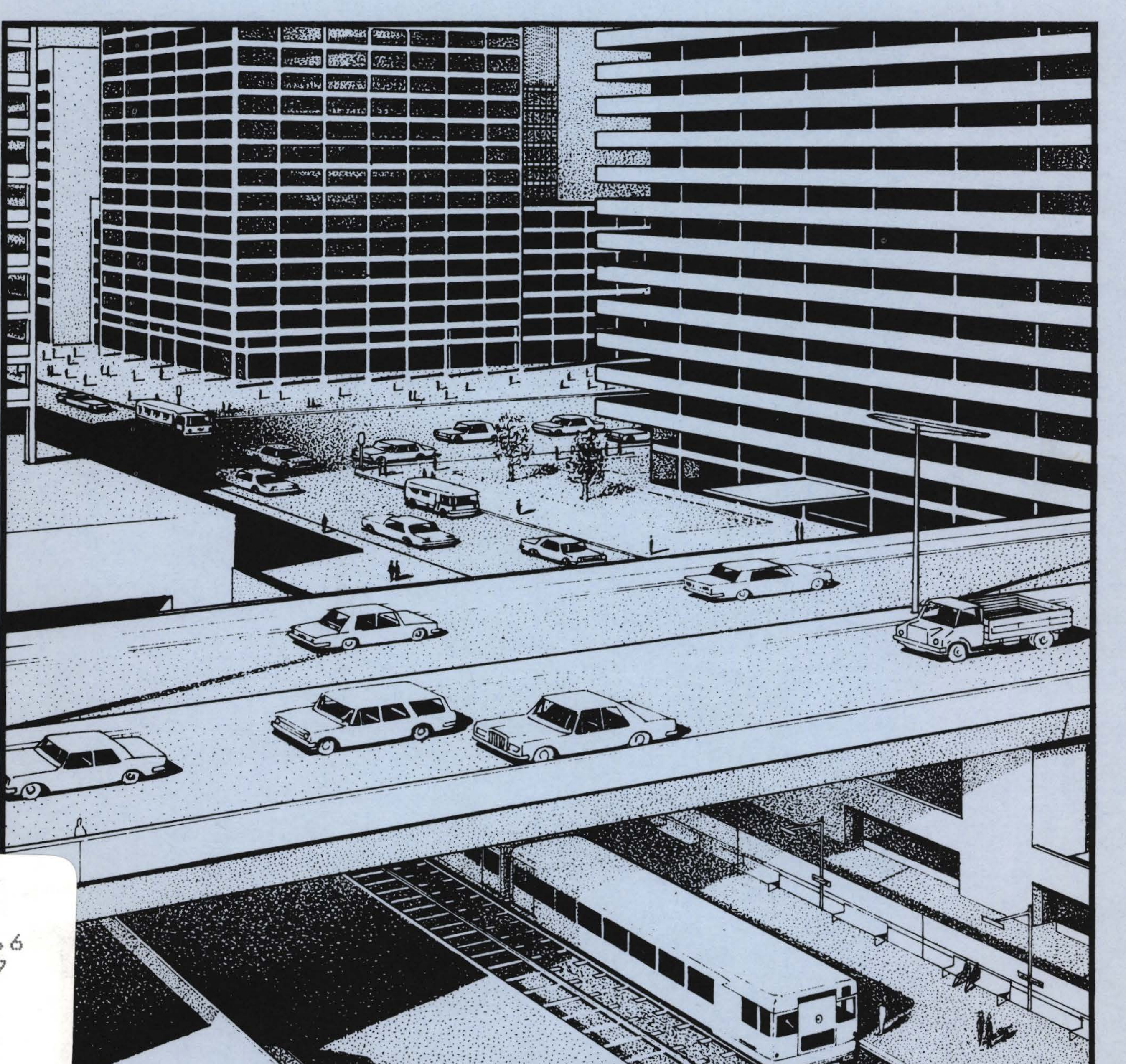
U.S. Department
of Transportation

Systan's Macro-Analytic Regionwide Transportation Model

Application Manual

March 1983



Systan's Macro-Analytic Regionwide Transportation Model: Application Manual

Final Report
March 1983

Prepared by
Carolyn Fratessa and Wei-Yue Lim
Systan, Inc.
343 Second Street
Los Altos, California 94022

Prepared for
Office of Technical Assistance
Urban Mass Transportation Administration
Washington, D.C. 20590

and

Office of Technology and Planning Assistance
Office of the Secretary of Transportation
Washington, D.C. 20590

DOT-I-83-57

PREFACE

SYSTAN's Macro-Analytic Regionwide Transportation (SMART) model is a sketch planning tool for evaluating public transportation alternatives for metropolitan areas. The model and its documentation were developed as part of the Paratransit Integration Program sponsored by the Office of Bus and Paratransit Technology and the Urban Mass Transportation Administration and by the Office of Technology and Planning Assistance of the Office of the Secretary of Transportation. The Paratransit Integration Program is concerned with the development and application of macro-analytic techniques for policy and preliminary planning at the local level.

The SMART model documentation consists of three volumes:

> Application Manual: This report describes the use of the model to formulate, evaluate, and compare public transit options for urban regions. It discusses the structure of the model and the purpose of each major component. It also includes detailed application information for four case studies. The document is designed for use by transit planners who must assess the suitability of the model and, if appropriate, use it to investigate urban transportation alternatives.
>
> User's Guide: This document focuses on the preparation and formatting of data for use in the model. Examples are presented, and error messages are explained. The document builds on material in the Applications Manual and is required to run the SMART computer program.
>
> Program Maintenance Manual: This manual describes the internal structure of the computer program, including module structure and linkage and data structures. It includes material on installation and on potential model alterations. Written for the skilled FORTRAN programmer, each installation of the SMART model computer program should have at least one copy of this manual.

The SMART computer program was written by Andrew J. Canfield. Site applications were performed by Carolyn Fratessa and Dr. Wei-Yue Lim. All work was performed under the direction of Dr. Paul S. Jones. SYSTAN gratefully acknowledges the technical and administrative guidance and support of Edward Neigut and Michael Markowski of UMTA. Many other UMTA and DOT staff members have given freely of their time and skill to offer valuable input to the work. However, SYSTAN is solely responsible for the results.

CONTENTS

EXHIBITS

Exhibits, continued

Exhibits, continued

1. INTRODUCTION

A variety of issues constrain a transportation planner today. Conservation of local fiscal resources, compliance with environmental regulations, reduction of energy use, and the needs of special interest groups are only a few of the concerns that must be addressed if an urban transportation plan is to be accepted and eventually implemented by transit operators and decision-makers. In order to address these concerns adequately, a large number of public transportation alternatives must be developed and evaluated quickly and inexpensively.[1]

SYSTAN's Macro-Analytic Regionwide Transportation (SMART) model can help to accomplish this task. It was designed to aid planners in the study and evaluation of large numbers of multimodal urban transportation systems and transportation policy actions. The model's utility rests in its ability to analyze the implications of major modal shifts between different transportation modes using a macro-level methodology that requires minimal data input and computer time. (Analysis of small-scale shifts is also possible.) SMART allows the study area to be described in general terms and default values to be used for many of the model parameters. (Both experienced and less experienced persons can profit from using the SMART model.) Special circumstances and special needs can be accommodated by changing zone sizes, inventively using population-density variants, and carefully specifying the services to be examined.

The model can be used effectively to help planners address some of the most critical local issues:

1. Future growth and development. SMART can explore the implications of growth and identify promising alternatives to traffic congestion.

2. Neighborhood traffic congestion. SMART can be used to investigate different transit and paratransit alternatives and to assess the impacts of each on traffic congestion.

3. Highway development. SMART can explore a wide range of alternatives to highway development, including arterial streets, heavy rail, light rail, express bus, subscription services, and diversified commercial development.

4. Fixed-route bus service. SMART can explore a large number of alternatives to fixed-route bus service and can examine a variety of application areas to produce supporting data for fare, subsidy, and service comparisons.

---

[1] At the time this project was initiated, the use of microcomputers was not as widespread as is the case today. Thus, the possible microcomputer applications of SMART are not treated within the scope of this study.

5. Carpooling and vanpooling. SMART can address the impacts of increased carpooling and vanpooling and give quantitative measures of congestion relief and energy savings.

6. Demand-responsive services. SMART can examine dial-a-ride and shared-ride taxi services in a variety of urban settings.

7. Mobility of transit-deficient groups. SMART can examine a large number of alternative ways to increase the mobility of the aged, infirm, and young.

8. Local resources and concerns. SMART can investigate present and future service, cost, and revenue for groups in different geographic locations and with different travel needs.

While the SMART model is particularly useful in analyzing policy issues (i.e., the feasibility of expanding the public transit service area or the impact of large increases in transit travel), it can also enhance preliminary planning activities. Determining the transit mode share necessary to justify heavy rail, assessing the viability of AGT systems in central business districts, and examining the cost and fleet size implications of more frequent service in selected areas are examples of some of the tasks that can be accomplished by SMART analysis. The SMART model can also be used for long-range development planning. Decision points can be established for changes in the course of development; service expansion can be tied to patronage milestones; changeover points can be identified for shifting from one type of service to another; and financial plans can be prepared and monitored.

The SMART model can be used at many levels of detail. At the least, it can be executed in its default mode to secure information about the relative performance of a city's different transit modes. Substitution of specific data for the default values can bring the model representation closer to a particular urban area, resulting in increasingly accurate information for the study area. In general, the smaller the area modeled, the greater the opportunity for detailed representation.

It is important to stress some of the model's limitations. SMART performs at a macro level and represents urban travel in a deterministic way. The model does not estimate travel demand, but rather explores selected mode shares for each investigation. Local trips within zones are expressed in terms of mean values; single routings are selected for all travel between pairs of network nodes; and vehicle performance and fleet size are the result of deterministic calculations. Thus, while the results are useful for making coarse comparisons among wide-ranging alternatives, they are not adequate for analyzing small differences between similar services. More detailed evaluation of the details important to the design and installation of new services is necessary before a proposed system is implemented.

This report is intended to inform the transportation planner of the potential uses of the SMART model and to offer guidance for its application. It describes the model, proposes a broad set of potential applications for the model and strategies for each use, and presents the results of the model's application in two U.S. cities.

2. THE SMART MODEL

Basically, the SMART model presents aggregate data on transit operations together with aggregate data on all trips and detailed data on a selected sample of trips. Variances in trip times are calculated as a measure of service variability and dependability. Transit alternatives can be compared in terms of mean travel time, fleet size, mean trip cost, fuel consumption, service reliability, and similar measures.

An urban region is represented for the mode in terms of three basic structural components: residential areas with minor activity centers, central business districts (CBDs), and a line-haul network. The urban structure, however, can have no more than 50 nodes, 100 zones, and 100 links. Residential and CBD zones are linked together by a network of freeways, major arterial streets, and exclusive transitways. No explicit attempt is made to define the surface street network in the residential or CBD zones; only the freeway/major arterial network need be specified in detail. Peak and off-peak travel volumes are generated between zones, and public transit trips are varied parametrically.

One or more CBD zones can be designated, but each must have at least one connection to the freeway/arterial network. Individual residential zones can vary widely in size—from less than one square mile to 100 square miles or more. Residential zones can either be grouped and described in terms of classes, or each zone can be described in terms of its unique characteristics. While all population and employment centers of the area should be represented, the entire area need not be included. Vacant and sparsely populated land can be omitted.

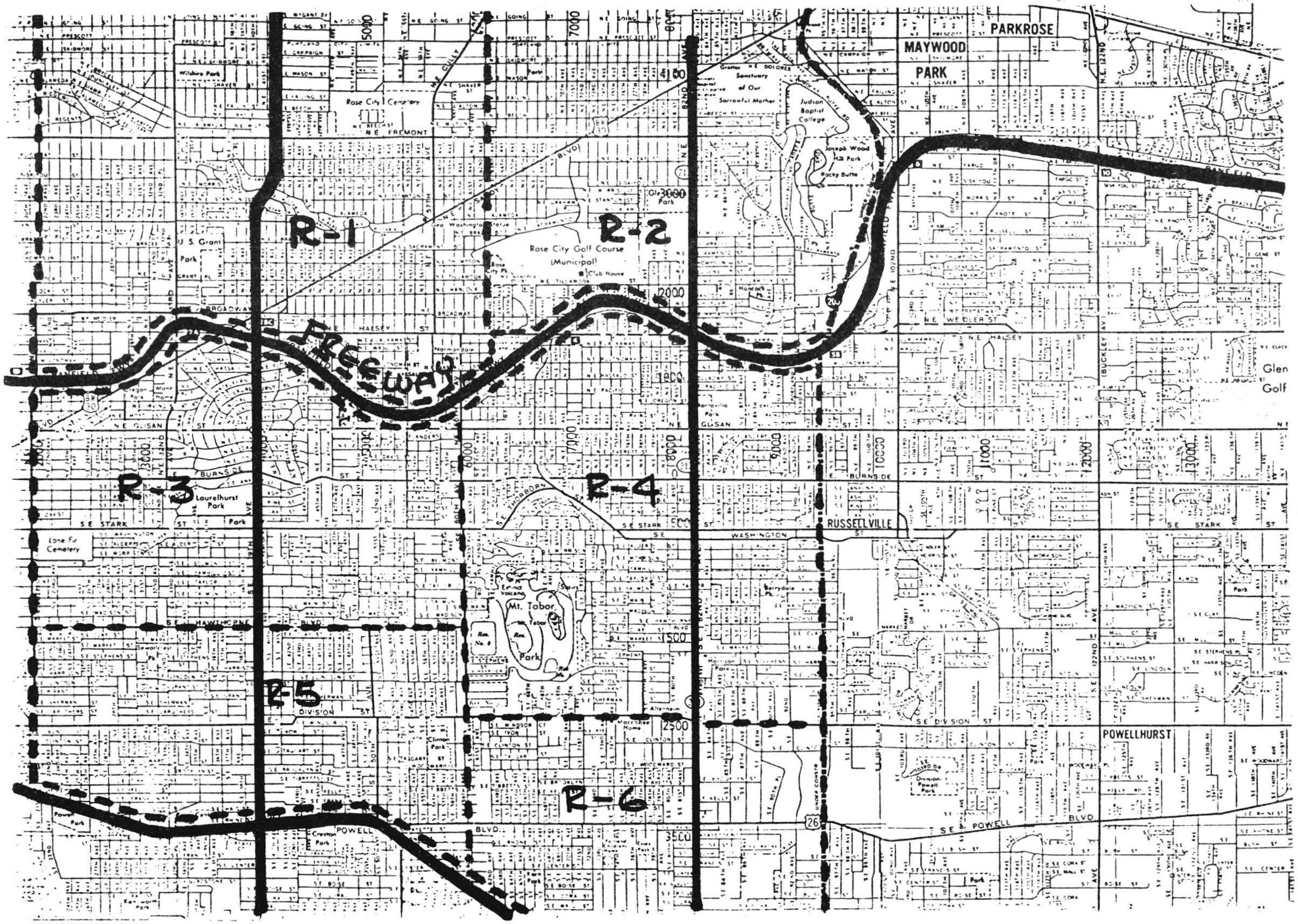
The model has a built-in demand generation procedure. Zone and link characteristics have been assigned default values, but these can be superseded whenever desired. Travel patterns can be defined by setting values for the number of origin-destination (O-D) trips, the volume of flows on links, zonal demand parameters such as population and employment densities, trip lengths for different trip purposes, and even transit loading and unloading rates.

2.1 URBAN STRUCTURE

Use of the model begins with the formulation of a model structure that represents the study area. Exhibit 2.1 shows a typical urban structure for use in SMART model analysis. Six residential areas have been identified (R-1 through R-6). Each area is bounded on one side by a transportation link and interchanges traffic with that link at a single point. The areas of the six zones vary from 2 to 4.5 square miles, which is typical for fully developed neighborhoods close to a city center. Parks, golf courses, and cemeteries are omitted from the model by simply reducing the zone areas. The transportation links form a grid network whose nodes are the zone traffic interchange points. One route is a freeway and the others are major arterial streets. Links pass through the centers of all residential areas to complete the grid, but the SMART model restricts traffic interchange with these links to each area's traffic interchange point.

EXHIBIT 2.1

TYPICAL INTERPRETATION OF URBAN STRUCTURE FOR SMART MODEL



Two types of networks are available to the SMART model user—a ring/corridor structure and an arbitrary network structure:

- The ring/corridor structure assigns a circular network to the area (Exhibit 2.2). By default, the center of the circle is the CBD from which traffic corridors radiate at angles specified by the user or default. Residential zones are grouped in rings, with exactly two zones adjacent to each radial corridor. The user specifies only the number of rings, the number of corridors, and the ring radii. Circumferential corridors interconnect the zones of a ring and offer transfer opportunities at intersections with radial corridors. Link lengths can be adjusted so that the actual representation is more like that shown in Exhibit 2.3. Zone areas, population densities, and employment densities can also be adjusted by ring or by zone. The areas need not fill the geometrical space; they can overlap or leave voids.

- The arbitrary network representation allows freedom from the formality of the circular structure. Any network configuration can be selected to suit the area, but the network must be completely specified by the user; all zone and link characteristics must be specified.

The model does not differentiate between the two structured designations. Both are treated as networks that have zones, links, and nodes with defined characteristics.

2.2 TRAVEL MODES

SMART models eight different travel modes:

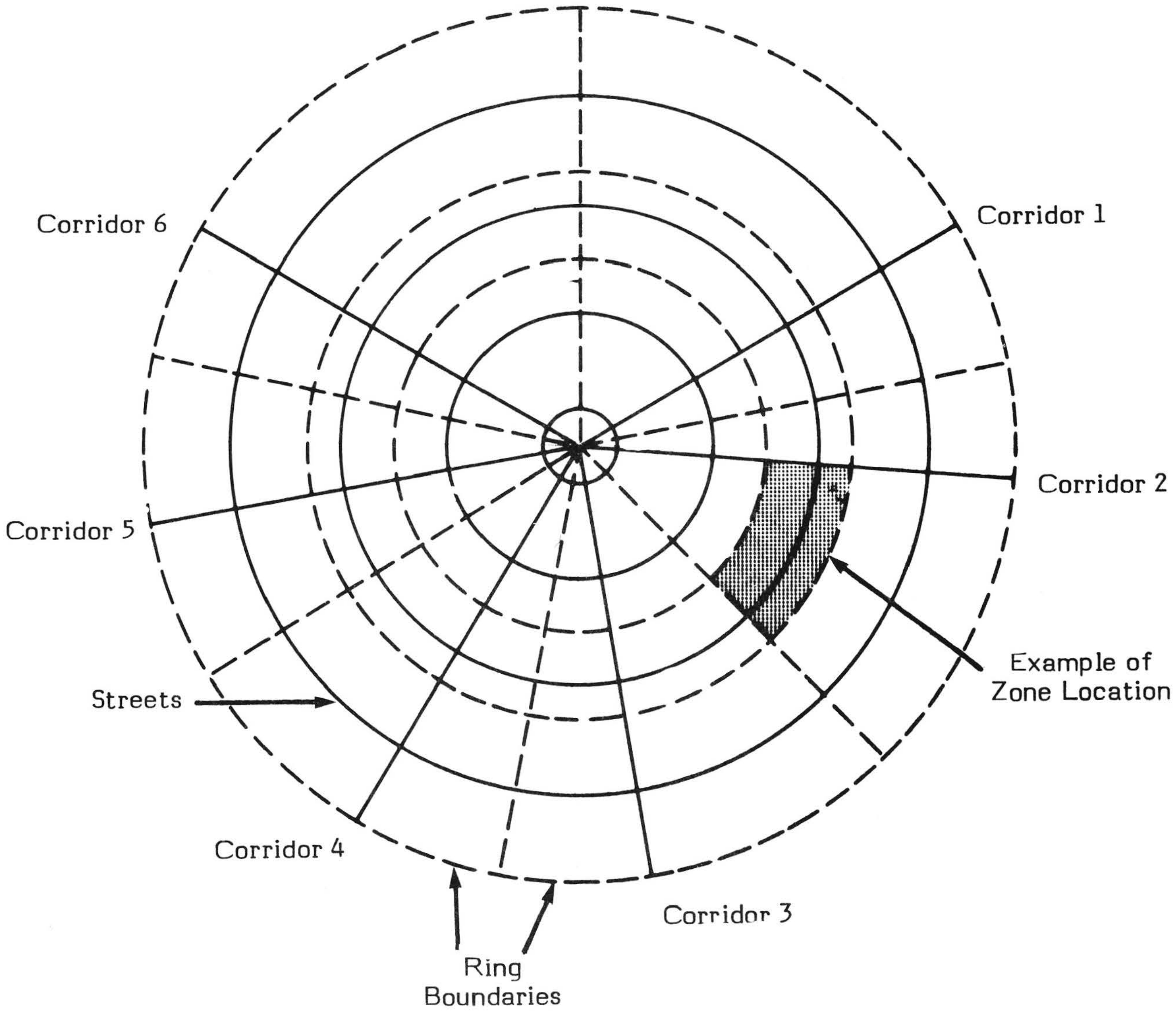
- Automobile—automobile drivers and passengers who travel directly between origins and destinations. The private automobile transit mode must be used for feeder trips to transit service.

- Carpool—carpools only, not vanpools. Each carpool collects passengers up to the mean carpool size and then travels directly to the destination area. The distance driven is equal to the O-D distance plus an allowance for carpool circuity, which depends on carpool size and population density. The fraction of automobile travelers who use carpools is an input to the SMART model and is independent of transit mode share.

- Private automobile transit—park-and-ride and kiss-and-ride. Park-and-ride provides direct automobile transit between the trip origin and a transit station/stop. In addition, there may be a charge for parking at the station. Kiss-and-ride provides round-trip automobile travel between the trip origin (usually a residence) and the transit station/stop. Driver wages or time value can be included if desired; there is no parking charge.

- Fixed-route bus—conventional bus service in residential zones, along network links, and in CBD zones. Many variants are possible. In

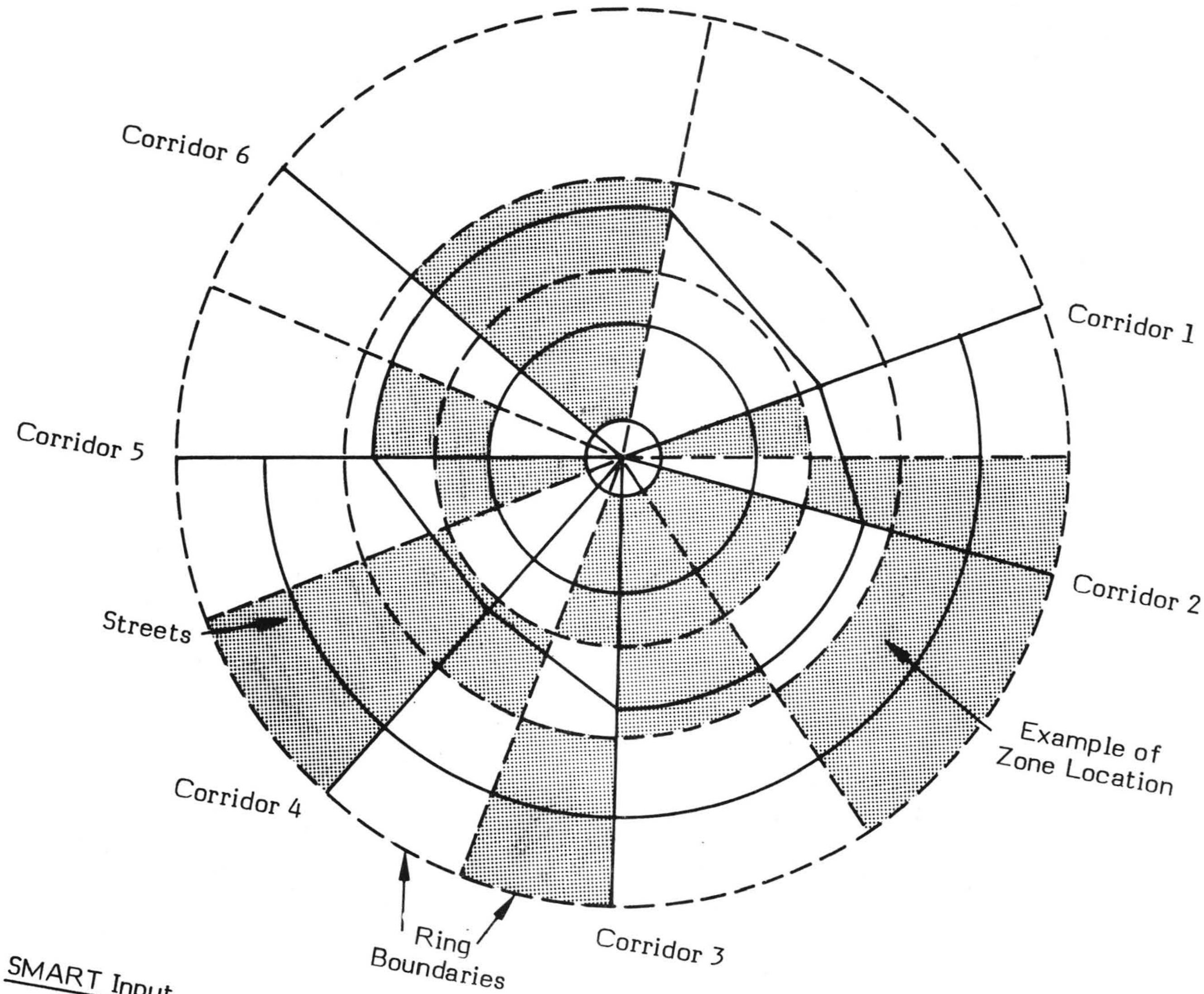
EXHIBIT 2.2
RING/CORRIDOR STRUCTURE



<u>SMART Input</u>

Rings = 4
Corridors = 6
Length of Raddi = 1, 3, 4, 6

EXHIBIT 2.3
RING/CORRIDOR ADJUSTMENT



SMART Input

Rings = 4
Corridors = 6
Length of Radii = 1, 3, 4, 6

residential zones, route deviation and point deviation services can be modeled by changing the distance driven and the passenger pick-up characteristics. SMART automatically calculates nonstop bus service between network zones that exchange enough travel volume to support the service. Jitney services can be modeled in CBD zones and elsewhere, if desired.

- Flexible service—subscription services and demand-responsive services in residential zones. The SMART default provides subscription service during peak periods and dial-a-ride demand-responsive service during off-peak periods. The modeling variants available include vanpooling, shared-ride taxi, and checkpoint demand-responsive services.

- Light rail—in residential zones and along network links. This mode can be used for any fixed-route service, although it is normally restricted to systems that require special physical facilities along the route (e.g., light rail, trolley coaches, and buses on exclusive guideways). In residential zones, light rail is restricted to a single route extending across the zone from the network traffic interchange points to the opposite zone boundary. Thus, if two transit modes that complement each other in a residential zone are to be modeled, one mode should be designated light rail and the other may be any of the transit modes (e.g., fixed-route bus, flexible-route service, or private automobile transit).

- Heavy rail—rail rapid transit service along network links. All travelers transfer to and from heavy rail at zone traffic interchange points. The user may specify maximum train length, station spacing, and guideway position (underground, at-grade, or elevated). Regional automated guideway transit (AGT) can be modeled with this mode. This mode can also be used to model automated guideway transit or the fixed guideway mode on network links.

- Automated guideway transit—only in CBD zones. AGT vehicles operate on grade-separated, exclusive guideways that are formed into grid networks. Vehicles are confined to single-line routes (SLT technology), requiring some passengers to transfer. AGT can serve all travelers in the CBD zones, with its major competitors walking.

Travel modes appear in three different kinds of analysis: feeder, line-haul, and distribution. Each can be applied in isolation to a particular zone or network link, or all three systems can be integrated to perform a door-to-door analysis of particular trips or a regionwide analysis of an entire urban area. Each travel mode type has a complete set of default parameters, such as speed and capacity, but these can also be modified as desired.

2.3 TRAVEL AND TRANSIT DEMAND

Travel demand can be introduced directly into the model in the form of a zone-to-zone trip table, or it can be generated from population and employment data. In either case, the SMART model recognizes three different trip types: home-based work trips, home-based nonwork trips, and non-home-based work trips. Each trip is treated as a round-trip, with outbound and inbound segments separated by trip type and by time period. In the default mode, it calculates travel rates for morning peak (6:00-9:00 a.m.), evening peak (3:00-6:00 p.m.), off-peak (9:00 a.m.-3:00 p.m.), and off-hours (6:00 p.m.-6:00 a.m.). Other hours can be assigned to the time periods if those for the study period differ from the default values.

Zone-to-zone demand data can be generated from the population and employment data given for each zone. To do this, the model requires trip type, average trip length by type, and a distribution of trips by type to the different periods of the day. Trip-ends by zone are calculated by applying travel characteristics to residential and employment densities for the zone. Zone pairs are matched for origins and destinations using a negative exponential function of zone-to-zone distance. With this function, the number of trips attracted to destination zones decreases with increasing distance from the origin zone. Daily trips are then distributed to the different time periods in accordance with time distribution factors by trip type. The resulting trip tables provide travel volumes for intrazonal analysis. Each trip-end is identified with employment or home and with time of day.

To generate traffic volumes on network links, all trips are assigned paths over the network between the node to which the origin zone is attached and the node to which the destination zone is attached. Slight variations in assignments can modify congestion and change travel times. A shortest-path algorithm is used to make this assignment, so that all trips between zone pairs follow the route that gives the shortest uncongested automobile travel time. SMART assumes that all travel between node pairs, both forward and reverse, follows the same path. It does not allow probabilistic multi-path routes.

Six different mode shares can be selected for each of three different time periods: morning peak, off-peak, and evening peak. (Off-hour mode shares are the same as the off-peak.) The model calculates performance and cost data for automobile, carpool, and transit modes for all six mode shares. With this information, the user can examine relative cost and performance among the different modes for the existing mode share and, in addition, identify the consequences of changes in transit mode share. Thus, the model provides enough information to identify the impact of changing mode share on transit performance and cost, which can be helpful in evaluating past performance and considering future strategies.

Because of the use of multiple mode shares, the SMART model cannot use different O-D pairs. However, by listing output for individual zones, local travel can be examined at different mode shares. Alternatively, reasonably good results have been achieved by using a single mode share that reflects the average mode share for all transit services to peak or off-peak times.

2.4 LOCAL TRIPS

Local trips are represented with algebraic expressions for mean trip characteristics—distance, time, cost, vehicle-miles, fleet size, and fuel consumption. The time variance for trips between mean trip origins and mean trip destinations is also estimated by summing the variances of all trip segments. The accuracy of the representation depends on the success with which the real geographic areas are represented by SMART's square areas and density variants.

The estimating procedure gives a good representation of the mean trip and gives reliable aggregate data on vehicle-miles, vehicle-hours, and the like. It does not describe the universe of all trips within a zone, nor does it identify the characteristics of the longest trips. If detail about all or part of a zone is needed, the zone can be divided into several small zones that are analyzed independently. Zones as small as four square blocks can be modeled satisfactorily. When small zones are used, much of the local travel is transferred onto the network links where differences in origins and destinations are recognized.

Average trip times are calculated for journeys between origin and destination zones and for internal trips within zones. Trip time includes walking time, waiting time, travel time in vehicles, and transfer time (walking and waiting), where appropriate. Walking and waiting times are not calculated for the residential zone ends of automobile or carpool trips. However, CBD trip-ends include walking time from parking lots or garages.

Walking time is calculated by using mean distance between residences or businesses and the nearest transit stop and average walking speed, which can be introduced by the user. Walking distances are based on rectilinear street patterns.

Two different methods can be used to calculate the waiting times that occur at the beginnings of transit trips. If transit headways are short, average waiting time is simply calculated as one-half the headway. When transit headways are long, the SMART model uses Turnquist's[1] equation to calculate waiting time at trip origins:

$$\text{Waiting time} = \text{Alpha} + \text{Beta} * \text{mean headway}/2,$$

where alpha and beta are constants.[2] When transit headways are short, the values given by the Turnquist equation are close to half of the mean headway.

---

[1] Turnquist, M.A., "A Model for Investigating the Effects of Service Frequencies and Reliability on Bus Passenger Waiting Times," Northwestern University, Evanston, Illinois, 1976.

[2] Default values in SMART are 1.71 (alpha) and 0.57 (beta).

SMART recognizes three situations when calculating waiting time for transfers:

1. There is no coordination of the vehicles between which the transfer is made. In this case, waiting time is one-half the departing vehicle headway.
2. Vehicle schedules are coordinated, but vehicles do not wait at the transferring stop until transfers are complete. In this case, waiting time is calculated with the Turnquist equation.
3. Vehicles exchange passengers in a timed-transfer mode, in which vehicles are held at the transfer point until all transfers are complete. In this case, there is either no waiting time or a short, uniform waiting time.

