stepwise-type regression analyses were then carried out to see whether any of the variables significantly improved the original regression relationships between vehicles operated and annual passenger trips. Detailed results of these statistical analyses are reported in the Background Document provided in the Supplementary Documents folder on *CRP-*

TABLE 2 Regression of vehicles in maximum service against annual unlinked trips

Vehicles Operated	Mean Vehicles	Mean Annual Trips (1000s)	Intercept (Vehicles)	Intercept *t* statistic	Coefficient Values for Passenger Trips Variable: Vehicles Per 1000 Annual Trips	Coefficient Values for Passenger Trips Variable: Approximate Daily Trips Per Vehicle	Coefficient *t* statistic	Regression r^2 statistic
1 to 5	3.2	16.4	2.5	1.93	0.042	87	4.34	0.21
6 to 10	7.8	54.3	7.2	5.73	0.011	329	2.83	0.12
11 to 20	15.0	78.0	13.2	4.82	0.022	166	2.90	0.11
21 to 50	32.0	147.2	23.0	3.53	0.060	61	6.38	0.35
> 50	130.0	534.9	–3.7	–0.07	0.249	15	15.9	0.79

CD-40. The most important findings for the development of the NU DRT software are the following:

1. DRT service area sizes and service area population densities are highly correlated with the trips carried. Fleet size increases with service area size and population density only when passenger trips carried increase as well.
2. Trip density is significantly and negatively associated with fleet size. For a given number of passenger trips carried, fewer vehicles are required when the density of trips is higher.
3. Vehicle utilization, measured by daily hours per vehicle, is also significantly negatively correlated with fleet size when used in combination with the number of daily passenger trips. Fewer vehicles are needed to carry a fixed number of trips when the vehicles are available for use for a longer period each day.
4. Trip duration is significantly and positively correlated with fleet size. When passengers must occupy the vehicles longer to make their trips, a larger fleet is required.
5. Similarly, the vehicle-hours per trip variable is significantly and positively correlated with fleet size when combined with passenger trips. For a constant number of passenger trips, additional vehicle resources are consumed when the average total time required per trip lengthens.
6. The number of daily passenger-miles per vehicle, another measure of vehicle productivity, is significantly and negatively associated with fleet size when trips are also included in the regressions. Fewer vehicles are needed to carry a given number of trips when this variable is large.

Rural and Smaller-City DRT Providers

Rural and smaller-city DRT providers that received federal 5311 grants during 1998 and 1999 were analyzed using data from the CTAA website. After removing records missing one or more key variables and records for 2 taxi operators, 369 records remained for analysis. The data set was stratified by type of agency (nonprofit organization and government agency) and divided into two fleet size categories for the DRT vehicles operated (see Table 3).

As in other analyses, regression models with fleet size as a function of the number of trips carried were estimated, and the results are summarized for the four categories of rural and smaller-city DRT providers in Table 4. These results have some of the same characteristics as the regressions for the NTD transit agencies. Providers with smaller fleet sizes, both government agencies and nonprofit organizations, again have a weaker relationship between fleet size and trips carried than larger agencies, in the sense that the decision to add vehicles to the DRT fleet is less influenced by an increase in the number of passenger trips carried.

The regression relationship estimated for nonprofit organizations with 10 or fewer vehicles is practically insensitive to annual trips carried. This relationship is of low quality (shown by the relatively low r^2 statistic), and the coefficient for annual passenger trips is not significant at the 0.95 probability level.

TABLE 3 Rural and smaller-city DRT categories

	Type of DRT Provider	
Fleet Size	Government Agency	Nonprofit Organization
1 to 10 Vehicles	180	38
> 10 Vehicles	102	49

TABLE 4 Regression of fleet size against annual passenger trips for CTAA providers

					Coefficient Values for Passenger Trips Variable			
DRT Provider	Mean Vehicles	Mean Annual Trips (1000s)	Intercept (Vehicles)	Intercept *t* statistic	Vehicles Per 1000 Annual Trips	Approximate Daily Trips Per Vehicle	Coefficient *t* statistic	Regression r^2 statistic
Government Agency								
1 to 10 Vehicles	4.1	36.3	3.2	1.36	0.025	160	7.32	0.23
> 10 Vehicles	40.1	326.7	14.3	0.19	0.079	51	5.77	0.25
Nonprofit Organization								
1 to 10 Vehicles	5.8	30.0	5.2	1.81	0.020	198	1.94	0.09
> 10 Vehicles	41.7	146.9	18.3	0.71	0.159	25	6.03	0.44

There are some distinctions between the regression models for government agencies and nonprofit organizations shown in Table 4. Nonprofit providers typically carry fewer passengers per vehicle than their government agency counterparts. This is no doubt because nonprofit organizations are providing transportation for selected clients and transportation is a service that is just part of their overall mission. Larger nonprofit organizations add vehicles to their fleets with increased ridership at twice the rate of government agencies.

The effects of service area and operations variables were evaluated for the rural and smaller-city DRT providers. The data were not available on passenger-miles traveled, and therefore the average trip duration and ratio of passenger-miles to vehicle-miles could not be computed. The remaining five variables—size of service area, population density, trip density, daily hours per vehicle, and vehicle-hours per trip—were evaluated in the same manner as for the NTD variables. The regression results for the evaluation of these five service area and operations variables, described in detail in the Background Document, are largely consistent with the NTD analyses. The regression results are the following:

- Larger vehicle fleets are typically associated with larger service areas.
- The positively signed relationship between population density and vehicles operated can almost surely be explained by the fact that more densely populated service areas feature larger populations as well.
- Trip density is negatively signed when the regression includes passenger trips, which again means that fewer vehicles are needed when trips are clustered closely together.
- Although the operations variables do not have statistically significant effects, the directions of the relationships suggest that the number of vehicles operated decreases when the variable of daily hours per vehicle goes up. The variable of vehicle-hours per trip is positively associated with larger fleets.
- The operations variables are generally less important in fleet decisions for rural and smaller-city agencies, and the service area variables (area, population density, and trip density) are typically more significant factors in explaining fleet sizing than the operations variables. Fleet sizes for larger transit agency DRT operations depend more on the variables that reflect operating characteristics.

SURVEY OF CURRENT PRACTICE OF DRT PROVIDERS

A national survey of DRT passenger transportation providers was conducted to gather updated market and operating statistics and to explore methods and variables used in fleet planning. The survey, discussed in more detail in the Background Document provided in the Supplementary Documents folder on *CRP-CD-40*, was conducted by e-mail and distributed to more than 800 transit agency, rural and/or smaller-city, and human service DRT providers. Nearly 100 completed questionnaires were returned.

Table 5 summarizes the survey responses to the question, "When your organization originally planned its paratransit service, or substantially expands its service, how are the required vehicles estimated?" Multiple responses were permitted, and the number of responses is greater than the number of providers completing the questionnaire. As shown in the Table 5, judgment and past experience are most heavily relied on in estimating vehicle requirements. Table 5 probably understates the reliance on judgment because the responses "based on similar paratransit operations" and "used judgment or past experience" are not very distinct from each other.

The questionnaire also asked, "What factors are or should be considered in estimating vehicle fleet requirements?" Ten factors were suggested in the survey instrument, and the respondent could add others. Figure 1 shows the number of respondents selecting each listed factor. Budget limitations, service area size, and ADA requirements were the most often identified factors on the survey. Population, service quality, and the location of special generators such as hospitals and shopping centers also stand out, whereas service area shape and remaining factors were less often cited.

When a specialized market—the elderly market or the ADA-complementary market, for example—was a factor in estimating vehicle requirements, respondents were requested

TABLE 5 Reported methods of estimating DRT vehicle requirements

Survey Response	Number
Used mathematical or computer analyses	16
Based estimate on similar paratransit operations	28
Used judgment or past experience	78
Have not planned new service or do not know	9

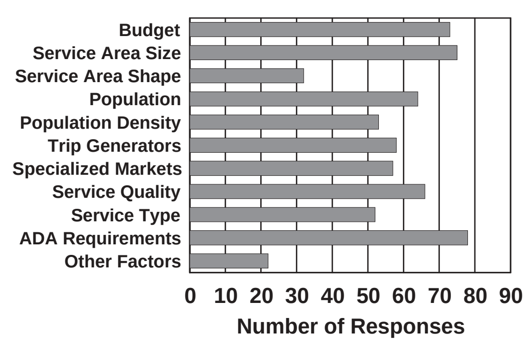

Figure 1. Reported evaluation of factors determining DRT fleet size.

to describe how the market was estimated. About a third of the 30 responses indicated that census data were the source of the market estimate. The next most popular response cited planning and human service agency data, and two human service agencies made forecasts based on their client lists.

Table 6 lists the other factors mentioned by survey respondents that influence, or should influence, fleet size decisions. Together, these factors reflect characteristics of the demand as well as (more implicitly) the service rates. It is apparent that the relationship between some measure of demand and some estimate of service rate is often a starting point for fleet-sizing decisions, with the cost and budget remaining important and perhaps dominant constraints.

PRIVATE-SECTOR DEMAND-RESPONSIVE SERVICES

Several types of private and quasi-private firms deliver demand-responsive services, including on-demand parcel and service delivery firms (e.g., FedEx, United Parcel Service, the U.S. Postal Service, and household product and service delivery firms) as well as taxis and airport shuttles. These services have the following features in common with DRT:

- Operations can be “one-to-many,” “many-to-one,” and/or “many-to-many” transportation;
- Pick-up and/or delivery within a prespecified service area and time window is an important service feature; and
- Control of service quality and cost of operations is essential for competitiveness and/or effectiveness.

TABLE 6 Other factors affecting fleet-size decisions

Factors Cited by One or More Survey Respondents
1. Other public/private providers in service area
2. Politically sensitive areas
3. Size of population, frequency of trips requested, consolidation of trips requested
4. Hours of service, political considerations
5. Passenger type ratio
6. Percent of non-ambulatory (wheelchair) disabled
7. Natural barriers to movement of vehicles
8. Maintenance, vehicle storage capacity
9. Hours of employment or other programs likely to generate groups of riders
10. Service hours and back-up vehicles
11. Passenger demand yields service provision; demand ALONE will impact how many vehicles you operate
12. Average trip distance, passengers per hour
13. Issues specific to the locality
14. Financial ability of passengers to pay
15. Growth factor of service area
16. Local match money available
17. Maximum capacity needs (i.e., estimated capacity needed per round trip)
18. Peak demand
19. Service requests
20. Whether there is city transit available in area
21. Repair history by manufacturer(s)
22. Status of current fleet (age, mileage, etc.)

Private demand-responsive services differ from public DRT in two important respects: operators intend to make a profit on the service or at least to break even, and competition is in terms of quality of service, price, or both. Thus, private demand-responsive firms are inclined to add vehicles to grow their businesses and increase market shares. For ground vehicles (which are relatively inexpensive), fleet-sizing decisions are not generally budget constrained. This is an important difference from public-sector DRT. Of course, private demand-responsive firms are cautious about how they spend money to acquire vehicles, but both their objectives and resource constraints make it less important to get a right answer to the fleet size question at the point of startup.

Using the assumed basic fleet-sizing model, private demand-responsive providers maintain comprehensive, proprietary databases that allow them to estimate both demand for service and service rates with considerable accuracy. Experienced, successful firms eventually develop highly reliable methods for estimating service rates in new markets. Importantly, fleet size adjustment is easy for private providers. Fleets are readily adjusted upward (by purchases or leasing for short-term needs) or downward (by divestment or reallocation among service areas) to meet shifting demand and improve utilization.

Service rates vary based on the nature of the service itself (e.g. straight delivery, on-site service, and bill collection); customer characteristics and location; spatial arrangement of the service area; network configuration; congestion; and so forth. Average values may be used or, if the distributional characteristics of service rates are well behaved, queuing models can be applied. In more complex cases, digital simulation may better reflect the complex interrelationship among variables.

Tradeoffs between service quality and fleet size are an integral part of the fleet sizing decision. Even if a single-valued fleet size solution is derived from the quotient of the demand for service divided by the service rate, service quality is implicitly defined in the service rate. A requirement for a higher service level will reduce the service rate and therefore increase the fleet size. Thus, planners must weigh service quality against fleet size (and thus cost), no matter what the setting. This is a problem that does not have a single-valued solution, but rather a set of feasible operating points from which the preferred service-cost combination is selected.

Small Parcel Delivery

Providers of small parcel delivery determine initial fleet size by dividing some measure of the demand for service by an average vehicle service rate, but these organizations use their extensive experience base to develop highly reliable estimates of both numerator and denominator. Because of the typically strong seasonality of demand, the market size is usually set somewhere above the off-peak (or base) demand

and below the peak demand. This means that there may be an excess of vehicles during the off season, and vehicles must be added through leasing during the peak time. The mission of such firms is to serve all demand, and as demand grows, the response may be to add vehicles proportionately and, in some cases, to add service centers as well. This may shorten the service time and thus maintain or improve vehicle productivity (service rates). When providers of small parcel delivery move into new service areas, they estimate demand and service rate by analogy with currently served locations; in radically different settings, they may conduct special market surveys to assess demand levels.

Household Delivery Services

Household (and business) delivery services may be extensions of primary businesses, bringing single, specialized commodities on demand—office supplies, fast food, liquor, and so forth. Other delivery services bring a broad spectrum of products, notably groceries and household items, to the customer's door on a prearranged schedule.

For example, Peapod is a grocery and household supply delivery service offering Internet-based shopping and "one-to-many" deliveries within precommitted time windows in selected parts of the United States and the United Kingdom. Because they deliver perishables and intend to serve busy, tightly scheduled households, it is important for them to observe the time windows. Service quality is their main competitive advantage, and, therefore, having sufficient vehicles in their fleets is essential. Peapod operates in carefully chosen areas, where market potential is strong and service can be provided efficiently. They use the same simple heuristic to guide fleet sizing: estimate demand, estimate service rate of the vehicles, and compute the approximate number of vehicles required. Usually vehicles are leased, which gives operators flexibility to adjust to demand.

Household delivery service providers, like other private demand-responsive service providers, face the same challenges as public DRT providers, but their ability and motivation to adjust fleet size are quite different. This difference means that there is less pressure on them to develop accurate initial fleet size estimates.

Taxis

Taxis offer passenger DRT on a for-profit basis and, therefore, might seem to provide a valuable model of private-sector fleet sizing. However, most communities set an upper bound on fleet size through government regulation rather than direct measures of the market. The control of operating licenses is used to manage taxi congestion at high-demand locations (e.g., central business districts [CBDs] and airports) while ensuring a reasonable level of service elsewhere. These licensing decisions are driven more by politics than economics. Problems with low levels of service often occur in what are perceived to be low-income and dangerous neighborhoods; this is not because there are insufficient vehicles, but because the largely independent drivers are motivated to avoid places that they perceive to be dangerous and/or unprofitable.

Taxi franchise operators and their usually independent drivers determine the number of vehicles in service. Drivers make their work-time decisions on the basis of the profit motive, and the active fleet size at any time is the result of a highly atomistic decision process. Taxi association owner-managers are motivated to manage the size of the active fleet (i.e., setting minimum levels for busy periods) to ensure some reasonable level of service quality, but their control over drivers is usually limited. Within the limits of regulations, taxi association owner-managers are motivated to let the fleet size grow because ownership costs are dispersed and often shared among several drivers. Every vehicle offers the potential to generate revenue for its owners, and increased association membership benefits central managers. These decentralized incentives and decisions suggest that taxis are not a good example of efficient and coherent DRT fleet sizing.

Airport Shuttle Services

Many airports are served by "many-to-one" specialized shuttle services. Typical vehicles are large vans, and drivers are usually independent contractors, much like taxi drivers, who have substantial freedom in choosing working hours. These services may be managed more centrally than taxis because a single large firm often provides the service.

As in the case of taxis, local governments usually set upper bounds on the number of vehicles licensed to serve an airport. Minimum fleet size is bounded by a desire to offer competitive service quality, which means short waiting times and sufficient capacity to meet peak loads. The airport shuttle planning process includes the following steps:

- Measure aggregate airport access volumes (generally publicly available);
- Estimate taxi market share;
- Assume that airport shuttles will take market share from taxis (based on competitive service quality and price) and then estimate market share based on analogous situations;
- Use average vehicle productivity (service rate) estimates to determine an initial fleet size; and
- Acquire vehicles and adjust the fleet size up or down based on demand and the desire to keep service quality high enough to sustain and grow that demand.

Taxis and airport shuttles are functionally similar, and their fleet-sizing decisions are similarly driven by the market and dispersed choices of drivers, with limits imposed by the regulatory process. In both cases, there is considerable short- and long-term flexibility in fleet size, and therefore decisions about vehicle acquisition (or driver additions) are readily made and easily adjusted.

EMERGENCY PUBLIC SERVICES

Emergency public services (e.g., police, ambulance, and firefighting services) are demand-responsive services for which response time (service quality) can be critical to saving lives. There is extensive experience with such services, and fleet-sizing decisions are well supported by data.

Police

Police provide services on a "many-to-many" basis, with some vehicles cruising the streets waiting for calls. Some vehicles are assigned to specific service areas (beats), whereas others may be on more general assignments. Vehicles cross beat and even jurisdictional boundaries in response to emergencies, which allows fleets to be sized for base conditions and uses mobility to handle local crises. Furthermore, calls for service (CFS) vary in their need for quick response, allowing dispatchers to deal with peak demands by deferring or denying low-priority requests. This takes pressure off of the fleet-sizing decision.

Police departments size their forces (personnel) first, not the vehicle fleet. However, because most police services are delivered from vehicles, there is a direct link between force size and fleet size. As in the case of public DRT, this decision is essentially always constrained by budgets.