2.5 ROUTING AND SCHEDULING

Transit vehicle headways and fleet sizes can be calculated from algebraic expressions. Separate vehicle calculations are made for local travel in zones and for travel over network paths and network links. Thus, in the model, a transit traveler may be treated as if he/she transfers vehicles at each node. Because zero time transfers are possible, through trips can be modeled. If there is sufficient travel and volume between node pairs, nonstop trips are modeled. Nonetheless, based on fragmented vehicular data, it is not possible to consider route combinations or schedules.

Because the SMART model analyzes different trip segments independently, it cannot treat the efficiency with which buses are assigned to routes. Fleet sizes are computed by summing fractional needs expressed in terms of fractional vehicles. The resulting fleet will underestimate actual fleet requirements by 10 to 15 percent, depending on the efficiency with which the actual schedules are filled. These errors do not affect comparisons between transit modes. For planning purposes, fleet size corrections can be introduced for scheduling as well as for service and maintenance time.

2.6 SPECIAL SERVICES

Special services can be modeled by creating large feeder zones to cover the residence locations of persons who travel to a set of destinations, which can be represented as the zone's minor activity center. The residences can be modeled with uniform or non-uniform density. The zones are analyzed separately from the normal SMART regional analyses, and the results of the special elderly and handicapped studies are added to the regional results.

Longer special service trips can be modeled with a conventional SMART representation for elderly and handicapped service only. All population densities would be those of the special service patrons. Care should be taken to use minimum service levels that reflect actual advance reservation and service frequencies. Such a study would provide the regionwide characteristics of special service. By varying mode shares for these services, an accurate picture of the impacts of different levels of service to the elderly and handicapped can be obtained.

2.7 THE SMART MODULES

The model is composed of independent modules that can be used alone or in any combination:

1. The FEEDER (residential area) module explores ten different transportation services in any given residential setting.
2. The DUMPER (minor activity center) module examines travel in commercial/employment centers that are often integrated into residential areas, such as suburban shopping centers and corridor or strip development.
3. The CBD (central business district) module examines travel characteristics in high-density centers characterized by a small geographic area, large employment, and little or no resident population.
4. The DOOR (door-to-door trips) module explores intermodule trips, including residential area movement, movement over one or more high-traffic corridors, and distribution movement.
5. The REGION (regionwide summary) module sums travel time, vehicle-miles, cost, fuel, and pollutants associated with travel by automobile and transit throughout an urban area. It produces travel volumes on freeways and major arterials, which can be compared with traffic counts, and provides average trip statistics for all urban trips.

Each module is discussed below.

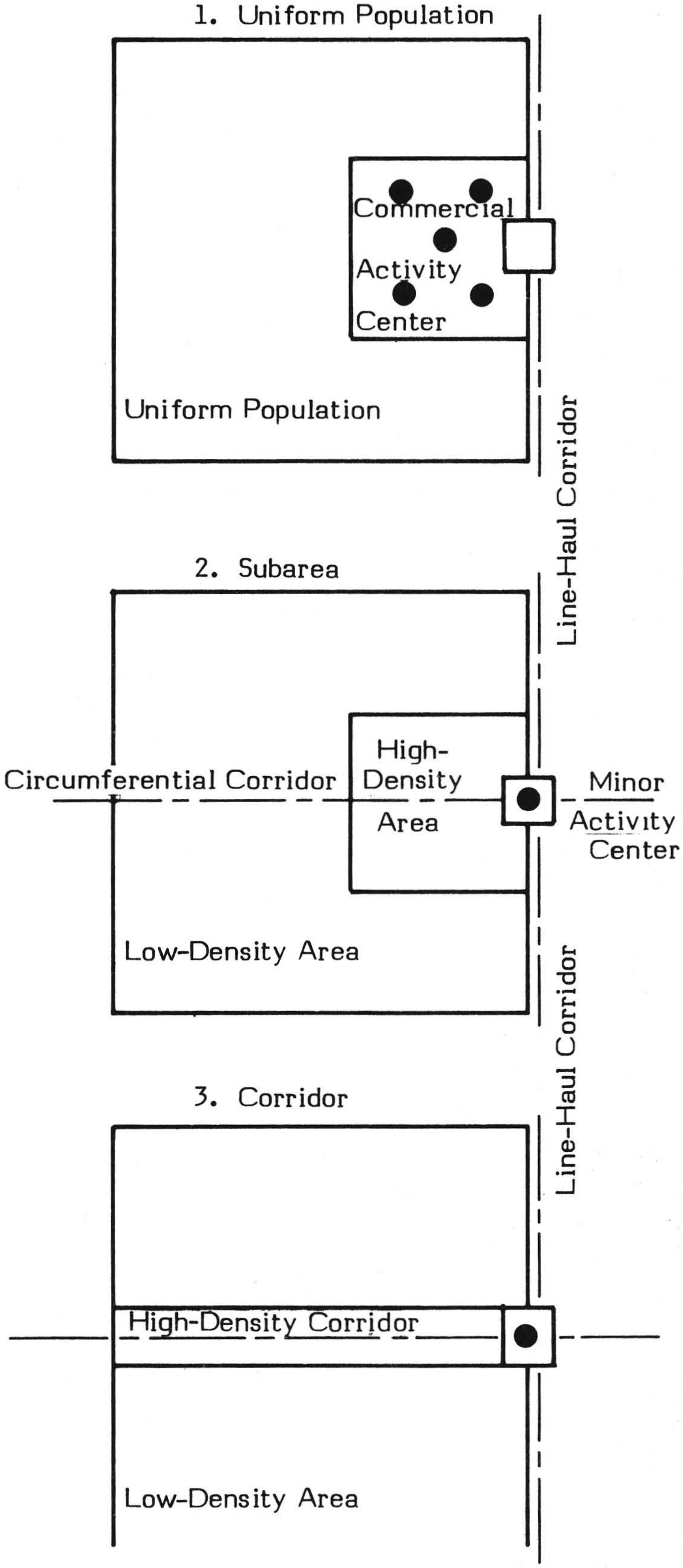
FEEDER Analysis

The FEEDER module calculates the characteristics of trips made between residences in a residential zone and the minor activity center. The activity center is the zone's commercial business district and is assumed to be clustered about the zone traffic interchange point. The residential zone, which is highly stylized in the SMART model, can be described in terms of the three different models illustrated in Exhibit 2.4:

- Uniform density. A square zone with uniform population throughout; commercial activity is concentrated at six locations near the traffic interchange point, which is located at the center of one side.
- Subarea. A square zone with two different population densities—a high density in a subsquare located adjacent to the traffic interchange point and a low density in the balance of the zone. Commercial activity is the same as for uniform density.

EXHIBIT 2.4

THREE RESIDENTIAL ZONE MODELS



- Corridor. A square zone with two different population densities—high density in a corridor one-half mile wide extending from the traffic interchange point across the zone, and low density in the balance of the zone. Commercial activity is concentrated along the corridor.

The three modules provide considerable diversity to the FEEDER analysis. By adjusting zone area, travel in irregularly shaped zones can be represented with reasonable accuracy. Skillful manipulation of residential densities and subarea size in the subarea and corridor models can also provide good representations of diverse zones.

Transportation service in FEEDER is provided by automobile, carpool, and any one of four transit modes: fixed-route bus, flexible service, private automobile transit, and light rail. FEEDER successively divides traffic among automobile, carpool, and one of the transit modes in the proportions specified by the six different mode shares selected by the user. FEEDER will examine as many as 25 different transit modes identified by the user. Each mode is treated independently with automobile and carpool travel for each of the six selected mode shares.

The light-rail mode can be examined only for the corridor option. In this instance, the light-rail mode serves the high-density corridor. Any of the other transit modes can be assigned to the low-density portion of the residential area.

Automobile performance measures are calculated for direct travel from the mean residential origin to the traffic interchange point over a rectilinear street system. Travel time is based on uncongested traffic. Fuel consumption is based on mean operating characteristics at residential speeds, and costs are based on ownership and operating costs for average annual mileage. Vehicle occupancy is an input option for the user.

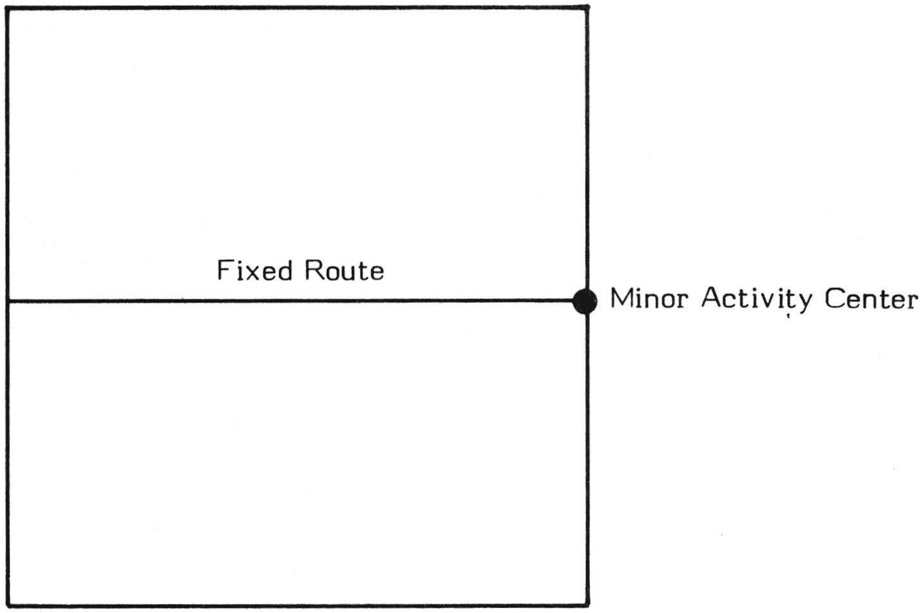
Carpool performance measures are similar to automobile performance with the addition of carpool circuity. Carpool costs are divided equally among all occupants. The driver is not paid.

Private automobile transit service provides a mechanism for carrying transit passengers to and from the traffic interchange point by automobile. The park-and-ride version includes one-way automobile travel time and cost and a parking fee if appropriate. Kiss-and-ride includes two-way automobile travel time and cost. It omits the parking fee, but can include time, cost, or wages for the driver. Automobile performance is calculated as for automobile travel.

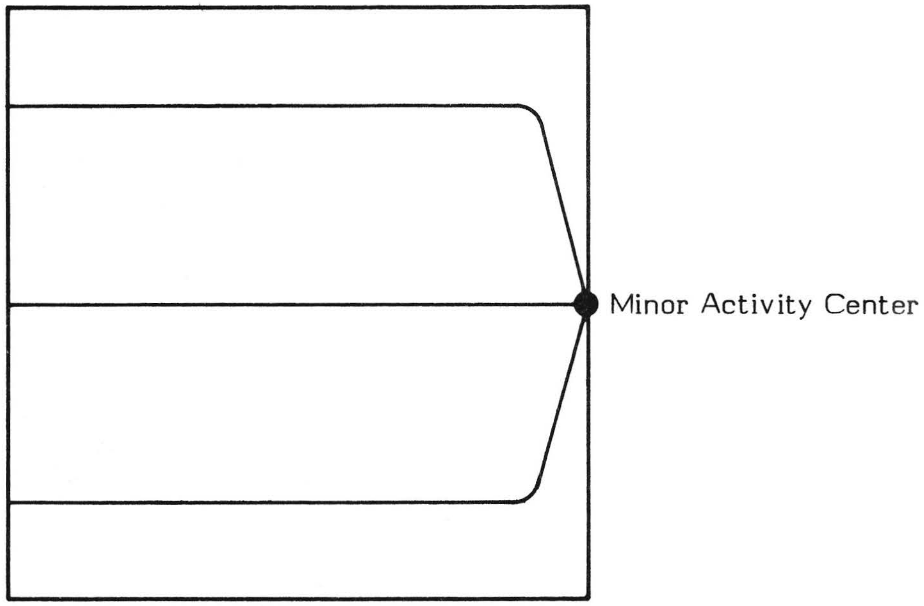
Fixed-route bus service is provided on parallel routes that are initially distributed across the residential area, with spacing equal to the designated or calculated route spacing (see Exhibit 2.5). Two service limits are identified: service-constrained and capacity-constrained. The service-constrained limits are dictated by maximum walking time (distance) and maximum vehicle headway, both of which are introduced by the user. If demand is too low to fill buses at a route spacing determined by the maximum walking distance and at a frequency determined by maximum headway, then the buses operate partially filled at this minimum level of service. If buses operating at the minimum service level cannot accommodate the demand, however, then the route spacing is reduced and the service frequency is increased

EXHIBIT 2.5

FIXED-ROUTE STRUCTURE IN RESIDENTIAL AREAS



One Route



Three Routes

until the demand can be accommodated. In this instance, service is capacity constrained. As demand grows, route spacing and headway continue to decrease together until a user-specified minimum route spacing is reached (normally one block). Thereafter, increased demand is accommodated only by increased service frequency.

Flexible, demand-responsive service provides door-to-door service for persons traveling between their homes and a residential zone's activity center. The service can be characterized as "many-to-few," because there are a large number of residential area trip-ends and only a few activity center trip-ends. Most operating demand-responsive services have "many-to-few" service configurations. Any number of demand-responsive vehicles can be assigned to a residential area to meet the travel demand. Each vehicle is assigned a unique residential area, where it picks up travelers bound for the activity center or the traffic interchange point (for transfer to a line-haul vehicle). As the vehicle travels around the activity center, it both drops off and picks up passengers and then travels to a distribution area, which may contain one or more pick-up areas (see Exhibit 2.6). Round-trip travel distance includes (1) the distance required for random passenger pick-up in a service area with rectilinear streets, (2) the travel distance to the activity center, (3) a tour around the activity center, (4) the return distance to the distribution area (which may be larger than the pick-up area), and (5) random drop-off within the distribution area. The mean travel distance is calculated for both inbound and outbound trips. Travel time is based on average vehicle speed.

Light-rail service is limited to the high-density corridor of the corridor FEEDER option. The light-rail vehicle picks up and drops off passengers on both outbound and inbound journeys along this corridor. The balance of the residential area is served by the transit service of the user's choice; if no choice is indicated, SMART will default to fixed-route bus. The light-rail track is generally assumed to be laid in an arterial street or in the median of an arterial street. Fully grade-separated guideway can be specified if desired.

DUMPER Analysis

The DUMPER module models the collection and distribution of travelers within the commercial districts (activity centers) of residential zones. Three classes of travelers are modeled: (1) interzonal travelers who enter the DUMPER zone at the corridor interchange point and travel to a destination within the activity center, (2) travelers who originate within the activity center and exit the zone at the corridor interchange point, and (3) local travelers who both originate and terminate in the activity center.

The activity center is always located at the corridor interchange point. It is modeled as six O-D points, of which one is the corridor interchange point (see Exhibit 2.7). These points form a rectangle that is 1/4 ASIDE by 1/2 ASIDE, where ASIDE is the length of one side of the square residential area. Activity center size can be adjusted by adjusting the size of the residential zone.

Transportation service in DUMPER is provided by automobile, carpool, and fixed-route bus, which is the only transit mode included in DUMPER, although fixed-

EXHIBIT 2.6
SUBSCRIPTION ROUTE REPRESENTATION

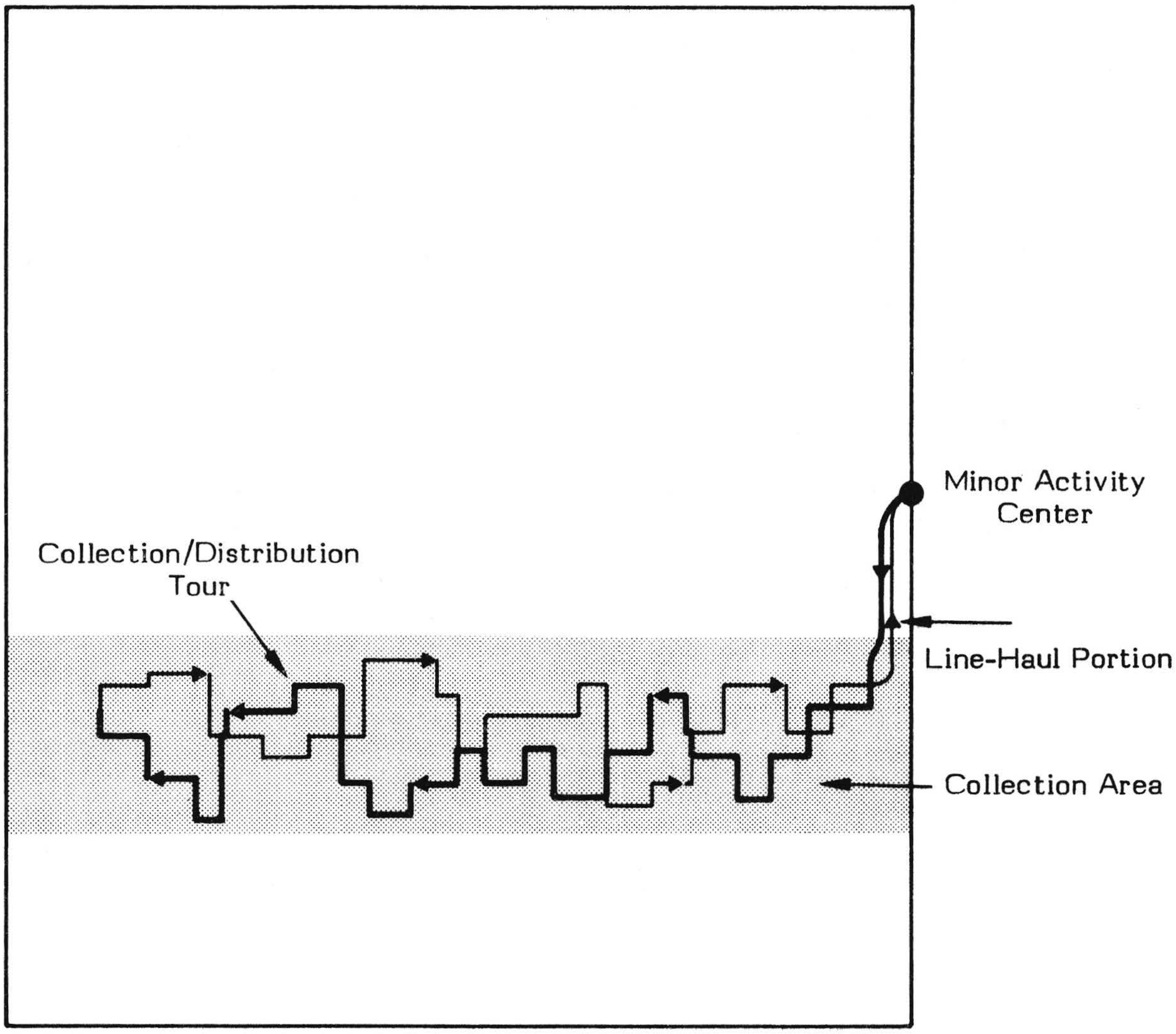
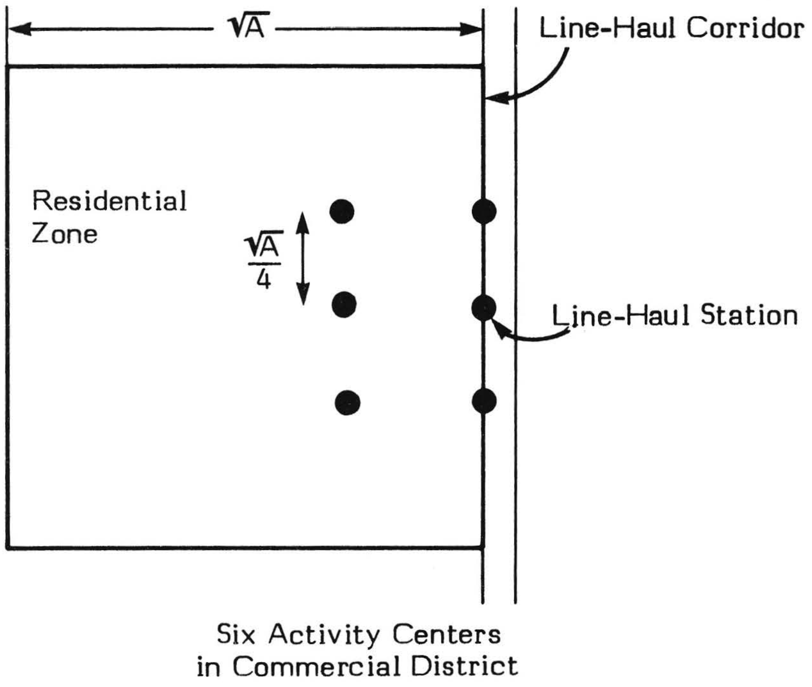


EXHIBIT 2.7

SPATIAL CONFIGURATION FOR DUMPER ANALYSIS



A = Area of residential zone

route bus characteristics can be modified to approximate jitney and other similar services. Flexible services are provided to the activity center by FEEDER modes that terminate in the activity center.

Automobile performance measures are based on a mean trip length of 0.42 X ASIDE. Uncongested automobile speed is used to calculate travel time. Fuel consumption and cost are based on mean unit values, which are set by the user. Vehicle occupancy is also a user input. If a parking charge is assessed, it is divided among all of the individuals in the travel party.

Carpool distance is calculated as a function of the mean number of travelers per carpool, which is a user input. Each carpool occupant is assumed to have an independent destination. Potential stops are uniformly distributed among the six O-D points. Once distance has been determined, tour time can be calculated from mean vehicle speed and time per stop. Mean travel time is based on the average occupant. Other measures are calculated in the same way as for automobiles.

Fixed-route bus service is available on a two-way loop route connecting all of the O-D points of the activity center. Bus service can be service-constrained by a user-specified maximum headway or capacity-constrained by the travel demand. Additional capacity is always added by reducing vehicle headways. Travelers may board or disembark at any of the O-D points. Mean travel distance is calculated from the expectation of equal demand at all points and random assignment of all trips. Vehicle capacity constraints are calculated on the basis of the highest volume route segments.

Tour time is calculated from route distance, average speed, stopping time, and stops per tour. Headway is user-specified or determined by the travel volume on the most heavily traveled route segment. Fleet size is calculated from tour time and headway. Mean passenger travel distance is determined from mean trip length and bus speed. Vehicle-miles, fuel consumption, and cost are calculated from these values.

CBD Analysis

The CBD module models travel in any designated CBD zone. It recognizes both interzonal and intrazonal trips. Inbound interzonal trips can enter the CBD zone at any point around its periphery. Destinations are uniformly distributed about the zone. Outbound interzonal trips are the reverse. Intrazonal trips may originate or terminate anywhere within the CBD. Interzonal and intrazonal trips differ in length as well as in origins and destinations. Nonetheless, if the average large number of intrazonal walking trips is eliminated, the two types generally resemble one another, and the interzonal trips occur in much larger numbers. For analytical convenience, the SMART model treats intrazonal vehicular trips like interzonal trips.

CBD zones are represented as squares with grid street patterns. Line-haul corridors may be attached anywhere on the periphery of the zone. Inbound travelers are uniformly distributed along the zone periphery. The CBD has a very small resident population and a large employment level. Both residents and employed persons are uniformly distributed throughout the CBD. This structure overlooks the concentrations of employment and traffic that can be observed in most real CBDs. Nonetheless, the SMART approximation can provide an accurate representation by simply adjusting zone size.

Street congestion is modeled in the CBD by means of a generalized expression for mean automobile speed that depends on CBD size, mean trip length, travel volume (in automobile equivalents), and the fraction of the CBD area devoted to streets.[3] The resultant speed is used for all highway vehicles in the CBD.

Four travel modes are modeled for the CBD: automobile, carpool, fixed-route bus, and automated guideway transit. Variations are possible by modifying the service characteristics of the available modes. Thus, fixed-route bus can be modified to approximate jitney services, and AGT can be modified to resemble any fixed-guideway service.

Automobile and carpool modes behave exactly alike in CBD travel. Each vehicle enters the CBD and drives directly to a parking lot or garage. The driver and passengers walk from the garage to their individual destinations. SMART can model preferential treatment for pool vehicles by reducing parking fees and average walking distance.

Average CBD driving distance is a user input that depends on the location of parking facilities. Average walking distance is also a user input. Default values for both parameters are based on random locations of parking structures and jobs. Mean vehicle speed is determined by the congestion equation. Travel time, walking time, fuel consumption, and cost are computed directly from distance and speed.

Fixed-route buses serve CBDs through a network of intersecting grid route structures. Many travelers are provided direct service from origin to destination; at most, one transfer is required. Buses travel in both directions on all routes. Mean walking distance for access is one-fourth of the route spacing. Route spacing and bus headway are determined by travel volume in the peak direction, in a manner similar to that described for FEEDER. Minimum route spacing is one block.

Buses can travel no faster than the congestion speed that is calculated with the Smeed equation.[3] One of the principles on which the Smeed equation is based is that traffic adjusts itself to the available capacity. (Thus, as traffic increases (congestion), the lower the speed at which vehicle can travel.) Travel time also includes delays incurred while picking up and dropping off passengers. Waiting time reflects knowledge of the bus schedule for originating trips (mean waiting time = alpha + beta * headway) and random arrival for return trips (mean waiting time = headway/2). Trip time is the sum of vehicle travel time, walking time, and waiting time. All transfers in the CBD are assumed to be uncoordinated; that is, no effort is made to match schedules or to control vehicle movements for the benefit of transferring passengers. Headways are generally sufficiently short (less than 10 minutes) that waiting and transfer times are not long by bus standards.

---

[3] Smeed, R.J., "Traffic Studies and Urban Congestion," Journal of Transport Economics and Policy, Vol. II, January 1968, pp. 33-70.

Fleet size is calculated from the bus route tour time, the number of routes, and the headway. Fuel consumption and cost are calculated from the fleet size, vehicle-miles driven, mean speed, and hours of service.

AGT is an automated vehicular system that operates on an exclusive, grade-separated guideway to provide travel service within the CBD. The essence of AGT service is that automated vehicles are available at frequent intervals, so that waits are very short. When entering a station, a traveler should be able to see an approaching vehicle. Thus, maximum waits are on the order of 1 to 3 minutes. Several AGT systems serve airports, amusement parks, and universities. As yet, none have been installed in CBDs in the United States.[4]

The AGT representation in the SMART model resembles the relatively simple single-line transit (SLT) version of AGT, in which vehicles stop at all stations. The grid route structure that has been adopted is somewhat coarser than that used for fixed-route buses. AGT stations are located at guideway intersections and at the ends of routes.

Vehicle headway can be determined by minimum service requirements or, as with fixed-route buses, by demand. Because of the high cost of exclusive guideway, the route spacing is not changed as demand increases. Instead, vehicle headways are reduced to accommodate increased demand until minimum headways are reached. Only then is the route spacing modified. Route spacing is reduced in steps until the minimum route spacing of one block is reached.

AGT vehicle speed is a function of vehicle size, propulsion power, guideway grade and curves, station spacing, and demand. For the SMART model, a notional vehicle has been adopted that is typical of operating SLT systems. With this vehicle, speed depends only on station spacing. Vehicle fleet size is determined from route length, headway, and speed. Cost per trip is calculated from travel volume, fleet size, vehicle-miles, and daily and yearly length of operation. All AGT vehicles operate throughout the day, irrespective of demand, so there is no degradation of service during off-peak periods.

Mean trip length is determined from a random distribution of traveler destinations that originate on the periphery of the CBD. Travel time is determined from trip length, vehicle speed, and station dwell time. Trip time includes, in addition, walk time and wait time.

LINKER Analysis

Unlike FEEDER, DUMPER, and CBD, which model travel in individual zones, LINKER models traffic on individual network links or on paths comprised of several connected links and their intermediate nodes. A network link is the portion of the regionwide network between two nodes. All residential and CBD zones are at-

---

[4] AGT systems serving CBDs are under construction in Kobe and Osaka, Japan, and in Lille, France. AGT systems are planned for Detroit and Miami.

tached to nodes at their traffic interchange points. Exhibit 2.8 illustrates the relationship between the interzonal network and the originating and terminating zones for a one-link trip. No traffic originates or terminates on the network. Traffic on network links includes only the interzonal traffic, which enters the network nodes at one end of a link and travels over the link under study to the node at the other end, where it may continue to another network link or leave the network to enter a zone that is attached to the second node.

LINKER analysis cannot begin until all of the traffic that moves over the link of interest has been identified. This can be accomplished by assigning all regionwide travel to the network or by stipulating the traffic on the link under study. LINKER analyzes link traffic in both directions.

A highway forms the central structure for LINKER analysis. This can be either a freeway or an arterial street. The user may specify the number of lanes in each direction on the highway and may instruct the model to set aside one lane (preferential lane) in each direction for the exclusive use of high-occupancy vehicles—buses, vanpools, and carpools. SMART models highway congestion by using a modification of the highway lane capacity curve.[5] The modification establishes a steady-state minimum speed rather than modeling the temporary stoppages that occur in practice.

LINKER always models automobile and carpool traffic along the central highway. In addition, it can examine three basic types of transit: fixed-route bus, light rail, and heavy rail. Other transit modes can be modeled in terms of these basic types. Buses always use the highway—either general lanes or an exclusive lane. Light and heavy rail exclusive guideways are not influenced by highway traffic.

The LINKER analysis focuses on travel along the links of the designated path. It calculates transit details for trips among the nodes connected by these links and produces output that describes this travel. However, the traffic carried by each link originates and terminates at a variety of different nodes. This diverse traffic shares the link facilities; it contributes to congestion, loads transit vehicles, and shares in both capital and operating costs. Automobile and carpool characteristics—fuel consumption, cost, travel time, vehicle-miles—are determined from the total travel volume and speed on the link.

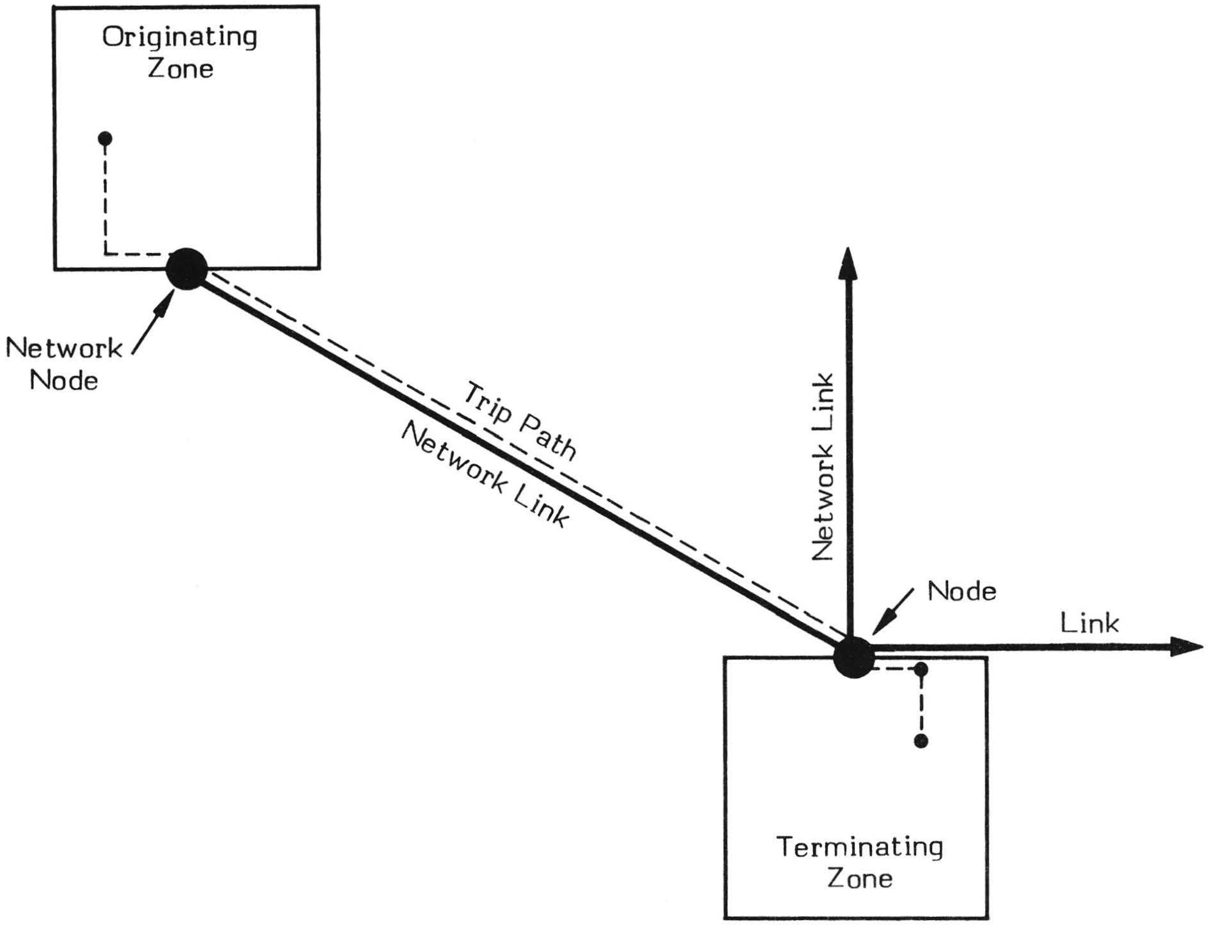
Transit buses travel along the highways using either an exclusive lane or a general lane. Bus speeds are determined by the congestion calculations for their lanes. Buses operate in either a nonstop or express node. Express buses stop to pick up and discharge passengers at all network nodes; bus speeds reflect time to make intermediate stops where appropriate. These buses carry all transit traffic down the link—both traffic that originates and terminates at the nodes under study and traffic that uses all or part of the network path as part of longer trips. Nonstop bus service is provided when there is sufficient travel volume between a pair of nodes to fill buses operating at intervals no longer than the maximum specified

---

[5] See Bureau of Public Roads, Highway Capacity Manual, U.S. Government Printing Office, Washington, D.C., 1965.