The ratio of population size to number of sworn officers in a given locale is measured and reported annually by the Federal Bureau of Investigation. These ratios range from 1 to 4 police officers per 1000 inhabitants. These ratios are essentially measures of service capacity (rate) and provide guidelines for sizing a force. The range reflects local conditions and needs and implies a demand-supply equilibrium, which is affected by budgets and local social values, as well as true CFS-driven needs. More sophisticated police force planning models use local data to refine estimates of both demand (CFS) and service rate (call processing and response time).

Firefighting and Ambulance Services

The standard approach to sizing firefighting and ambulance fleets is also to divide the demand for service by the service rate, with both numerator and denominator adjusted for the setting. For example, in a congested area, the market (CFS) may increase disproportionately to the population (perhaps as a function of density) and inversely as a function of income (fires are more common in low-income areas). Service rate, including response time, will be affected by activity density, network structure, congestion, and, of course, the number and location of stations. Fire agencies maintain detailed data on both CFS and service rates, which provide a basis for supporting fleet-sizing and adjustment decisions.

As with police, resources for fighting fires are assigned to service areas, but it is common practice to deploy resources across jurisdictional boundaries to respond to emergencies. This mutual aid concept allows agencies to size their fleets for a base demand and to share resources during major events.

BACKGROUND RESEARCH FINDINGS

There is a strong similarity in methods and factors used for fleet sizing across private demand-responsive service providers and among private and public entities. The general approach is based on the relationship between demand for service and service rate. The key variations in approaches are centered on the level of sophistication with which both demand for service and service rate are estimated. Service rate characterization may consider only simple averages, or it may account for many factors in detail, using queuing models to deal with uncertainty or simulation methods to deal with spatial and temporal complexity.

In all cases, service quality is important because of competitive pressures, regulatory requirements, or the human and economic consequences of poor service (long response times). Service quality may be a requirement to be met or the outcome of a demand-supply analysis given a proposed fleet size. The task for the analysts and decision makers is to select a fleet size that balances resource costs against service quality.

There are a number of important conclusions drawn from these findings that guided the development of NU DRT, the resource estimation tool presented in this report:

- There is much experience in sizing DRT fleets for public (nonprofit) and private-sector application that supports development of fleet planning tools.
- Private- and public-sector DRT fleet-sizing and management problems differ in important ways; private-sector applications have and use more flexibility to adjust fleet size, which reduces the importance of accurately forecasting fleet size.
- Public agencies are likely to have budgets that are more constrained, which forces examination of tradeoffs among service quality, fraction of the market served, and costs.
- Quality-cost tradeoffs are salient for private operators, as well, but budget constraints are less important or nonexistent.
- There is no commonly used closed-form model to determine DRT fleet size; instead, the general strategy for fleet sizing is to estimate the demand for service and service rates per vehicle and then to determine how many vehicles are needed to meet the demand.
- More sophisticated and more accurate fleet size determination comes from using more realistic information on demand for service and service rate as a basis for

modeling fleet operations (scheduling and routing) to get the most efficient use from each vehicle. The use of better demand and service data makes it more likely that fleet planning and management will be on or close to the efficient frontier, which means that the vehicles are being used most productively to meet the demands.

- The extensive experience with DRT means that there is a great deal of empirical evidence about demand and service characteristics that can be used to guide future planning and to provide default measures of demand for service and service rates when local data are poor or unavailable.

Tradeoff analysis will still be the strategy for making fleet-sizing decisions. Finding ways to achieve the level of flexibility common in private applications—through vehicle leasing or sharing, for example—will be particularly desirable to ensure that the public DRT fleet meets evolving demand at reasonable cost.

CHAPTER 3

OVERVIEW OF NU DRT SOFTWARE

Background research examining DRT practice was the basis for developing the resource estimation tool, NU DRT, a simulation model that runs on personal computers using current versions of the Microsoft Windows operating system. NU DRT relates the demand for DRT trips to vehicle service rate to develop an estimate of the number of vehicles required. Although the user must provide the demand estimate in terms of weekday trips carried, NU DRT uses a variety of resources and procedures to develop a very good estimate of service times, taking into account such factors as the traveler type mix, spatial distribution of activities, boarding and alighting times, vehicle scheduling sophistication, geographic barriers, and other factors. This is accomplished automatically and with minimum input from the user.

NU DRT SOFTWARE MODULES

Given specification of a service area location within the 50 states and the District of Columbia and a general description of the market to be served, NU DRT first simulates the spatial and temporal pattern of daily trips for a sample of days large enough to be representative. These trips are then assigned to a fleet of vehicles that is gradually increased in size until all of the demand is satisfied. The software then reports performance statistics. Figure 2 shows the major elements of NU DRT, and these are discussed in more detail below.

Four principal software modules control the operation of NU DRT. These are the following:

1. The **User Interface** allows the user to define a DRT service area in terms of Census 2000 geographic units, define the operational characteristics of the DRT service, and specify the types of riders and number of weekday trips to be served. It also controls the display of graphic and text output at the completion of the calculations.
2. The **Trip Simulation** allocates a census block group origin and block group destination to every trip. It also selects trip departure and arrival times. The simulated weekday trips reflect the types of riders to be carried, the proposed hours of service, and the location of households and employment trip attractions in the service area. Multiple sets of daily trips are simulated to ensure that the final results are reasonably representative of average weekday trip patterns.
3. The **Trip Scheduler** prepares daily vehicle itineraries of trip pick-ups and drop-offs. In assigning trips to vehicles, the trip scheduler simulates the common practices of vehicle scheduling carried out by operators of DRT fleets. After scheduling trips, the **DRT Service Simulator** stochastically simulates a day of DRT service by taking into account random factors that affect vehicle travel times and passenger boarding and alighting times. Trips are scheduled and the DRT service simulated for the multiple days of trips, again for statistical reliability. Results from this final software module are passed back to the **User Interface** and **Summary Report Generator** for analyses and presentation.
4. The **Summary Report Generator** produces a table of standard DRT service performance measures for selected percentages of trips served.

NU DRT SOFTWARE OPERATION

Because the underlying strategy for NU DRT is to provide the user with tradeoffs between level of service and fleet size, the performance of the DRT service, measured as a function of demand fulfillment, is estimated *as a function of the number of vehicles in the fleet* rather than the number of vehicles required to serve a specific level of demand. The following high-level algorithm describes how this occurs:

1. Given the number of DRT trips demanded daily, multiple sets of weekday trips are generated with the characteristics of every trip assigned through Monte Carlo simulation. Each synthesized trip includes desired pick-up and drop-off times; origin and destination block group centroid coordinates; service requirements (whether the passenger uses a wheelchair, requires an attendant, or two persons are traveling together); and information on whether or not the trip is subscription eligible (a repetitive trip that has a standing order for service).
2. For each simulated day of service, the Trip Scheduler schedules and routes vehicles by using an algorithm that adds one vehicle at a time until all daily trip demand is satisfied. Computer assisted vehicle scheduling is

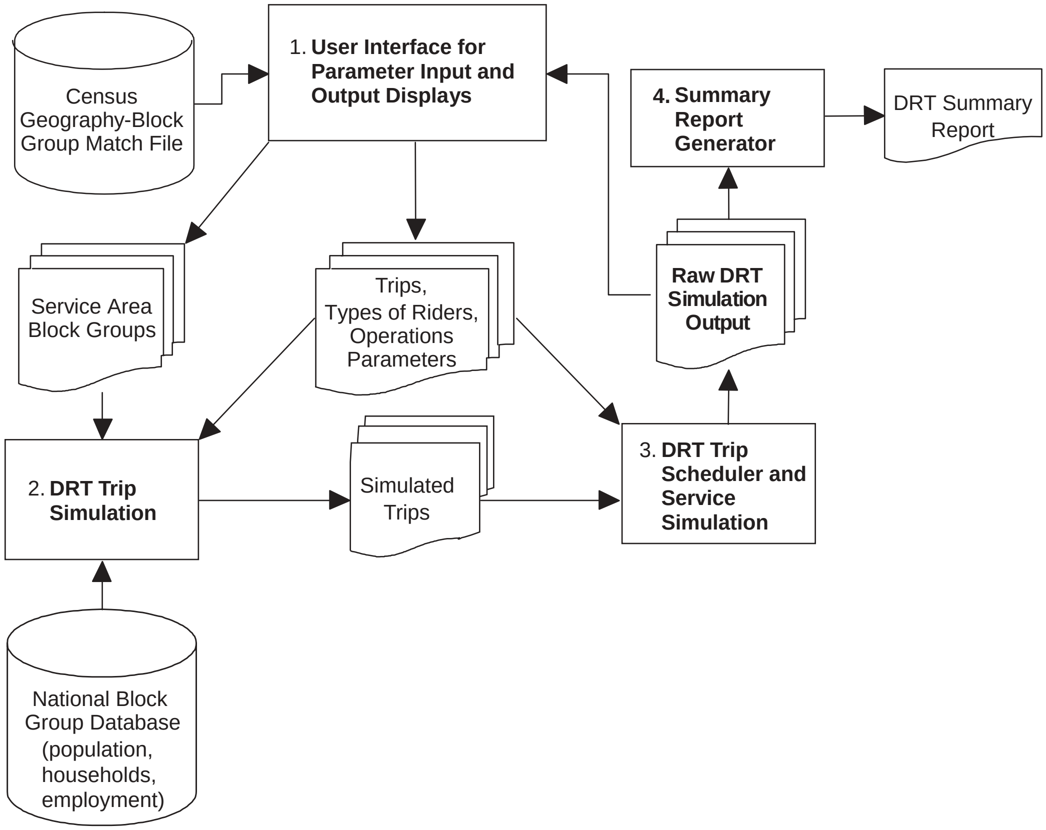

Figure 2. Schematic diagram of major elements of NU DRT.

approximated by extending the algorithm to adjust the initial vehicle schedules. Wheelchair and subscription trips also receive scheduling priority in the algorithm.

3. Given a schedule and routes, the Service Simulator simulates the actual delivery of service with vehicle travel times and passenger boarding and alighting times randomly distributed around realistic mean values.
4. Performance measures are aggregated across all synthetic days of service to obtain statistically significant estimates of the various level-of-service measures.

This approach is computationally more efficient than running a distinct simulation experiment for each possible fleet size because it allows entire performance response functions to be constructed from a single set of experiments. Further, there is no need to commit to a single comprehensive objective, which would be required to estimate the *optimal* number of vehicles.

TRIP SIMULATION

The Trip Simulation software module of NU DRT prepares weekday sets of demand-responsive trips, which are then passed to the DRT Trip Scheduler and Service Simulator for assignment to vehicles. It does not estimate the actual demand for DRT travel because the average number of weekday trips to be served is an input parameter specified by the user of the software; instead, selected characteristics of these trips are simulated. The primary logic of the Trip Simulation is depicted in Figure 3.

The service area's full and partial block group data are first extracted from the national database by matching the service area census geographic units selected in the User Interface. The trip module then sets up a number of internal arrays and matrices to hold service area variables. The balance of the Trip Simulation module consists of two nested logic loops. The outer loop is indexed by the number of weekdays that must be replicated to ensure statistical significance of the resulting estimates of DRT vehicle requirements (one loop for each day simulated), and the inner loop is indexed by the average weekday trips specified by the user (one loop for each trip simulated).

Trip Characteristics Simulated

Within these two nested loops, a series of subroutines determine the characteristics of a DRT trip by answering a series of questions, primarily through the technique of Monte Carlo simulation. The questions are the following:

- Given the types of riders to be served specified in the User Interface, what type of rider is traveling?

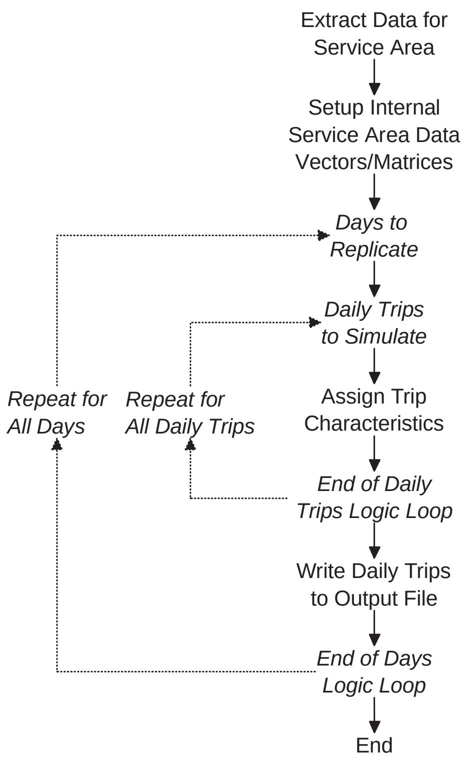

Figure 3. Logic of the DRT trip simulation module.

- What block group produces the trip, and what block group attracts the trip?
- Is the trip one way or does it also entail a return trip?
- What are the desired travel times?
- Does the traveler require a wheelchair tie-down or attendant?
- Are two persons traveling together?

These questions are driven by observed patterns in data from NPTS and other published sources, as documented in Appendix D, available in the Supplementary Documents folder on *CRP-CD-40*. Trips and their characteristics are written to an output file at the completion of an iteration of the weekday trips loop. After all days are completed, the file contains m (where m equals the average number of trips per day) times n (the number of weekdays replicated) trip records.

Days of DRT Service Simulated

A single simulated day of DRT service represents only one possible scenario for trip timings, locations, and distances. To obtain precise estimates of the long-run performance of the DRT service, a number of days of service (replications) must be simulated, and the appropriate number of replications depends on characteristics of the service area and demand for service. The NU DRT Trip Simulation uses queuing theory to approximate the number of replications required. The approximation is based on the following scenario:

- Riders request trips with desired pick-up times occurring at any time during daily operations. The trip request rate is approximated as

  λ = (user-specified trips per day)/ (length of the service day in hours).

- The time that a vehicle is occupied by a trip consists of a loading and unloading time for the passenger, a travel time to the destination, and a deadhead time to pick up another passenger. The mean time to serve a trip is approximated as

  $$1/\mu = (1 + \beta)\tau + \gamma$$

  where

  μ = a service rate,
  τ = an approximate average trip duration ($^2/_3$ of the duration of the longest possible trip),
  β = an inflation factor for deadheading (0.1), and
  γ = an approximate mean loading and unloading time ($^1/_{12}$ hour).

- The average loading of a vehicle is approximated as

  c = max{1, (vehicle capacity/4)}.

  No distinction is made between passengers whose mobility is limited and other passengers in this approximation.
- Adequate vehicles are available to satisfy all demand.

Under these conditions, the number of vehicles in use at any point in time can be approximated by an M/G/∞ queuing model (inter-arrival time exponentially distributed, general service times, and an unlimited number of servers) with mean and variance both equal to η, which is determined by

$$\eta = \lambda/(c\mu).$$

With this assumption, the number of replications is set to estimate the *mean number of vehicles in use* to within ±1 vehicle or ±10-percent relative error, whichever is larger. This results in the number of replications (R) being

$$R = \min\{z^2/(\alpha^2\eta), z^2\eta/\delta^2\}$$

where

z = the 95-percent confidence level (1.96),
α = a 10-percent relative error (0.1), and
δ = the acceptable absolute error in vehicles (1.0).

TRIP SCHEDULER

This initial description of the Trip Scheduler assumes that there are no wheelchair passengers, no subscription trips, and computer assisted scheduling is not in use. Later, the description is extended to show how the algorithm accommodates these three conditions.

A "trip" produced by the Trip Simulation includes a pick-up location and desired pick-up time; a drop-off location and a desired drop-off time; and indicators for whether the passenger has a wheelchair, is traveling with an attendant or another person, or is making a trip that is subscription eligible. Because NU DRT does not use network maps (which would require cumbersome national coded networks), the pick-up and drop-off locations are given in terms of x-y block group centroid coordinates from which a rectilinear travel distance can be computed. The rectilinear travel distance is then transformed into an expected (or mean) travel time that depends on characteristics of the region being served (this transformation is described below).

Users may indicate generic barriers to travel in the service area as part of the input data. These could be any impenetrable feature, such as a bay, river, or mountainous region. Users can select from 15 barrier patterns, as well as 2 river configurations. The software will increase the travel distance with a circuity multiplier for barrier-affected trips based on results of generic simulation tests conducted during the development of the software. Although the barrier representations in the software are all shown for a square service area configuration, the software works with the spatial coordinates of the actual census-based service area defined by the user.

The NU DRT Trip Scheduler takes each day of synthetic trips and performs the following steps:

1. Initializes by computing the expected travel times for all trips and the expected travel time between the drop-off location of each trip and the pick-up locations of all other trips, beginning with the first vehicle in the fleet.
2. Solves a longest path problem for the current vehicle, for which "longest path" means assigning the maximum number of unscheduled riders to this vehicle, treating the vehicle capacity as one (only one rider at a time), and picking up each rider exactly at their desired pick-up time and dropping them off no later than their desired drop-off time.
3. Finds the one unscheduled trip, among all unscheduled trips, that can be inserted into this vehicle's schedule incurring the minimum earliness-lateness penalty (the penalty function is defined below) without exceeding the vehicle's capacity. The Trip Scheduler continues doing this until there are no unscheduled trips remaining, or this vehicle's total accumulated penalty exceeds the allowed threshold.
4. Records the maximum number of simultaneous boardings (all, and wheelchair only) on this vehicle during this service day and the percentage of the day's demand served by this vehicle.
5. Stops if there are no unscheduled trips remaining. Otherwise, the Trip Scheduler adds another vehicle to the fleet and goes back to Step 2.

Special Features of the Trip Scheduler

To emulate computer assisted scheduling, Step 3 in the list above is modified as follows: for each unscheduled trip that could be inserted, the Trip Scheduler optimizes the scheduled pick-up and drop-off times for *all* trips in the schedule to minimize the total accumulated penalty for the vehicle. The Trip Scheduler inserts the trip that gives the minimum total accumulated penalty.