EXHIBIT 2.8

NETWORK-ZONE RELATIONSHIPS



headway. Where this volume exists, an exclusive service is provided in which buses travel directly between the O-D nodes without intermediate stops.

Light and heavy rail vehicles travel at speeds that are determined by system characteristics and station spacing. The user may specify any speed that reflects the physical counterpart of the link under study; congestion is not a factor between the maximum and minimum headways that are specified. Station stopping times depend on the numbers of boarding and disembarking passengers. Travel time includes time between nodes and time spent at intermediate stops. Trip time also includes waiting time at the origin node; no walking time is modeled by LINKER. Fleet sizes are determined by travel demand and by vehicle speed, including stopping time. A fleet size is associated with each link, irrespective of the routes that the vehicles would actually serve.

Light and heavy rail costs include substantial capital investments, particularly for systems with considerable underground construction. SMART apportions these costs among all riders that use each link.

DOOR Analysis

DOOR assembles the results of FEEDER, LINKER, DUMPER, and CBD analyses to model individual trips from their origins to their destinations. The user need only specify O-D zones, the trip type (home-based work, home-based nonwork, and non-home-based), and the transit mode or mode combination to be explored. DOOR will establish a route between O-D nodes. It will always examine automobile and carpool travel.

The transit trip representation requires transfers at the interchange between the originating zone and the first network node and also between the last network node and the destination zone. It may also be necessary to change transit vehicles at different nodes in the network path. The user may select the convenience with which transfers are made. The least convenient transfer is random. In this instance, there is no relationship between the arriving and departing services; the traveler exects to wait one-half of the headway time of the departing service at each transfer. In the most convenient scenario, there is no wait at all; this is analogous to through service on the same vehicle, which is available on light rail and could be available for subscription bus service or other services. To model timed-transfer or other coordinated service, the user may insert a fixed delay to account for transferring activities. This typically requires from 5 to 7 minutes.

When the O-D zones differ,[6] each trip is divided into three parts: origin, line-haul, and destination. For each part, SMART models one automobile, one carpool, and

---

[6] DOOR will examine intrazonal trips if requested. In this instance, LINKER analysis is omitted.

one transit mode.[7] The output lists performance measures for each mode for each part; it also lists total trip characteristics for automobile, carpool, and transit. Characteristics of interest include trip time, trip cost, fuel consumption, fleet size, and fleet activity in vehicle-miles per minute.

REGION Analysis

REGION or regionwide analysis is the process of summing the activities in all of the zones and along all of the network links to give regionwide totals of travel and transit activities. The user may sum the data for an entire urban area, or may elect to sum only a sector or even a smaller portion of the network. Sectors are best modeled by using an abbreviated network. Individual zones can be omitted from the regionwide summation. This is particularly useful for omitting zones outside the primary area of interest that are added to the network to handle external trips.

For each zone and link, REGION models automobile, carpool, and one transit mode. Transit modes differ from zone to zone and from link to link. Therefore, for each zone and each link, the user may specify transit mode, maximum transit headway, and vehicle characteristics (speed, size, cost), and the nature of the transfers that are possible. The analysis does not recognize differences in travel direction. SMART merely sums travel time, vehicle-miles, fleet size, and fuel consumption for automobile, transit, and carpool modes. It also computes mean trip characteristics: distance, time, and cost by mode.

---

[7] Private automobile transit will connect with line-haul transit and is considered a transit mode.

3. USING THE SMART MODEL

The SMART model can be used in many different ways to explore the application of alternative public transit services to a particular urban setting. It is possible to examine travel (1) in a single residential area, (2) in a single major activity center, (3) in a single traffic corridor, (4) between any pair of urban neighborhoods, (5) in a portion or sector of an urban area, or (6) in an entire urbanized area. Data requirements differ for each type of application, as do the preparatory steps. Exhibit 3.1 lists the SMART modules needed to model different types of problems. If only a single residential or CBD zone is to be analyzed, there is no need to be concerned with arterial corridors or structural relationships among zones and corridors. In contrast, a single corridor is more difficult to analyze because traffic on the corridor can come from almost any part of the urban area. LINKER requires that an urban structure be specified and that travel demand be calculated. Even if only one door-to-door trip is to be examined, SMART must have an urban structure and travel demand to select the O-D route and to calculate congested speeds along the route. City sector and urbanized area analyses require the full capabilities of the SMART model, and both zone and network structures are needed.

For ease of presentation, the application procedure is described in terms of an entire urban region. Shortcuts available for other analyses are noted where appropriate. The steps in this analysis are identified in Exhibit 3.2 and are discussed in the following sections.

3.1 DATA REVIEW

The following data categories must be considered:

- Travel data
- Transit data
- Street and highway data
- Traffic data

Each must either have valid quantitative data or there must be some means of making reasonable estimates.

Travel Data

The source of travel data will probably set limits on the zone structure that can be used in the analysis. If census data are used to estimate travel, then zones can be no smaller than census tracts without some rather elaborate data manipulation. Zones can easily be combinations of census tracts.

If travel data are available from a comprehensive planning study, the minimum zone size is a traffic zone. Except in deep suburbia, traffic zones are almost al-

EXHIBIT 3.1

SMART MODULES NEEDED FOR DIFFERENT PROBLEM TYPES

Problem Type	SMART Modules
Residential Area	FEEDER
Major Activity Center	CBD
Corridor Segment	LINKER
Between Neighborhoods (zones)	FEEDER, LINKER, DUMPER (CBD), DOOR
City Sector	FEEDER, LINKER, DUMPER, CBD, REGION
Urbanized Area	FEEDER, LINKER, DUMPER, CBD, REGION

EXHIBIT 3.2

PROCEDURE FOR ANALYZING AN URBAN REGION

1. Data Review
2. Select Zone Boundaries
3. External Zones
4. Network Configuration
5. Selecting Network Links
6. Calibration
7. Choosing the Runs
8. Evaluating the Results

ways smaller than the zones desired for SMART analysis, but they can easily be combined into zones of about the right size.

Traffic zone boundaries cannot be violated. In constructing the SMART zones, this limitation will sometimes cause difficulties with zone shape, the nature of the minor activity center, and the traffic interchange point with the network. The search for a complete zone-to-zone trip table may also introduce some difficulties. For example, to save storage space, UTPS stores trip-ends rather than zone-to-zone trips. The trips are distributed to zone pairs in the UTPS programs and then assigned to routes without storing the entire trip table. As a result, it may be necessary to generate the trip table from trip-end data. If possible, the trip distribution algorithms in the planning package should be used. If this is not possible, SMART trip distribution procedure can be used.

Transit Data

Transit data are needed to describe the services available to calibrate the SMART model and to provide a do-nothing alternative with which transit improvements can be compared. Information such as route structure, headways, and hours of service are available from schedules. Expected speeds over different route segments can be calculated from schedule data.

Patronage data are needed to calculate the mode shares currently carried by transit. It is useful to collect these data by route, where route patronage is available. Often, only daily ridership data are available. Average mode share for an entire urban area is calculated by dividing the daily transit patronage by the total estimated person-trips as calculated from the trip or census data. For a portion of the urban area, transit mode share is calculated from travel data representing that portion of the urban region.

Data are needed on the size of the transit fleet and on the characteristics of different vehicle types. Vehicle capacity is the most important characteristic; performance is of interest only when it varies appreciably from the balance of the fleet. For example, if special vehicles are available to carry the elderly and handicapped, the characteristics of these vehicles should be stated separately.

Transit cost data are needed if changes are to be made in the default cost parameters of the SMART model. It is always desirable to use actual costs when they are available. These include the capital cost of each vehicle type and the average operating cost expressed as cost per vehicle-mile, cost per hour, or other cost measure.

Street and Highway Data

Street and highway data are needed for all freeways and arterial streets that will form links in the network. Data on the number of lanes, lane capacity, and mean uncongested automobile speed are particularly important. The number of lanes is almost always available from the city engineer or traffic engineer. Capacity data are more difficult to find. The Highway Capacity Manual,[1] an excellent source of general data, is particularly useful for freeways without elaborate interchanges. Arterial street capacity depends on the type of traffic signals used and the characteristics of those signals. For congested streets, traffic flow as measured by traffic counters gives a good indication of capacity.

Speeds are difficult to estimate without actually driving the streets, although some indication can be obtained from the terrain. Flat streets and freeways are likely to support traffic at the speed limit or at the maximum safe speed for that class of street. Hills, sharp turns, difficult intersections, and other impediments reduce the mean speed.

Traffic Data

Traffic data are of interest primarily for model calibration. The first step in model calibration is to compare SMART-generated automobile traffic with the measured traffic for each highway link in the network. Most cities have traffic data, expressed in average vehicles per day or average vehicle-miles per mile. These numbers include private automobiles, commercial vehicles, trucks, buses, and other vehicles. The data also include traffic that is passing through the area as part of intercity trips. In some cities, truck data are differentiated from automobile data. It is also possible to get estimates of intercity traffic.

3.2 SELECTION OF ZONE BOUNDARIES

The most difficult and least structured task in SMART model application is the selection of zone boundaries. The process is intertwined with link selection. In fact, zones and links are generally selected iteratively, with many adjustments to accommodate changes and constraints in one structure or another.

To the extent possible, criteria for residential zones should be homogeneous residential development, commercial activity near network interchange points, and logical travel orientation toward those points. These criteria suggest small zones and a fine network that is analogous to many highway planning studies but quite opposite to the macro approach embodied in the SMART model. In fact, in experiences with planners, as more thought is given to zone boundaries and as more detail creeps in, the zones become smaller and the network more detailed. Invariably, the SMART limits are exceeded and the entire structure needs to be simplified.

It is useful to begin the zone definition process by selecting targets for the number of zones and the number of network links. The study area can be divided by the target zone number to get mean zone size, which is a useful guide. If the study

---

[1] Bureau of Public Roads, Highway Capacity Manual, U.S. Government Printing Office, Washington, D.C., 1965.

area includes the CBD, it is helpful to begin there and work outward spirally. This approach focuses attention first on the inner city where problems are likely to occur and provides an orderly progression for covering the entire study area.

Each potential zone should be examined in turn, keeping the following guidelines in mind:

1. Work only with complete traffic data zones (census tracts or traffic zones).
2. Be conscious of the three zone configurations that SMART allows—uniform density, subarea, and corridor.
3. Seek natural boundaries as zonal boundaries where possible—rivers, lakes, freeways, railroads, bluffs.
4. Locate commercial/shopping facilities—a key element. Consider how these facilities could be represented within the SMART model limitations.
5. Do not leave voids between zones unless they are undeveloped, park, or open space.
6. Pay close attention to access for interzonal trips. Try not to force neighborhoods together that do not use the same access route.

While a few square residential areas can be identified (Exhibit 3.3a), some even with uniform population densities and grid street patterns, rectangular areas are more common (Exhibit 3.3b). These have a number of rectilinear streets, with some irregular streets. The error introduced by modeling a rectangular area as a square is not large unless the rectangle is long and narrow. Errors in mean trip length for different length/width ratios are as follows:

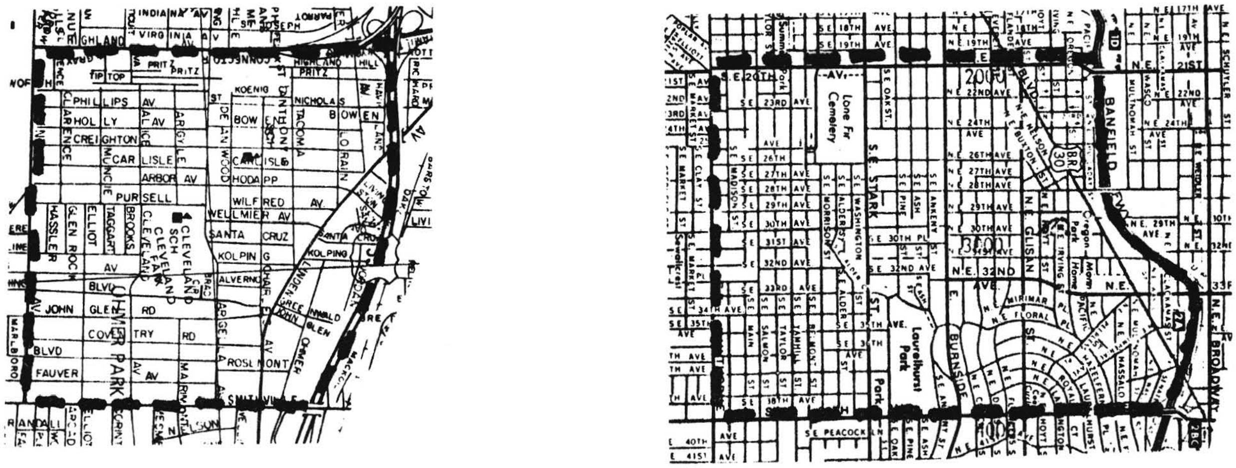
Length / Width	Mean Trip Length Error (percent)
1.0	0
1.1	1
1.25	4
1.33	5
1.5	9

For length/width ratios of less than 1.5, these errors are no greater than those that result from variations in population density or irregularities in street patterns. Even larger length/width ratios produce errors no greater than 20 percent.

Some zones have barriers that block or impede traffic (Exhibit 3.3c). The easiest solution to this dilemma is to divide the zone into two zones so that the traffic is correctly modeled on arterial streets. If the program structure cannot accommodate additional zones, the zone pieces might be combined with other zones.

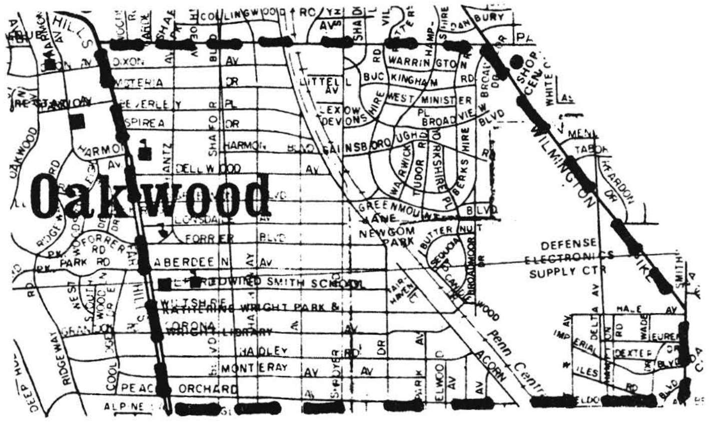
EXHIBIT 3.3

EXAMPLES FOR MODELING LOW-DENSITY RESIDENTIAL AREAS



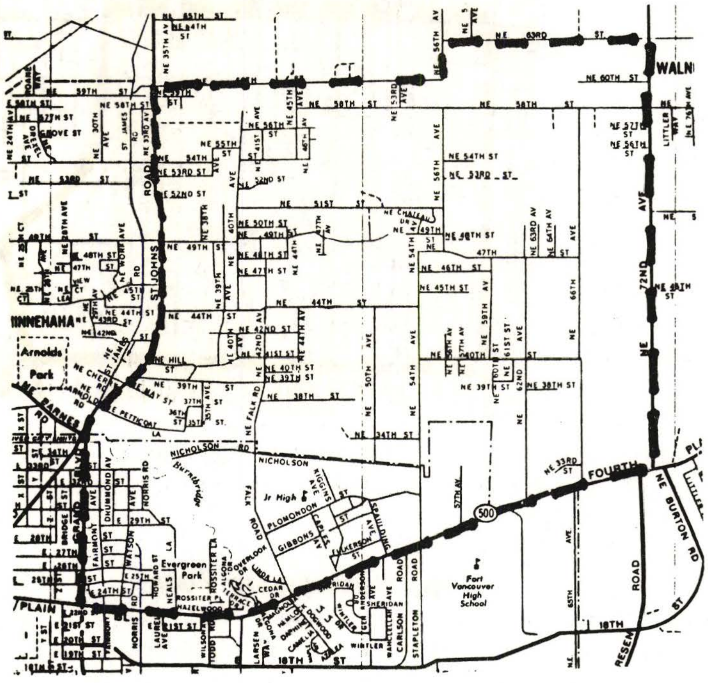
a. Nearly Square Zone

b. Rectangular Zone

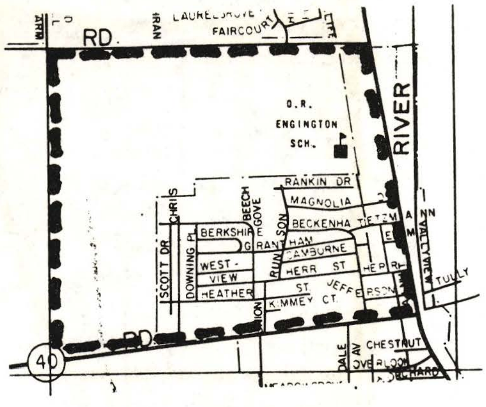


c. Barrier

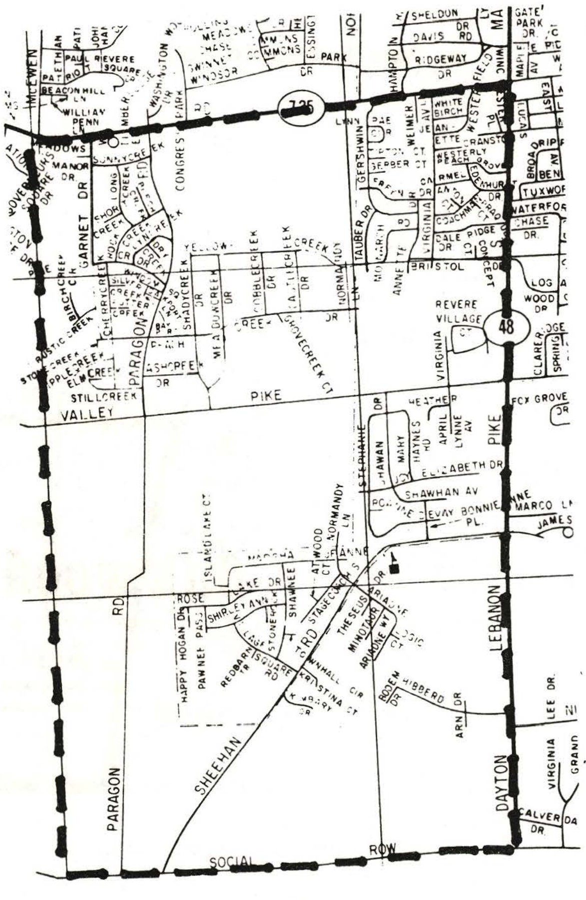
EXHIBIT 3.3 (continued)



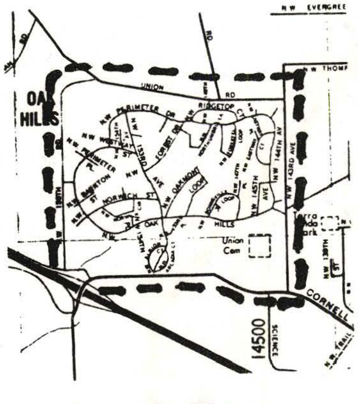
d. Uniform Low-Density Area



e. One Portion of Low-Density Area Occupied



f. Irregular Development



g. Irregular Streets

Low-density residential areas present problems. Some residential areas (Exhibit 3.3d) have streets throughout the area, but open spaces in the centers of blocks. These areas can be modeled in a conventional way, by distributing the population uniformly throughout the zone. Other low-density areas have development concentrated in a portion of the zone (Exhibit 3.3e). Travel in these zones can be correctly modeled by merely reducing the size of the residential zone to that portion which has been developed. Other zones (Exhibit 3.3f) have irregular development patterns. In this zone, there are more short trips than long ones. Actual traffic is best modeled by reducing the zone size. Sample trip measurements can be made to estimate mean trip length.

Nongrid street patterns also pose problems (Exhibit 3.3g). Nonetheless, distances between the entry points and internal points are not much different from those in a comparable area with a rectilinear street system. If necessary, a small adjustment can be made in mean trip length.

High-density residential areas pose different kinds of problems. The areas are fully developed, except for parks or other planned open spaces. They often contain strip development along arterial streets and arterial streets tend to be more frequent than in lower-density areas. Hence, they are modeled with small zones. Residential density varies widely from high-rise apartment buildings to single-family homes. The radial corridor option is often used to model the strip development. The dual-density representation is effective where a traffic interchange point near the high-rise developments can be selected.

Industrial parks and large industrial sites present modeling difficulties. They are characterized by modest employment densities over large areas. They lack the focus of CBDs, and yet do not fit the role of minor activity centers to adjacent residential areas. Exhibit 3.4a illustrates a large industrial site that is adjacent to an old residential area and employs 8,500 persons. The site is separated from the residential area by a bluff and can be reached only from one street, which is accessible from the nearby freeway. In this situation, the industrial site may be sufficiently important to be modeled as a CBD. The CBD size can be established by estimating mean trip length.

Exhibit 3.4b illustrates a large industrial property that is close to the zone's traffic interchange point. In this instance, the industrial employment was added to the minor activity center, and the entire area was modeled as a single residential zone.

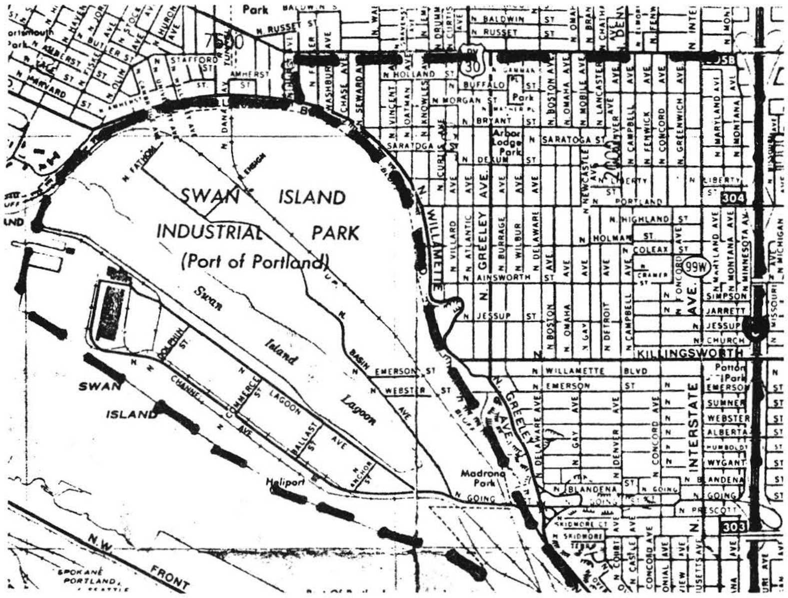
Exhibit 3.4c shows a very large industrial area that lies between a freeway and a residential area. The area has only limited-access streets for a very large employment base. This area could be effectively modeled as a large CBD or, on a larger scale, it could be combined with adjacent residential areas.

3.3 EXTERNAL ZONES

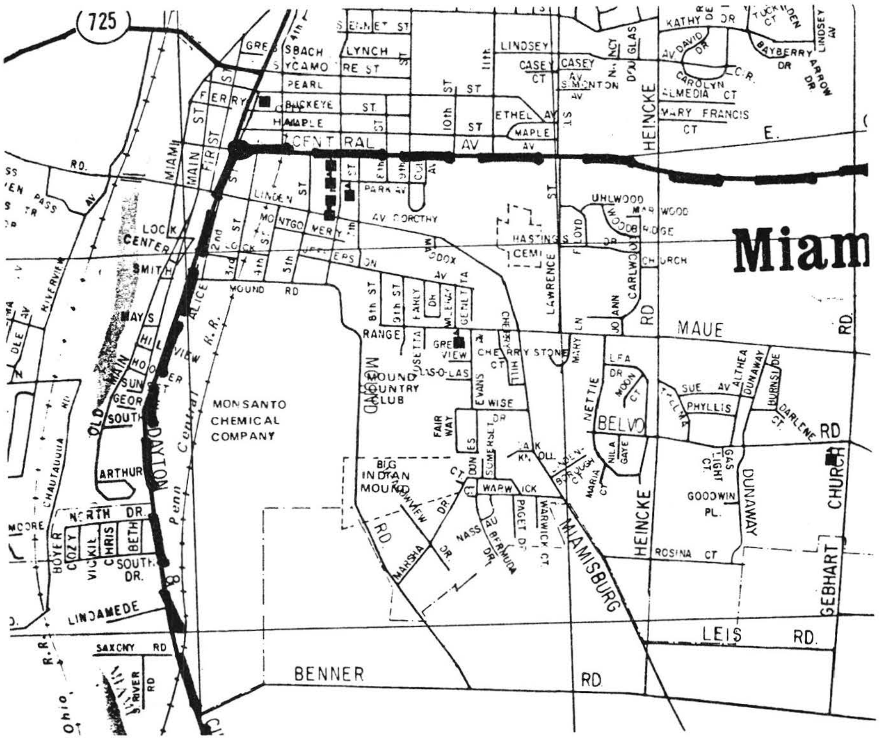
The SMART network model cannot be used for part of an urban area without representing all travel in some fashion. Regardless of the size of the area studied, there are some trips of distant origin that terminate in the study area, some trips originating in the study area that have far outside destinations, and some trips unrelated

EXHIBIT 3.4

EXAMPLES OF MODELING INDUSTRIAL AREAS

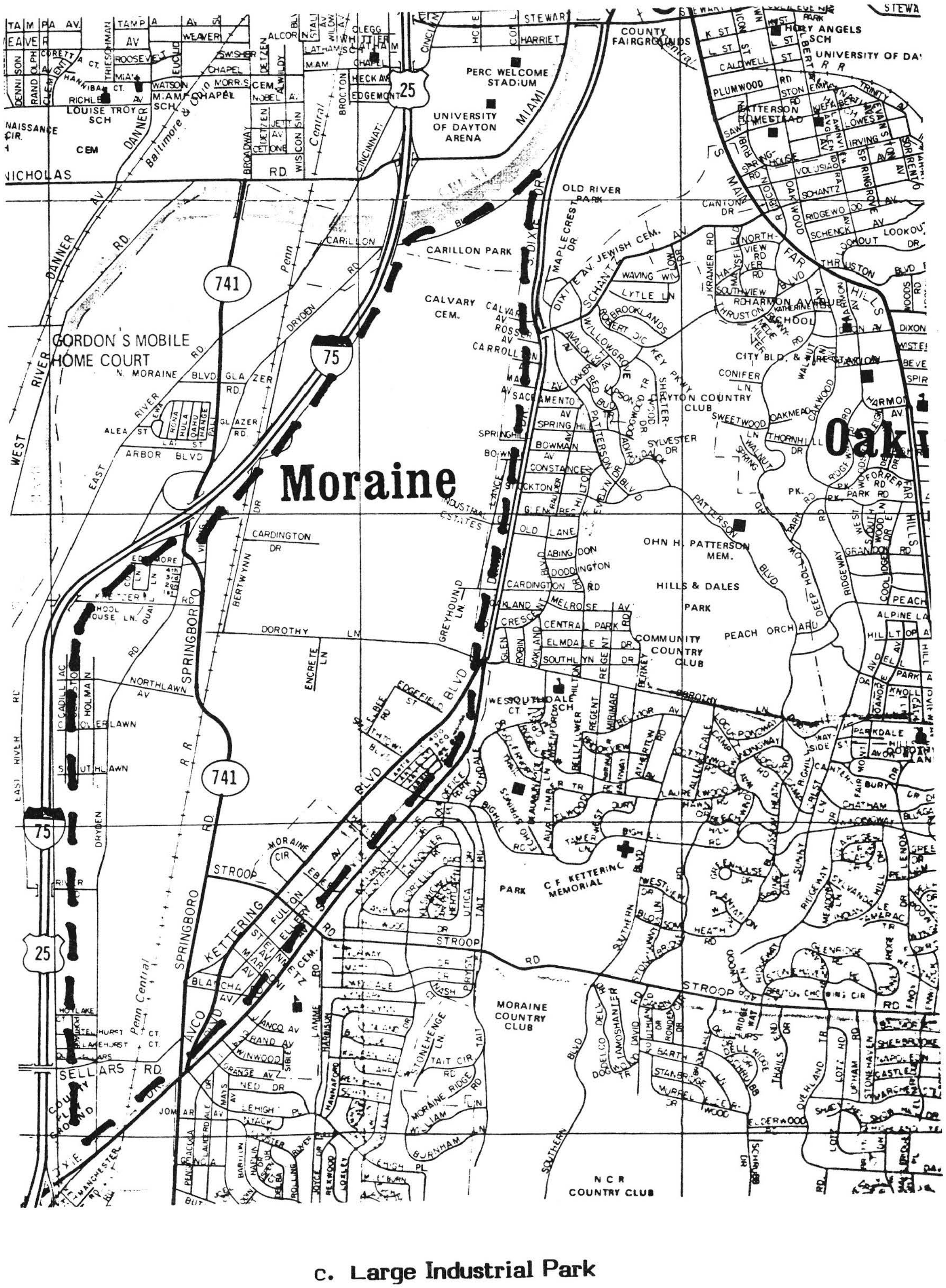


a. Industrial Park Near Residential Area



b. Large Industrial Property

EXHIBIT 3.4 (continued)



c. Large Industrial Park

to the study area but that pass through it. External zones lying outside the study area but connected to it with network links provide a mechanism for treating external origins and destinations.

External zones can be attached anywhere to a network. They are normally located so that the traffic flow between an external zone and the study area has a realistic impact on the study area's network links.

External zones may have any size. If SMART trip generation is used, the normal practice is to make them large enough so that local trips that do not involve the study area are modeled as intrazone trips, which do not enter the network. For example, if only half of an urban area is represented by the SMART model (Exhibit 3.5a), four external zones might be selected, each connected to the study area by one link each and connected to each other. Each zone would have an area comparable to its actual area and a population density that corresponds to its area and population. Network nodes would be located away from the study area to give a proper distribution of external trips within the study area.

Exhibit 3.5b illustrates a study area that is completely surrounded by urban development. In this instance, external zones are needed in all directions. Because of the highway network, however, it is not necessary to connect all of the external network nodes together. In this case, external links are all freeways; no arterial connections to external nodes are modeled.

If travel demand is taken from trip tables, the size of the external zones is unimportant. It is only necessary to collect all trips to and from the study area in convenient external zones (Exhibit 3.6). Care must still be taken with distances, however, so that the zone-to-zone routes selected by SMART resemble actual traffic.

Because of the large traffic volumes assigned, external links need to be provided with enough traffic lanes to avoid severe congestion. It is often necessary to perform a few trial runs with the SMART model to adjust both the capacity and the length of external links.

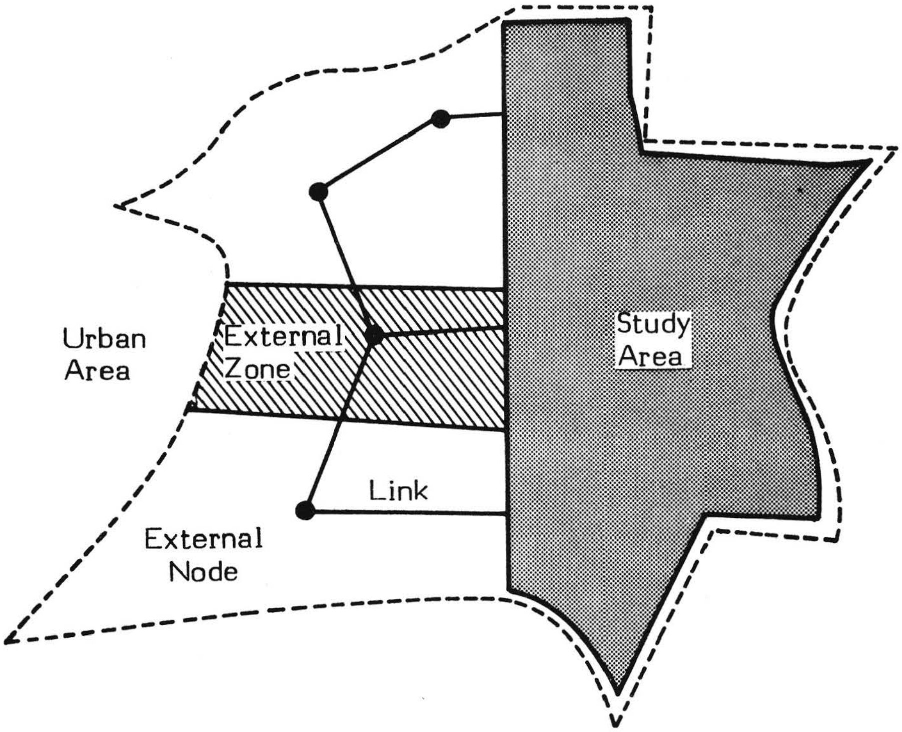
3.4 NETWORK CONFIGURATION

The choice between the ring/corridor configuration and the arbitrary network configuration depends on the data that are available to the user, the care that the user wishes to take in preparing an accurate model of the study area, and the number of different network variations that the user wishes to examine.

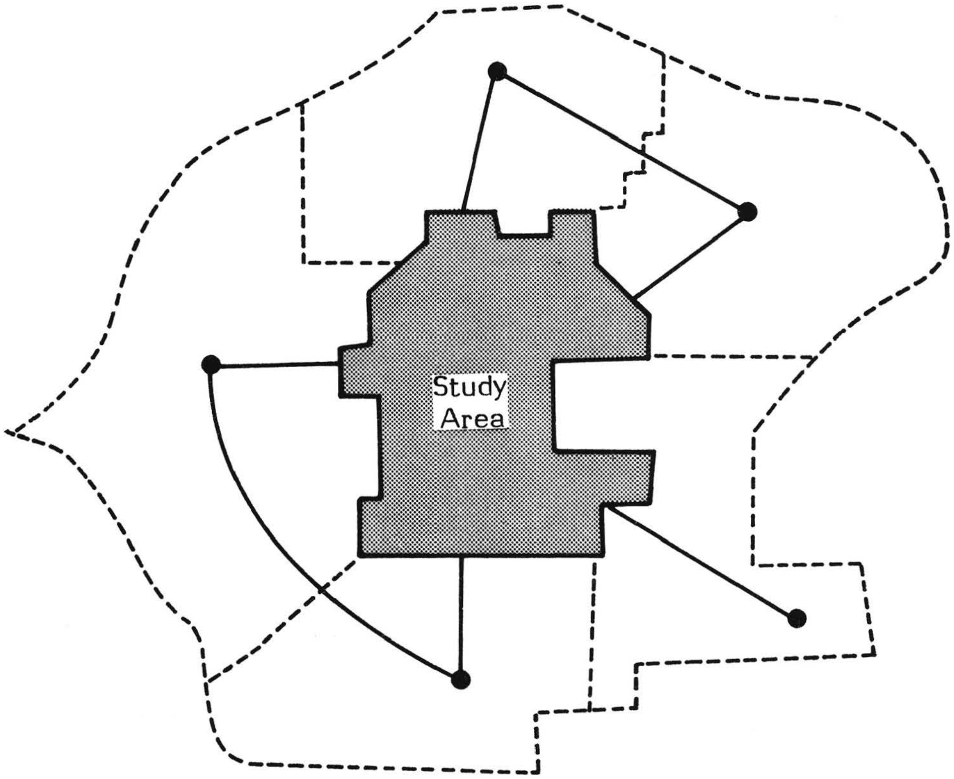
As a general rule, the ring/corridor network is easier to specify for a very approximate representation. The user need only specify the number of rings and the number of corridors. SMART has default values that will flesh out the network and provide all the data needed for an analysis. However, this simple representation is only rarely adequate. The user normally wishes to size and select the zones that are attached to the network and to specify which corridors are served by freeways, by arterial streets, and by fixed-guideway modes. The user may also wish to specify individual link lengths rather than use a common length for all the radial links that connect two rings and the geometrically calculated circumferential link lengths.

EXHIBIT 3.5

TREATMENT OF EXTERNAL ZONES



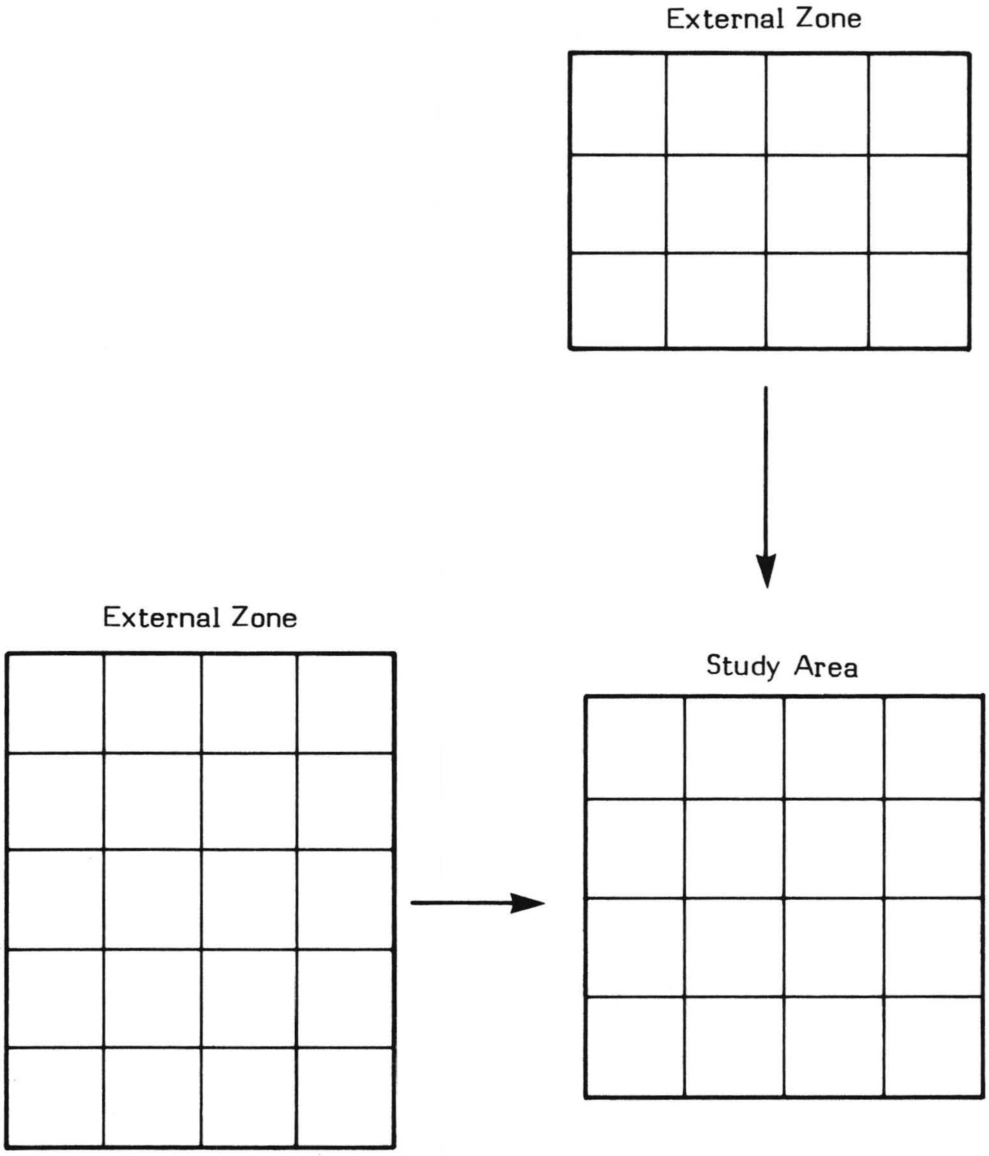
a. Half of Urban Area Modeled



b. Study Area Surrounded

EXHIBIT 3.6

HANDLING EXTERNAL ZONES FROM A TRIP TABLE



Some links may be omitted, and connections to external zones may be added. As the user supplies more information and uses fewer of the descriptive features of the ring/radial structure, the network begins to approach what would have been specified as an arbitrary network. Full specification via the ring/corridor route is equal to specification of an arbitrary network. Therefore, the user selects the ring/corridor structure in order to use some or all of the built-in features of that structure. Otherwise, the user specifies an arbitrary network.

3.5 SELECTING NETWORK LINKS

Selecting network links is almost as critical as selecting network zones. It is not possible to select all arterial streets as links, and some compromises must be made. SMART models only interzonal traffic on network links. Freeways and arterials carry both the equivalent of interzonal traffic and local traffic. The proper balance for the SMART model is to include a sufficient number of arterial streets as links so that the interzonal traffic on the selected links is approximately equal to the actual traffic on their real counterparts. In practice, the balance among zone size, trip length distribution, and frequency of arterial streets satisfies this relationship.

The link selection process (Exhibit 3.7) begins with the identification of freeways and freeway interchanges. Freeway segments are almost always network links. It would take a very unusual circumstance to exclude a freeway segment from the network. Using preliminary zone designations, those zones are attached to the freeway interchanges where the interchanges are points of natural flow between the zone and the freeway and where the zone's minor activity center is near the freeway interchange. Each attachment point becomes a network node. Several zones can be attached to a single node. Some accommodation is needed in this step. Adjustments of two or three blocks for the minor activity center do not cause problems, but when this step is complete, many zones will not be attached to a freeway and some freeway interchanges will have no zones attached.

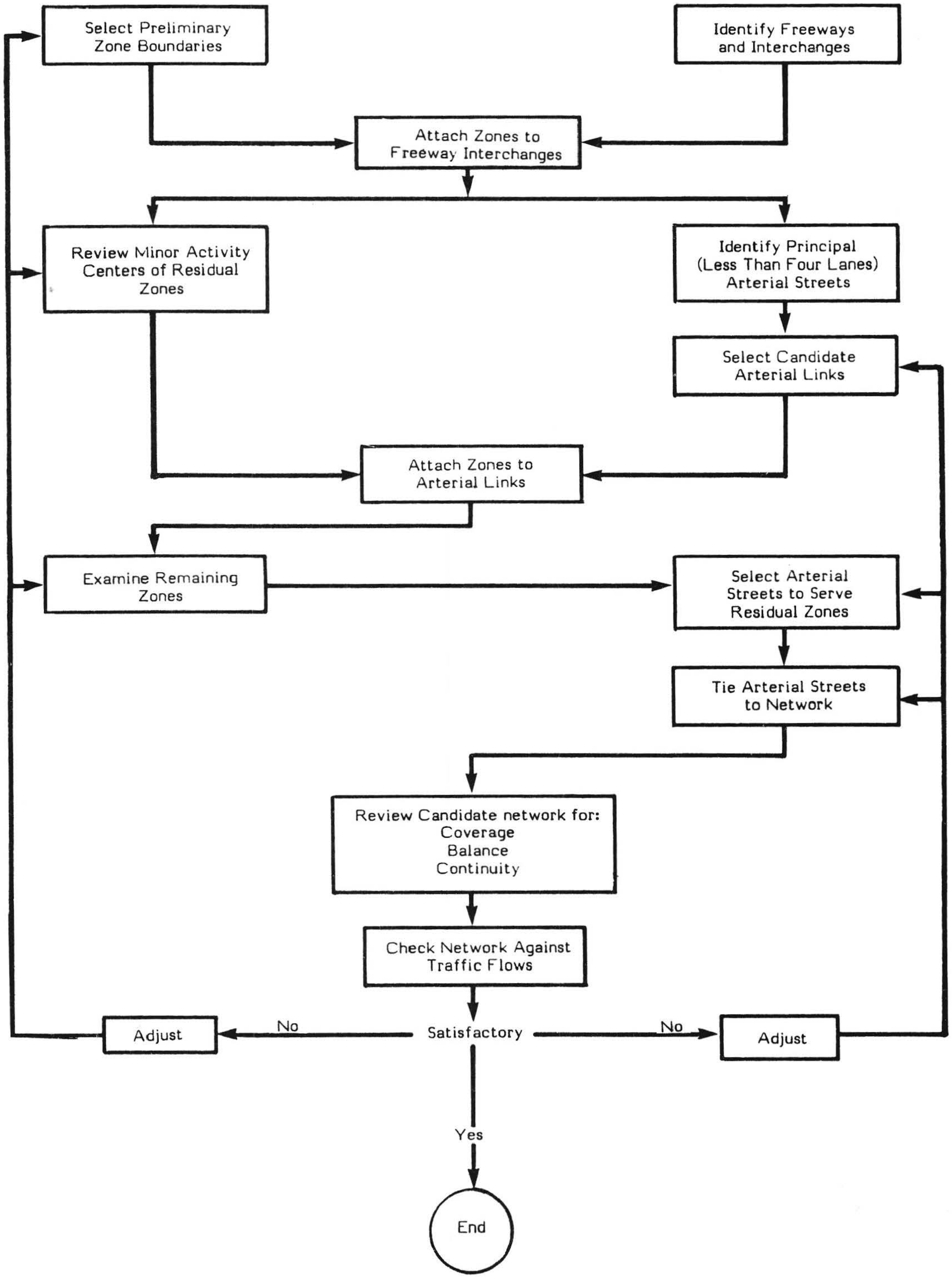
The next two steps involve reassessment. The unassigned zones are examined, and their minor activity centers are located with respect to the arterial street network. At the same time, the major arterial streets with four or more lanes of traffic are identified.

Candidate links are selected from among the major arterials streets by a combination of addition and elimination. Major arterials that intersect freeways at interchanges with zones attached are strong candidates for links. These arterials support traffic flow and often provide freeway access to more distant zones. Arterials that closely parallel freeways can often be eliminated. These streets may carry local traffic between freeway interchanges; they may also carry some interzonal traffic. Arterials that serve principally as frontage roads are eliminated; capacity can be added to freeway links to account for interzonal arterial traffic. Major arterials that roughly parallel freeways at a distance of one mile or more are generally good link candidates.

More zones can be attached to the new arterial links. Attachment points are selected to suit a zone's minor activity center. If an arterial street passes through

EXHIBIT 3.7

INTERACTION BETWEEN ZONE SELECTION AND LINK SELECTION



the zone perpendicular to the arterial link, the intersection of these two streets often makes a good attachment point. This process will dispose of a large number of additional zones.

The next step is to examine the unassigned zones, locate their minor activity centers, and place them on the nearest arterial streets of any importance. These streets or nearby arterials become candidate links and need to be tied to the network. In some instances, a little license must be taken to produce a satisfactory network.

The product of these steps is a candidate network, which should be tested for coverage, balance, and continuity before it is accepted. Coverage should be adequate to provide access to all parts of the study area where access is available on city streets. The network should provide the same relative number of principal streets in all parts of the study area as actually exist. Sparse street patterns are represented by fewer network links than dense street patterns. Finally, the access between all network nodes should resemble the access on actual streets. The final check compares the network with the city's traffic volume map. Major traffic-carrying arteries should be network links. In some instances, a low-traffic street will have to be chosen in preference to a high-traffic street, but this decision should be reversed if at all reasonable. Where traffic volumes are the same on two parallel streets, the choice should favor zone boundaries and other network considerations.

Network problems can be resolved by switching links, changing node locations, changing zone boundaries, or some combination of the three. A good deal of compromise and fine-tuning may be needed before a satisfactory network can be specified.

When the network has been satisfactorily completed, data on type, length, number of lanes, lane capacity, and uncongested speed should be collected for each link. These data are necessary for arbitrary network models, and they are helpful in adjusting the ring/corridor networks closer to reality.

3.6 TRAFFIC CALIBRATION

Two types of calibration are possible with SMART analysis:

1. SMART automobile traffic assignments can be compared with traffic counts that have been corrected to remove truck and intercity traffic.

2. SMART transit trip characteristics can be compared with scheduled performance of transit routes; vehicle fleet size and vehicle-mile estimates can be compared with actual fleet sizes and vehicle-miles.

The calibration process consists of selectively adjusting SMART parameters until an acceptable fit is obtained. The calibration technique depends on the type of travel data used as a starting point and on the basic network structure: ring/corridor or arbitrary network.

Automobile Traffic Calibration

Because of the simplicity of the SMART representation, it is not possible to get exact correspondence between link traffic and street traffic. Traffic on actual streets varies along the length of a network link; traffic enters and leaves the artery on streets that are not included in the SMART network. Mean traffic is often an appropriate measure, but it does not apply in situations where one link represents more than one street. The analyst needs to exercise considerable judgment to select a proper traffic volume for comparison with SMART results. This judgment should be exercised before any SMART runs are made to avoid the temptation to select the rationale that leads to the best comparison.

Before comparisons can be made, the SMART output (expressed in vehicles per minute in each direction for each time period) must be converted to average daily vehicles, the measure used on most traffic maps. This can be done by multiplying the traffic volume by time period length and summing for all time periods.

The first SMART model run is not likely to produce traffic estimates that look like the measured volumes. A number of corrective steps can be taken. Exhibit 3.8 lists a number of discrepancies and remedial steps that may help. There are no sure cures for any of the ailments. The following paragraphs discuss the impacts of the different changes that can be made.

Vehicle occupancy and carpool fraction uniformly reduce the vehicle traffic throughout the study area. Vehicle occupancies are on the order of 1.2 to 1.4 persons per vehicle, and carpool fractions are on the order of 2 to 4 percent. Only minor adjustments can be made to these numbers; however, it may be that no local numbers have been supplied to the model, and so the output reflects default values that may be different from local experience.

Mean trip length is used for population-generated travel. It determines the balance between intrazonal and interzonal trips by setting the scale of the negative exponential trip length density function. Small zones are influenced more than large zones by changes in mean trip length. Local data on mean trip length are often uncertain, so that relatively free use can be made of this parameter. Even so, mean trip length should not vary outside the 5-15 mile range for most urban areas.

Uncongested automobile link speed determines uncongested travel time along the link—a key factor in determining the shortest path between the origin and destination nodes. Small changes in link speed can shift large volumes of traffic from one link to another. Thus, speed is a powerful adjustment device. However, it should be used with care because large portions of the network can be easily upset.

Using the available adjustments, the SMART model results can be brought as close to the measured values as the patience of the user will allow. The adjustment process is an art. Because of the wide divergence of measured data, no universal convergence technique can guarantee an eventual fit. The goodness of fit needed depends on the questions that the user is trying to answer and the fineness of the differences that the user must measure. For preliminary planning, a 10 to 20 percent variation in link traffic does not seem to cause problems. When trying to calibrate an entire urban area, it is probably not worthwhile to bring all link traffic

EXHIBIT 3.8

METHODS FOR ADJUSTING SMART AUTOMOBILE TRAFFIC ASSIGNMENTS

Problem	Adjustment
1. All traffic estimates are lower than measured values.	1. a. Check SMART's estimate of daily vehicle-miles against measured demand. If population-based demand is used, the trip generation factors may be too low for one or more time periods. The mean trip length may be too high. If a trip table was used, check the dates of the table and the traffic. b. Check mean vehicle occupancy in SMART against the measured or estimated values. c. Check the carpool fraction against measured or estimated values. d. Examine the manner in which external zones are modeled. Are trips lost here?
2. All traffic estimates are higher than the measured values.	2. Use the reverse of the adjustments suggested in 1.
3. Traffic on a link is higher than the measured traffic.	3. This is a local problem that requires local adjustment; however, because of traffic interactions, one cannot confine the effects of a local adjustment. Adjustments that have been effective include the following: a. Link Speed. By reducing uncongested link speed, fewer zone-to-zone trips will be routed over the link. Link speeds can also be adjusted on adjacent links. b. Zone Size. By increasing the size of the zones attached to nearby modes, the fraction of intrazonal trips will

Exhibit 3.8 (continued)

Problem	Adjustment
	be increased at the expense of interzonal trips.
4. Traffic on a link is lower than the measured traffic.	4. Use the reverse of the adjustments suggested in 3.
5. Traffic on several parallel links is lower than measured traffic.	5. This is a sector problem. It may be that the network is too dense in the sector, spreading interzonal traffic over too many links. Remedies may include the following: a. Combine links to form a sparser network. b. Examine employment totals in zones. Be very careful in adjusting employment to maintain a balance between trip to work origins and destinations. c. Check external zones; should there be an external zone attached to the sector?
6. Traffic on several parallel links is higher than measured traffic.	6. Use the reverse of the adjustments suggested in 5.

within this range. Larger errors can be tolerated on unimportant links. A 10 to 20 percent variation is somewhat less than the weekly variation in traffic on any artery and substantially less than the variance of most measurements.

Transit Calibration

Transit calibration entails matching SMART's estimates of fleet size, vehicle-miles, and travel time with actual operations. Cost does not provide a good basis for calibration because of the wide variation in recording and allocation practices among transit properties. It is easier to calibrate the performance factors and then adjust costs to suit the needs of the study. Key performance factors that are needed for calibration include the following:

- Transit mode share
- Maximum headway
- Mean speed
- Trip time

Each factor presents unique modeling problems.

Mode share determines patronage, which also influences travel time. Regionwide analyses use average systemwide mode share; individual FEEDER and DUMPER studies use mode shares for the areas served. SMART's multiple mode share feature is particularly attractive here because a range of mode shares can be examined in each run. (Refer also to Exhibit 3.1.)

Maximum headway is a key determinant of wait time and vehicle-miles. Most existing transit systems are service-constrained. Even though vehicles are full to standing capacity during the peak half-hour of operation, average load factors over the 3-hour morning and evening peak periods are less than vehicle capacity. Therefore, maximum headways specify existing service. Headways vary from route to route. Actual routes do not serve residential zones and corridors in the fashion that SMART models them; rather, most combine residential area pick-up with line-haul service on arterial streets and freeways and distribution in the CBD or other activity center. Thus, each route contains a portion of FEEDER, LINKER, and DUMPER service. Considerable success has been realized by using mean headways that are calculated over the peak hours of operation.

The SMART model uses uncongested vehicle speed as a starting point for calculating travel time. Additional time is added to account for congestion and passenger loading and unloading. Uncongested vehicle speed depends on the terrain, street or route configuration, sharpness of turns, traffic signalization, and other factors. It is best calculated from schedule times during off-peak hours. Time is taken from schedules, and distance can be measured on city maps. At off-peak times, calculated speeds contain minimal delays for passengers and traffic.
For calibration purposes, trip time is the time from when the traveler boards a vehicle near the origination until the traveler debarks near the destination. This

includes time spent on vehicles and transferring between vehicles, but it does not include the initial walk and wait or the terminal walk. Expected trip time data are available for individual trips from schedules. Mean transfer times can be calculated from the arriving and departing schedule times. Transit properties do not accumulate trip times, nor are they generally aware of what trip times might be. The SMART model's calculation of regional mean trip time has no counterpart in actual operating data. Therefore, calibration must be based on trips between specific origins and destination that are available through the DOOR module.

The SMART model assigns transit to all network zones. If the user does not specify the requisite transit modes, the model will select default modes. This can result in transit being specified for zones that do not and will not have transit service. This inconvenience is overcome by reducing the network to include only those zones that have or are to have transit service. This procedure eliminates all trips that cannot be served by transit, and as a result, the selected mode shares accurately reflect the fraction of potential trips that can use transit.

The transit calibration process requires the same sort of iteration that is needed for traffic calibration. The following procedure is recommended:

1. Select a set of representative trips between zone pairs. These should reflect the general transit pattern in the area. Trips will focus on the CBD, but some cross-town trips should be included. Ten to twelve trips will normally suffice. Locate the origin for each zone that is on the locus of mean trips about the zone's attachment point. Locate destinations in the same way.

2. Using transit schedules (schedule performance if available), calculate travel time for each sample trip.

3. Calculate transit parameters for the SMART model: mode share, maximum headway, and mean speed. Prepare other input data for SMART.

4. Run DOOR for each sample trip. Compare SMART results with calculated results. Adjust SMART parameters as needed to obtain an acceptable match. The most promising parameters are mean vehicle speed and maximum vehicle headway. Rerun DOOR until an acceptable match is achieved.

5. Run REGION for the transit network. Compare fleet size and vehicle-miles with actual fleet size and vehicle-miles for the transit service. Remember to correct for schedule inefficiency, which SMART does not consider, vehicles out of service, and deadhead miles, which SMART does not calculate. If a reasonable match is not obtained, check services, maximum headways, and mean speeds in zones and along corridors that were not included in the sample trips. It is best not to disturb the sample trips unless all else fails.

As with the highway traffic calibration, SMART cannot be expected to completely reproduce actual operating experience. The sample trips will produce some differences from scheduled service because of the variability of actual service. Experience with fleet size and vehicle-miles has been that these results will be close to operating experience if the sample trips are close to scheduled trips. As with traffic volumes, errors of 10 percent should not be alarming, for variations in transit performance occur from day to day.

3.7 CHOOSING ANALYTICAL RUNS

Once the SMART model has been calibrated to the study area, the user is ready to conduct the policy or planning investigation. Experience has shown that an orderly progression of runs is preferable to random trial and error searching for the answer. It is generally prudent to begin with the best calibration run as an expression of the present state of transportation in the study area and then to begin making changes on an incremental basis. Some strategies that have proven useful are as follows:

1. Object: Improve Service. Service in a residential area can be improved by reducing the maximum vehicle headway, the maximum route spacing, or both. At constant mode share, the impact of this change is to reduce the vehicle load factor and increase the cost per trip. The variable mode shares give the user an indication of the increased patronage that would be needed to keep cost per passenger constant. Several increments of reduced maximum headway (e.g., 60, 45, 30, 15 minutes), together with carefully selected mode shares, give the user a comprehensive picture of the impacts of improved service. Intermediate values can easily be interpreted.

2. Object: Extend Service. Service can be extended to new areas by adding zones to the transit network and designating service for those zones. The set of mode shares selected for the new zones should be small enough to reflect realistic start-up conditions. Once again, it is wise to investigate a set of service frequencies that will give broad enough data to identify attractive operating levels. Crossovers between flexible and fixed-route service can be identified at those mode shares where the cost per trip is the same. Impact of new service on LINKER is reflected in travel volume increases over the base case. DOOR runs can be used to identify the type of door-to-door service that is available and to compare it with automobile, carpool, and other services. A half dozen carefully selected runs will give enough data for a thorough analysis.

3. Object: Explore Fixed-Guideway Service. Fixed-guideway service can be specified along any network link or path of several links. This service can be light rail, heavy rail, or some other transit form, such as AGT. Maximum headways need to be specified, as do speed, stop frequency, and other system characteristics. Several maximum headways should be tested. Mode share is not defined for corridors. Patronage depends on the number of trips for which the link is part of the most attractive route. In instances where two or more corridors are under consideration, the two cases can be run at the same time

because they would be considered independently. The SMART model routes traffic in terms of uncongested automobile travel time. DOOR runs can be made to test the impact of fixed-guideway transit on certain zone-to-zone trips and to compare results with automobile travel. Fixed-guideway service in the form of light rail, trolley coach, and other surface modes can also be tested in residential zones by using the corridor zone option. This feature gives considerable flexibility in testing those zones that should be served in conjunction with corridor service. Trunkline service with branches to a number of residential zones is possible. Care must be taken to ensure consistent headways among the links and zones. Exhibit 3.9 illustrates such a system.

4. Object: Explore Impact of Increased Transit Patronage on Road Congestion. This is easily accomplished by looking at door-to-door travel times at different transit mode shares. One set of runs will normally suffice.

5. Object: Explore Development Strategy. The SMART model is perhaps most effective when exploring large numbers of future possibilities. These are most easily accomplished by testing service improvements, service extensions, and new services with present travel demand at different mode shares. Future demand can be introduced by changing zone population or altering the trip table, but this is a tedious chore and not worthwhile unless significant shifts in development are expected. With low transit mode shares, an equivalent result can be obtained by merely exploring larger mode shares.

These problems are examples of what can be accomplished with the SMART model. The imaginative user can do much more.

3.8 EVALUATING THE RESULTS

The SMART model provides deterministic evidence about the quality of different transit alternatives set on a background of automobile travel. If the model has been carefully calibrated, the SMART results are probably within about 10 percent of some reasonable measure of experience. While this provides some measure of comfort to the user, it does not provide solid evidence that the SMART answer is correct. That evidence must come from elsewhere.

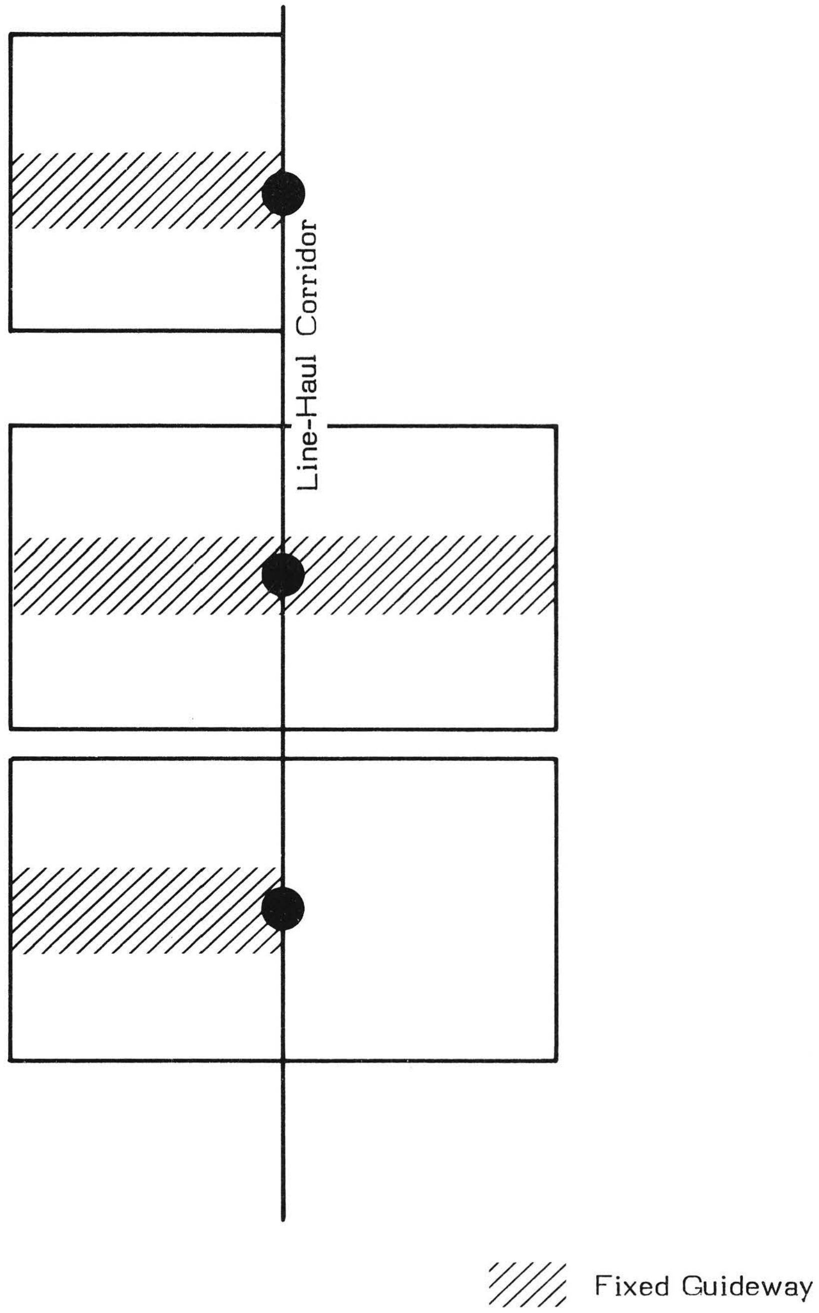
Because of the model's deterministic nature, statistical examination of the SMART results is not relevant. Earlier validation work demonstrated that the results from the algebraic expressions in the SMART model could have come from the same universe as transit operating data.[2] The calibration process has provided the same

---

[2] See Burton, P.M. and Jones, P.S., Macroanalysis of Regionwide Public Transportation: SMART Model Validation, SYSTAN, Inc., Los Altos, California, November 1978.

EXHIBIT 3.9

FIXED GUIDEWAY IN RESIDENTIAL ZONES



sort of evidence to support the combination of these expressions into regionwide transportation analysis.

The principal value of the SMART model is its ability to provide quickly comparative data on different transit candidates for a range of mode shares. Exhibit 3.10 contains curves of mean trip time, mean trip cost, and fuel consumption as a function of mode share for automobile, carpool, fixed-route bus, and flexible service in a typical residential area. As expected, personal automobile travel is always the fastest mode. Carpool times are longer because of the time spent picking up carpool members. Flexible bus (dial-a-ride) service offers the longest trip time for mode shares above 5 percent. For low mode shares, fixed-route service has such long headways and route spacing that trip times exceed dial-a-ride times.