To account for wheelchair passengers, Step 2 in the list above is modified in such a way that wheelchair passengers are more likely to be scheduled in the initial assignment. Specifically, the "length" of a trip in the longest path problem equals the passengers picked up plus the number of seats occupied by a wheelchair if the passenger uses a wheelchair (user input). Thus, the value of a regular passenger trip in the longest path problem is one, whereas one wheelchair passenger with an attendant occupies three seats (one seat for the attendant plus two seats for the wheelchair tie-down), so this trip has a value of five (two passengers plus three occupied seats). Of course, all limits on vehicle capacity (number of seats and number of tie-downs) are enforced.

The NU DRT Trip Simulation indicates which trips are eligible to be subscribed, and the user provides an upper limit on the percentage of subscription trips allowed. To account for this, Step 2 considers only subscription-eligible trips until there are either no such trips remaining or the maximum percentage of subscription trips has been reached, whichever occurs first. Thus, subscription trips impose restrictions on the schedule because an attempt is made to accommodate them first. All unscheduled trips are still eligible for insertion into the vehicle schedule in Step 3. Finally, the information obtained in Step 4 is averaged over all simulated days of service and displayed on the three graphs produced by NU DRT at the end of the run.

Travel Time Estimation

Travel times are a function of the distance traveled and the area type through which the trip passes. Five area type categories are used to characterize block groups: urban, suburban, second city, town, and rural, as originally defined in the 1995 NPTS (*2*). The distance traveled is either the rectilinear distance between origin and destination block group centroids or a minimum travel distance (if the trip is within the same block group). With the distance traveled known, the travel time is estimated as being normally distributed with Mean Travel Time = $\alpha_m D + \beta_m D^{1-\gamma_m}$ and Standard Deviation of Travel Time = $\alpha_s D + \beta_s D^{1-\gamma_s}$.

In these two equations, travel time is in minutes; D is the distance traveled in miles; α_m, β_m, and γ_m are area type specific parameters in the mean travel time equation estimated through regression; and α_s, β_s, and γ_s are similarly estimated area type specific parameters for the standard deviation of travel time. Values for the six area type parameters are listed in Table 7. These parameters were estimated using automobile travel time data from the 1995 NPTS (2), and the estimation process is described in Appendix D in the Supplementary Documents folder on *CRP-CD-40*.

The travel time calculations use the area type parameters for either the origin or destination block group, depending on which set of parameters yields the slowest travel times. The mean travel time function is also used to determine travel time for the Trip Scheduler.

Boarding and alighting times are modeled as normally distributed, with means given by the user-specified input parameters. Standard deviations are taken as 20 percent of the mean value for boarding and 25 percent of the mean value for alighting.

Earliness-Lateness Penalty Function

The NU DRT Trip Scheduler builds a vehicle's schedule iteratively until a penalty threshold is reached. The penalty threshold is defined as 25 percent of the length of the service day. Each trip in a schedule incurs pick-up and drop-off penalties if the trip is scheduled to be picked up and dropped off outside of the rider's desired times. The total penalty for a vehicle is the cumulative penalties for all trips assigned to that vehicle.

For either a pick-up or drop-off, let $\Delta = |\text{difference between desired time and scheduled time}|$, and let w be the pick-up/drop-off window specified by the software user. If $\Delta \leq w$, then the penalty is 0.1Δ, which is essentially 0 but slightly favoring a schedule where scheduled time equals desired time. For $\Delta > w$, the penalty is $\Delta \times \lfloor \Delta/w \rfloor$, where $\lfloor \Delta/w \rfloor$ means the largest integer less than or equal to $\lfloor \Delta/w \rfloor$. Thus, as Δ increases, the penalty increases more and more rapidly.

SERVICE SIMULATION AND SUMMARY REPORT GENERATOR

The NU DRT Trip Simulation and Trip Scheduler provide enough information to generate three tradeoff curves that describe the relationship between the number of vehicles in the fleet and the fraction of the demand served, the distribution of vehicle loadings (passengers on board) over the simulation period, and a similar distribution of the number of wheelchair passengers on board. These are provided as graphs that can be copied and pasted into other documents, and the raw data used to generate these graphs can be reviewed.

The tradeoff between fleet size and trip demand served is the fundamental output that can be used to make fleet-sizing and feasibility decisions. It allows users to understand how many vehicles are needed to satisfy all the demand under the assumed service conditions provided as user inputs, and it shows the service implications of having fewer vehicles. This curve can also be used to assess the approximate market coverage of an established service with a known fleet size.

The loading distributions are useful for testing vehicles of different sizes or number of wheelchair tie-downs. For example, if a service using 15-passenger vehicles never carries more than 12 passengers in a vehicle during the simulated period, it may be more efficient to purchase a smaller vehicle. Similarly, if a service using vans with two wheelchair tie-downs frequently has both tie-downs in use, then service might be improved by using a vehicle with an additional wheelchair position. Although the model tests only one vehicle design at a time, a sequence of model runs can be used to test alternative vehicle designs (see Chapters 4 and 5).

For users who are interested in more detailed information on vehicle utilization and the distribution of earliness and lateness of pick-ups and drop-offs, the Service Simulation module provides this data by simulating the actual delivery of DRT service based on the schedule generated by the Trip Scheduler. The Service Simulation is a standard, discrete-event stochastic simulation in which the actual travel times, boarding times, and alighting times are sampled from appropriate distributions. A convenient table of results from this simulation can be obtained (and copied or printed) by invoking the Summary Report Generator. The report includes statistics on vehicles in use, riders carried, riders per vehicle, vehicle-trips, vehicle-miles, vehicle-hours, vehicle-speed, and passenger-miles for 80 percent, 90 percent, and 100 percent of all requested trips served. The raw data from which the summary report is generated can be found in the Detailed Report generated by NU DRT.

TABLE 7 Area type parameters for the mean and standard deviation travel time equations

	Mean			Standard Deviation		
Area Type	α_m	β_m	γ_m	α_s	β_s	γ_s
Urban	1.0	6.3	0.7	0.4	3.1	0.9
Suburban	0.6	5.4	0.6	0.4	2.2	1.1
Second City	0.8	5.7	0.7	0.2	3.1	0.9
Town	1.0	4.4	0.7	0.1	3.0	0.7
Rural	1.1	4.0	0.7	0.0	3.2	0.7

SOFTWARE SOURCE CODE

Software modules for NU DRT were written and compiled in several different programming languages. The User Interface was written and compiled in Microsoft Visual Basic (SP5) 6.0. Compaq Visual FORTRAN, Version 6.6, was used for programming and compiling the Trip Simulation and Summary Report Generator. Finally, the Trip Scheduler and Service Simulation were written and compiled in Microsoft Visual C++ 6.0.

NU DRT has been tested to run on Microsoft Windows 95, Windows NT4, Windows 98 SE, Windows 2000, Windows ME, and Windows XP. The user should have at least 10 megabytes (MB) of hard disk space available before installing the software, which will require approximately 5 MB of hard disk space. Additional hard disk space is needed to store DRT project files. The amount of space required for each DRT project depends on the size of the service area and number of trips to be served, but only very large projects (service areas composed of more than a thousand block groups and/or more than several thousand daily trips) will require more than one or two MB.

CHAPTER **4**

EXAMPLE APPLICATIONS

This chapter guides users through two fully developed applications of NU DRT that illustrate its features. The first is a simple service design application in which the focus is on testing to select a vehicle design. The second "many-to-one" example demonstrates the use of census maps to edit service area block groups. For both example applications, users are given step-by-step instructions for using the NU DRT software as well as extensive explanation of how various software features work.

EXAMPLE APPLICATION FOR ROCKFORD, ILLINOIS

This section guides users through a straightforward application of NU DRT to fleet size planning. The software tool is applied to the City of Rockford in Illinois. The data for this example application were obtained from NTD and the website for the Greater Rockford Mass Transit District (http://www.rmtd.org/ as of March 2003) (see Table 8).

Data Entry for the Rockford Example

The following steps are required to enter the Rockford example data and run NU DRT:

1. Once NU DRT is installed on a desktop computer, the software can be started by selecting NU DRT from the Start menu and then clicking on it. The software takes a few moments (10 to 15 seconds) to load, and then it presents users with an opening screen. Because this is a new project, it is necessary to enter a project name. To enter a project name, do the following:
   - Select "File" from the taskbar,
   - Then select "New Project," and
   - Enter the project name, "Rockford."
2. At this point, the user may select the NU DRT wizard, which simply steps through the sequence of screens to enter data, or the user may choose to enter data manually. In this example, the manual approach will be used.
3. The user must first specify the service area. NU DRT comes with U.S. Census data for all states and the District of Columbia. To select the service area:
   - Click on "Edit Project" and select "Service Area and Barrier" from the dropdown menu. Click on "Service Area."
   - Rockford is a place; therefore, click on "Place."
   - In the next panel, first scroll down the list of states and select Illinois. Entering the letter "I" will advance the state list to Idaho, the first state beginning with "I." Illinois is listed immediately after Idaho.
   - Double click on "Illinois" to get a list of all places in Illinois.
   - Scroll down to "Rockford city." The first-letter search process will advance the list of places to those beginning with the letter "R."
   - Double click on "Rockford city." It then appears in the "Selected Places" panel on the right. This display should look like Figure 4.
   - Because there are no additional components in the service area, click on "Save" and then "Finish." Once back at the service area selection screen, click on "OK."
   - After reselecting "Service Area and Barrier," now click on "Barrier." This will take the user to the barrier-type selection page. The only barrier of importance in Rockford is the Rock River flowing through its center, and therefore this option should be entered by the user.
   - Finally, "OK" is selected to indicate that the service area definition has been completed.
4. Continuing to work from the dropdown menu under "Edit Project" on the taskbar, select "Type of Riders." This leads to the screen shown in Figure 5. The market to be served will be determined by policy. If passengers with mobility limitations are to be served, NU DRT will generate more requests for wheelchair and attendant trips. If the general public is to be served, travel will focus more on workplaces and the peak periods. For this example application, the user should select "Mobility Limited" and click on "OK."
5. The next data entry screen on the "Edit Project" dropdown menu is "Operating Specifications," which includes weekday hours of service, passenger capacity of the vehicle, number of wheelchair tie-downs, number of seats lost whenever a single tie-down is used, and the pick-up and drop-off window size in minutes. (See

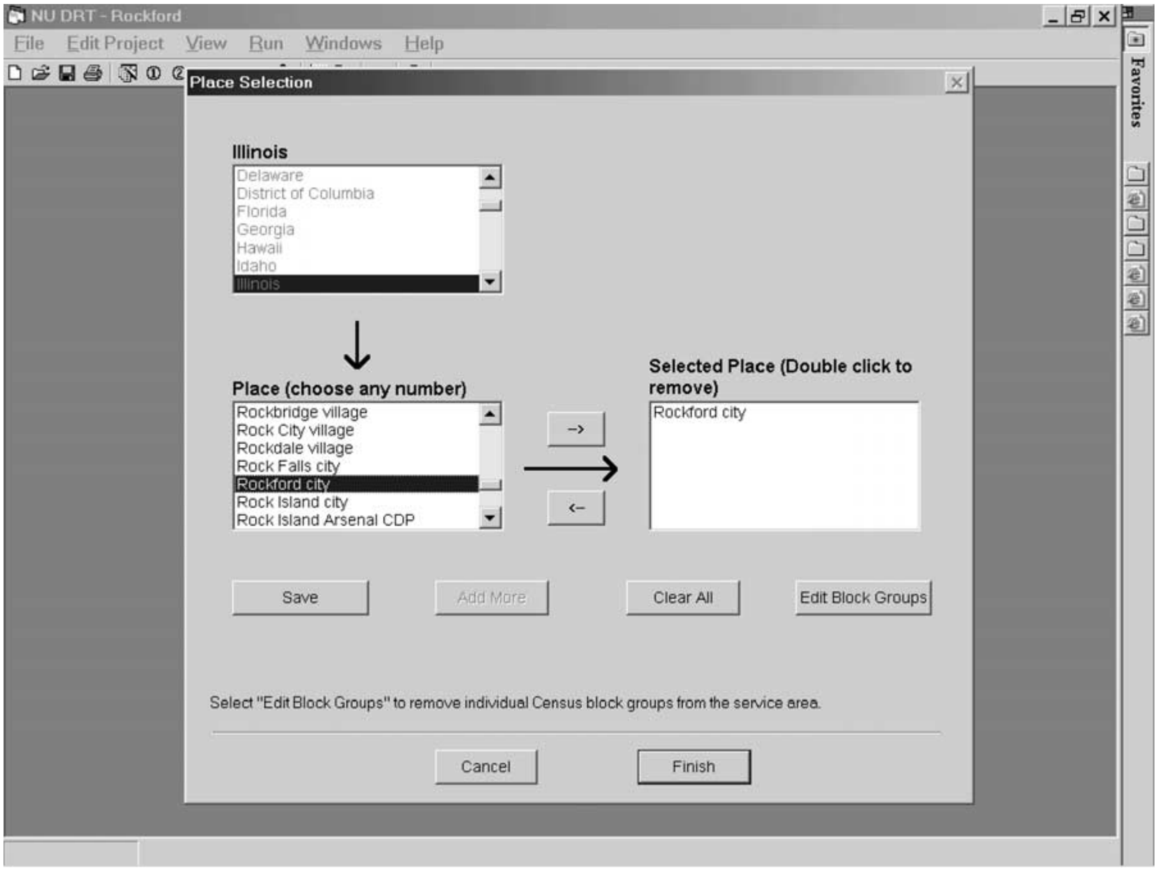

Figure 4. Service area selection screen.

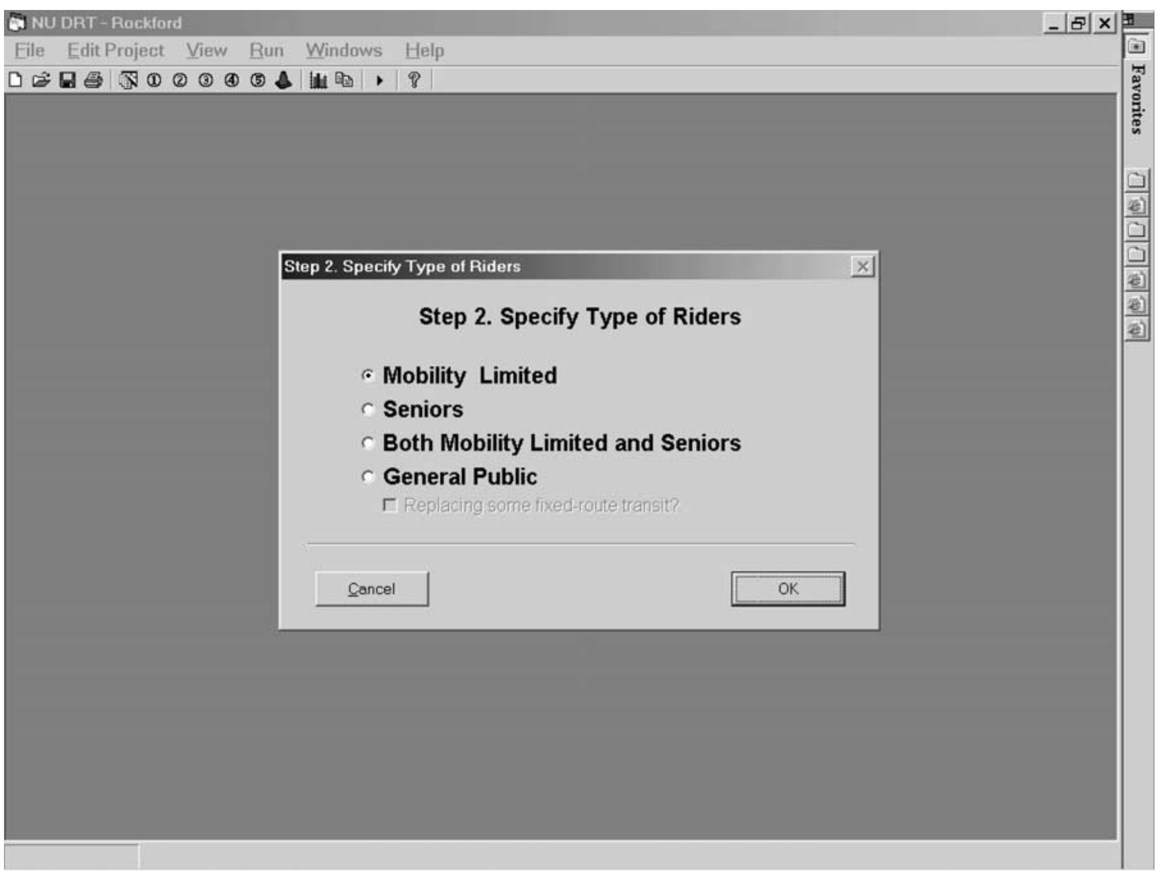

Figure 5. Rider type specification input screen.

TABLE 8 DRT example data for Rockford, Illinois

Input Data	Value
Area	85 square miles
Population	185,000
DRT market	Mobility limited
Daily trips	229
Hours of Service	5:15 a.m.–11:45 p.m.
Time Window	15 minutes
Barrier	Rock River traverses center of town crossed by multiple bridges
Vehicles operated in maximum service	14

Figure 6.) The latter is the earliness or lateness allowed for picking up or dropping off travelers; the model imposes a significant penalty for exceeding the pick-up and drop-off window. A default value of 15 minutes is supplied for the pick-up and drop-off window, but the user can enter other values.