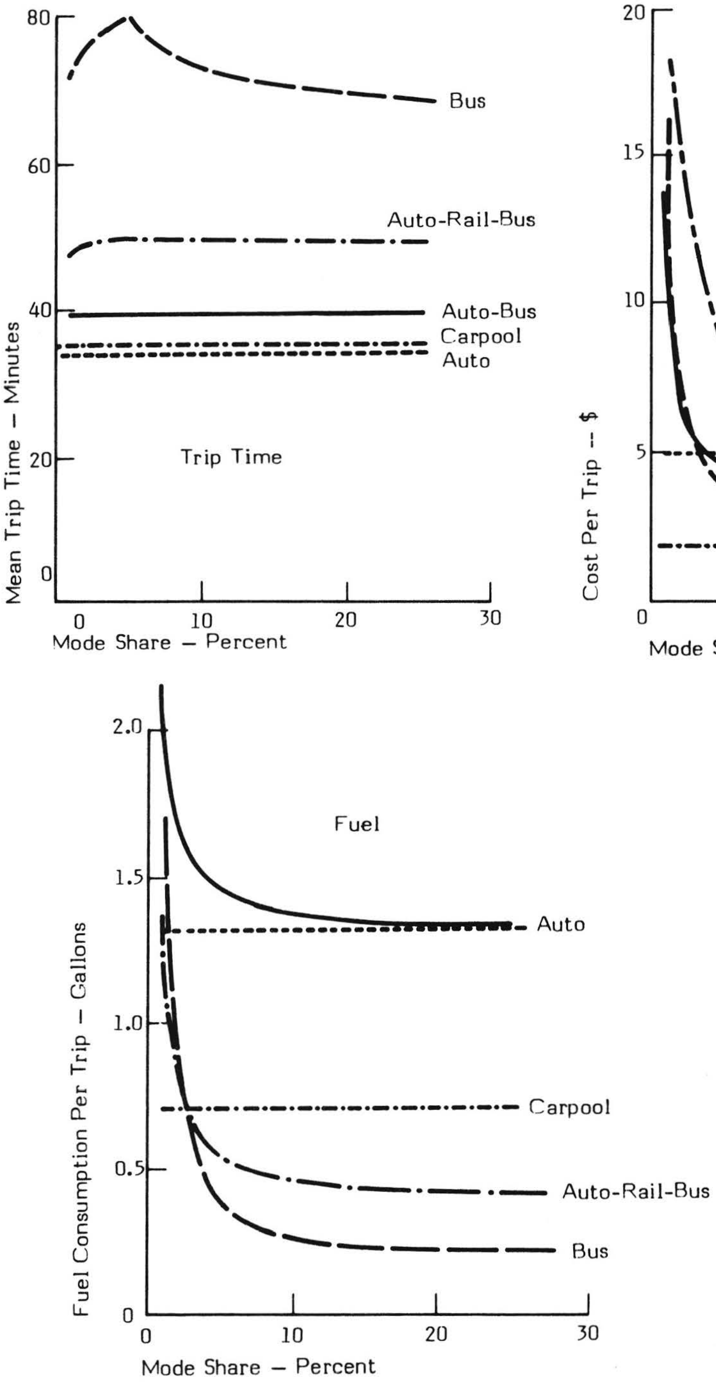
In these times of energy concern, the relative fuel consumption per passenger trip presents an interesting picture. At very low mode shares and correspondingly low bus occupancies, fixed-route bus requires much more fuel per passenger trip than automobile. This suggests that in fuel-constrained situations, transit planners can afford to lead demand by only a limited amount. Other interesting results can be obtained by varying mean vehicle occupancy and carpool fractions. Such studies can be used to evaluate alternative energy conservation programs.

The SMART model is also useful for financial planning. SMART gives cost per passenger and total cost for the specified transit services at different mode shares. Expected revenue under different plans can be subtracted from this cost to yield subsidy requirements. The impacts of different responses to new services can be investigated by examining cost and cost revenue differences at different mode shares.

Fleet size estimates at different mode shares are also useful in strategic planning. The vehicle requirements for different mode shares and the service implications of vehicle constraints can be weighed and evaluated as input to capital grant programs. SMART can also be used to compare the relative value of different sized vehicles. For example, it can compare minibuses with standard coaches in terms of cost and fuel consumption. Although other inputs are needed on relative maneuverability and ease of maintenance, SMART can bound the differences so that the detail of supporting information can be identified.

The next two chapters describe the application of the SMART model to South Dayton, Ohio, and Portland, Oregon. These descriptions are intended to specify modeling requirements and to illustrate problems, opportunities, and results. These examples can be used as a guide for those making new applications. They also illustrate the kinds of problems that can be investigated and the nature of the results that can be obtained.

EXHIBIT 3.10
DOOR-TO-DOOR MODEL COMPARISONS



4. SOUTH DAYTON, OHIO, STUDY AREA

The South Dayton communities of Kettering, Centerville, Miamisburg, Moraine, Oakwood, and West Carrollton were selected for the initial SMART application because they have developed a unique cooperative approach to solving the problems of suburban America. The six communities span the range of suburban development. Miamisburg is an old community that has only recently become part of the urban expansion. Kettering is a post-World War II development that has grown up with imagination and style. Oakwood is an old established suburb. West Carrollton is the site of Dayton's largest shopping center, which effectively rivals the Dayton CBD. Centerville has experienced most of its of growth during the past decade, and much more is expected in the next decade. In contrast, Moraine has recently suffered the loss of major employers and faces an uncertain future. These six communities with their diverse backgrounds have banded together to solve their common problems. They have developed a common cable television system, complete with a common communication network. They are now working on common transportation problems.

The Miami Valley Regional Transit Authority (RTA) serves Dayton and parts of Oakwood with two bus routes that extend into Kettering and a third that provides some circulation service in Kettering. The other cities are without public transportation. Several plans have been put forward to extend RTA service throughout Montgomery County. The six cities have been cautious about accepting these plans because they concentrate on providing access to the Dayton CBD while overlooking many local needs. Representatives of the six cities have been anxious to get an objective view of some of the plans and proposals.

The transportation planning data in the study area resemble those available in many cities. The last comprehensive plan was completed in 1969. Since then, substantial growth has occurred in the study area. Population and employment estimates were updated in 1975, by traffic zone, and projections have been made to the year 2000; 1975 traffic volumes are available only for major streets in the study area. Thus, demand data for the SMART model are best generated from population and employment data. Estimates of link travel can be compared with measured traffic.

4.1 OBJECTIVES

The three objectives of this South Dayton application were to (1) test the ring/corridor network configuration, (2) use zonal population and employment data to generate demand data, and (3) examine different transportation alternatives that are under consideration by local Dayton area planning agencies.

4.2 SCOPE

The research team intended that there be an exact equivalence between transportation networks developed by means of the ring/corridor approach and those developed by means of the arbitrary network approach. To test this equivalence, both the ring/corridor and arbitrary networks were developed and compared; present traffic patterns in the South Dayton area were used.

Once the equivalence was demonstrated, the ring/corridor network configuration was used for the balance of the South Dayton analysis.

The ring/corridor network was calibrated; first, to determine that it could reproduce approximately the same automobile traffic that has been measured on city streets, and second, to determine that it could reproduce present transit activity in the study area. When SMART model calibration was complete, runs were made to examine eight different situations:

- The 1975 present transit system
- A proposed countywide transit system
- A modification to the countywide transit system with checkpoint deviation loop routes
- The present transit system with shared-ride taxi/van in the Kettering area
- The proposed countywide transit augmented with shared-ride taxi/van in the Kettering area
- An areawide transit system with a light rail corridor for the year 2000
- An area transit system with a busway corridor for the year 2000
- The proposed countywide transit system with a light rail corridor replacing fixed-route bus where duplication occurs

4.3 STUDY AREA DESCRIPTION

The study site is a six-city suburban area in Montgomery County, Ohio, south of Dayton. In the southern portion of the study area, land use has been changing rapidly from rural farmland to developed and partially developed residential areas. A major regional shopping mall was constructed in the 1970s and serves as an important traffic generator. There is currently no public transportation service to the mall. The study area population is more than 200,000; employment is estimated at 143,000 jobs.

The regional setting is a planning area encompassing Montgomery and Greene Counties, with a population of 712,000 and employment of 317,000. The largest single employment center is Wright Patterson Air Force Base, northeast of the study area.

Transit for the region is provided by the Miami Valley Regional Transit Authority formed in 1972, but there is currently little public transit in the study area. Seven diesel and trolley bus routes serve the northern part of the study area. In addition, Kettering has developed a Community Responsive Transit plan that uses shared-ride taxis.

4.4 GETTING STARTED

Workshop Session

The SYSTAN project team met with representatives of the regional planning agency, the transit agency, and the cities to prepare a representation of the urban structure in the South Dayton study area. Study area boundaries were defined: a major highway and river limited the west side; another major highway bound the east; the Dayton CBD became the northern terminus; the county line, the southern terminus. Exhibit 4.1 shows the study area.

On a large base map showing the two-county planning area, the following were marked:

- The major road network, including freeways, major arterials (20,000 or more automobiles daily), and important collector streets
- Major employment sites, including an important Air Force base
- Major activity centers, including a regional shopping mall

Land use was discussed to determine changes that had occurred since the base map was produced and to assess the impacts of expected future developments, including a proposed freeway.

After the dominant features were sketched, a logical zonal structure was developed. Dayton's current and projected employment, population, and land use data were based on 825 traffic zones. Using these zones as building blocks, new zones were constructed for the SMART model. The first aggregation of 70 SMART zones was later reduced to 42 zones with an additional 4 zones to represent the county areas outside the study site (see Exhibit 4.2). The road network was considered while the large zones were developed to ease later data manipulation problems.

Using the aggregated zones, the road network, and the activity center locations, the next step was to construct an integrated highway network. A review was made of the freeway network, then of major arterial streets (more than 20,000 automobiles daily), and, finally, of other streets to connect and complete the network structure. Some adjustments and judgments were made regarding zone size and location of activity centers. In SMART, all zones must have a single contact point with the highway network. The activity center is located around this contact point.

For zones with more than one activity center, a judgment was made about which center to use. In some instances, the larger and more important of the two centers was used; in others, the center that was most compatible with the highway network

EXHIBIT 4.1
SOUTH DAYTON STUDY AREA

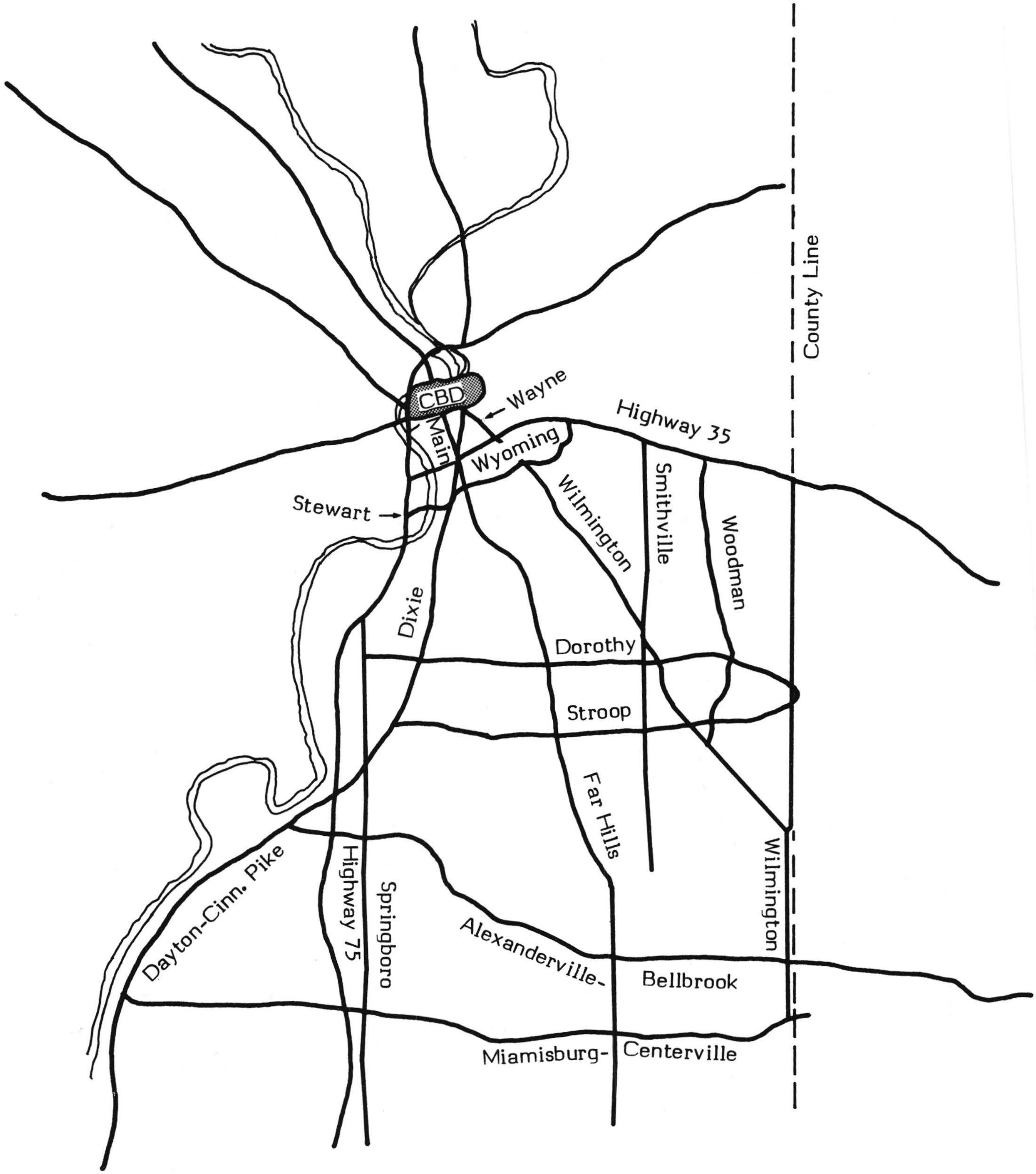
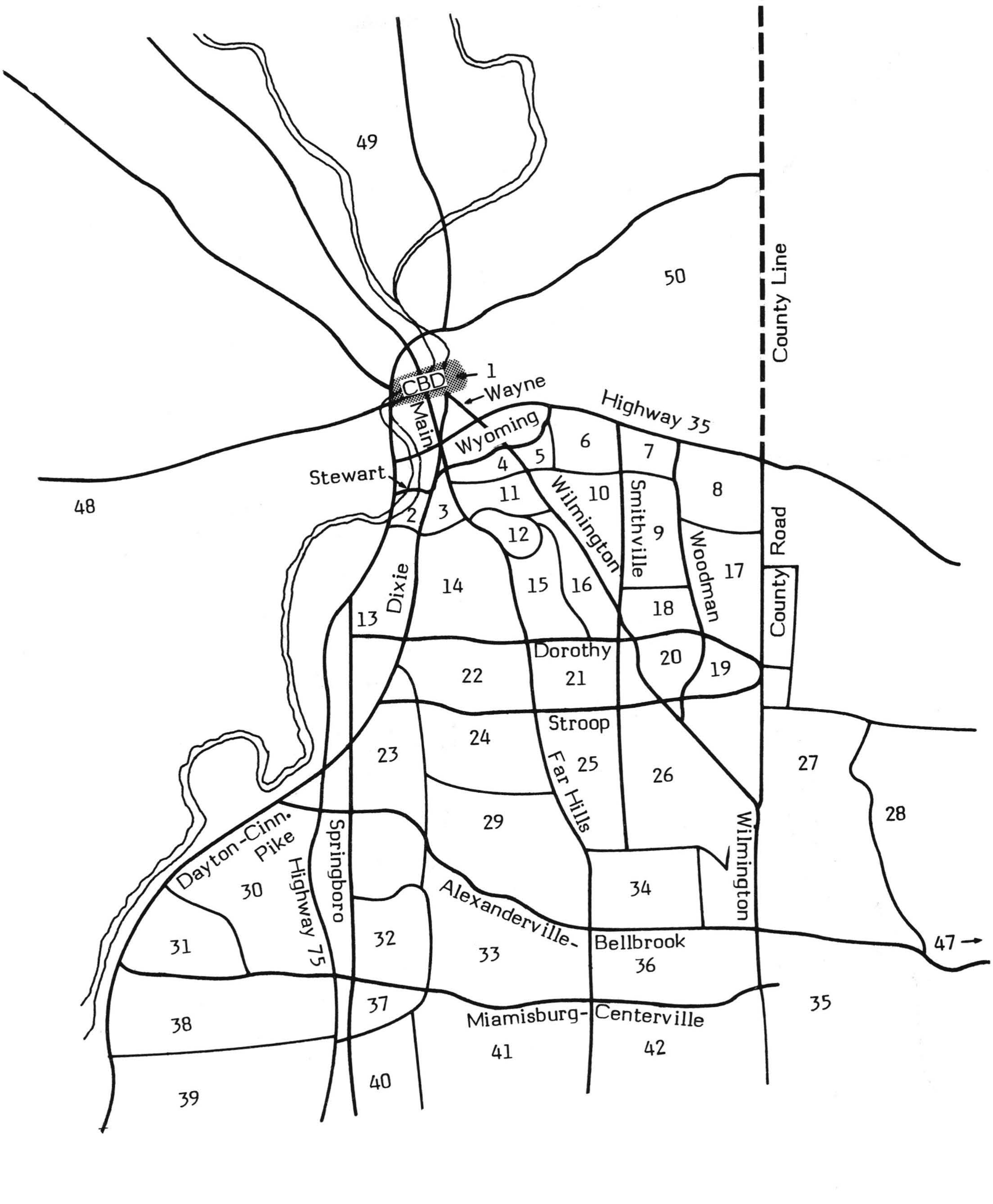


EXHIBIT 4.2

STUDY AREA ZONES (46)



was selected. In cases where important road junctions occurred with no suitable activity center, a dummy mode was designated to allow traffic to flow through that network intersection.

Data Preparation

Two tasks needed to be accomplished before the SMART model could be used:

- Develop demand input
- Define a ring/corridor network of links, nodes, and zones

Travel data in South Dayton were developed from population and employment statistics for the 825-zone traffic network. The first step was to compress the population, employment, and land use data from traffic zones into the 46 SMART zones. Exhibit 4.3 shows the relationship among (1) the centroid numbers (traffic zones), (2) SMART zone numbers, and (3) names produced by SMART for the ring/corridor network configuration. Exhibits 4.4 and 4.5 contain samples from the 1968 data file for the two-county area. The residential population and total employment figures from Exhibit 4.4 were aggregated by SMART zone and divided by zone size to give population and employment densities.

Determining the zone size required imaginative application of the data from Exhibit 4.5. Most zones had a fairly uniform use of the land that was developed. Thus, zone size could be based on usable land (total acres minus unusable acres) converted to square miles.[1] A similar exercise was performed for the year 2000.

For reference, the total population and employment base figures were as follows:

Year	Population		Employment	
1968	696,000		302,000	
1975	713,000	(+ 2%)	309,000	(+ 2%)
2000	972,000	(+36%)	465,000	(+51%)

These data produced 2.4 million trips for 1975 and 3.5 million for 2000 in the two-county area.

To estimate travel demand from population and employment data, trip-origin rates per person per day were needed for each of the three trip types. Data supplied by the regional planning agency indicated that 1968 person trips for the two-county area were divided as follows:

---

[1] Later, a decision to change the base year from 1968 to 1975 complicated the preparation of demand data. The regional planning agency supplied 1975 person trip-ends by census tract, and census tract data were converted to SMART zones using the traffic zone data to produce 1975 zone trip-ends.

EXHIBIT 4.3

ZONE CORRESPONDENCE

SMART Zones (No.)	Centroid Numbers (Traffic Zones)	SMART Zone (Name)
1 (CBD)	1-57	LZONR1C1
2	58, 63-65	RZONR2C5
3	680, 681, 683, 684, 685, 687, 693, 695, 696	RZONR2C3
4	605, 677-679, 682, 686, 694	LZONR2C3
5	609-612, 614-616	LZONR2C2
6	617, 618, 621, 622	RZONR2C1
7	481, 482, 620, 627	RZONR3C1
8	490, 634, 635	RIGHTH8*
9	628-633	RIGHTH9
10	623-626, 712, 714, 725, 727	LZONR3C2
11	688, 689, 691	LEFTH11
12	690, 692, 709	LEFTH12
13	771, 772, 781-787	RZONR3C4
14	697, 698, 773, 774, 778, 779	RZONR3C3
15	729-732, 734, 735	LZONR3C3
16	710, 726, 728, 733, 736	LEFTH16
17	636, 637, 665	RZONR4C1
18	724, 737, 739	LZONR4C2
19	638-640, 657, 721	LZONR5C2
20	717, 722, 723, 738	RZONR4C2
21	708, 711, 713, 715, 716	RIGHTH21
22	699, 777, 780, 788	LZONR3C4
23	768-770, 775, 776, 789, 805, 806	LZONR4C4
24	700-702	RZONR4C3
25	703-707, 718, 749, 751	LZONR4C3
26	719, 720, 748, 752-754	RZONR5C2
27	647-649, 755, 760	RZONR6C2
28	645, 650, 651	SZONR6C2
29	740, 741, 750	RZONR5C3
30	730-793, 807, 808, 817	LZONR5C5
31	801, 809-816	LZONR6C5
32	818-820	LZONR6C4
33	742, 743, 746	RIGHTH33
34	756-759	LZONR5C3
35	641-643, 646	RIGHTH35
36	761-764	LZONR6C3
37	803, 804	LEFTH37
38	794-800	LEFTH38
39	822, 823	RZONR6C4
40	802, 821, 824, 825	LEFTH40
41	744, 745, 747, 767	RZONR6C3
42	765, 766	RIGHTH42
47 (EZ4)	484, 487-489, 492, 495-498, 503-603, 644 652-656, 658-664, 666-676	RZONR6C1
48 (EZ3)	59-62, 66-150, 164-196, 210-226, 229-232, 253-259, 268, 281-295, 303-307	LZONR5C6
49 (EZ2)	151-163, 197-209, 227, 228, 233-252, 260-267, 269-280, 296-302, 308-361, 364, 365, 372, 373, 386, 389, 390, 397	RZONR5C6
50 (EZ1)	362, 363, 366-371, 374-385, 387, 388, 391-396, 398-480, 483, 485, 486, 491, 493, 494, 499-502, 604, 606-608, 613, 619	LZONR3C0

---

*This zonal description indicates that more than one zone is attached to this side of a node. When using this description, the node attachment is also given.

EXHIBIT 4.4

1968 EMPLOYMENT AND POPULATION DATA SAMPLE

CENTROID	CITY	ZONE	HOUSING UNITS	RESIDENT POPULATION	GROUP QUARTERS RES.POP.	/RESTRICTED	EMPLOYED RESIDENTS	NON-WORK POP	TOTAL EMPLOY	BASIC EMPLOY	POP SERVE EMPLOY	TOTAL POP
101	630	1206	579.	2066.	0.	0.	760.	1306.	77.	0.	77.	2066.
102	630	1207	111.	285.	0.	0.	101.	184.	17.	0.	17.	285.
103	9006	1208	102.	295.	0.	0.	82.	213.	94.	0.	94.	295.
104	630	1209	438.	1388.	0.	0.	417.	971.	63.	0.	63.	1388.
105	630	1210	115.	261.	0.	0.	117.	144.	1570.	765.	735.	261.
106	9006	1211	337.	931.	0.	0.	279.	652.	31.	0.	31.	931.
107	9006	1212	291.	1048.	0.	0.	243.	805.	163.	0.	163.	1048.
108	9006	1213	324.	1101.	0.	0.	397.	704.	31.	10.	21.	1101.
109	9005	1214	147.	457.	0.	0.	135.	322.	271.	0.	271.	457.
110	9005	1215	717.	2764.	0.	0.	1106.	1658.	121.	0.	121.	2764.
111	9006	1301	271.	984.	0.	0.	460.	524.	100.	87.	13.	984.
112	9006	1302	107.	491.	0.	0.	152.	339.	9.	0.	9.	491.
113	9005	1303	123.	492.	0.	0.	165.	327.	10.	8.	2.	492.
114	9006	1304	160.	592.	0.	0.	228.	364.	6.	0.	6.	592.
115	9005	1305	203.	711.	0.	0.	225.	486.	20.	0.	20.	711.
116	9006	1306	55.	110.	0.	0.	38.	72.	0.	0.	0.	110.
117	9009	1307	118.	457.	0.	0.	137.	320.	8.	0.	8.	457.
118	1570	1308	336.	1084.	0.	0.	411.	673.	78.	12.	66.	1084.
119	9009	1309	139.	528.	0.	0.	144.	384.	73.	19.	54.	528.
120	9009	1310	61.	244.	0.	0.	62.	182.	5.	0.	5.	244.
121	9006	1311	196.	604.	0.	0.	202.	402.	94.	0.	94.	604.
122	9006	1312	71.	227.	0.	0.	60.	167.	17.	0.	17.	227.
123	9006	1313	68.	238.	0.	0.	103.	135.	10.	0.	10.	238.
124	9006	1314	56.	145.	0.	0.	41.	104.	1.	0.	1.	145.
125	9009	1315	174.	606.	0.	0.	184.	422.	41.	0.	41.	606.
126	9009	1316	351.	1024.	0.	0.	433.	591.	272.	0.	272.	1024.
127	625	P401	256.	828.	0.	0.	292.	536.	53.	0.	53.	828.
128	9005	1402	63.	189.	0.	0.	126.	63.	3.	3.	0.	189.
129	9003	1403	81.	270.	0.	0.	85.	185.	61.	0.	61.	270.
130	9003	1404	89.	338.	0.	0.	93.	245.	10.	0.	10.	338.
131	9003	1405	56.	261.	0.	0.	57.	204.	4.	0.	4.	261.
132	930	1406	164.	533.	0.	0.	208.	325.	0.	0.	0.	533.
133	930	1407	236.	691.	0.	0.	291.	400.	69.	6.	63.	691.
134	930	1408	341.	979.	0.	0.	426.	553.	261.	179.	82.	979.
135	930	1409	437.	1296.	0.	0.	553.	743.	25.	0.	25.	1296.
136	930	1410	151.	498.	0.	0.	230.	268.	29.	7.	22.	498.
137	9003	1411	180.	645.	0.	0.	231.	414.	22.	0.	22.	645.
138	9003	1412	197.	803.	0.	0.	325.	478.	77.	0.	77.	803.
139	9003	1413	75.	225.	0.	0.	65.	160.	1.	0.	1.	225.
140	9003	1414	112.	256.	0.	0.	100.	156.	4.	0.	4.	256.
141	9005	1415	157.	585.	0.	0.	202.	383.	6.	0.	6.	585.
142	9005	1416	10.	40.	0.	0.	11.	29.	0.	0.	0.	40.
143	9005	1417	98.	308.	0.	0.	115.	193.	0.	0.	0.	308.
144	9005	1418	46.	184.	0.	0.	34.	150.	3.	0.	3.	184.
145	9005	1419	37.	111.	0.	0.	75.	36.	30.	0.	30.	111.
146	1745	1420	151.	535.	0.	0.	196.	339.	96.	0.	96.	535.
147	1745	1421	454.	1443.	0.	0.	547.	896.	39.	0.	39.	1443.
148	1745	1422	613.	1913.	0.	0.	805.	1108.	81.	48.	33.	1913.
149	9005	1423	61.	146.	0.	0.	63.	83.	2.	0.	2.	146.
150	9005	1424	193.	675.	0.	0.	296.	379.	0.	0.	0.	675.

EXHIBIT 4.5

1968 LAND USE DATA SAMPLE

CENTROID	CITY	ZONE	TOTAL ACREAGE	UNUSEABLE ACREAGE	STREETS, HIGHWAYS	BASIC ACREAGE	POP-SERVE ACREAGE	RESIDENTIAL ACREAGE	INDUST. AVAILABLE	OTHER AVAILABLE	NON-INF. VACANT
101	630	1206	339.	40.	34.	0.	46.	66.	0.	153.	0.
102	630	1207	66.	31.	10.	0.	11.	14.	0.	0.	0.
103	9006	1208	492.	68.	23.	0.	144.	52.	85.	120.	0.
104	630	1209	179.	41.	9.	0.	18.	61.	30.	20.	0.
105	630	1210	353.	38.	34.	105.	132.	34.	10.	0.	0.
106	9006	1211	208.	0.	23.	0.	12.	75.	0.	98.	0.
107	9006	1212	311.	71.	17.	0.	44.	69.	10.	100.	0.
108	9006	1213	367.	112.	25.	1.	12.	97.	10.	110.	0.
109	9006	1214	1029.	200.	30.	0.	29.	39.	31.	700.	0.
110	9006	1215	583.	10.	66.	0.	29.	244.	20.	214.	0.
111	9006	1301	1452.	316.	50.	6.	28.	88.	64.	900.	0.
112	9006	1302	1541.	555.	42.	0.	69.	260.	15.	600.	0.
113	9006	1303	1414.	583.	39.	5.	48.	39.	500.	200.	0.
114	9006	1304	1240.	900.	47.	0.	2.	137.	100.	0.	54.
115	9006	1305	3587.	3097.	89.	0.	43.	293.	0.	0.	65.
116	9006	1306	2466.	2284.	48.	0.	0.	14.	0.	0.	120.
117	9009	1307	1447.	968.	24.	0.	3.	162.	0.	290.	0.
118	1570	1308	740.	378.	39.	7.	58.	178.	15.	65.	0.
119	9009	1309	1239.	731.	36.	3.	67.	162.	190.	0.	50.
120	9009	1310	898.	755.	19.	0.	33.	41.	0.	20.	30.
121	9006	1311	2546.	1230.	72.	0.	59.	85.	100.	1000.	0.
122	9006	1312	1827.	1657.	34.	0.	16.	34.	0.	0.	86.
123	9006	1313	609.	366.	11.	0.	4.	32.	50.	90.	56.
124	9006	1314	983.	343.	24.	0.	3.	113.	100.	400.	0.
125	9009	1315	2314.	1500.	37.	0.	34.	186.	0.	457.	100.
126	9009	1316	601.	200.	47.	0.	171.	117.	0.	66.	0.
127	925	1401	367.	54.	51.	0.	20.	88.	54.	100.	0.
128	9005	1402	5287.	4958.	81.	4.	0.	124.	20.	100.	0.
129	9003	1403	2233.	1700.	45.	0.	31.	27.	42.	388.	0.
130	9003	1404	939.	781.	30.	0.	17.	71.	10.	30.	0.
131	9003	1405	1697.	1103.	32.	0.	11.	28.	173.	350.	0.
132	930	1406	309.	141.	32.	0.	0.	61.	5.	70.	0.
133	930	1407	332.	28.	21.	6.	24.	153.	20.	80.	0.
134	930	1408	426.	172.	37.	4.	38.	100.	0.	75.	0.
135	930	1409	306.	60.	29.	0.	1.	76.	0.	140.	0.
136	930	1410	112.	20.	16.	1.	6.	44.	0.	25.	0.
137	9003	1411	3506.	3099.	125.	0.	33.	149.	0.	100.	0.
138	9003	1412	7118.	6719.	142.	0.	77.	80.	0.	100.	0.
139	9003	1413	4361.	4192.	62.	0.	40.	27.	0.	40.	0.
140	9003	1414	2694.	2531.	41.	0.	41.	51.	0.	30.	0.
141	9005	1415	5099.	4567.	98.	0.	2.	98.	15.	69.	250.
142	9005	1416	575.	543.	11.	0.	0.	7.	0.	0.	14.
143	9005	1417	4608.	4465.	89.	0.	0.	40.	0.	0.	14.
144	9005	1418	1667.	1560.	38.	0.	12.	15.	0.	0.	42.
145	9005	1419	597.	429.	17.	0.	31.	20.	23.	77.	0.
146	1745	1420	305.	0.	30.	0.	34.	103.	9.	129.	0.
147	1745	1421	167.	30.	13.	0.	6.	86.	7.	25.	0.
148	1745	1422	308.	16.	34.	2.	12.	169.	35.	40.	0.
149	9005	1423	571.	236.	10.	0.	23.	79.	10.	213.	0.
150	9005	1424	4737.	4336.	88.	0.	0.	93.	0.	0.	220.

		Trips	Percent
1.	Home-based work	440,570	31
2.	Home-based school	232,247	
3.	Home-based shop	323,736	44
4.	Home-based other	649,842	
5.	Non-home-based	547,143	25
		2,193,538	100

The first four categories were grouped together as indicated to produce the three trip types that SMART uses. Based on these combinations, the factors used in SMART, by the DEMPARM keyword, were 0.5 for home-based work trips, 0.7 for home-based nonwork trips, and 0.8 for non-home-based work trips. The first factor was multiplied by the residential population of each zone to produce morning origin trip-ends for each work trip. Destination trip-ends were equal to the employment values for each zone. The second factor was multiplied by residential population to give the residential origins; destinations were factored from employment by zone. Non-home-based work trip-ends were calculated by applying this factor to each zone's employment. The factor 0.8 was intentionally set high to reflect the non-work trips included in the non-home-based category.