6. The service hours can only be specified to the nearest 30 minutes, so the Rockford “Start Time” should be moved by the user to 5:00, and the “End Time” should be moved to 22:30. This will have little effect on the results, which are more sensitive to the length of the service period than clock time. In service design applications, the user should set the service hours based on knowledge of the market to be served and community activity patterns.
7. The analysis will begin by assuming the use of a van with six seats (excluding the driver) and one wheelchair tie-down that eliminates two seats when in use. Thus, the user should enter six in the box for number of seats, one in the box for number of tie-downs, and two in the box for number of seats per tie-down. This will be termed a 6/1/2 vehicle design. Typically, fewer vehicles may be needed if larger-capacity vehicles are used. However, as the vehicle size grows, at some point service quality concerns will override capacity, and it will not be possible to reduce fleet size further without compromising service. Vehicle design can be based on vehicles currently used by the agency or knowledge of vehicles currently on the market (which will reflect what DRT services are buying). As will be shown below, it is easy to use NU DRT to test the fleet size implications of different vehicle designs.
8. Vehicle scheduling is initially assumed to be done without computer assistance, so the user should leave the box for computer assisted scheduling unchecked. The completed input screen is shown in Figure 6. When all of the inputs have been provided, click “OK.”
9. “Daily Trips” is the next data entry screen on the “Edit Project” dropdown menu. This key input cannot be

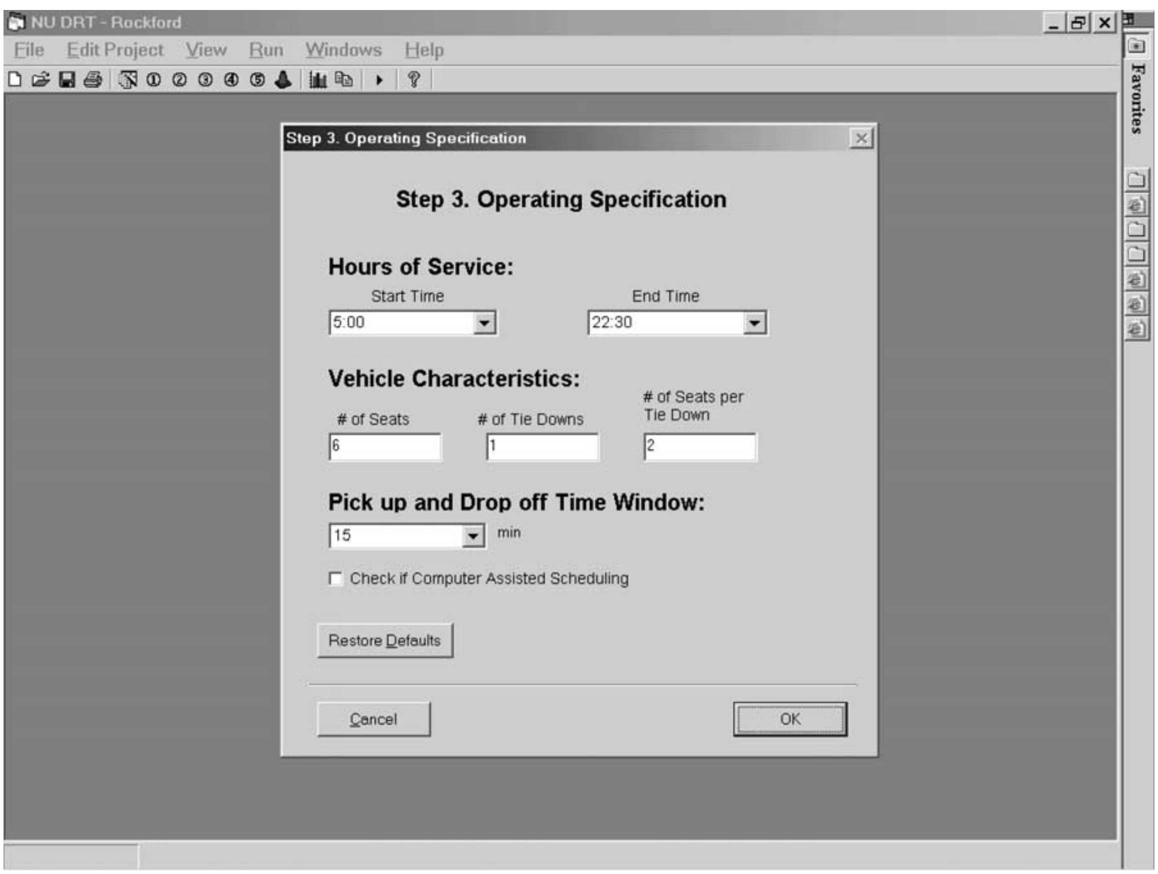

Figure 6. Operating specification input screen.

entered before the type of rider is selected. The number of trips can come from a rough demand estimate based on reported trip rates for the market to be served, or the number of trips can be determined by analogy with a similar service elsewhere. NU DRT can also be used to explore the vehicle requirements associated with a range of demand estimates so that service can be scaled to the resources available. For this example application, the user should enter 229 in the "Number of Weekday Trips" box (see Figure 7). (In the "Specify Number of Trips" screen, the user can also define a "many-to-one" service by checking that option. The "Edit Block Groups" button will then activate, and the user can indicate which block group[s] is[are] the primary destination[s]. The second example in this chapter demonstrates an application of NU DRT to a "many-to-one" DRT service.)

10. The final data entry screen in the "Edit Project" option on the taskbar is "Trip Characteristics." The user may modify default boarding and alighting times, as well as the maximum percentage of subscription (regular) trips permitted, using the "Advanced Settings" input screen shown in Figure 8.
11. Now all of the inputs have been specified, and NU DRT is ready to run. Prior to running the model, the user may return to any of the input screens to modify the design assumptions. Input parameters may also be reviewed without the ability to change them by clicking on the "View" taskbar option and selecting "Parameters" from the dropdown menu.
12. To run the software, select "Run" and then "Run NU DRT" from the toolbar or press the F5 key.

NU DRT Graphical Displays

When NU DRT starts to run, a trip simulation window opens and the software first loads the census and other data from the CD-ROM and then estimates the number of simulation replications (simulated days of service) needed for statistical validity. In this example, 17 weekday sets of trips are simulated (the most time-consuming component of the software), and a day-by-day progress indicator is displayed. Once the simulated trips are available, the Trip Scheduler and Service Simulation take over. Three primary graphical outputs are displayed after the last day of the simulation is completed.

At this point, the user can view the results of the simulation. Figure 9 shows the tradeoff between fleet size and fraction of trips served. This information might be used to scale the fleet to serve 100, 95, or 90 percent of the trip demand. Alternatively, this relationship can be used to

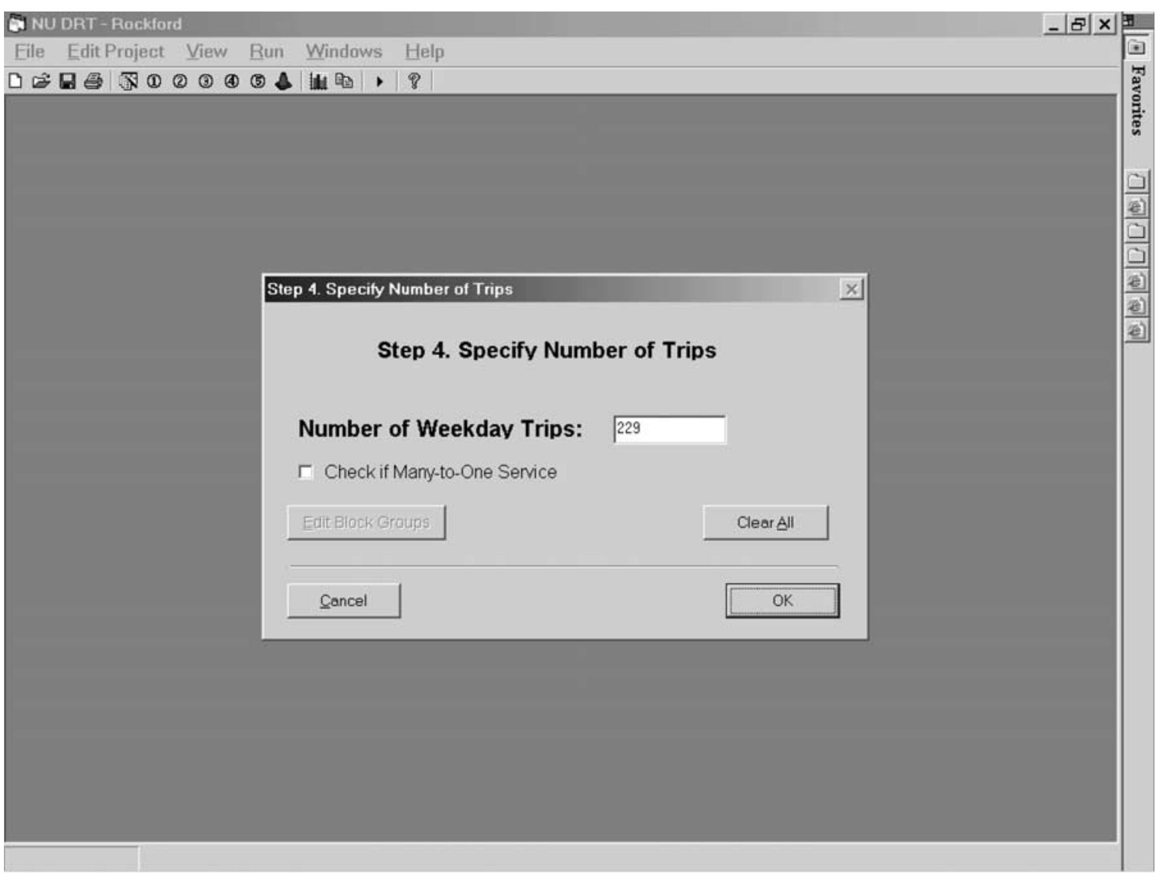

Figure 7. Number of trips input screen.

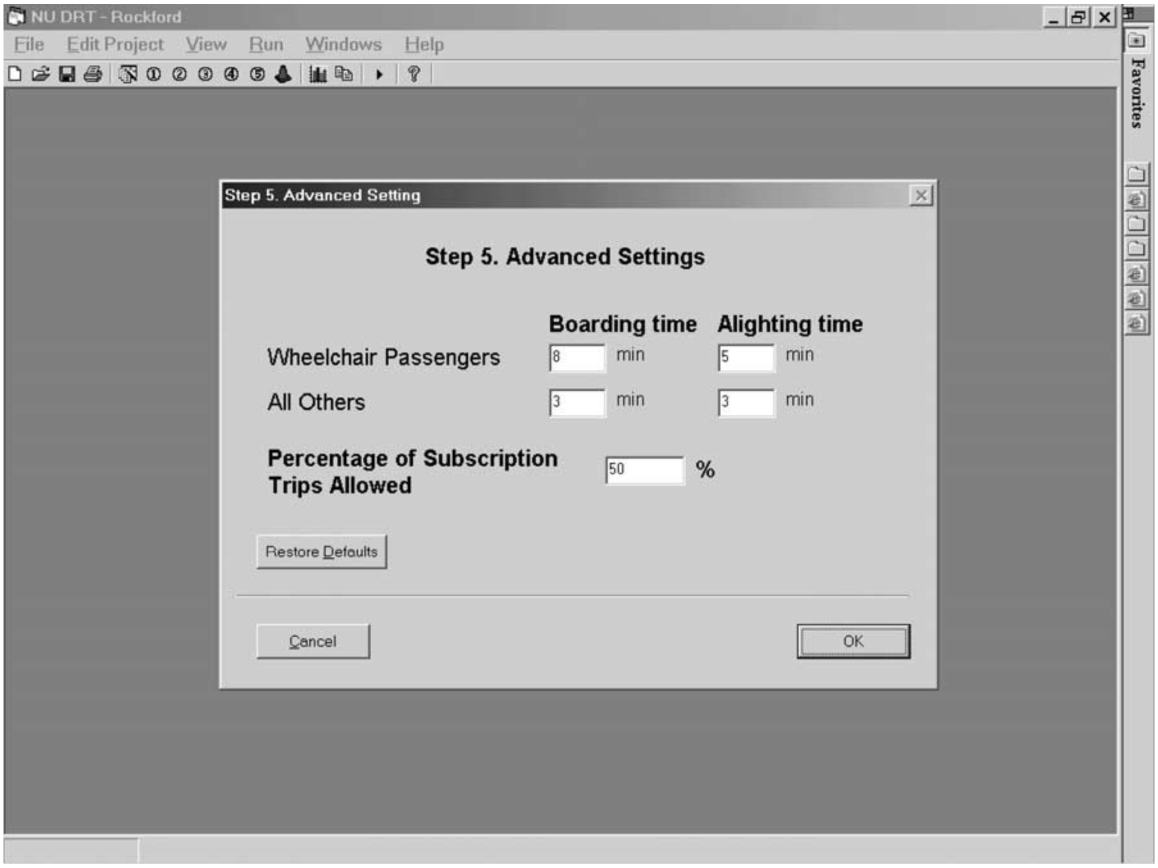

Figure 8. Advanced settings input screen.

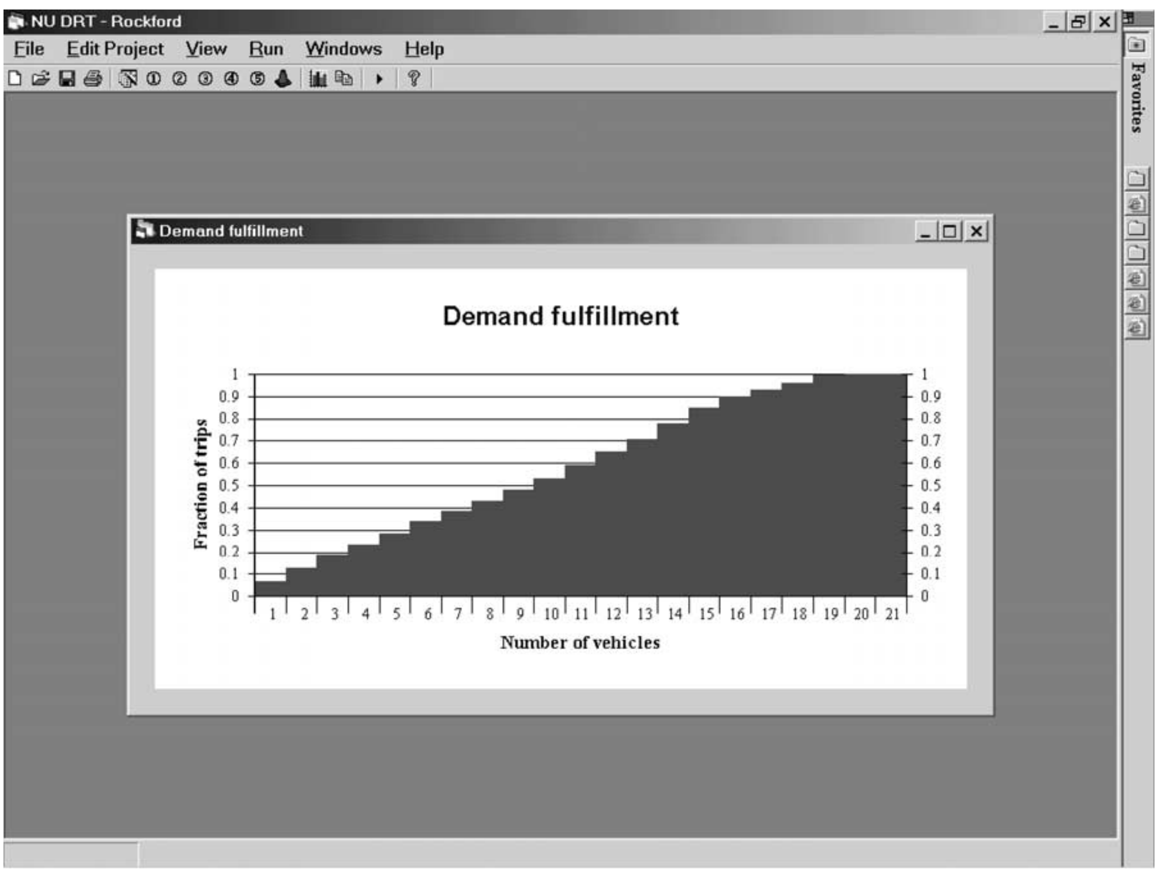

Figure 9. Fleet size versus demand fulfillment tradeoff.

answer what-if questions such as, “What fraction of the market can be served with only four vehicles?” In this example, NU DRT estimates that a fleet of 14 vehicles would, on average, serve about 78 percent of the 229 weekday trips demanded.

Once a run has been completed and as long as input parameters remain unchanged, the three graphs can be viewed by selecting “View” from the toolbar and clicking on “Graphs.” The data used to create the graphs can also be reviewed using the option “Graph Data” on the same menu.

Figure 10 shows the histogram of vehicle loadings averaged over all simulation runs. The horizontal axis is the maximum number of passengers onboard a vehicle, and the vertical axis is the number of vehicles experiencing this maximum load on an average day. Vehicle capacity is five passengers, and vehicles rarely operate at full capacity (on average, approximately once every 17 days). Approximate numbers can be estimated from the graph, and the exact values can be found by clicking on “Graph Data” under the “View” option on the taskbar. Because this is a DRT service for passengers whose mobility is limited, wheelchair riders sometimes reduce the vehicle capacity. As a result, there may be times when the demand calls for adding another passenger to the vehicle when there is no available capacity, and a larger vehicle may be justified.

Figure 11 shows a similar histogram for wheelchair passengers onboard. The maximum of one wheelchair onboard (the wheelchair capacity of this vehicle) is experienced by an average of 12.6 vehicles. This result suggests that a vehicle with greater wheelchair capacity may be preferred.

Computer Assisted Scheduling

This initial run of NU DRT suggests that the Rockford Mass Transit District may want to operate more vehicles than the 14 paratransit vehicles that they currently operate to serve the average weekday trip demand. This estimate of vehicles required does not reflect the potential vehicle utilization efficiencies that might be achieved when a DRT service has been in operation for some time with more experienced vehicle scheduling personnel, when riders adjust their travel times to make scheduling easier, and/or when computer assisted scheduling is used.

Rerunning the Rockford example with the computer assisted scheduling feature turned on (an option located on the “Operating Specifications” screen) changes the tradeoff between fleet size and percent of trips served to the relationship shown in Figure 12. With computer assisted scheduling, the 14 vehicles now serve roughly 98 percent of the average weekday trips, rather than 78 percent with manual scheduling. (For other results from the computer assisted scheduling run, see NU DRT Run 2 in Table 9.) The maximum number

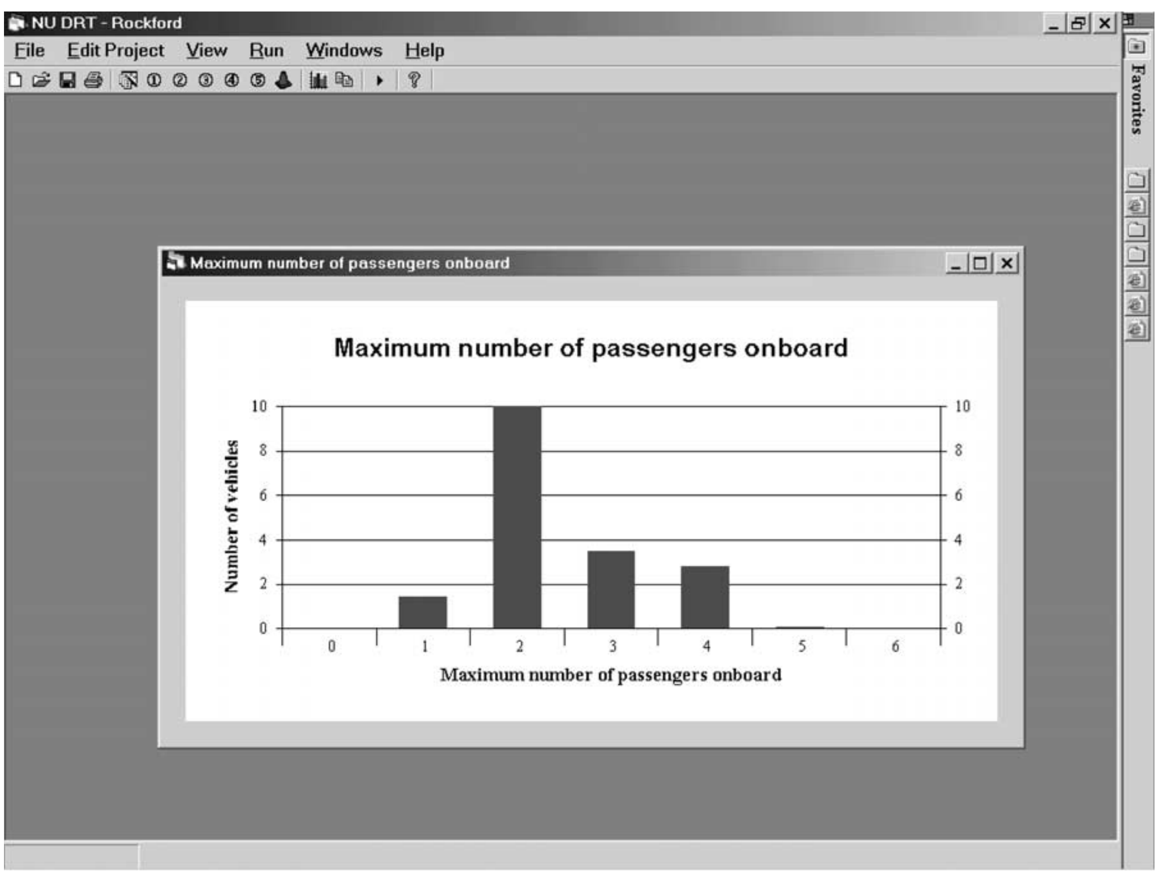

Figure 10. Maximum number of passengers onboard.

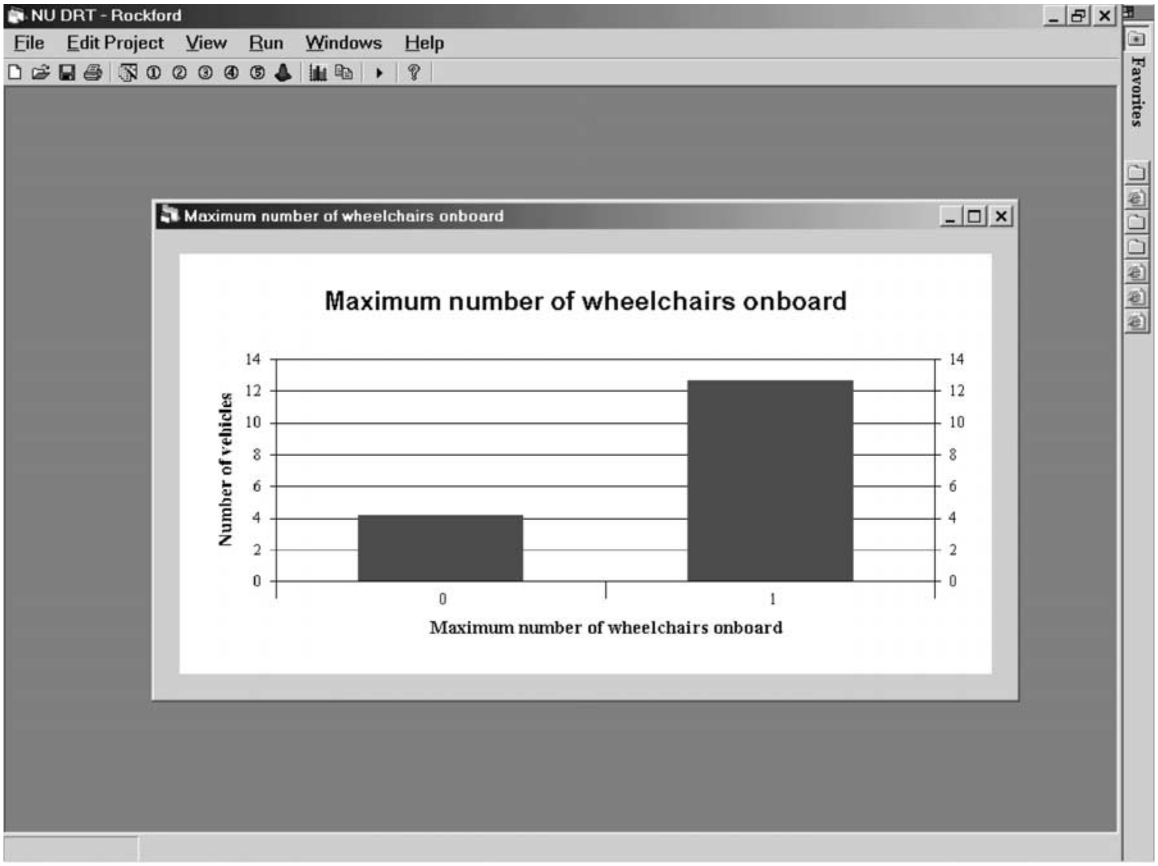

Figure 11. *Maximum number of wheelchair passengers onboard.*

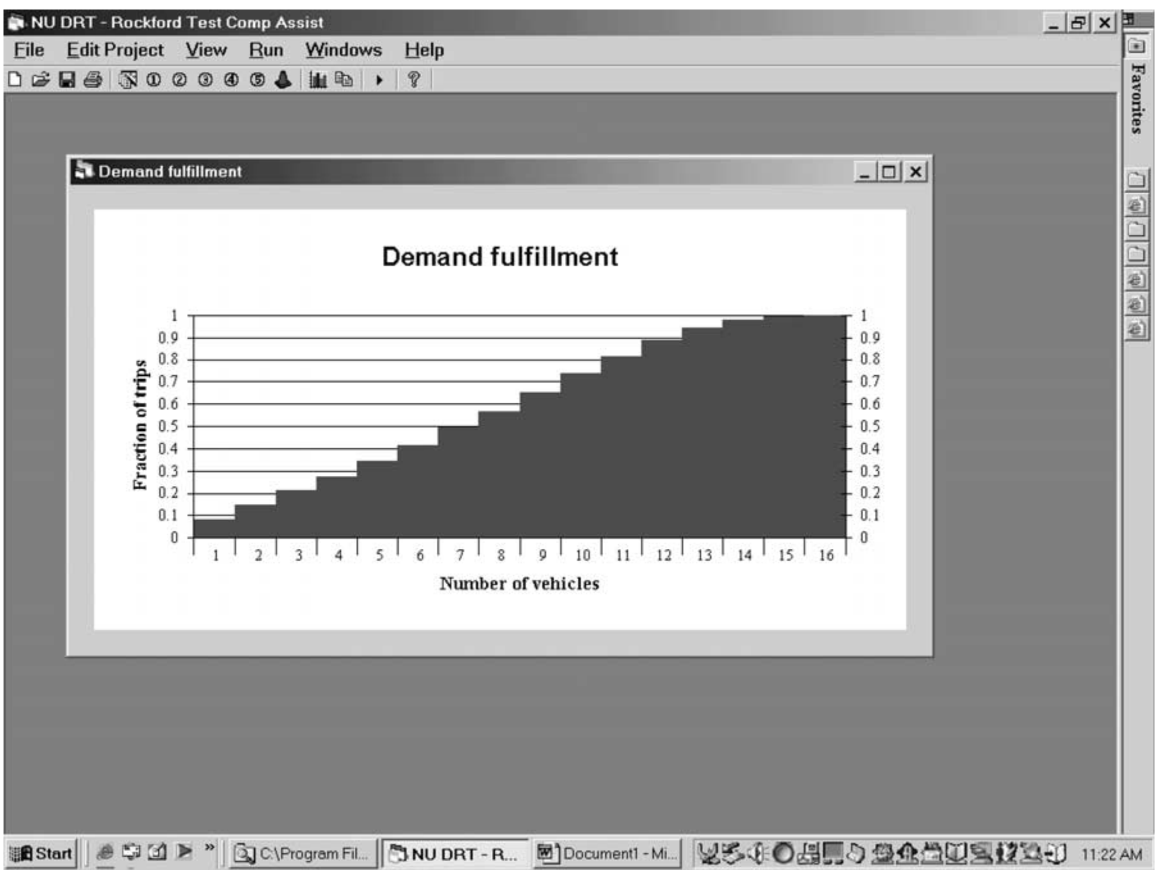

Figure 12. *Fleet size versus demand fulfillment tradeoff with computer assisted scheduling.*

TABLE 9 Results of vehicle size and operating characteristics sensitivity tests

NU DRT Run	Scenario	Vehicle Capacity (Seats/ Wheelchair Tie-downs/ Seats per Tie-down)	Vehicles Required for Percent of Trip Demand Served 90%	95%	100%	Maximum Passengers on Vehicles	Maximum Wheelchairs on Vehicles
1	Baseline	(6/1/2)	15	17	22	5 on 0.6 vehicles	1 on 11.9 vehicles
2	Add Computer Assisted Scheduling	(6/1/2)	12	13	15	5 on 0.1 vehicles	1 on 10.7 vehicles
3	Add Larger Vehicle and 30-minute Window	(15/2/2)	9	9	11	6 on 0.3 vehicles	2 on 1.3 vehicles
4	Add Additional Wheelchair Tie-downs	(15/4/2)	9	10	12	7 on 0.1 vehicles	2 on 2.3 vehicles

of passengers and wheelchairs onboard vehicles continues to suggest that a larger vehicle may be advantageous.

Vehicle Sizing Sensitivity Analyses

The results of a series of model runs exploring different vehicle designs and service attributes are summarized in Table 9. In addition to results for a baseline model run and the computer assisted scheduling run, results for two other runs are shown. First, a larger vehicle with 15 seats, 2 wheelchair tie-downs, and 2 seats eliminated per tie-down (15/2/2), a common DRT model, was tested. Because of the size of the vehicle, the time window was also increased to 30 minutes to allow increased aggregation of trips on vehicles. Fewer vehicles are required with these changes, but the passenger loading never exceeds six. The two wheelchair positions are used only on slightly more than one vehicle during an average day.

A vehicle with additional wheelchair positions was tested next; 2 more wheelchair tie-downs are added to the vehicle with 15 seats (15/4/2). Because each wheelchair tie-down occupies two seats, there is room for seven more passengers when four wheelchair passengers are onboard. Results from this run show that on rare occasions a vehicle carries as many as seven passengers, and, even with four wheelchair positions, no more than two are carried at once. These model runs illustrate the application of the model and show how it can easily be used to explore different vehicle designs and operating strategies.

"MANY-TO-ONE" SKOKIE SWIFT EXAMPLE

In this second example application, the NU DRT software is applied to estimate the number of vehicles required to provide feeder bus service to a rail transit station. This proposed DRT service also replaces existing fixed route bus routes in the service area. The example illustrates the editing of service area block groups and the identification of a block group as the destination for a "many-to-one" DRT.

Figure 13 shows the service area for the proposed "many-to-one" DRT in two northern suburbs bordering Chicago. The DRT is supposed to provide access to the Dempster Street terminal of the Chicago Transit Authority's Skokie Swift, a rail transit express line that connects to the Howard Street terminal in the east, where riders can transfer to other rail transit lines serving the Chicago CBD, as well as express and local bus lines. The DRT service area (the shaded area in Figure 13) covers the village of Morton Grove and the northwestern portion of the village of Skokie, bounded by Skokie Boulevard in the east and Oakton Street in the south.

The example proceeds as follows:

1. Start the NU DRT software and select a project name (as described in the Rockford example).
2. Select the "Parameter Wizard" under "Edit Project" to enter the service area and other input parameters. Click on the "Next" button to get the "Specify Service Area" data entry screen.
3. In the "Specify Service Area" screen, click on the "Place" button. As shown in Figure 14, in the "Place Selection" screen, double click on Illinois and then in the "Place" box on Morton Grove village and Skokie village. Click "Save" to save the block groups in the two villages. Then select "Edit Block Groups" and the Notepad program pops up displaying the Service_Area.txt comma-delimited text file (see Figure 15). This file has a record for every full or partial block group in Morton Grove and Skokie.

The Service_Area.txt File

In the Service_Area.txt file for this example, the block group records have a "P" in the first field to indicate that they are from a place selection. Block groups selected using county

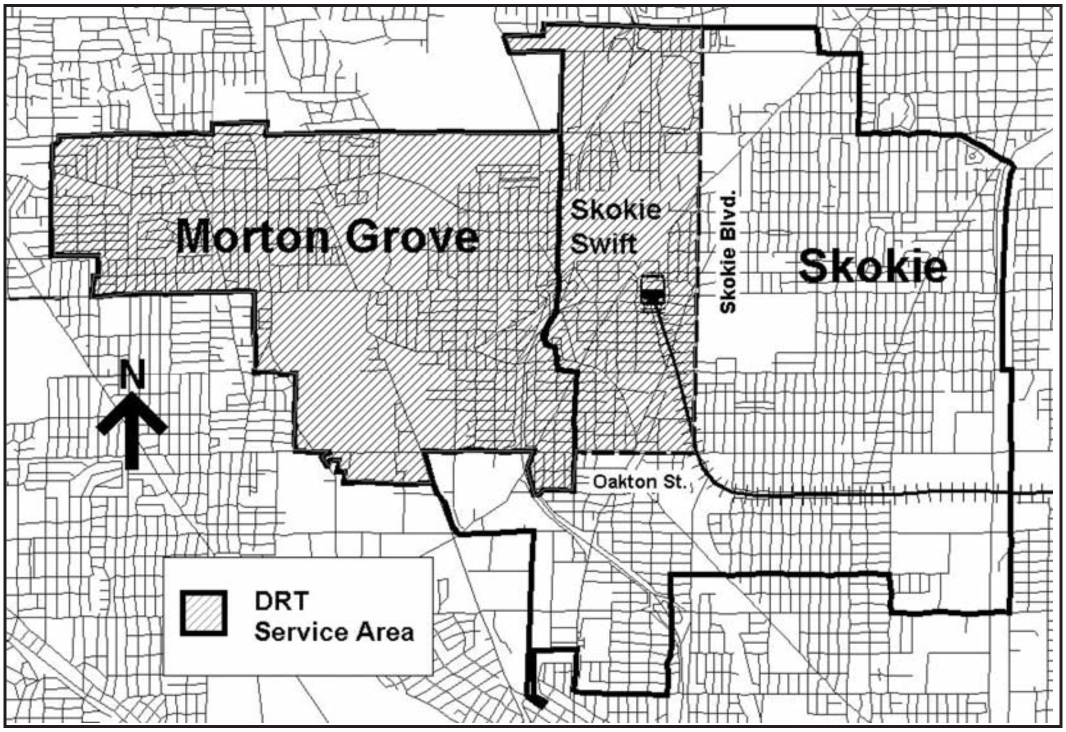

Figure 13. "Many-to-one" example DRT service area.