Each trip type was distributed over time according to the following fractions:[2]

Trip Type	A.M. Peak		Off-Peak	P.M. Peak	Off Hours
Work/school	In:	0.90	0.10	--	--
	Out:	--	--	0.90	0.10
Shop/other	In:	--	0.60	0.10	0.30
Home-based	Out:	--	0.40	0.30	0.30
Non-home-based	In:	0.10	0.80	0.10	--
Work/work	Out:	0.10	0.80	0.10	--

Both the A.M. and P.M. peak periods were set at 3 hours and the off-peak period was set at 6 hours.

---

[2] Home-based in trips have residential origins and work or shopping destinations; out trips are the reverse. Non-home-based trips have employment origins and destinations for both in and out directions.

Using these data, SMART calculated trip-ends for each zone, associated origins, and destinations, using the negative exponential density function, and selected shortest paths for each O-D pair on the basis of uncongested automobile travel time.

Ring/Corridor Representation of South Dayton

The basis for the ring/corridor network was the network that was sketched in a workshop session with Dayton area planners. This network was reconfigured into five major corridors plus one corridor to connect with the two external zones that are northwest of the study area. The relative angular locations of these six corridors from a reference north were measured from the base map. The circumferential link lengths were measured for six rings, and the mean lengths of the ring radii were calculated.[3] The calculated network radii and area were based on mean distance from the CBD for the zones that are prime candidates for each ring. This procedure preserves the circular geometry of the study area. To achieve more representative results, radial and circumferential link lengths were finally modified to actual distances. This step did not destroy the ring/corridor structure, but it did unexpected things to the graphic representation.

By defining six rings and six corridors for the study area, SMART created the zone-link network shown in Exhibit 4.6. Two zones are attached to each node that is formed by the intersection of a ring and a corridor. This uniform network was modified to delete links that are not needed in the representation of South Dayton. These links were removed by describing them as missing. Zones can also be removed by describing them with the word "IGNORE." The use of IGNORE for external zones that have demand associated with them allows the user to enter the external trips into the network without having to deal with the internal trips.

The next step was to assign locations to the 46 zones within the ring/corridor structure. Two of the four external zones (48 and 49) were attached to corridor 6, which was designated to handle external movement from the northwest, and to ring 5, which approximated the distance from the CBD to the external zone centroids. One external zone (50) was attached to the northern end of ring 3 outside of the corridor structure, and the other external zone (47) was attached to corridor 1 at ring 6. The 42 internal zones were given standard zone locations to the extent possible. At one node (ring 6, corridor 4), two additional zones needed to be attached and several nodes required that one additional zone be attached. Each zone was considered independently when making the central mode assignments. Each zone was assigned to the node closest to its activity center. When the initial assignments were complete, the overall assignment was examined in terms of known traffic access and patterns or movement, and some adjustments were made. Exhibit 4.7 shows the zone assignments to the revised network. This structure was reviewed with study area planners before the work proceeded.

---

[3] See Lim, W.Y. and Canfield, A.J., SYSTAN's Macro-Analytic Regionwide Transportation Model: Users' Manual, SYSTAN, Inc., Los Altos, California, for a description of the method for calculating mean ring radii.

EXHIBIT 4.6

SIX-RING CORRIDOR NETWORK CREATED BY SMART

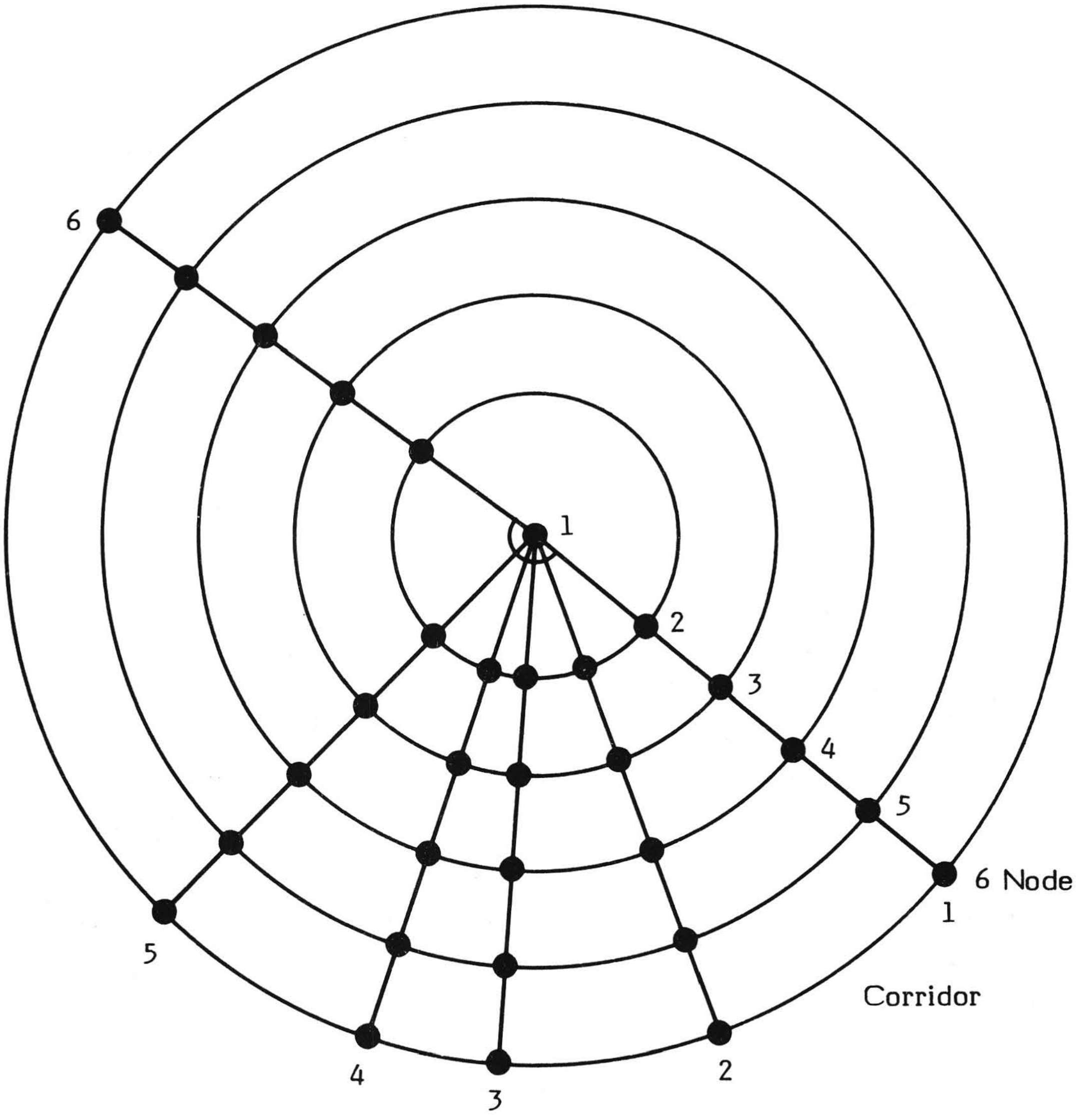
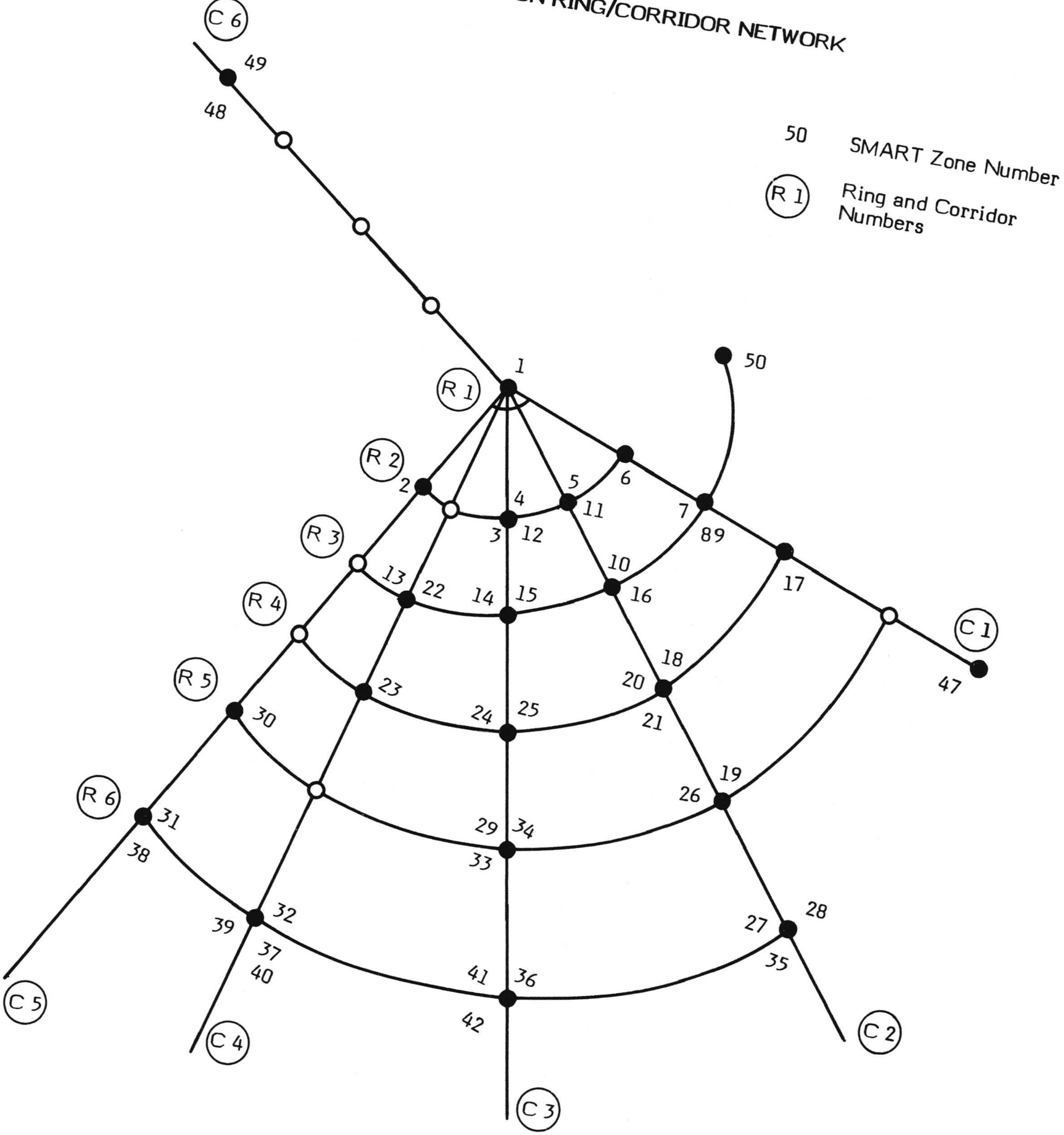


EXHIBIT 4.7
SOUTH DAYTON RING/CORRIDOR NETWORK



When agreement was reached on the network configuration, input data were prepared for the SMART model. Exhibit 4.8 illustrates a worksheet that was useful in keeping track of the link and zone assignments. This form was particularly useful later in the study when different transit service areas were being considered. Appendix D of the full study contains a complete input deck for the South Dayton ring/corridor network, with explanatory notes.

4.5 SMART MODEL CALIBRATION

Before the SMART model could be used to explore transit development opportunities in South Dayton, it had to be tested for credibility and, if necessary, modified to improve this credibility. Two tests, or calibration steps, were used. The first tested the model's ability to reproduce highway traffic data that resembled the traffic counts on the different streets used as network links. The second test determined the model's ability to represent existing public transit services in the South Dayton area.

Traffic Analysis

Test runs were made to check how accurately the ring/corridor SMART network represented the average daily traffic (ADT) counts made in 1975 for South Dayton. This calibrated three important aspects of the network representation:

1. Whether the interzonal traffic is assigned to routes that resemble today's traffic routes
2. Whether the proper number of network links have been selected to carry the interzonal traffic
3. Whether the network is geographically balanced

It was only necessary that SMART traffic volumes resemble actual traffic counts; a direct one-for-one correspondence or complete calibration was not appropriate because

1. The 1975 population estimates were given by census tract and, therefore, required adjustment to the SMART zones.
2. The traffic generation factors were applied uniformly to both population and employment.
3. The external zones tended to channel traffic along particular network links.

Exhibit 4.9 shows link-by-link comparisons between ADT values and SMART results. There is general agreement between the two, as illustrated by the following summary of traffic differences:

EXHIBIT 4.8

RING/CORRIDOR NETWORK WORKSHEET
SOUTH DAYTON STUDY AREA

Condition: 6-ring 6-corridor network

Radial Links			Zones			
		Status	Left	Zone No.	Right	Zone No.
Ring 1		✓	✓	(CBD)	n.a.	
Ring 2 Corridor	1	✓	I	–	✓	6
	2	✓	✓	5,11	I	–
	3	✓	✓	4,12	✓	3
	4	✓	I	–	I	–
	5	✓	I	–	✓	2
	6	✓	I	–	I	–
Ring 3 Corridor	1	✓	I	–	✓	7,8,9
	2	✓	✓	10,16	I	–
	3	✓	✓	15	✓	14
	4	✓	✓	22	✓	13
	5	✓	I	–	I	–
	6	✓	I	–	I	–
Ring 4 Corridor	1	✓	I	–	✓	17
	2	✓	✓	18	✓	20,21
	3	✓	✓	25	✓	24
	4	✓	✓	23	I	–
	5	✓	I	–	I	–
	6	✓	I	–	I	–
Ring 5 Corridor	1	✓	I	–	I	–
	2	✓	✓	19	✓	26
	3	✓	✓	34	✓	29,33
	4	✓	I	–	I	–
	5	✓	✓	30	I	–
	6	✓	I	48	I	49
Ring 6 Corridor	1	✓	I	–	I	47
	2	✓	✓	28	✓	27,35
	3	✓	✓	36	✓	41,42
	4	✓	✓	32,37,40	✓	39
	5	✓	✓	31,38	I	–
	6	MISSING	I	–	I	–

I = Ignore

Exhibit 4.8 (continued)

Circumferential Links

Ring 2 Corridor	1	✓	Ring 4 Corridor	1	✓	Ring 6 Corridor	1	MISSING
	2	✓		2	✓		2	✓
	3	✓		3	✓		3	✓
	4	✓		4	✓		4	✓
	5	MISSING		5	MISSING		5	MISSING
	6	MISSING		6	MISSING		6	MISSING

Ring 3 Corridor	1	✓	Ring 5 Corridor	1	✓
	2	✓		2	✓
	3	✓		3	✓
	4	✓		4	✓
	5	MISSING		5	MISSING
	6	MISSING		6	MISSING

Additional Zones, Links

Circumferential Link		Zone	
R3C0	✓	LZONR3C0	I
		RIGHTH8	✓
		RIGHTH9	✓
		LEFTH11	✓
		LEFTH12	✓
		LEFTH16	✓
		RIGHTH21	✓
		RIGHTH33	✓
		RIGHTH35	✓
		LEFTH37	✓
		LEFTH40	✓
		RIGHTH42	✓

EXHIBIT 4.9

TRAFFIC VOLUMES—SOUTH DAYTON

Radials	ADT	SMART	Percent	Comments
R2C1	61,000	59,603	-2	Highway 35
R2C2	28,600	41,480	+45	Wayne & Xenia (2)
R2C3	38,500	70,754	-7	Main & Dixie (4)
R2C4	37,500			
R2C5	93,000	78,809	-15	Highway 75
R3C1	57,000	69,263	+22	
R3C2	35,125	49,470	+41	Wilmington
R3C3	40,500	45,486	+12	Far Hills
R3C4	31,400	22,181	-29	
R3C5	85,000	82,468	-3	Highway 75
R4C1	32,500	26,339	-19	
R4C2	42,000	55,389	+32	
R4C3	39,000	59,376	+52	
R4C4	23,500	11,627	-51	
R4C5	84,000	77,095	-8	
R5C1	28,250	15,104	-47	
R5C2	25,500	46,437	+78	
R5C3	44,000	42,815	-3	
R5C4	22,500	31,673	+41	
R5C5	59,500	61,367	+3	Highway 75
R6C1	23,000	16,001	-30	
R6C2	5,200	22,151	+326	
R6C3	30,400	29,507	-3	
R6C4	34,000	43,705	+29	
R6C5	20,800	33,348	+60	Highway 75

Exhibit 4.9 (continued)

Circumferential	ADT	SMART	Percent	Comments
R2C1	13,500	17,490	+30	Wyoming (3)
R2C2	36,750	36,877	0	Wyoming (4)
R2C3				
R2C4	13,500	13,158	-3	Stewart
R3C1	28,850	38,679	+34	Smithville
R3C2	38,700	48,582	+26	Dorothy
R3C3	28,500	32,603	+14	Dorothy
R3C4	12,000	36,879	+207	Dorothy
R4C1	18,750	3,445	-82	Woodman
R4C2	19,200	13,834	-28	Stroop
R4C3	18,000	15,791	-12	Stroop
R4C4	8,100	15,729	+73	Stroop
R5C1	8,000	877	-89	County road
R5C2	21,500	6,739	-69	Bellbrook-Wilmington
R5C3	9,900	6,519	-34	Centerville
R5C4	53,000	17,224	-68	Highway 75
R6C1	missing			
R6C2	10,250	6,563	-36	
R6C3	26,500	9,631	-64	
R6C4	21,000	12,123	-42	

No. of Links	Percent Difference
9	10
5	11-20
7	21-30
9	31-50
10	51-100
2	100
·42	

Of the 12 links with significant differences (50 percent), SMART traffic was lower on the outer circumferential links (four in rings 5 and 6). ADT traffic volumes were generally not heavy on these links. These differences are not alarming because they treat peripheral links and because they are not pressing highway capacities. SMART traffic is greater on two radial links in rings 5 and 6 of corridor 2 because the population and employment attractors are aligned along this corridor and not toward the zones on the circumferential links. The greater SMART traffic on the circumferential links in the western part of the network (on rings 3 and 4 of corridor 4) can be attributed to the attraction of Interstate Highway 75, which adjoins these links (radial link R4C5). As a result, the traffic on radial link R4C4 nearby is less than the documented value. The traffic differences were not expected to affect the transit alternatives under study because these focused on the area around Kettering where ADT and SMART traffic volumes were very similar (see Exhibit 4.10).

Transit Analysis

A small area of the South Dayton study site is served by fixed-route bus. Operating data that describe transit service existing in 1975 were used to evaluate the reality of the SMART transit representation. Representative data include the following:

System cost per day	$ 14,509.00
Cost per vehicle per day	112.47
Cost per vehicle-minute	0.28
Cost per vehicle-mile	1.42
Miles per gallon	4.3
Passengers per vehicle	46
Maximum headway	20 minutes

SMART default values were used for

Minimal stop time	0.2
Stop time increment per passenger	0.02
Stops per mile	8
Transfers	random

EXHIBIT 4.10

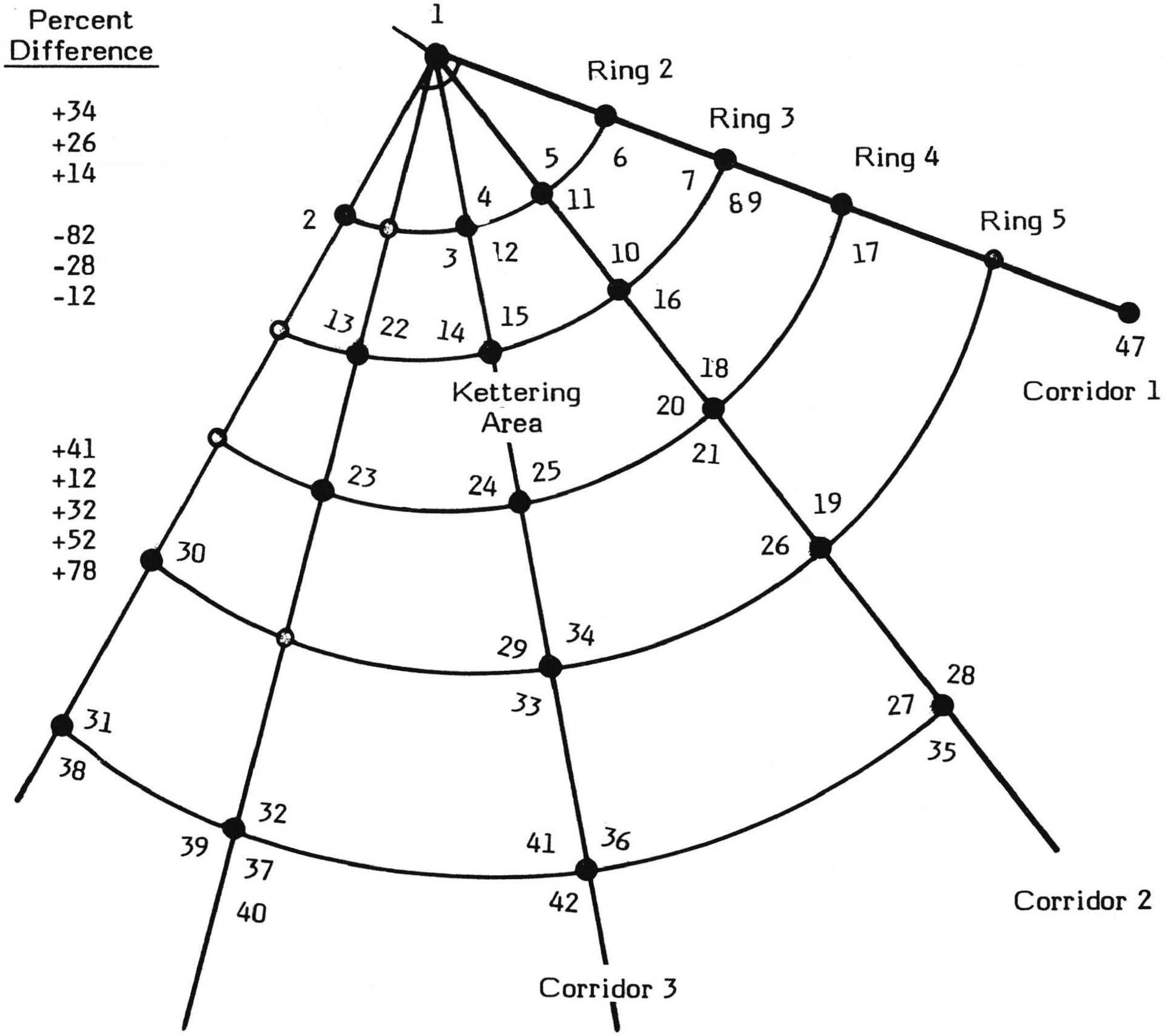
KETTERING AREA TRAFFIC

Circumferential

	ADT 76	SMART	Percent Difference
R3C1	28,850	38,679	+34
R3C2	38,700	48,582	+26
R3C3	28,500	32,603	+14
R4C1	18,750	3,445	-82
R4C2	19,200	13,834	-28
R4C3	18,000	15,791	-12

Radials

R3C2	35,125	49,470	+41
R3C3	40,500	45,486	+12
R4C2	42,000	55,389	+32
R4C3	39,000	59,376	+52
R5C2	25,500	46,437	+78



The carpool fraction was 0.32 percent. Six transit mode shares were examined: 2, 3, 5, 7.5, 10, and 15 percent during the morning and afternoon peaks; the off-peak mode shares were 60 percent of the peak mode shares. The current mode share in the South Dayton area is 5 percent during peak hours and 3 percent during the off-peak.

A small SMART network with only 11 links and 13 zones was created to represent the present transit service in the area. Seven lines operate in the area with service that continues north into Dayton and outside the study area. Adjustments were made to scheduled trip lengths and trip times so that they could be compared with the SMART model results. The comparisons shown below are based on the 5 percent afternoon peak transit mode share:

	SMART Estimate	Documented Results	Difference (Percent)
Fleet size (per hour)	20	25.3	- 27
Vehicle-miles	314	330.6	- 5
Travel time	62.6	63.2	- 1

The SMART model estimated a lower fleet size than was calculated from the transit schedules because SMART deals with fractional values of buses that precisely meet the required headways. The calculated values are rounded, so that an integer number of buses are assigned to each route. These values were constructed from peak-hour headways, by line. Vehicle-miles for South Dayton were produced from information supplied on route lengths and travel times from bus schedules.

Travel time comparisons were made for trips from three Kettering area zones to downtown Dayton. Private automobile transit service was used for the residential trip ends. Wait times were added to the bus schedule time, as was a 5-minute walk at the trip destination. The results of these estimates and calculations are listed in Exhibit 4.11. It is also of interest to compare these trips by automobile. A busway report prepared by the Montgomery County Planning Commission listed automobile travel times for a number of trips, including the 8-mile trip from Kettering to the CBD (zone 19 to CBD).[4] SMART produced a travel time of 27.7 minutes during the peak hours for this trip on the full street network, giving an average speed of about 17 miles per hour. This slow speed can be explained by congestion on the network links because the shortest uncongested travel path would be on Wilmington, which SMART has identified as congested.

The Planning Commission reports a 1968 automobile travel time of about 22 minutes. In view of the traffic increase that has occurred in recent years, these two estimates are reasonably compatible.

---

[4] Montgomery County Planning Commission, Urban Corridor Demonstration Program, System Planning Report No. FH-11-7553, October 1971.

EXHIBIT 4.11

TRAVEL TIMES FOR REPRESENTATIVE TRIPS

(A.M. PEAK—5 Percent Transit Mode Share)

Origin	Destination	SMART (minutes)	Schedule Estimate (minutes)	Route Number
Zone 19 (Kettering)	Dayton CBD	62.6	63.2*	K
Zone 16 (No. Kettering)	Dayton CBD	43.4	39.2	12
Zone 15 (Oakwood area)	Dayton CBD	44.4	38.2	5

---

*Feeder mode (private auto transit) and wait times at the origin and a walk time at the CBD (3.2, 10, 5 minutes, respectively) were added to the bus schedule figures.

4.6 RUNNING ALTERNATIVES

Overview

Several transit development alternatives are under consideration by the South Dayton planning staff. These options include

- A countywide fixed-route bus system with 13 major transfer points spread throughout the study area
- A countywide bus system with three checkpoint deviation loops (two running east and west and one, north and south)
- The current fixed-route bus system augmented with shared-ride taxi in nine zones around the Kettering area
- The proposed countywide system with shared-ride taxi in the Kettering area

Future options under consideration for the year 2000 include a light rail line or a busway that would be located in an existing railroad corridor that is now partly used for freight service and partly abandoned. These services could be added to the existing bus system or to the countywide bus system. In either case, the light rail line would replace bus routes where the two modes overlapped.

It was necessary to revise the transit network with each introduction of a new transit alternative that changed the transit coverage in the study area. The affected zones needed to be changed; demand was modified so that transit service was considered only for those trips that could use it. Adjusting the network might include

- Changing links to missing for a small transit area or to reflect changes in a transit alternative's configuration
- Adding a lane to links when a diamond lane (exclusive lane) was desired on a highway link
- Changing circumferential links to freeway-type link when a new freeway is to be considered as an alternative
- Adding light/heavy rail to links along a corridor

Changes to zones might include

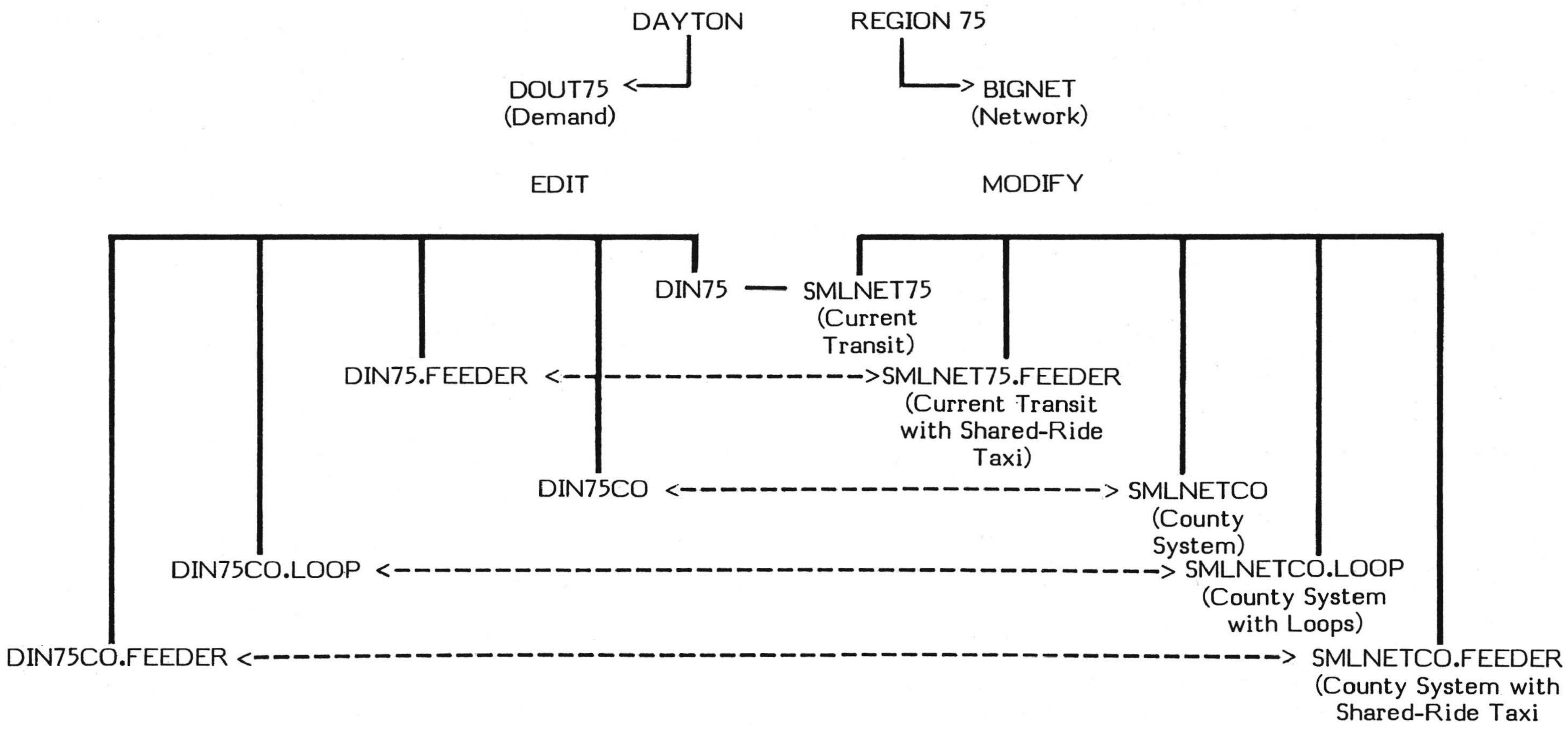
- Change zone to IGNORE so that no internal transit will be modeled[5]

---

[5] By using IGNORE for a zone that has population and employment data, the demand created for trips to and from the zone is not eliminated until it is edited out of the DOUT file (see Exhibit 4.12).

EXHIBIT 4.12

EXAMPLE OF SMART INPUT FOR 1975 RUNS



- - - Indicates demand and network used together for SMART runs.

- Add newly selected modes, e.g., checkpoint circulator buses or park-and-ride as feeder modes.

Adjusting demand required editing the regional network output to delete zonal demand for zones outside the transit coverage area. Exhibit 4.12 shows the different demand and network inputs used to generate runs for the five transit alternatives using the 1975 population and employment data base. The designations BIGNET and SMLNET refer to the automobile network and the smaller network created to represent the transit service area. BIGNET was used to model automobile traffic moving over the highway links of the study area; SMLNET represented the transit links. To eliminate transit from BIGNET, the transit mode share was set very low (0.001). Comparisons could then be made between auto travel (BIGNET75) and transit (SMLNET75, et al.).

Countywide Systems

Two proposed countywide systems that would greatly increase the transit coverage in South Dayton were examined: one would use checkpoint deviation loops and the other would not. Differences in SMART input are listed below or as graphically presented in Exhibits 4.13 and 4.14:

	Radial Links	Circumferential Links	Zones
County system	21	4	28
County system with loops	22	13	29

In the loop system, checkpoint deviation service was modeled by adding a walking time to the checkpoint, at a mean walking speed of 3 miles per hour, and by reducing bus speed (to 15 miles per hour) to reflect the increased time needed to pick up riders.

The results of the two-county system SMART runs are shown below for the morning peak period. The loop system requires 39 percent more vehicles, which travel 21 percent more vehicle-miles. Mean travel time is increased 12 percent by the route deviations, and the cost per trip is increased 7 percent.