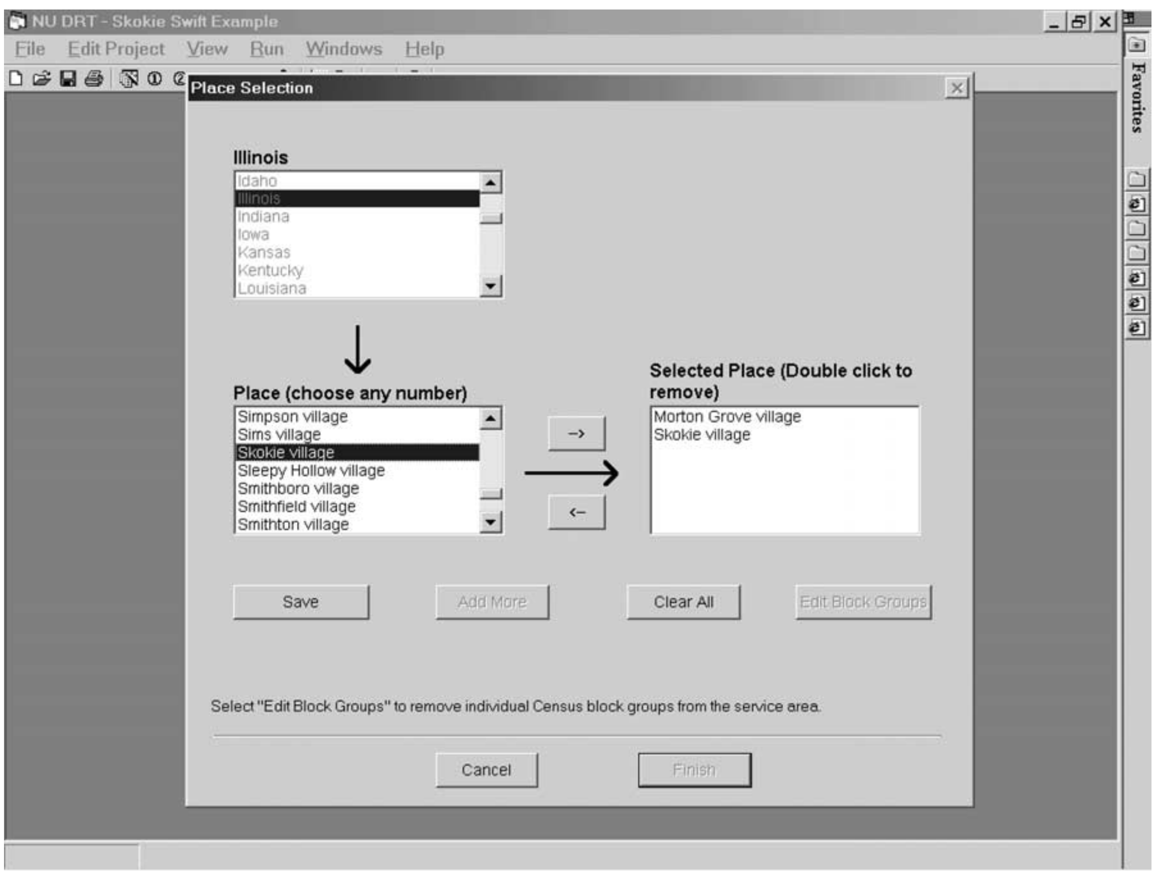

Figure 14. Place selection for "many-to-one" service area.

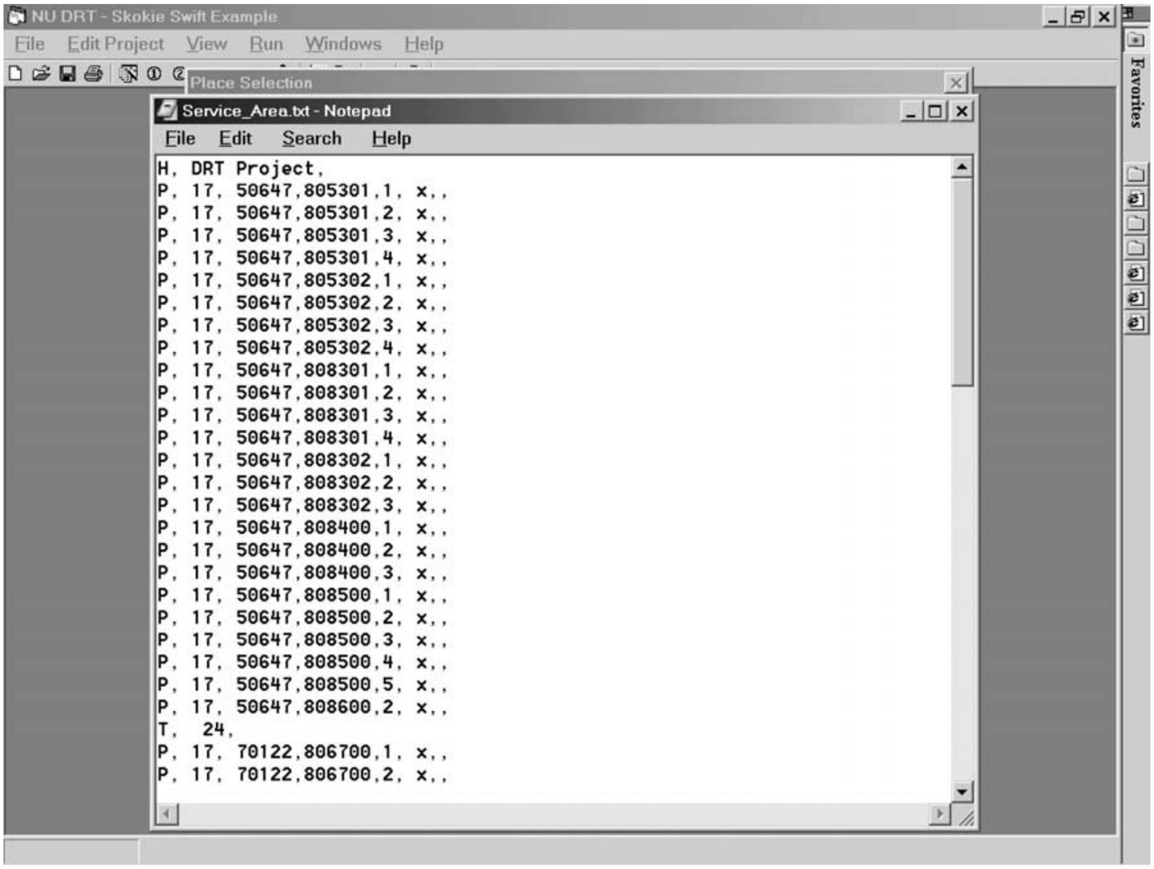

Figure 15. Service_Area.txt file for Morton Grove and Skokie.

subdivisions have a "C" in the first field, and block groups chosen by the tribal lands option have an "A." The file also has one or more header records with an "H" in the first field, plus "T" records containing a count of the block groups in the preceding place, county subdivision, or tribal land area.

The portion of the Service_Area.txt file displayed in Figure 15 lists the 24 full and partial block groups in Morton Grove and the first 2 of the 53 records for Skokie block groups. Each of the "P" block group records has a series of Census 2000 codes that uniquely identifies the block group. The "17" in the second field in each record is the Federal Information Processing Standards (FIPS) code for Illinois. The third field is the FIPS code for places, which is "50647" for Morton Grove and "70122" for Skokie. FIPS codes for states and places are available through links on the U.S. Census Bureau's website at: http://www.census.gov/geo/www/fips/fips.html (as of February 2003). The fourth field in the "P" record is a census code identifying the census tract where the block group is located. It is followed by the number of the block group in the fifth field.

Slightly different sequences of census codes are found in the Service_Area.txt block group records when the block groups are selected using county subdivisions or tribal lands. "C" records, selected using county subdivisions, identify block groups with the state FIPS code, county FIPS code, county subdivision FIPS code, census tract code, and block group number. The "A" type of block group records, obtained using tribal land units, have the state FIPS, tribal lands FIPS, county FIPS, census tract code, and block group number.

U.S. Census Bureau Reference Maps

The most direct way to locate tract and block group boundaries is through U.S. Census Bureau reference maps. Large printed copies of these reference maps and electronic versions on DVD may be purchased directly from the U.S. Census Bureau at a nominal cost. They can also be freely downloaded from state links provided on the U.S. Census Bureau website at http://www.census.gov/geo/www/maps/CP_Map Products.htm (as of February 2003). For DRT planners with geographic information systems (GIS) software, there are additional ways to locate tracts and block groups, either by downloading boundary files for tracks and block groups from the U.S. Census Bureau website or by purchasing these map layers from GIS vendors.

Because the DRT service area in the "many-to-one" example excludes a large portion of Skokie, the Skokie block groups in the Service_Area.txt block group records must be edited. To determine which block groups to exclude from the analysis, census block reference maps covering Skokie must be consulted. In addition to being obtainable by place, block level reference maps can be downloaded by county and county subdivisions.

There are five U.S. Census 2000 block maps for Skokie; they are numbered CBP1770122_000.pdf through CBP1770122_004.pdf. "CBP" stands for census block by place, and the numeric code is the combined Illinois and Skokie FIPS codes. The map files are portable document files (PDF) requiring the Adobe Acrobat Reader, which can be obtained without cost from the Adobe website (www.adobe.com).

The block reference map numbered "_000" is an index sheet showing the locations of the other four, more detailed, Skokie map panels. Figure 16 is the index sheet for Skokie, depicting the quadrants of the village covered by the four detailed block reference maps. Map Panels 1 (northwest quadrant) and 3 (southwest quadrant) contain the DRT service area in Skokie. These two map panels are shown in Figures 17a and 17b.

The PDF versions of these maps were created from large (33-inch by 36-inch) originals that show all the detail that is required to identify tracts, block groups, and blocks. In the printed versions included in this report, many map features will be too small to be easily identified. Copies of the Census 2000 PDF files for the three maps are included in the supplementary documents folder on *CRP-CD-40*. These can be viewed onscreen, and the user can zoom in on map features for increased legibility.

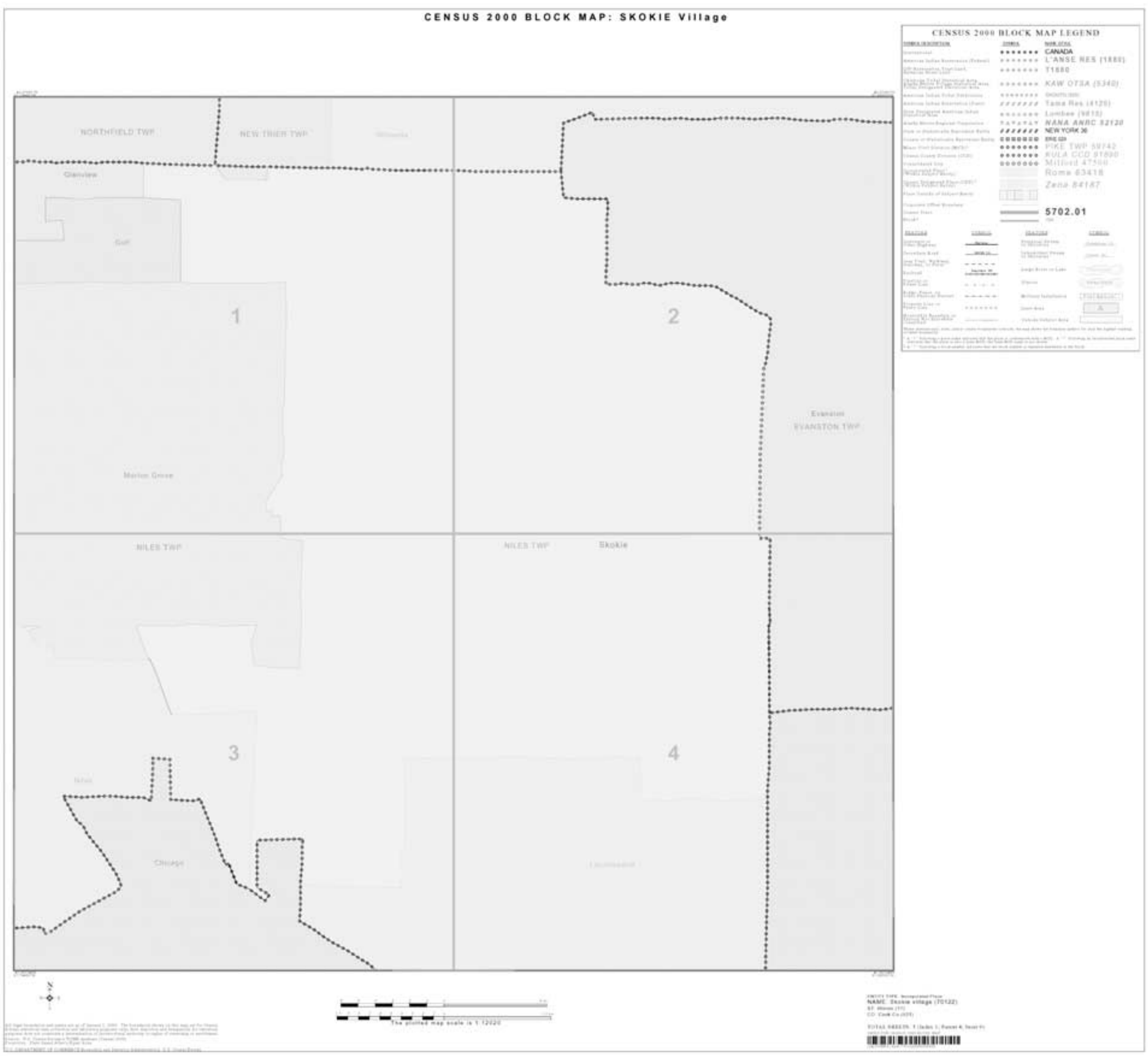

Figure 16. Census 2000 index sheet for Skokie Village block reference maps.

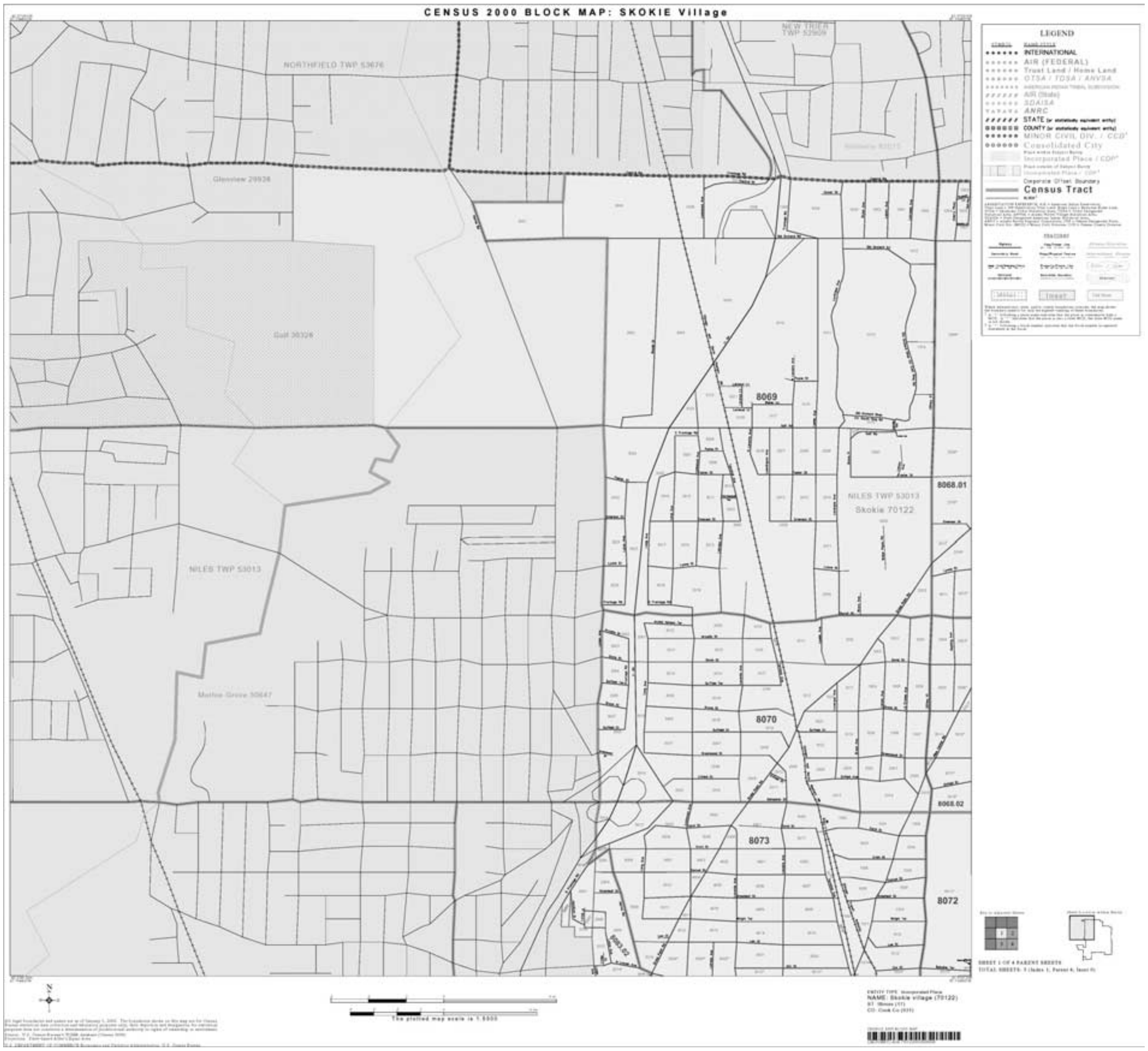

Figure 17a. Census 2000 Skokie village block reference map, Map Panel 1.

Editing Service Area Block Groups

Using these reference maps, it can be determined that the portion of the DRT service area in Skokie lies entirely within four census tracts: 8069, 8070, 8073, and 8083.02. Therefore, block groups outside these four census tracts must be removed from the service area. To remove block groups, return to the Service_Area.txt file shown in Figure 15. The sixth field contains an “x” that must be present when the block group belongs in the DRT service area. Therefore, to edit the Service_Area.txt file to match the proposed DRT service area in Skokie, delete the “x” in the sixth field from block group records that lie outside the four census tracts in the service area.

A portion of the edited Service_Area.txt file is shown in Figure 18. The “x” characters are removed from block groups outside tracts 8069, 8070, 8073, and 8083.02. Note that in the Service_Area.txt file, the census tract codes are six characters in length without a separating decimal point, and the Service_Area.txt codes for the four tracts inside the service area are 806900, 807000, 807300, and 808302. After completing the editing of the “x” characters, the Service_Area.txt file should be saved and the Notepad program exited using commands on the dropdown “File” menu. The service area is now completely defined, and “Finish” should be selected to allow the “Parameter Wizard” to continue.

Continuation of Data Entry

Once users have returned to the “Parameter Wizard,” the next several screens (examples are shown in the User’s Manual available on *CRP-CD-40*) are completed as follows:

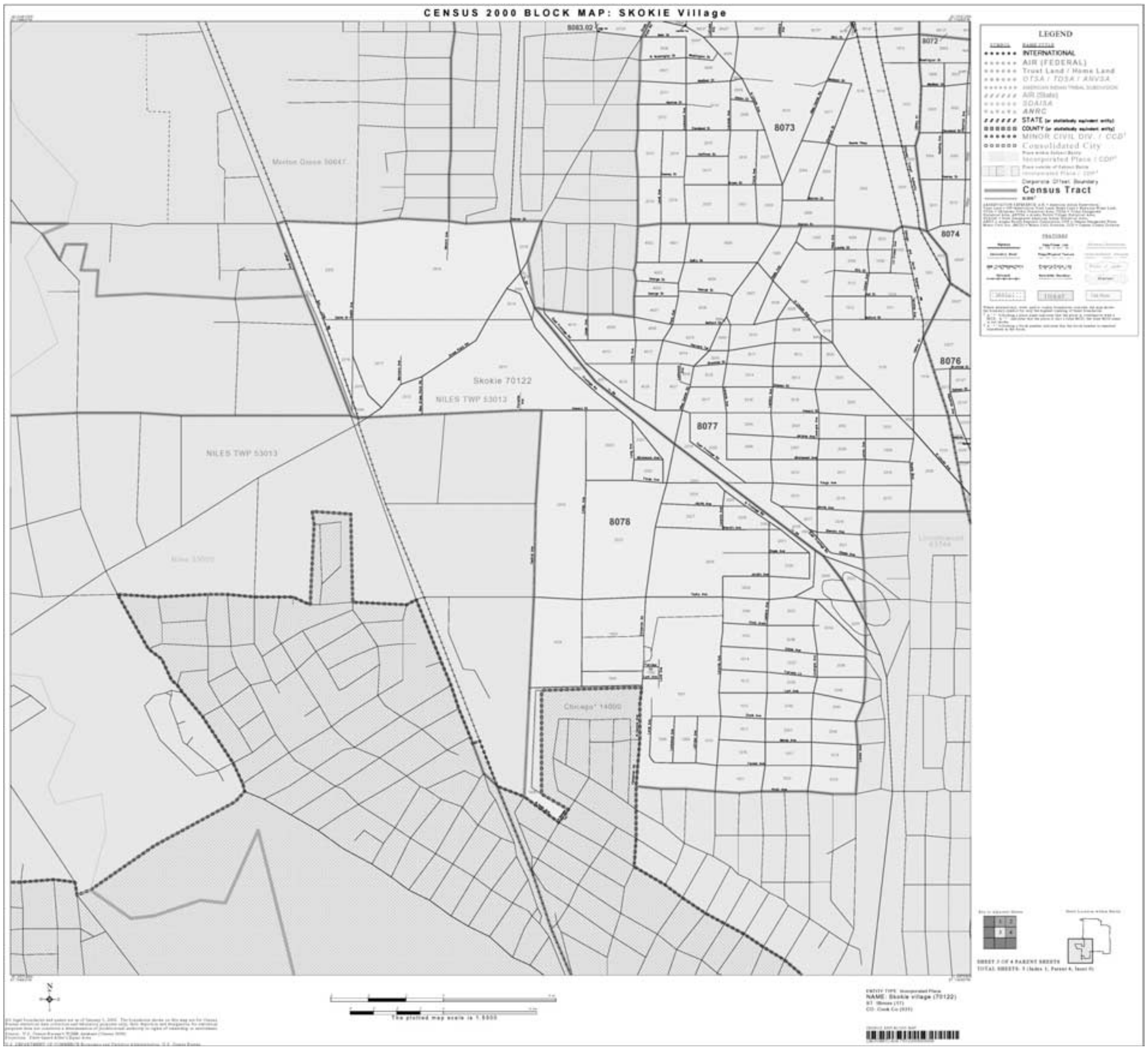

Figure 17b. Census 2000 Skokie village block reference map, Map Panel 3.

1. There is an expressway barrier (a linear barrier) in the DRT service area, but multiple bridges cross the expressway. Therefore, the box for "river or linear barrier" should be checked.
2. On the "Specify Type of Riders" screen, select "General Public" and click in the "Replacing some fixed route transit?" box.
3. On the "Operating Specifications" screen, input 5:30 in the "Start Time" box and 22:00 in the "End Time" box. The number of seats should be 10 with 2 wheelchair tie-downs (a wheelchair tie-down eliminates 2 seats when in use). Fifteen-minute windows (before and after the scheduled time) should be selected, and the computer assisted scheduling box should be checked.
4. Ridership is estimated starting with the journey-to-work data in the Census 2000 Summary File 3 (obtained using the American FactFinder feature on the U.S. Census Bureau's website at http://factfinder.census.gov/servlet/BasicFactsServlet), which lists 464 workers who currently commute by subway or elevated rail transit in the proposed DRT service area. It is estimated that 50 of these commuters ride to the Skokie Swift on bus lines that will be replaced by the DRT. The DRT is also expected to attract 100 new transit travelers diverted from automobiles; these are commuters who currently drive or share a ride to the Skokie Swift. Another 400 riders are projected to use the DRT for nonwork purposes. Fifty of these noncommuting riders will be former bus riders. Therefore, the DRT will serve a total of 1100 trips: 150 commuters plus 400 riders traveling for nonwork purposes, each of whom makes a round trip to and from the Skokie Swift. Two hundred of these trips will

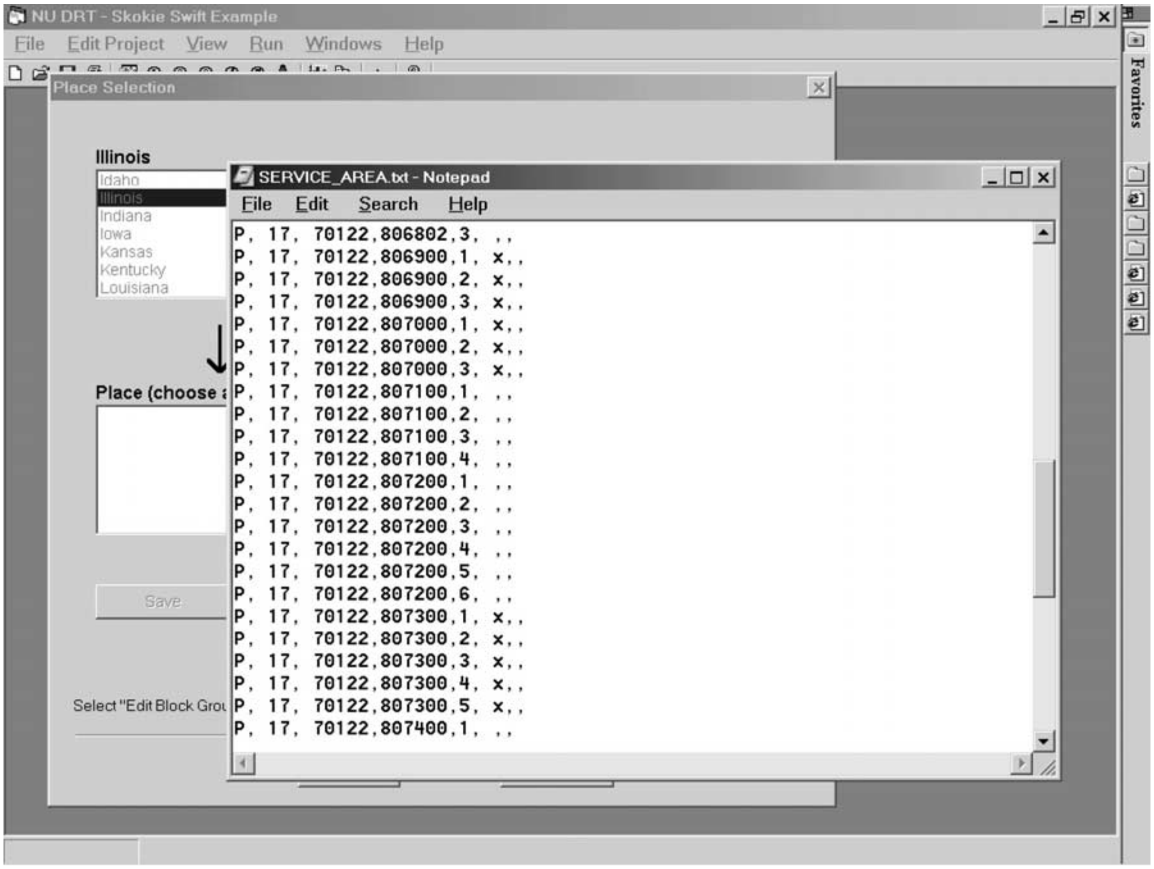

Figure 18. Edited Service_Area.txt file for DRT service area.

replace existing bus boardings. On the "Specify Number of Trips" screen insert 1100 into the "Number of Weekday Trips" box and click in the "Many-to-One" box.

"Many-to-One" Block Group Editing

When the "Many-to-One" box is checked, the Service_Area.txt file must again be manually edited to identify the block group where one or more "one" destinations are located. Figure 19 shows a portion of Map Panel 1 (CBP1770122_001.pdf) of the Skokie census block reference maps; the Skokie Swift Dempster Street terminal is located in block group 1 in tract 8073.

Select "Edit Block Groups" on the "Specify Number of Trips" screen and the Service_Area.txt screen comes up. Place an "m" in the seventh field in the record for the block group with the "one" destination. Up to three block groups in a DRT service area can be labeled as focal destinations for the "many-to-one" service. Figure 20 shows the completed "many-to-one" editing of the example Service_Area.txt file. Save the edited Service_Area.txt file and exit Notepad.

Completion of Data Entry

Once the "many-to-one" editing has been completed, data entry with the "Parameter Wizard" can continue.

1. Defaults are selected in the "Advanced Settings" screen for boarding and alighting times. Subscription trips should be set to zero. Click on the "Next" button.
2. The final "Parameter Wizard" screen appears. Select "Finish" to close the "Parameter Wizard."
3. Select "View" on the taskbar to review the input parameters and Service_Area.txt file.
4. Once the setting of input parameters and the definition of the service area have been finished, NU DRT is ready to run. Click "Run" on the taskbar, and the software executes.

Summary Report

In addition to the graphical output discussed earlier, NU DRT produces a summary text report that provides additional operating statistics (REPORT1.txt). The summary

Figure 19. Skokie Swift terminal block group.

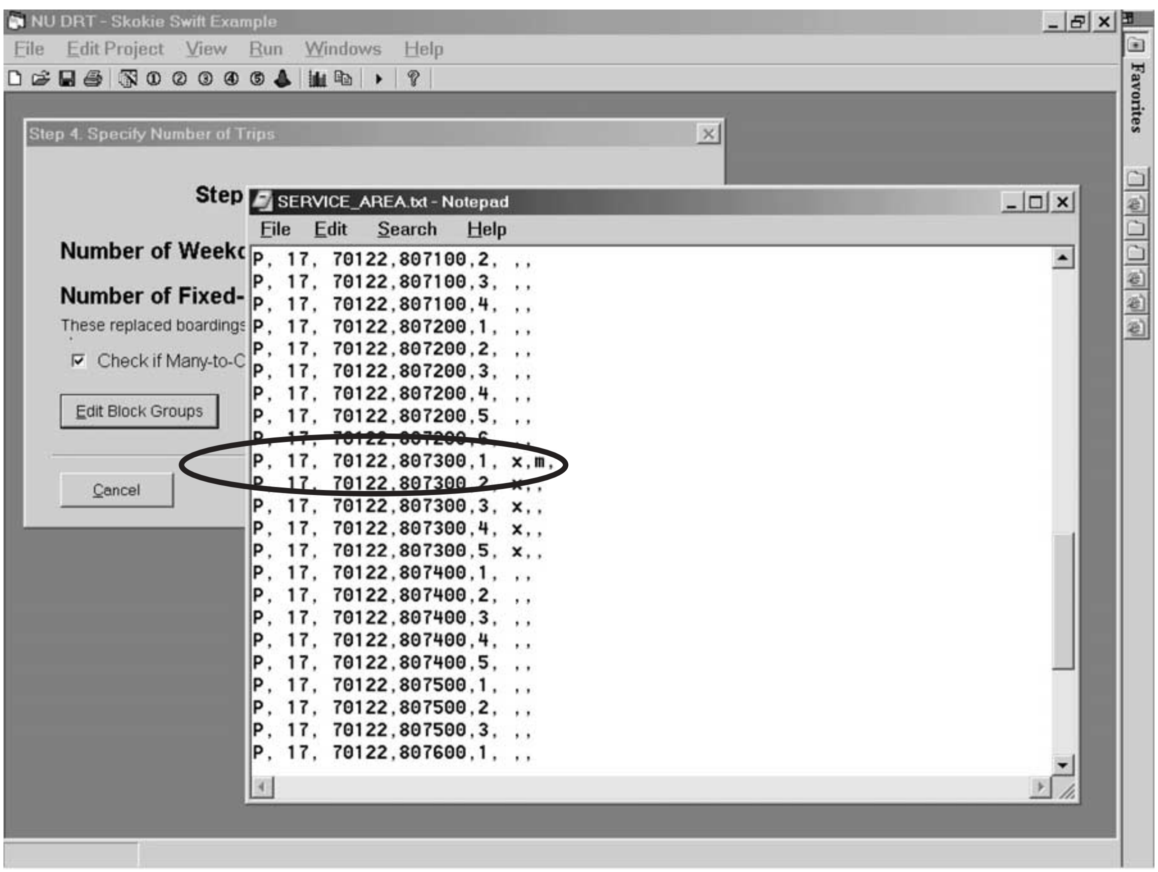

Figure 20. Edited Service_Area.txt file for “many-to-one” destination.

text report can be accessed by selecting “Summary Report” under “View” on the taskbar. These Summary Report statistics are computed for DRT fleet sizes that serve 80, 90, and 100 percent of weekday trips. The Summary Report for the Skokie Swift “many-to-one” example is shown in Figure 21.

Most of the measures in the Summary Report are self-explanatory, but several require some clarification:

- **Vehicles in Use.** This measure is calculated by summing the vehicles in use for all simulated days and then dividing by the number of days simulated. This calculation is different from that used to develop the tradeoff between percent of trips served and vehicles required (e.g., as illustrated in Figure 9). The latter is the *maximum* number of vehicles required to serve a given fraction of trips over all of the simulated days. The maximum number of vehicles needed to serve 100 percent of the trips will be greater than or equal to the average number needed. The average might be a better value to use for service design.
- **Riders Carried.** This measure includes all persons traveling, including attendants and multiple persons making the same trip.
- **Vehicle Trips (with Riders)** and **Vehicle-Miles (with Riders).** These two statistics count only vehicle movements when a rider is onboard. The numerator in **Vehicle Trips per Vehicle** is determined in the same manner.
- **Vehicle-Miles, Vehicle-Hours,** and **Speed.** These statistics do not include any mileage for traveling from the garage to the first pick-up or returning to the garage after the last passenger drop-off.
- **Passenger-Miles per Vehicle.** This value is the sum of the onboard riders times the mileage traveled between rider pick-ups or drop-offs divided by the number of vehicles in service.

SUMMARY REPORT OF AVERAGE DAILY ACTIVITIES
FOR SIMULATED DRT OPERATION

Skokie Swift Example

	PERCENTAGE OF TRIPS SERVED		
AVERAGE OF 25 SIMULATED DAYS	80%	90%	100%
VEHICLES IN USE	25.4	28.9	36.9
RIDERS CARRIED	917.7	1009.7	1101.0
RIDERS/VEHICLE	36.1	35.0	29.8
VEHICLE TRIPS (WITH RIDERS)	649.0	730.0	810.7
VEHICLE TRIPS/VEHICLE	25.6	25.3	22.0
VEHICLE-MILES	1655.0	1861.8	2061.9
VEHICLE-MILES/VEHICLE	65.2	64.5	55.8
VEHICLE-HOURS	344.5	388.2	432.5
VEHICLE-HOURS/VEHICLE	13.6	13.4	11.7
VEHICLE SPEED	4.8	4.8	4.8
VEHICLE-MILES (WITH RIDERS)	1068.1	1208.5	1355.7
PASSENGER-MILES	1750.7	1953.5	2196.5
PASSENGER MILES/VEHICLE	68.9	67.6	59.5
CIRCUITY (DRT MI/AUTO MI)	1.2	1.2	1.3

Figure 21. Skokie Swift example summary report.

- **Circuity.** This statistic is the DRT mileage traveled by riders divided by the equivalent mileage for direct travel without intermediate passenger pick-ups or drop-offs (the rectilinear distance between block group centroid coordinates).

Given the relatively high ridership per vehicle shown in the Summary Report, the Skokie Swift DRT service appears to be an efficient DRT operation. The Summary Report also illustrates the generally decreasing efficiency of each added vehicle. Vehicle utilization that serves 90 percent of riders is generally less efficient than vehicle utilization that serves 80 percent of riders. Vehicle utilization that serves 100 percent of riders declines even more in efficiency.

The data underlying the Summary Report are contained in the Detailed Report file (Results1.csv). This file can be viewed by selecting "Detailed Report" under the "View" option on the taskbar. It can also be conveniently loaded into a spreadsheet or database management program for additional analyses.