Comparison of Two County Systems
(A.M. Peak – 5 Percent Mode Share)

	County System	County-Loop System
Fleet size	56	78
Vehicle-miles	938	1,136
Travel time	47.3	53.0
Cost per trip	6.44	6.91

EXHIBIT 4.13
COUNTY SYSTEM WITHOUT LOOPS

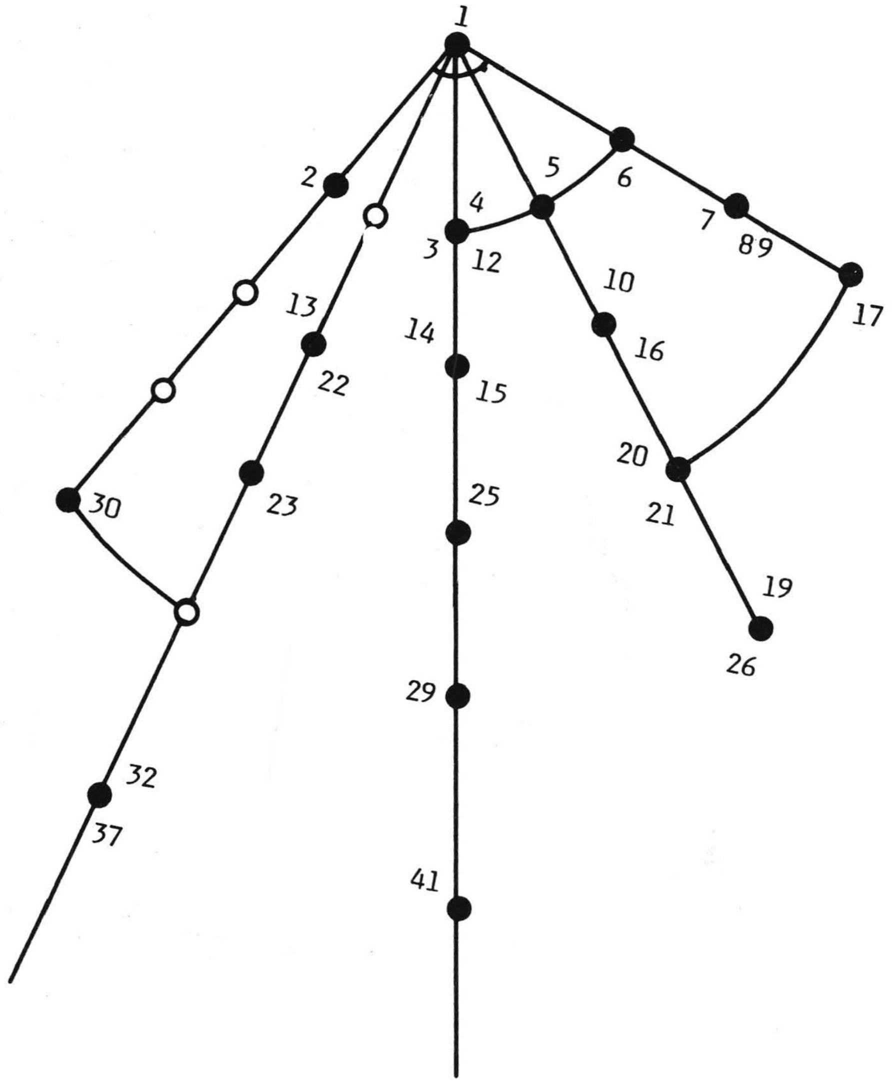
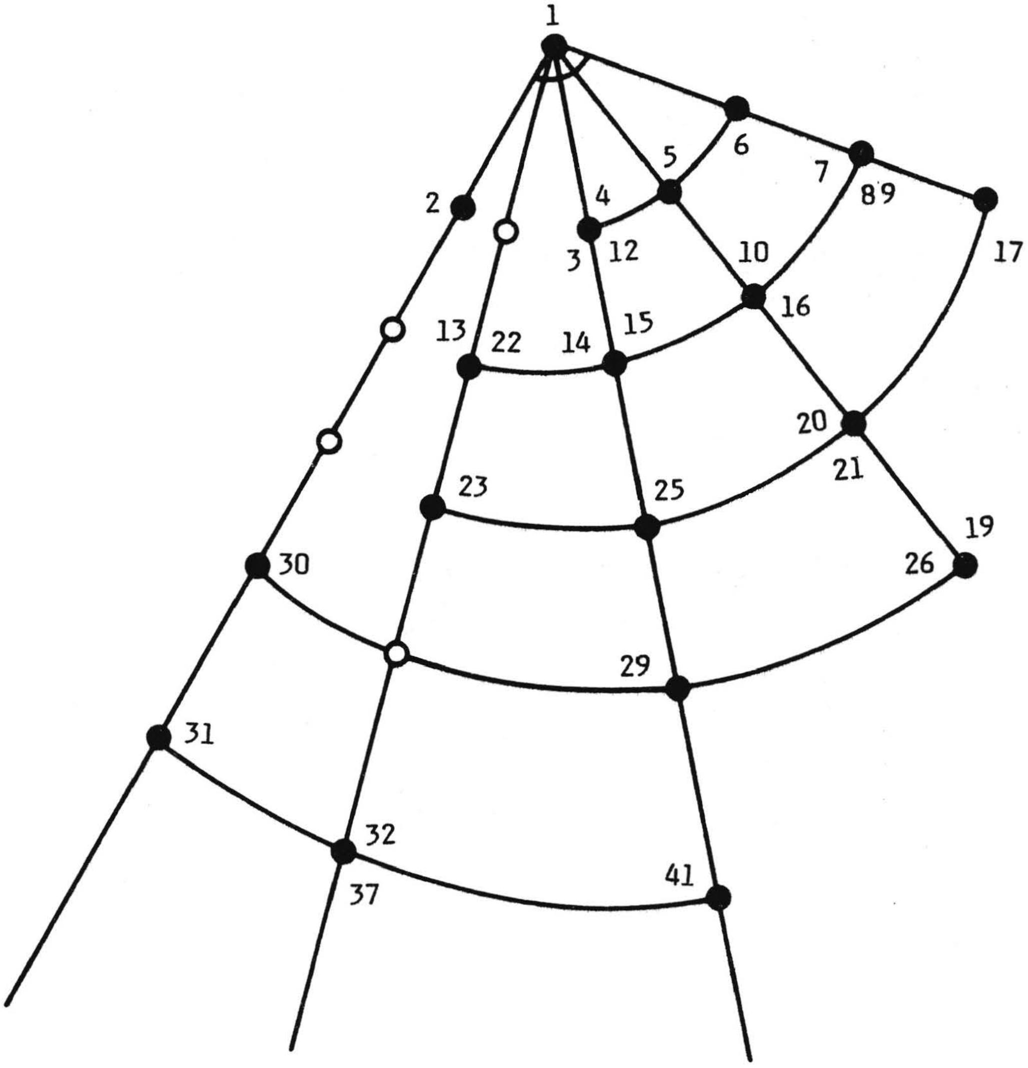


EXHIBIT 4.14

COUNTY SYSTEM WITH LOOPS



Fleet size was not sensitive to modal split in the range of 2 to 10 percent, but at 15 percent, the fleet size increased to 68 (county system) and 88 (county-loop system) vehicles. As expected, vehicle-miles followed the same pattern, an increase to 1,082 (county system) and 1,208 (county-loop system) at 15 percent mode share.

Cost per trip during the morning peak increased to $10.68 and $11.46, respectively, for the two systems at a 3 percent modal split and dropped to $4.32 and $4.62 at 7.5 percent mode share.

Representative trips were selected and examined to estimate door-to-door trip times on each of the county systems (Exhibit 4.15). Under the county system the Kettering to CBD trip time is increased over present transit service. A link that formerly existed to carry buses to the Far Hills corridor was eliminated under the county system. The alternative route available under county plans uses the crowded Wilmington corridor, adding trip time due to congestion. The three other representative trips shown in Exhibit 4.15 are not served by transit today. The proposed systems, with and without loops, are so different that trip time comparisons between the two are not meaningful.

It is of interest to note that all of the transit trip times are more than twice as long as automobile driving time. A substantial part of this time is spent waiting because of the infrequent service planned.

Shared-Ride Taxi

Two shared-ride taxi (SRT) options were proposed for one area shown in Exhibit 4.16. One SRT operation was studied in the present transit service environment, the other with the proposed county transit system. Since SRT is to serve only feeder and intrazonal trips in a nine-zone area, there was no need to study regionwide travel. A FEEDER analysis was conducted for each zone with the sum of the FEEDER analyses reflecting the operation for the entire area. Modal parameters reflected the smaller vehicle size (ten passengers), vehicle cost, and operating cost. The SRT operation consisted of subscription service during the peak hours and demand-responsive service during the off-peak hours.

Network comparisons for the two options are summarized below:

	Radial Links	Circumferential Links	Zones
SRT/present system	21	4	29*
SRT/county system	6	6	19*

---

*9 with SRT

EXHIBIT 4.15

REPRESENTATIVE TRIPS TRAVEL TIME

(5 Percent Transit Mode Share)

	Estimated Trip Distance (miles)	County System	County-Loop System	Auto*
Kettering to CBD (Zone 19)	8	71.8 **		32.7
West Carrollton to Moraine (Zone 30 to Zone 13)	4	66.6		20.0
Centerville to Delco (Zone 29 to Zone 20)	5		68.0	21.0
Kettering to Moraine (Zone 20 to Zone 13)	4		70.2	21.0

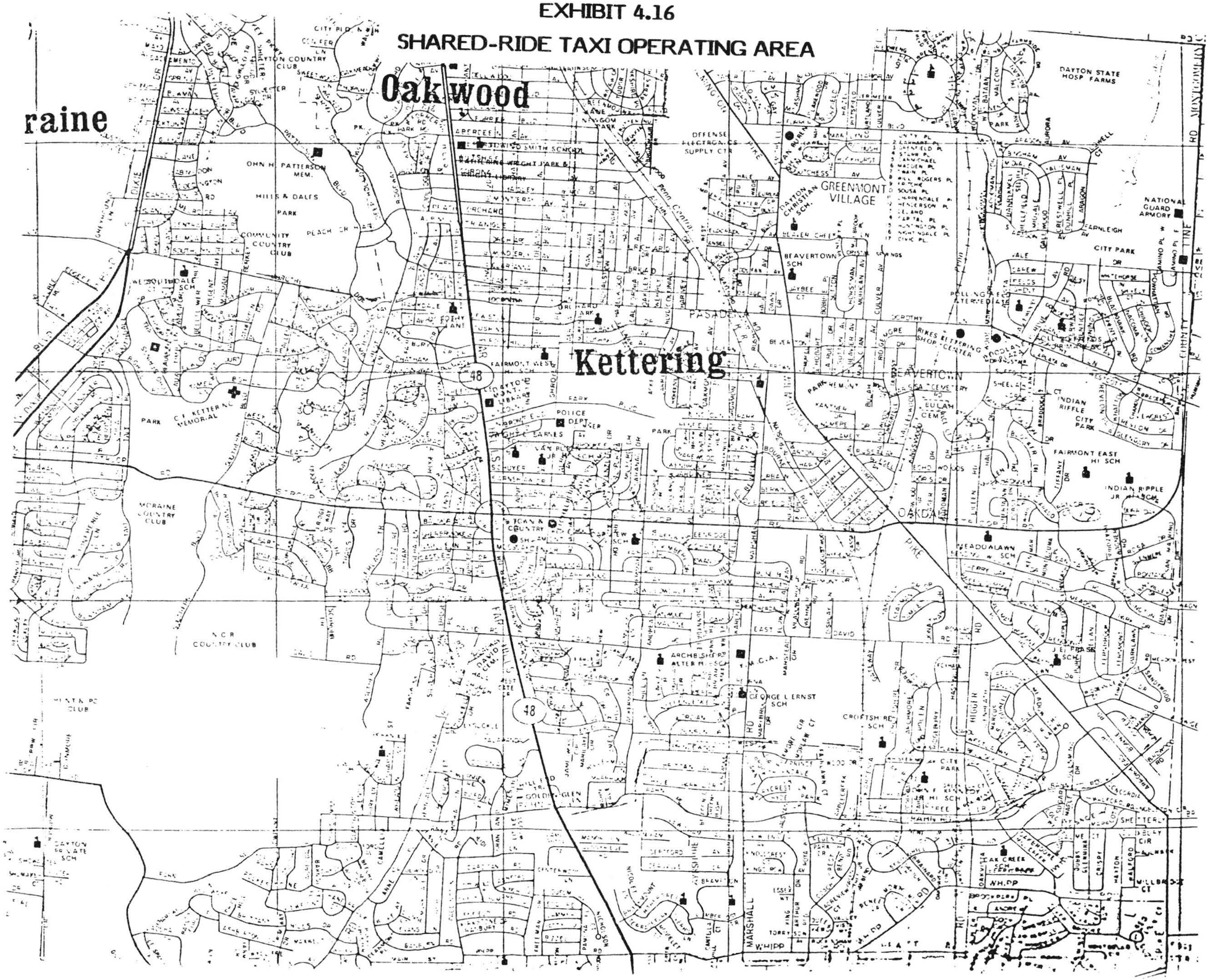
Note: SMART transit figures include walk and wait times at the trip origin, wait times for the LINKER segment, wait time for FEEDER, and walk time at the destination.

*A walk time of 5 minutes has been added for the destination end of the trip.

**Present service in small transit area is 62.6 minutes in the SMART model.

EXHIBIT 4.16

SHARED-RIDE TAXI OPERATING AREA



The SMART results were rich in information, some of which is displayed in Exhibit 4.17 and summarized below:

	SRT With	
	Present System	County System
No. of vehicles	15	10
Vehicle-miles per hour	260	176
Cost per trip* (P.M. peak)	$0.26-$0.42	$0.27-$0.49
Pickups per hour	812	523

*Range over 9 zones.

The headways were not changed from the default value of 60 minutes; however, in off-peak hours, SRT operates in a demand-responsive mode, and these headways are shown in Exhibit 4.18. There was great variation among the zones in terms of number of vehicles needed. As expected, the small, low-demand zones (e.g., zone 18) would not need as much service as a high-demand zone (e.g., zone 26, 25, or 9). Fleet size and vehicle-miles are also sensitive to mode split. Exhibit 4.19 charts fleet size vs. mode split, from the SMART run of SRT with the county system during the P.M. peak.

The cost per SRT trip does not vary significantly between use with the present system and with the county system. Cost per trip does vary with population density as shown in Exhibit 4.20.

To meet the demand under the present transit system, SMART estimated that off-peak demand-responsive service would need eight vehicles operating at 20- to 36-minute headways. More than five vehicles operating at 23- to 42-minute headways would be needed with the county system. Exhibit 4.18 shows some of the key measurements of SRT service under the present system and the county system. As expected, cost per trip and headway times increase with low demand. The relationship between headways and population density is charted in Exhibit 4.21, which illustrates closer estimated headways to accommodate higher demands.

This sketch of SRT operations working in conjunction with two different transit systems gives early indications of the scope of the system. It appears that Kettering should be indifferent as to whether RTA establishes its countywide plan or not. In either case, Kettering residents will need some sort of feeder service that will provide access to transit routes. Shared-ride taxi appears attractive; however, it should not be accepted on the basis of the analysis described here alone. Additional SMART runs should be made to test the attractiveness of smaller vehicles. It may also be desirable to combine services in some of the smaller zones.

Once a better picture of the potential service can be drawn, more detailed analysis is needed to establish the precise characteristics of the desired service. More

EXHIBIT 4.17

SRT OPERATIONS WITH PRESENT AND COUNTY TRANSIT SYSTEMS

(PM Peak; Mode Share = 5%)

Zone	Square Miles	Travel Trip Volume (per Minute)			No. of Vehicles P.M.-Peak		Pickups per Hour		Vehicle-Miles per Hour		Travel Time Inbound and Outbound		Cost per Trip P.M.-Peak	
			Present	County	Present	County	Present	County	Present	County	Present	County	Present	County
Zone 9	1.2	Out:	5.664	3.564	2.1	1.6	142	101	7	27	12.8	13.0	0.27	0.28
		In:	41.698	30.195							37.9	37.9		
Zone 16	0.9	Out:	2.204	1.574	0.9	0.7	62	43	16	12	12.7	13.2	0.26	0.27
		In:	18.620	12.778							37.6	47.8		
Zone 18	0.8	Out:	0.498	0.302	0.3	0.2	13	8	5	4	15.5	16.8	0.39	0.49
		In:	3.904	2.527							16.8	40.6		
Zone 19	1.8	Out:	3.694	2.001	1.9	1.1	103	56	34	20	14.2	14.8	0.34	0.36
		In:	30.692	16.783							38.6	38.9		
Zone 20	1.0	Out:	2.232	1.346	0.9	0.6	59	38	16	11	13.2	13.7	0.28	0.30
		In:	17.360	11.200							37.8	38.1		
Zone 21	1.3	Out:	2.48	1.479	1.1	0.8	65	42	19	13	13.6	14.0	0.30	0.32
		In:	19.26	12.421							38.1	38.3		
Zone 22	1.6	Out:	2.176	1.675	1.0	0.9	48	46	16	16	15.1	14.7	0.36	0.35
		In:	13.766	13.787							38.7	38.7		
Zone 25	2.9	Out:	3.822	2.635	2.4	1.7	103	69	42	30	15.9	16.4	0.42	0.44
		In:	30.410	20.453							39.5	39.8		
Zone 26	2.2	Out:	7.762	4.294	4.1	2.4	217	120	75	43	14.4	14.7	0.35	0.36
		In:	64.601	35.582							38.8	38.9		
Total					14.7	10.0	812	523	260	176				

EXHIBIT 4.18

OFF-PEAK SRT SERVICE
(Demand-Responsive)

(Mode Share = 3%)

Zone	No. of Vehicles		Headways		Pickups		Vehicle Miles per Hour		Travel Time		Cost per Trip	
	Present	County	Present	County	Present	County	Present	County	Present	County	Present	County
Zone 9	1.1	0.8	19.8	22.6	53	34	16	12	Out: 22.2 In: 24.8	24.5 27.6	0.29	0.33
Zone 16	0.5	0.4	23.2	26.0	21	15	7	6	Out: 24.9 In: 28.2	27.1 31.0	0.34	0.38
Zone 18	0.2	0.1	36.4	42.5	5	3	3	2	Out: 35.3 In: 41.4	40.1 47.5	0.53	0.63
Zone 19	1.0	0.6	26.6	32.1	35	19	15	10	Out: 27.6 In: 31.6	31.9 37.1	0.39	0.47
Zone 20	0.5	0.4	24.5	28.7	21	13	8	6	Out: 25.9 In: 29.5	29.2 33.7	0.36	0.42
Zone 21	0.6	0.4	25.5	30.0	24	14	9	7	Out: 26.7 In: 30.5	30.2 35.0	0.37	0.44
Zone 22	0.6	0.5	30.0	32.2	20	16	9	8	Out: 30.3 In: 35.0	32.0 37.2	0.44	0.47
Zone 25	1.2	0.9	31.8	35.1	36	25	19	14	Out: 31.6 In: 36.8	34.3 40.1	0.47	0.52
Zone 26	1.8	1.2	23.1	27.6	74	41	27	18	Out: 24.8 In: 28.1	28.3 32.6	0.34	0.41
	7.5	5.3	20-36	23-42	289	180	113	83			0.29-0.53	0.33-0.63

EXHIBIT 4.19

FLEET SIZE VS. MODE SPLIT SRT WITH COUNTY SYSTEM—P.M. PEAK

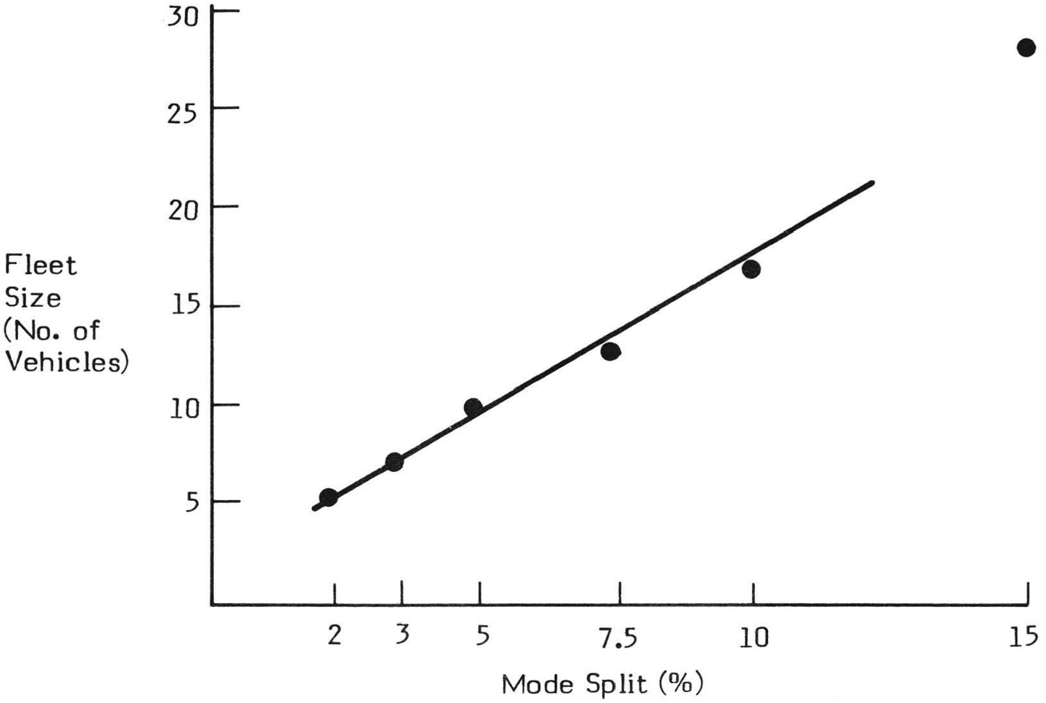


EXHIBIT 4.20

SRT COST/TRIP VS. POPULATION DENSITY (Present System, A.M. Peak, Mode Share 5%)

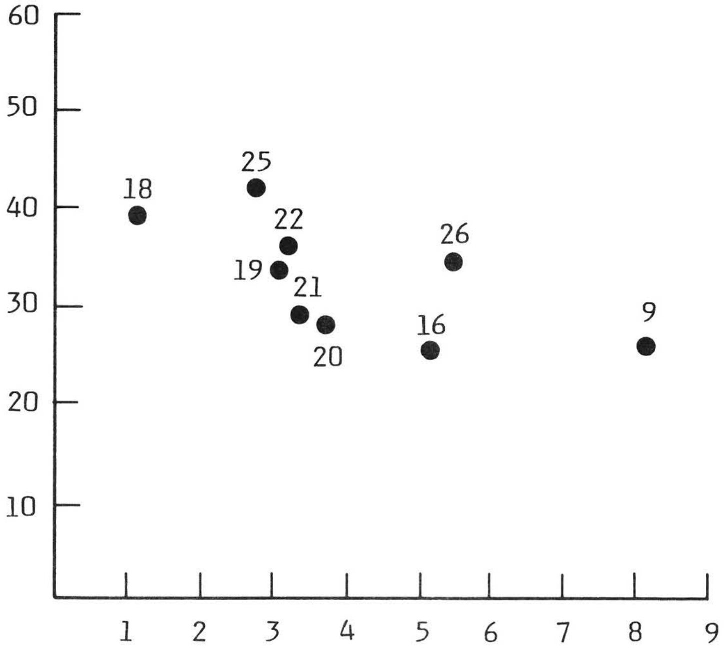
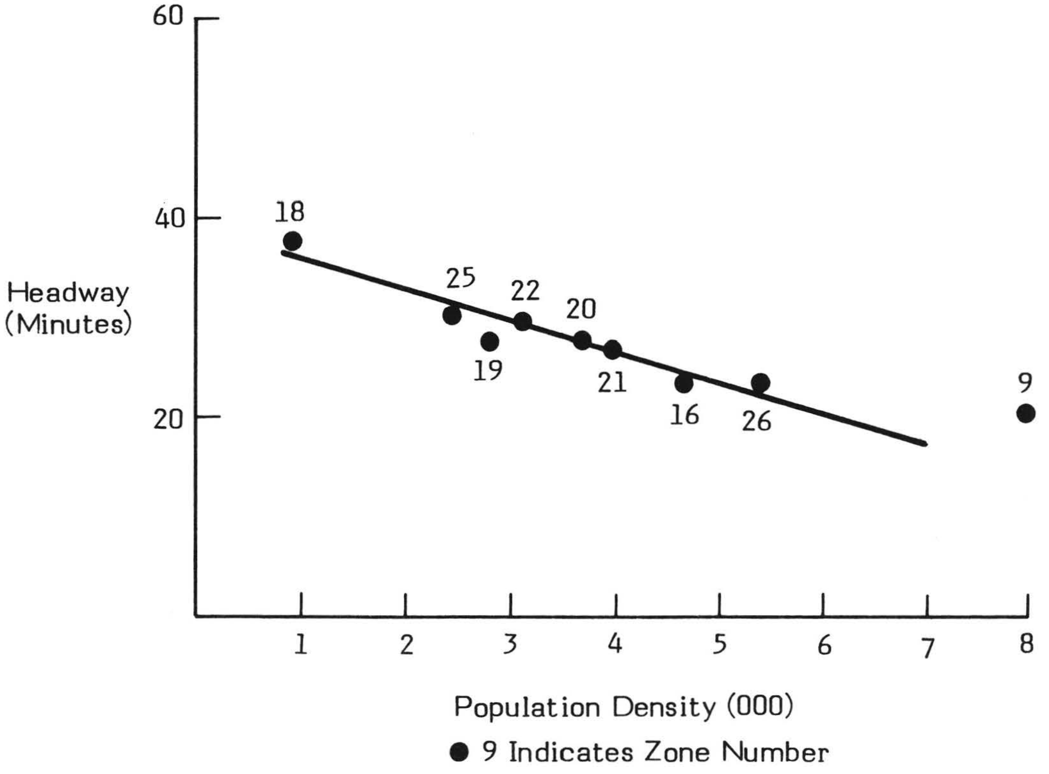


EXHIBIT 4.21

SRT IN DEMAND-RESPONSIVE MODE
(Present System, Off-Peak, Mode Share 3%)



detailed guidelines to develop feasibility plans further can be found in documents such as the Paratransit Handbook.[6]

4.7 SOUTH DAYTON IN THE YEAR 2000

Three different transit alternatives were considered for the study area in a year 2000 timeframe:

1. A light rail transit line in an existing railroad corridor.
2. An exclusive busway in the same corridor. SMART treated this option as a diamond lane and required an additional lane to be added to each link to which the busway was added.[7]
3. A light rail line with the countywide bus system. Fixed-route bus links were replaced with light rail where the two overlapped.

The first two alternatives were supported by an extensive network of circulator buses feeding the corridor system, express buses operating on freeways with feeder systems, suburban/crosstown buses, and numerous park-and-ride lots, in addition to regular fixed-route bus service.

The SMART default values were used for the light rail and the busway except that

- One stop per mile was used to conform with the sketch plan supplied by RTA.
- Maximum headway was set at 20 minutes.
- Peak LINKER speed was set at 50 miles per hour.
- Flexible route checkpoint stops per mile were set at four.

The population and employment information for the year 2000 was developed from computer printouts supplied by the regional planning agency (RPA). A trial run with these data produced fewer trips than were estimated by the RPA staff. To remedy this situation, it was agreed to assume that people would be taking more trips in 2000. Accordingly, the number of non-home-based trips (work/work) was increased to focus the adjustment on work, school, and shopping trips. The demand parameters were therefore raised to 0.55, 0.75, and 0.98 for home-based work, home-based other, and non-home-based trips, respectively. Increased and more widespread parking costs were projected by RPA staff and added to the SMART input.

---

[6] SYSTAN, Inc., Paratransit Handbook, sponsored by UMTA's Paratransit Integration Program, 1979 (available from Transportation Systems Center, Cambridge, Massachusetts 02142).

[7] As an alternative this could have been modeled as a light rail line using exclusive busway characteristics.

The light rail and busway network consisted of 23 radial miles, 9 circumferential links, and 36 zones, as illustrated in Exhibit 4.22.

Fifteen transportation modes[8] were considered:

FEEDER	Private Auto Transit (park-and-ride)
	Flexible Service (checkpoint circulators)
	Fixed-Route Bus (suburban/crosstown)
	Automobile
	Carpool
LINKER	Light Rail
	Fixed-Route Bus (express bus)
	Automobile
	Carpool
DUMPER	Fixed-Route Bus (distributors/circulators)
	Automobile
	Carpool
CBD	Fixed-Route Bus
	Automobile
	Carpool

The countywide option used a slightly smaller network with 21 radial links, 4 circumferential links, and 28 zones.

As illustrated in Exhibit 4.23, this representation reflects the strong CBD orientation of the countywide plan. Fewer transportation modes were examined because flexible feeder services were not considered for this alternative.

A summary of SMART results for all three runs—county system with light rail, light rail with extensive circulator/feeder network, and busway with the same circulator/feeder network—are shown in Exhibit 4.24.

---

[8] There were only 14 modes in the busway alternative, since it automatically uses fixed-route bus with limited stops.

EXHIBIT 4.22

LIGHT RAIL AND EXCLUSIVE BUSWAY
(Year 2000)

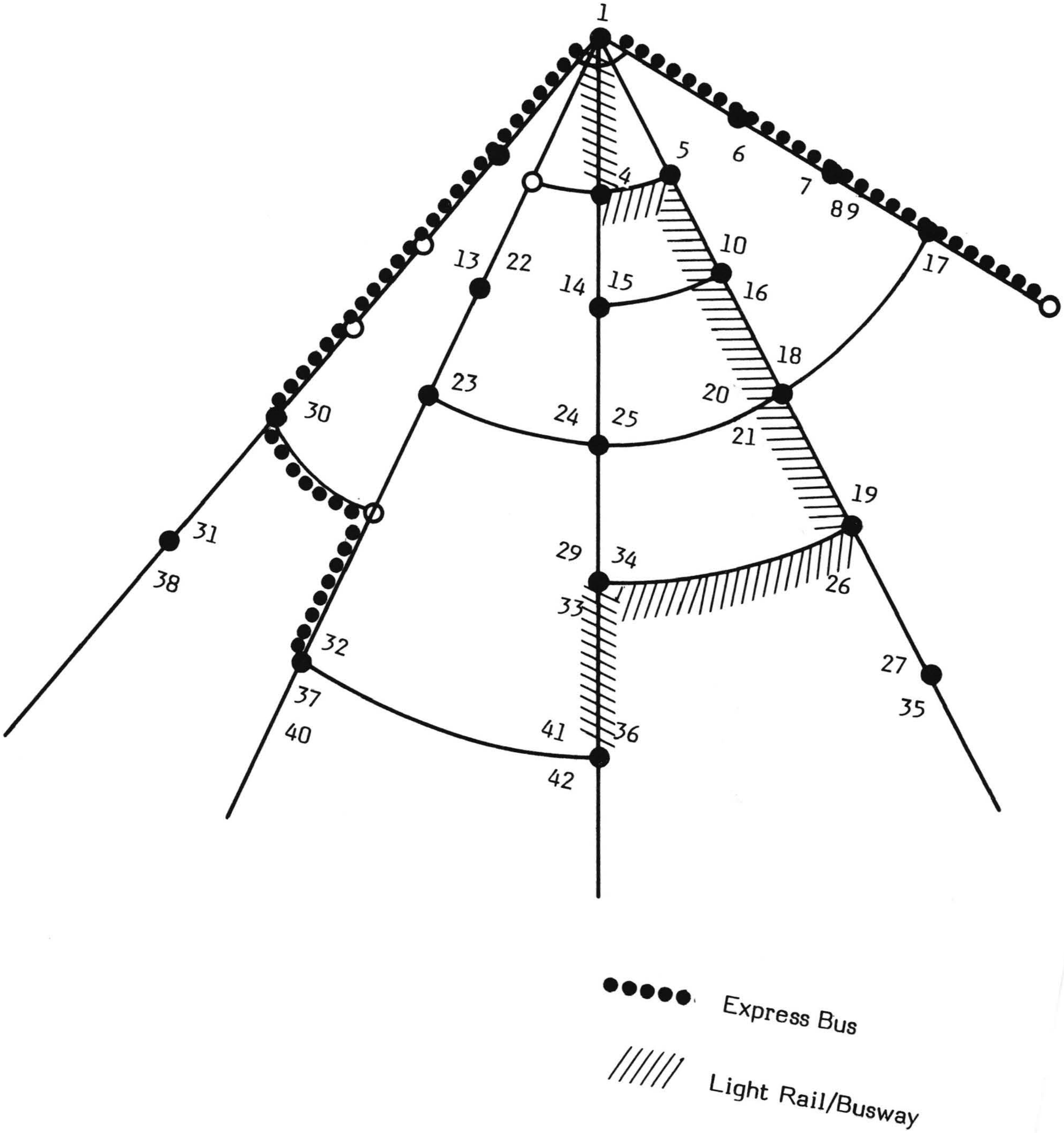


EXHIBIT 4.23
COUNTY SYSTEM WITH LIGHT RAIL

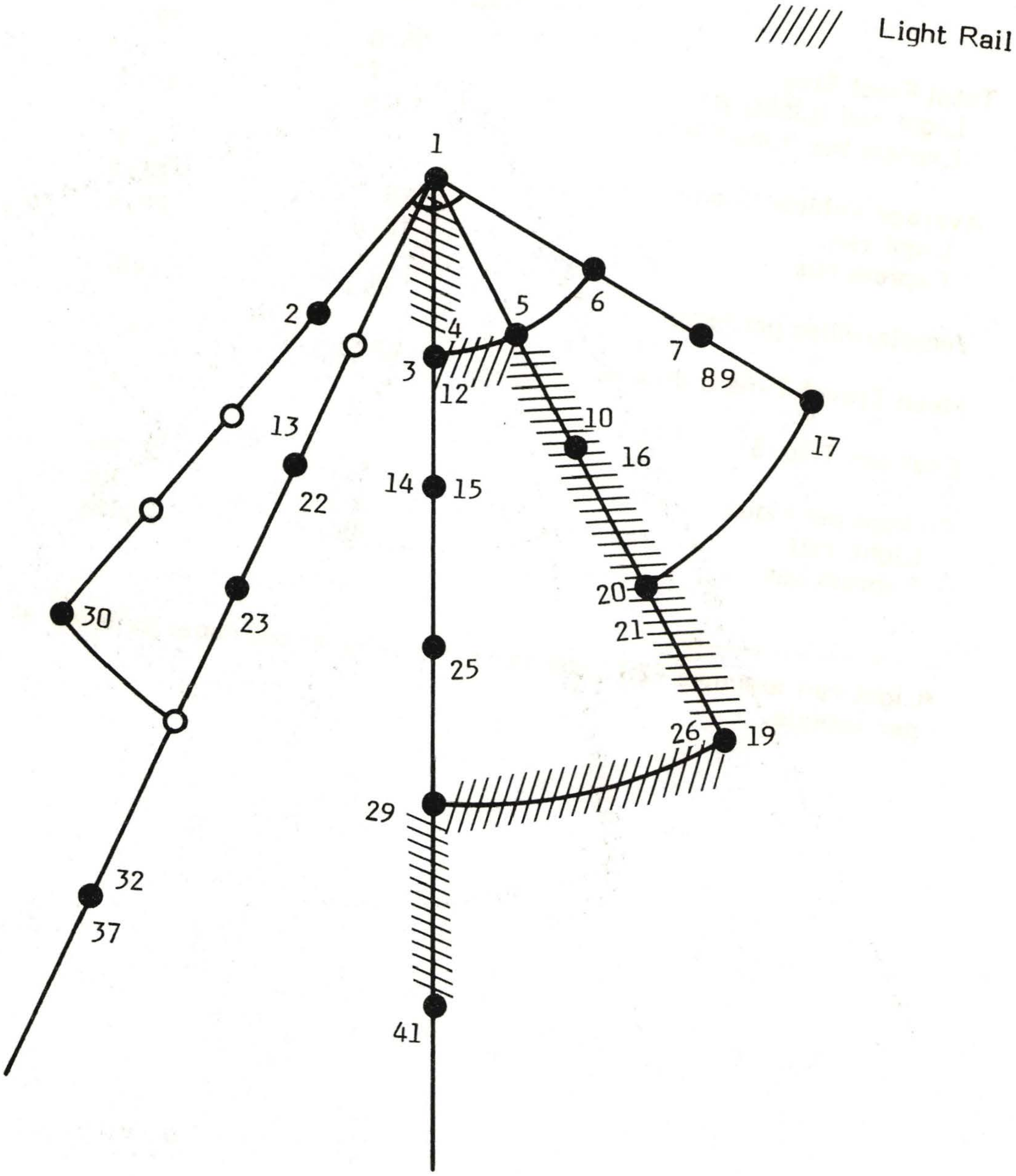


EXHIBIT 4.24

COMPARISON OF THREE ALTERNATIVES FOR YEAR 2000

(Mode Share = 5 Percent, A.M. Peak)

	County System With Light Rail	Light Rail	Busway
Total Fleet Size	55.0	79.2	79.7
Light rail (LINKER)	1.7*	2.2*	--
Express bus (LINKER)	12.3	10.3	13.0
Average Vehicle Loadings	7.3	6.4	6.5
Light rail	25.3	23.9	--
Express bus	16.6	20.4	20.8
Vehicle-Miles per Hour	940	1,482	1,482
Mean Travel Time (minutes)	48.2	46.3	43.5
Cost per Trip ($)	1.91	1.84	0.71
Pickups per Hour	1,517	2,094	2,094
Light rail	611	704	--
Express bus	850	1,185	1,255

---

*Light rail assumes 220 passengers per vehicle; bus capacity is set at 46 passengers per vehicle.

Because the county light rail system covers a smaller area than the other two alternatives, its fleet size, vehicle-miles, and pickups are lower. Mean travel time by light rail is slightly longer than the busway because the larger light rail vehicles operate on longer headways. Both alternatives with light rail are more expensive because of the higher cost per route-mile of the light rail system ($2,000 is the default value). Cost per trip is sensitive to mode share as follows:

	Mode Share					
	2%	3%	5%	7.5%	10%	15%
County system with light rail	$4.71	$3.16	$1.91	$1.30	$1.00	$0.70
Light rail	4.41	2.99	1.84	1.28	1.00	0.72
Busway	1.59	1.11	0.71	0.52	0.44	0.35

This suggests that light rail will not become economically attractive unless it can command a very large share of the traffic along its corridor. If the light rail mode share were increased to about 25 percent, it might be competitive with the busway. This would mean that some 3,500 passengers per hour would need to be carried by light rail. This is a large number, but not impossible.

4.8 REFERENCES

Study Area Planning Aids

- Base map of Montgomery and Greene Counties
- Traffic zone map for the two county area
- Regional map with major activity centers, commercial centers, physical barriers, and roads indicated

SMART Input	Data Source/Comments
Population and employment densities	Computer printouts of population and employment data by traffic zone for 1968 and 2000 supplied by RPA. Data divided by zone size to produce density figures.
Zone size	Land use computer printouts provided by RPA. Zone size equals total area minus unusable land.
Link lengths	Radial links measured from base map; circumferential links set by SMART given location of radial links (in degrees).

SMART Input	Data Source/Comments
Highway configuration	Information supplied by RPA, marked on base map.
• Number of lanes • Type of road • Auto speeds	
Length of time periods	A.M. peak and P.M. peak—3 hours each; off-peak—6 hours.
Trip distribution by time of day	Data supplied by RPA from O-D study.
Average trip length for trip type	Graphs supplied by RPA showing trip lengths vs. distance from CBD by trip type.
Traffic data for calibration	Map of 1976 average daily traffic (ADT) for two-county area (RPA).
Carpool fraction	0.32 agreed on with RPA as appropriate figure.
Parking costs	Computer printout of parking costs by traffic zone for 1968 and 2000.
Transit data	
• Documentation of existing fixed-route bus service	Miami Valley Regional Transit Agency (MVRTA).
• Bus size	46 passengers per vehicle.
• Bus speed	Average 14.3 miles per hour.
• Headways	SMART uses 20 minutes. In the present South Dayton system, routes vary from 8.5 to 70 minutes during the A.M. peak.
• Proposed countywide systems	MVRTA map with sketch plan.
• Modal split	Calculated by RPA at 5 percent for peak hours, 3 percent for off-peak.

5. WESTSIDE PORTLAND, ORGEON, STUDY AREA

The Portland example differs from the South Dayton example in the nature of the available data and in the modeling approach taken. TRI-MET, the Portland regional planning agency, had updated its comprehensive planning study in 1977, using DOT's UTPS models. This provided a current source of data that was as accurate as any available and more detailed than would be needed for the SMART model. In addition, TRI-MET prepared a macro-structure that combined all of the UTPS traffic zones into 80 super districts for which there were trip production and attraction data. These zones appeared to be about the right size for SMART analysis. The travel data provided a different source for SMART analysis and an opportunity to test different data-handling procedures in the program.

5.1 OBJECTIVES

The objectives of the West Portland case study were to (1) test an arbitrary network configuration, (2) test a production-attraction trip matrix to supply the demand data, and (3) assess the impacts of four different transit alternatives in the Portland setting:

- Timed transfer
- Fixed guideway
- A fixed/flexible route tradeoff
- A carpool/vanpool diversion

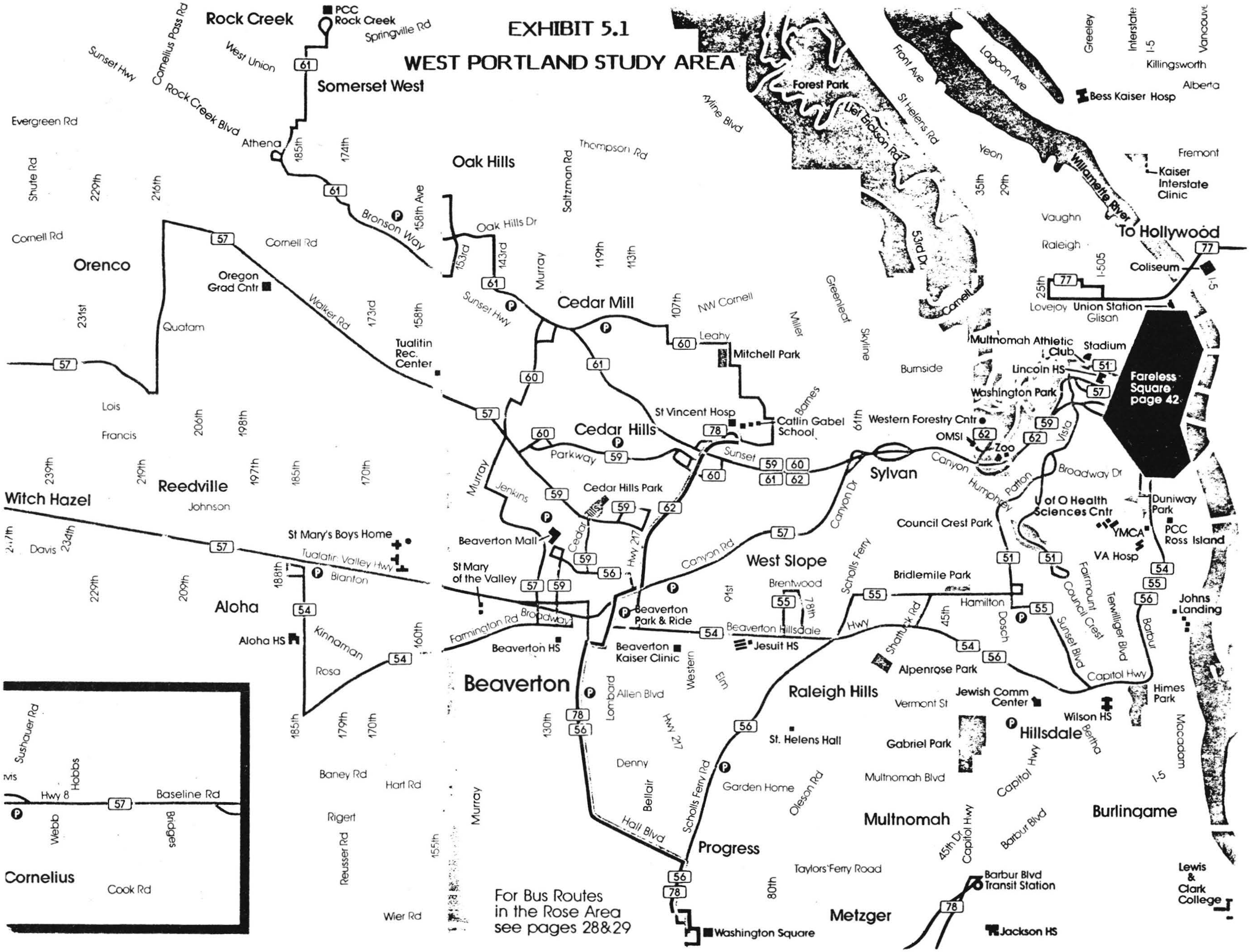
5.2 SITE DESCRIPTION

The selected study area comprises most of the developed portion of the Portland-Vancouver SMSA west of the Willamette River. It includes the Portland CBD, some industrial property south of the CBD, and a large and heterogeneous residential sector of the city. The residential sector, which contains varied commercial development and some industry, is largely located west of the Portland hills. The 1977 estimated population was 173,000, and the employed population was 49,000. The area is illustrated in Exhibit 5.1.

TRI-MET has developed a Westside plan (1) to improve local transfer centers, (2) to provide good peak-hour service to Portland, and (3) to increase Westside bus ridership. This plan is based on the timed transfer concept, which includes (1) synchronized schedules of all bus routes operating through two transfer centers, (2) trunk routes connecting the transit centers with downtown Portland, (3) local and cross-town routes radiating from the transit centers into the surrounding communities, and (4) special peak-hour-only routes.

A light rail route is under construction east of the Portland CBD and is an active candidate for extension to the Westside.

EXHIBIT 5.1
WEST PORTLAND STUDY AREA



For Bus Routes in the Rose Area see pages 28&29

5.3 GETTING STARTED

Workshop Session

The Westside application was launched at a meeting among representatives of the regional planning and transit agencies and SYSTAN staff. The group discussed the concept of macro-analysis, the modularity of the SMART model, and the availability and format of data. The first major decision was to accept the 80 super districts as zones for the SMART analysis.

The next step was to identify the characteristics of the zones and of the available link candidates. Using a district map, staff sketched in the locations of (1) major activity centers, (2) geographic barriers, and (3) the major road system. The 1977 comprehensive study provided a recent data base on magnetic tape, including a production-attraction trip matrix for the 80 planning districts. This information was used to generate a trip table that was the basic demand input to the SMART model. The 1977 data were a welcome source of travel information, because they gave a good representation of travel data and minimized the data manipulation that was needed.

Data Preparation

Demand — Given the production-attraction trip matrix for Portland, an external demand file of approximately 20,000 records was created to be read by SMART through the READDEM keyword. Trips in Portland were defined by both a production and an attraction end. For home-based trips, the production end was always the home end of the trip, and the attraction end was the business or socio-recreational activities end. For non-home-based trips, both the production end (origin) and the attraction end (destination) occur in activity centers. The data base included both outbound and inbound home-based trips. Three production-attraction trip tables were supplied: (1) home-based work (HBW), (2) home-based other (HBO), and (3) non-home-based trips (NHB).

When compared with Dayton, data processing for Portland was relatively straightforward. However, it was not without incident. The major problems encountered in transforming these data for SMART use were

- Aggregation of Portland's 80-zone demand data to a more manageable 42 zones for use in SMART's representation of Portland. Exhibit 5.2 shows the zone-to-zone correspondence.
- Determine trip distribution by time of day.

Area Representation — The Westside study area encompasses 27 super-district zones with 15 external zones outside of the study area. The 15 external zones were aggregated from 53 super-districts. SMART zones were connected to 43 nodes: 28 in the study area and 15 outside. The nodes were connected through 88 highway network links. Of these, 53 were inside the study area, 10 were bridge links across

EXHIBIT 5.2

ZONE-TO-ZONE CORRESPONDENCE

Portland Zone No.	SMART Zone No.	SMART Zone Name
1	1	1
2	2	2
3	3	3
4, 8, 9, 11; 18, 20, 21, 23,	4	4/23
5, 7, 10, 22, 24, 25	5	5, 7, 25
6	6	6
12, 13, 14, 15	12	12/15
16	16	16
17, 66 through 80	17	17, 66/80
19	19	19
26	26	26
27	27	27
28	28	28
29	29	29
30	30	30
31	31	31
32	32	32
33	33	33
34	34	34
35	35	35
36	36	36
37	37	37
38	38	38
39	39	39
40	40	40
41	41	41
42	42	42
43	43	43
44	44	44
45	45	45
46	46	46
47	47	47
48	48	48
49	49	49
50	50	50
51	57	51
52	58	52
53	59	53
54, 56, 57, 58	10	54, 56/58
55, 62	11	55, 62
59, 60, 61	13	59/61
63, 64, 65	14	63/65

the Willamette River to East Portland, and 25 were outside the study area. Exhibit 5.3 is a graphic representation of the network.

Once the zones, nodes, and links had been selected, it was necessary to prepare other input data for the SMART model. Key data items included the following:

- Zone types for all zones and subtypes (uniform density, subarea, or corridor) for residential zones
- Zone area, so that traffic densities could be calculated
- Link lengths, numbers of traffic lanes each way, uncongested speed, whether or not diamond lanes are included (Care should be exercised that there is at least one general lane in each direction.)
- Transit service available in each zone and along each link
- Transit service characteristics, including maximum headway, uncongested speed, vehicle size, and cost data

When all of the input data were prepared, the SMART model was ready for the first calibration run.

5.4 MODEL CALIBRATION

Traffic Analysis

The initial SMART calibration runs were made to compare the traffic volumes, speeds, and average trip length generated on the network with those documented values from the 1977 Portland UTPS study. In the first calibration attempt, traffic on 13 links differed 20 percent or less from measured traffic; 4 links had a difference between 20 percent and 30 percent; 4 had a difference of between 30 and 100 percent. The links with the largest differences were the links adjoining US26 and Burnside Road (93 percent) and the Steel Bridge-Burnside Bridge link (140 percent). The overload on US26/BS2 can be explained by the fact that a good many arterial streets that extend from the downtown area (zones 2 and 30) to zone 31 were not represented as links in SMART. Thus, traffic that would normally move on these arterials was assigned to link US26/BS2, causing an overload of 93 percent. The discrepancy in the Burnside-Steel Bridges link cannot be explained in detail, but it is probably related to the manner in which the Steel Bridge is tied into I-5 and the way that Burnside Bridge serves East Portland.

After the first trial, the network links were adjusted to correct the US26-Burnside Road problem. Other minor adjustments were made in link characteristics and link speeds. The second calibration run gave a closer fit. Eleven links had a difference of 10 percent or less; nine had differences between 11 and 30 percent; five had differences between 31 and 45 percent. Sample traffic results are shown in Exhibit 5.4. It would have been possible to continue adjusting the SMART model to

EXHIBIT 5.3

PORTLAND NETWORK REPRESENTATION

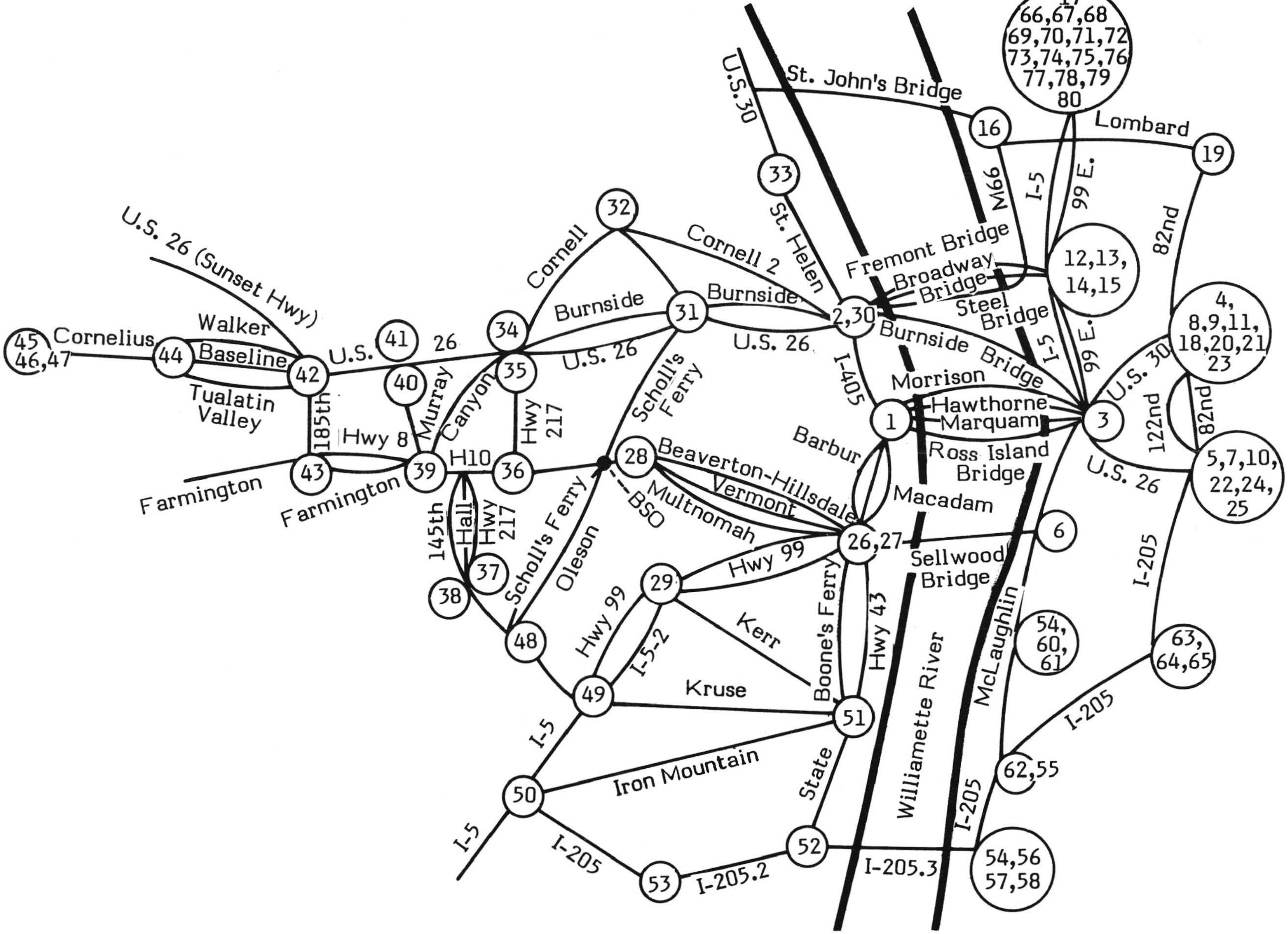


EXHIBIT 5.4
PORTLAND TRAFFIC COMPARISON (AUTOS/DAY)

Link	SMART*	Actual Count/ UTPS	Percent Difference
Hwy 43.2/Boone Ferry	31,100	28,000	+11
Cornell - 2	4,800	4,800	0
Barbur/Hwy 99/MacAdam	150,200	148,500	+1
US26/Burnside-2	104,400	105,900	-1
Baseline/Walker/Tualatin	32,600	33,181	-2
Hwy 8/Farmington	49,100	44,400	+11
145th/Hall/Hwy 217	50,600	56,900	-11
US26/Burnside	85,000	102,200	-17
I205.3	65,200	81,700	-20
Kerr	4,300	5,300	-19
Morrison/Hawthorne/Marquam/ Rhode Island Bridges	169,200	207,600	-19
US26/Walker	32,900	45,756	-28
Burnside/Steel Bridges	75,100	61,400	+22
St. John's Bridge	13,500	14,600	-8
Beaverton-Hillsdale/Vermont/ Multnomah	30,200	45,200	-33
Fremont/Broadway Bridges	54,200	84,900	-36
I5.2/Hwy 99	43,900	76,600	-43
I5.3/Hwy 99	53,700	90,700	-41
Sellwood Bridge	59,300	24,400	+143

---

*At auto occupancy of 1.38, valid for trips made by people more than 5 years old.

achieve a closer agreement with the 1977 UTPS results. However, the project team considered that the quality of fit was adequate to demonstrate the capability of the SMART model. Additional changes in link speed would adjust the volume of traffic assigned to each link. Links could be added or removed to change the traffic pattern. Each adjustment influences the shortest path for a number of zone-to-zone movements. Any small adjustment may improve the fit or make it worse.

The UTPS Portland data estimated mean travel speeds on individual links during peak and off-peak periods. The UTPS links could be combined, and weighted average speeds could be calculated for comparison with speeds computed by SMART. This offered a basis for further calibration. The off-peak speeds were essentially free-flow speeds and were used as SMART link descriptors. The peak-period speeds were influenced by congestion. Differences between the UTPS speeds and the SMART speeds can be partly explained by differences between UTPS traffic flow and SMART traffic flow. Of 19 network links tested, 14 had speed differences between SMART estimates of 6 miles per hour or less (see Exhibit 5.5). For 8 of these 14 links, the differences in the traffic volumes estimated by SMART and UTPS were 11 percent or less. Traffic levels for the other 6 links were sufficiently below capacity that differences in traffic volume estimates did not influence estimated speed. For 3 of the 5 links with significant differences in estimated peak-hour speeds, differences can be explained by congestion associated with different traffic volume estimates. The other 2 links are special cases. The SMART model did not adequately account for the circuitous approaches to the Sellwood Bridge across the Willamette River. The congestion at traffic lights on this route severely reduces peak-hour speed. The 17-mph difference in peak-hour speed occurs where US26 and Burnside pass through the Portland hills. Apparently, cautious drivers have a significant impact on peak-hour speed that is not recognized in the SMART model. Despite these two discrepancies, there was remarkably good agreement between the two sources of estimated speeds.

As a further check on the credibility of the SMART model, the average automobile trip length, as calculated by the SMART model, can be compared with a similar figure produced in the UTPS analysis.[1] The two mean trip lengths need not be the same because SMART measures trip length in minutes, while UTPS measures it in miles. Direct conversion is awkward because expected speeds differ on the different network links. Distances were calculated for SMART by using the best average speed that could be determined. Nonetheless, the results of the comparison, listed in Exhibit 5.6, are remarkably similar. Off-peak trip lengths are the same, and peak-period trip lengths are within a few tenths of a mile per hour of each other.

A more rigorous comparison was made by taking mean fuel consumption per trip and multiplying it by the automobile miles per gallon, to yield miles per trip:

$$\frac{\text{gallons}}{\text{trip}} \times \frac{\text{miles}}{\text{gallon}} = \frac{\text{miles}}{\text{trip}}$$

---

[1] Trip-length values were calculated by using information taken from CRAG Technical Memorandum No. 10.

EXHIBIT 5.5

PORTLAND LINK SPEED COMPARISON

(Miles per hour)

Link	From Zone	To Zone	Mean Speed			
			Off-Peak	Peak Period UTPS	Peak Period SMART	Difference
Baseline/Walker/Tualatin	42	44	39	39	37	-2
Hwy 8/Farmington	39	43	37	36	36	0
145th/Hall/Hwy 217	36	37,38	30	30	30	0
Hwy 217	35	36	37	32	36	+4
I5.2/Hwy 99	29	49	42	38	40	+2
US26/Burnside	2,30	31	41	24	37	+13
St. John's Bridge	16	33	30	24	28	+4
Barbur/Hwy 99/MacAdam	1	26,27	35	27	33	+6
I5.3/Hwy 99	26,27	29	40	33	39	+6
Beaverton-Hillsdale/ Vermont/Multnomah	26,27	28	34	33	33	0
Sellwood Bridge	6	26,27	28	8	27	+19
I205.3	6,7,8	52,53,54	38	28	35	+7
Kerr	29	51	28	27	28	+1
US26/Burnside-2	2,30	31	41	20	37	+17
Hwy 43.2/Boone Ferry	26,27	51	29	27	28	+1
Cornell-2	2,30	32	26	20	25	+5
Morrison/Hawthorne/Marquam/ Rhode Island Bridges	1	3	25	10	17	+7
Burnside/Steel Bridges	2,30		10	10	7	-3
Fremont/Broadway Bridges	2,30	12,13, 14,15	37	35	35	0

EXHIBIT 5.6

WESTSIDE AUTO TRIP LENGTHS

Time of Day	SMART (mile)	UTPS Portland (mile)	Percent Difference
Using reasonable speed			
A.M.	5.3	5.6	-5
Off-peak	4.9	4.9	0
P.M.	5.0	5.2	-4
Using fuel consumption per trip			
A.M.	6.4	5.6	+14
Off-peak	5.6	4.9	+14
P.M.	5.9	5.2	-13

Although the results of this comparison (Exhibit 5.6) are not quite so good as the first, they are still quite reasonable.

Transit Analysis

The second major calibration step was to model the existing transit service in the Westside and to compare the results of the SMART analysis with actual transit service parameters. Transit service today is limited to fixed-route bus; however, the innovative timed transfer plan, which was recently placed in service, presents a different modeling problem than conventional bus service. Great care was taken to model the transfer centers at network modes so that the characteristics of the coordinated services could be properly represented. Mean headways were calculated for the peak and off-peak periods and introduced to SMART as maximum headways. The transit mode share, as calculated from patronage figures and estimated tripmaking, averages 4 percent for the Westside area. The other mode shares selected for analysis were 0.1 percent (all automobile), 10 percent, 20 percent, and 30 percent.

Typical operating characteristics used as input to SMART were

	Bus		
	CBD	LINKER	FEEDER/DUMPER
Headway (minutes)	10	25	30
Route spacing (blocks/route)	3	n.a.	3-4
Passengers/vehicle	45	45	45
Speed	15	12	16

Documented average bus speed for the Portland area is 14.4 mph.

The SMART-generated transit data were compared with documented values for the Portland area that were furnished by TRI-MET. A comparison of fleet size and vehicle-miles (6-day/week operation) produced the following:

	Smart	Documented
Fleet size	412	424-477*
Vehicle-miles/year	23.7×10^6	20.2×10^6

---

*Assumes 10-20 percent inoperative buses in a fleet of 530.

These figures are substantially the same if one takes into account the efficiency of bus scheduling and the fact that SMART runs peak-period schedules for a full 3 hours, morning and evening. A slight adjustment in the length of the peak period would reduce the vehicle-miles to a value that is very close to the reported figure.

SMART generated 114,638 pickups per day, while the documented value was 126,500. However, SMART's figure does not include trips originating and terminating in five zones whose internal activity is ignored because they lie outside the study area.[2] These results were sufficiently encouraging to accept the transit calibration on a macro level. More work was needed to test the ability of SMART to represent individual zone-to-zone trips.

DOOR will produce door-to-door trip time for comparison with actual service data. Unfortunately, no operating data were available on total trip time, including walking and waiting time. Bus schedules give scheduled or expected bus travel time. Transfer time can be estimated by a careful examination of intermediate schedules. Several SMART runs were made to obtain estimates of zone-to-zone travel times for representative trips. These travel times were then compared with scheduled bus travel time. A fairly good match was obtained, as shown in Exhibit 5.7. In the first test run, SMART travel times were low. Investigation revealed that the FEEDER bus speeds were too high (17 mph). After these speeds were adjusted, the estimated times were much closer to the scheduled times.

It is important to note that one cannot adjust one parameter without having an impact on others. In addition to increasing travel time, the FEEDER bus speed adjustment increased the fleet size and lowered the vehicle-miles, thus bringing SMART and actual values closer together.

This final test completed the calibration of the SMART model. The model was now ready to test some transit strategies.

5.5 SCENARIOS

Four different transit innovations were of interest in Westside Portland:

1. Timed transfer—an evaluation of the two timed transfer sites to determine the value of this service to TRI-MET passengers.
2. Fixed guideway—there is considerable interest in expanding the Banfield light rail line now under construction to the Westside.
3. Fixed Route/Flexible Tradeoff—some of the low-density areas on the Westside might better be served with flexible transit (dial-a-ride, shared-ride taxi, or subscription service, or some combination of the three).
4. Carpool/Vanpool Diversion—an active promotion of ridesharing might eliminate the need for low-density service or reduce patronage to the point that transit service is not feasible.

Each of these scenarios was explored with a series of SMART runs.

---

[2] Zones 32 (North), 45, 46, and 47 (West), and 51 and 52 (South).

EXHIBIT 5.7

ZONE-TO-ZONE TRAVEL TIMES, FIRST TRIAL

Origin-Destination	Time	SMART (minutes)	Schedule Estimate (minutes)	Schedule Routes
Zone 1 to Zone 39 Downtown to Beaverton	A.M.	43	39*	54
Zone 2 to Zone 34 Downtown to Cedar Hills	A.M.	22	27	59, 60
Zone 30 to Zone 29 Northwest of downtown to Metzger	A.M.	31	33	20, 43
Zone 49 to Zone 39 Tigard to Beaverton	A.M.	26	31	43, 45, 56, 54
Zone 35 to Zone 36 Cedar Hills to Beaverton	A.M.	13	18	77, 59

---

*A time of 5 minutes was assumed for the traveler to get to the transit station from other parts of the CBD.

Timed Transfer

SMART runs were made for three different kinds of transfers—random, timed, and through:

1. SMART's random transfer assumes a transfer wait time = Headway/2.
2. SMART's timed transfer assumes a transfer wait time = 1.7 + 0.285 headway.
3. SMART's through transfer assumes a transfer wait time = 0.

SMART models transfers when passengers leave a residential area for a network link, between network links, and between a network link and a destination zone. The procedure used for timed transfer was to vary both the residential zone/link transfers and the link/destination transfers to reflect the different types of service. This produced twice as many transfers per trip as Portland passengers experience. Link-to-link transfers along a single bus route are set equal to zero (through) to correspond to the bus route.

Using Portland's mode share of 4 percent and random coordination, SMART estimated a transfer wait of 12 minutes during the peak periods and 16 minutes during the off-peak periods. This is actually a minimum wait time; SMART assumes that the first bus to come along will take the traveler to his/her destination.

For timed transfer, SMART gives a transfer wait of