CHAPTER 5

VALIDATION AND SENSITIVITY ANALYSES

To verify the functionality of NU DRT and to compare its results with actual fleet sizes, a large number of test applications were conducted for places varying in size, markets, and service requirements. This chapter presents selected results of these tests and reminds readers of the applicability and limitations of the NU DRT software tool.

SENSITIVITY ANALYSES

NU DRT was tested on a midwestern city of about 24,000 people with existing DRT service for the general public. The goals were both to compare the fleet size results from the model with the actual fleet and to demonstrate the response of the model to variations in input data. Thirteen model runs were used to explore the response of the tool to different input variables.

Data from the NTD show that the service tested carries an average of 90 trips per weekday using 3 vehicles. No information is available on the fraction of trip demand served. The test DRT service operates from 8:30 a.m. until 4:30 p.m.

Vehicle Sizes and Computer Assisted Scheduling

Table 10 lists the results of testing different vehicle sizes, starting with a 15-passenger vehicle with 2 wheelchair tie-downs, each of which takes the place of 2 regular seats when in use (identified in Table 10 as a 15/2/2 vehicle size). Table 10 shows NU DRT estimates of the fleet size necessary to serve 95 percent and 100 percent of the demand to be five and six vehicles, respectively. The three vehicles in use are estimated to serve only 76 percent of the requested trips. Decreasing the vehicle size to 10/2/2, 8/4/2, or 6/1/2 would require more vehicles to serve the same market share. For example, six vehicles with capacity for six passengers and a single wheelchair tie-down (6/1/2) are needed to serve 95 percent of the demand.

Table 10 also lists test results for using a 15/2/2 vehicle under the assumption of computer assisted scheduling. These results show that one to two fewer vehicles could serve the demand if they were scheduled more efficiently. Even though a three-vehicle operation may not need computer assisted scheduling, utilizing this NU DRT option may better reflect actual service, because experienced dispatchers can develop a good understanding of market and service characteristics so that efficiency of vehicle use improves over time. With computer assisted scheduling, NU DRT estimates that the three vehicles in the actual fleet could serve 90 percent of the demand.

Trips Requested

In the next series of tests, the number of daily trip requests was increased from 90 to 135 and then decreased to 45. Table 11 shows, as expected, that vehicle fleet requirements change by a percentage similar to the change in demand.

Types of Riders Served

Different types of riders place different requirements on the vehicle fleet. Riders whose mobility is limited make more wheelchair trips and often require an attendant. Senior citizens have more mobility limitations that the general public, and they take fewer peak-period trips to workplaces. The trip simulation module of NU DRT reflects these kinds of differences in travel characteristics.

Table 12 lists the results of changing the market type for the 90 daily trips, and for travelers whose mobility is limited, the results of using a larger vehicle with more wheelchair tie-downs (15/4/2/ instead of 10/2/2). These simulation runs show that markets that require more wheelchair tie-downs and travel attendants generally need additional vehicles. Using somewhat larger vehicles with additional tie-down positions reduces fleet size because each vehicle accommodates more riders and wheelchairs.

Expanding Hours of Service and Service Area

Table 13 shows the result on fleet requirements of changes in service hours and area. The second column illustrates the effects of increasing the hours of service by 50 percent (4 hours) without increasing the number of trips (which remain at 90 per day). There is a small decrease in vehicle requirements for carrying 100 percent of the demand because there is less demand at any point in time. The third column shows the effect of increasing the service area by a factor of about 10, in this case expanding the service area beyond the city limits

TABLE 10 Testing vehicle size and computer scheduling

Sensitivity Measure	Vehicle Sizes: 15/2/2	10/2/2	8/4/2	6/1/2	15/2/2 Vehicle, Computer Assisted Scheduling
Fleet Size to Serve 95% of Trips	5	5	6	6	4
Fleet Size to Serve 100% of Trips	6	7	8	8	4
Trips Served by Three-vehicle Fleet	76%	75%	75%	71%	90%

to the entire 2,600-square-mile county. The county is sparsely populated, with demand concentrated in the central city, but the large increase in land area leads to some substantially longer trips. As a consequence, the service rate goes down, and thus more vehicles are needed.

In all of the sensitivity tests, NU DRT shows intuitively reasonable responses to changes in inputs. None of the results are extreme; rather, they show small deviations in the number of vehicles required in response to small changes in service and market characteristics.

VALIDATION TESTING

In the development of NU DRT, many test runs were made with data from actual services to fine-tune the software and make sure that its results were realistic. The final version of NU DRT was tested with data supplied by Pace, a northeastern Illinois suburban bus operator, which is responsible for a number of DRT paratransit services throughout the region. Table 14 lists both the input data and results from NU DRT simulations for nine of these services.

The inputs to the NU DRT runs are the service area definitions, market types, daily hours of service, and average number of trip requests per day. All services were tested using 30-minute pick-up and drop-off windows and computer assisted vehicle scheduling. The actual number of vehicles in service is shown in the fifth row of Table 14. Three quantities estimated by NU DRT are shown in the shaded rows: the numbers of vehicles required for 95 and 100 percent of the daily trip demand and the estimated percentage of demand served by the actual fleet of vehicles. The last three rows of Table 14 show measured trip characteristics reported by Pace.

NU DRT results correspond to the data rather well. The largest differences between model results and actual service are underestimates in DuPage County and the village of Schaumburg. The underestimate for DuPage County may be due to the low productivity of the actual service, only 3.9 trips per vehicle per day. This might be caused by a market characteristic not reflected in NU DRT, or perhaps fewer vehicles might well serve the market.

A similar argument might be made for Schaumburg. There is a high level of local interest in public transit and a broad mix of land uses (residential, office, and retail) in this community. These factors, combined with the fact that the Schaumburg DRT operation serves the general public, may cause trips to be widely dispersed around the village or to peak at certain times during the day. For example, the short average trip distance suggests that there may be a number of shopping trips during the lunch hour that call for additional vehicles.

The comparison between actual and estimated fleet sizes shown in Table 14 is further illustrated in Figure 22, which compares the NU DRT estimated vehicle fleet size needed to carry 95 percent of the daily trip demand with the actual fleet size. As Figure 22 shows, the correspondence is reasonably good.

TABLE 11 Fleet requirements by daily trip requests

Sensitivity Measure	Weekday Trips (10/2/2 Vehicle): 135	90	45
Fleet Size to Serve 95% of Trips	8	5	3
Fleet Size to Serve 100% of Trips	14	7	5
Trips Served by Three-vehicle Fleet	52%	75%	97%

TABLE 12 Fleet requirements by type of rider and vehicle

Sensitivity Measure	Types of Riders and Vehicles: General Public, 10/2/2 Vehicle	Mobility Limited, 10/2/2 Vehicle	Mobility Limited and Seniors, 10/2/2 Vehicle	Mobility Limited, 15/4/2 Vehicle
Fleet Size to Serve 95% of Trips	5	6	5	5
Fleet Size to Serve 100% of Trips	7	8	7	7
Trips Served by Three-vehicle Fleet	75%	66%	73%	80%

TABLE 13 Fleet requirements by service hours and area

Sensitivity Measure	Hours of Service and Service Area (General Public Service, 10/2/2 Vehicle): 8:30 a.m.–4:30 p.m., Citywide	7:00 a.m.–7:00 p.m., Citywide	8:30 a.m.–4:30 p.m., Countywide
Fleet Size to Serve 95% of Trips	5	6	9
Fleet Size to Serve 100% of Trips	7	6	13
Trips Served by Three-vehicle Fleet	75%	76%	59%

TABLE 14 Validation tests for selected Pace DRT services in the northeastern Illinois suburbs

	Location of Pace DRT Service								
	Aurora	Bensenville	DuPage County	Kane County	Rich Township	Robbins	Schaumburg	Skokie	Woodstock
Pace Data									
Types of Riders	Senior and ADA	General Public	Senior and ADA	ADA	Senior and ADA	Senior and ADA	General Public	Senior and ADA	General Public
Weekday Hours	7:00 a.m.– 5:00 p.m.	6:00 a.m.– 6:00 p.m.	7:00 a.m.– 5:00 p.m.	5:30 a.m.- 8:00 p.m.	8:00 a.m.– 4:00 p.m.	10:00 a.m.– 4:00 p.m.	6:00 a.m.– 6:00 p.m.	9:00 a.m.– 6:00 p.m.	6:00 a.m.– 6:00 p.m.
Trips/Day	142	95	63	85	195	7	275	35	95
Vehicle Size	15/2/2	15/2/2	8/2/2	15/2/2	15/2/2	15/2/2	15/2/2	15/2/2	8/2/2
Vehicle Fleet	7	3	16	8	10	1	20	4	4
NU DRT Estimates									
Fleet Size to Serve 95% of Trips	9	3	5	7	10	1	11	2	3
Fleet Size to Serve 100% of Trips	10	4	5	8	12	1	13	2	4
Trips Served by Actual Vehicle Fleet	80%	98%	100%	100%	95%	100%	100%	100%	100%
Trip Characteristics									
Vehicle-miles/Trip	3.6	2.4	12.8	12.6	5.0	1.6	3.8	3.9	1.9
Average Speed	14.2	11.6	18.0	20.2	30.5	7.3	16.5	9.3	13.0
Trips/Vehicle/Day	20.3	31.7	3.9	10.6	19.5	7.0	13.8	8.8	23.8

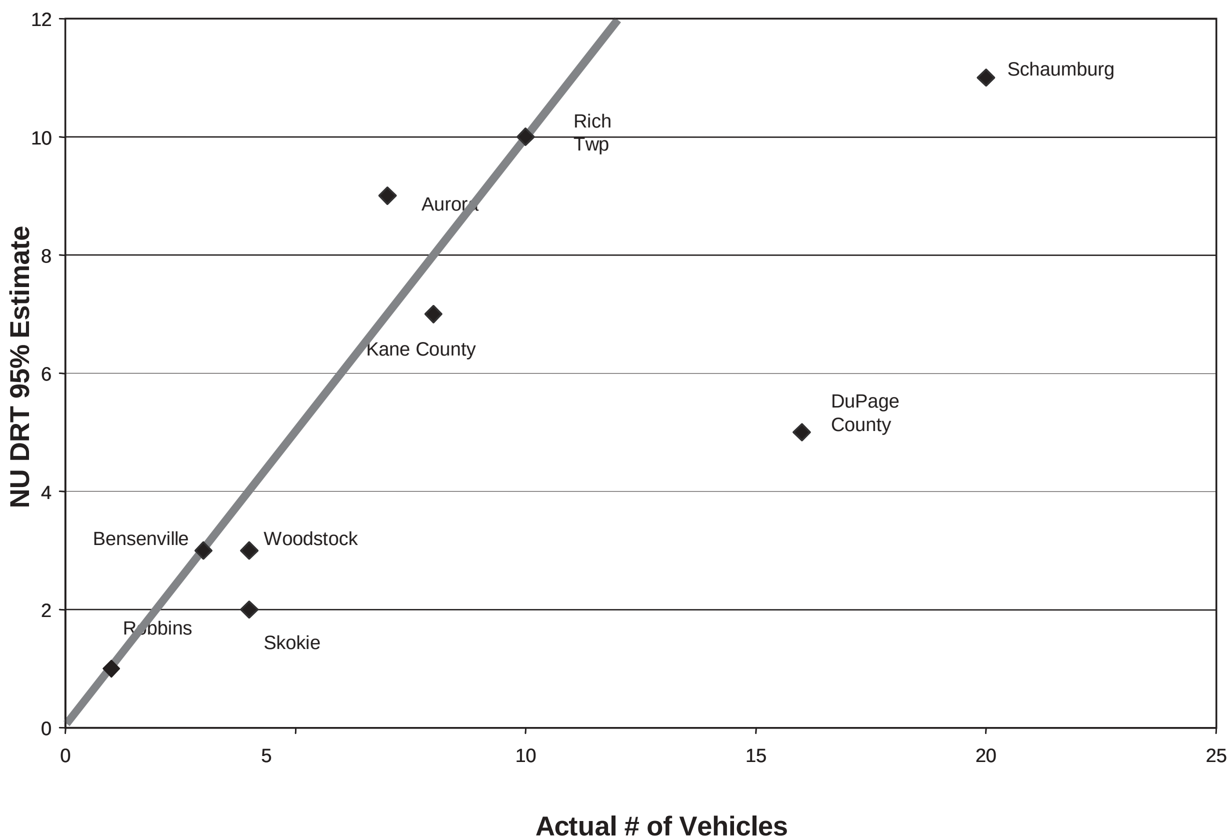

Figure 22. NU DRT estimate of the fleet size required to carry 95 percent of daily trips versus actual fleet size.

NU DRT produces estimates of vehicle requirements that are fairly close to the actual fleet sizes for the nine Pace services tested here. When there are large differences, there is usually a plausible explanation for the error. This and other tests support the validity of NU DRT for producing a rough estimate of vehicle requirements. It is important for the reader to keep in mind that (1) this is a rough model intended to estimate vehicle requirements when little else is known, (2) the actual fraction of demand served is not known, and (3) there may be additional factors affecting fleet size that are not or cannot be reflected in the NU DRT estimating tool.

Users should recognize that many assumptions are built into the NU DRT software that support its general applicability, but, at the same time, these assumptions may limit its ability to replicate particular situations. This may be the case when the actual trips demanded and/or the network and travel time characteristics produce significant distortions of the service times. It is important for users to anticipate these factors and to build them into the input data.

In cases where special circumstances cannot be reflected in the input data, judicious adjustments may be required. Although there is no substitute for local knowledge and good judgment in making estimates of required fleet size, NU DRT can quickly provide users with rough guidance on vehicle requirements and can support rapid and extensive sensitivity analysis to assess service design options.

CHAPTER **6**

CONCLUSIONS AND FUTURE RESEARCH

CONCLUSIONS

NU DRT is a useful and easily applied tool for supporting planning of new DRT services, extensions of DRT to larger service areas or additional types of riders, and conversions of fixed route transit lines to DRT services. The fleet size estimates it produces compare favorably with observed values; and, when substantial deviations occur, they can usually be explained in terms of unique area or market characteristics. Although NU DRT represents a significant simplification of the operation of a DRT service, the underlying simulation model accounts for the most important factors affecting required vehicle resources.

NU DRT is designed to balance realism with ease of use; and, in particular, the software is designed to minimize the task of supplying input data. Although it is not network-based, NU DRT does account for the geography of the service area through the spatial coordinates of census block groups. Demographic and spatial data from Census 2000 are packaged with NU DRT, and built-in parameters were derived from widely used sources describing travel in general and travel by those with mobility limitations in particular. The program is well grounded in the existing knowledge of DRT travel patterns.

NU DRT is, however, a rough model, and as such it cannot be expected to represent any particular area with a high level of precision. It can support DRT feasibility assessment and initial fleet planning, but more detailed analysis may be warranted for service design. Because it is not network-based, NU DRT cannot capture every nuance of a specific setting, and, therefore, users can expect some difference between the number of vehicles actually required for service and the number called for by the estimation tool. Under most circumstances, these differences should not be large.

There is no substitute for local knowledge and experience, and users should be cautious of NU DRT estimates when trips are unusually distributed between origins and destinations or by time of day, such as when trips are focused during only a few hours of the day (more than just normal trip peaking) or when unusual spatial patterns occur (other than "many-to-one" markets). Because NU DRT is not a network-based simulation, travel time distortions caused by severe bottlenecks or other unusual travel barriers (beyond those that the model can represent) may substantially affect the accuracy of the model estimates.

FUTURE RESEARCH AND DEVELOPMENT

A number of improvements could enhance the value of NU DRT. For example, additional model parameters could be made available for user control. One example would be to allow users to specify average travel speeds by time of day. This might increase accuracy by a small amount, but it would also place additional burdens on users.

The model might be adapted to deal with multiple vehicle types to support testing of DRT fleets composed of vehicles with different capacities. This would require a significant increase in model complexity and processing time, but it might provide the improved planning capabilities required by more advanced users, even though most users would continue to work with a single-vehicle design. The current single-vehicle-type model structure seems adequate for initial planning because it is a very simple matter to test different vehicle sizes and to develop judicious estimates of the effect of a mix of vehicle types on total fleet requirements.

The most useful enhancement of NU DRT would be the addition of a simple demand estimation module. It would be important to develop and deliver this as another rough model to limit the effort required of the user to supply input data. For example, DRT trips demanded might be estimated based on available census demographic data and definitions of rider markets. To develop such a model, it will be necessary to have actual DRT demand for enough different settings to perform statistical estimation. Although the annual NTD reports the number of trips carried for the DRT services of most transit operators, these data do not include information on what fraction of the true demand is actually served. A model built on these data would tend to underestimate actual DRT demand. Finally, it would be valuable for the community of users of NU DRT to share their experiences to identify estimation biases and ways to account for them.

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APPENDIX A

NU DRT SOFTWARE OPERATING SYSTEM REQUIREMENTS, INSTALLATION INSTRUCTIONS, AND START-UP

This appendix provides information on operating system requirements and installation procedures for the NU DRT software provided on *CRP-CD-40*, which accompanies the report. Also provided on the CD-ROM is a user manual for NU DRT and supplementary documents.

OPERATING SYSTEM REQUIREMENTS

Operating systems that will run the NU DRT software include Windows 95, Windows NT4, Windows 98 SE, Windows 2000, Windows ME, or Windows XP. At least 10 MB of hard disk space should be available.

INSTALLATION INSTRUCTIONS

To install the program, insert the CD into the CD-ROM drive. Open the CD-ROM (via the operating system) and click on the setup.exe file on the installation CD. The installation process will begin and should proceed automatically. To remove the software, use the "Add/Remove Programs" feature of your operating system.

STARTING THE PROGRAM

After installation, the program can be launched from the Start → program menu. Click on "NU DRT" in the program menu and then on "NU DRT" in the submenu to launch the program. *NOTE: When running the program, the installation CD must be in the CD-ROM drive.*

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation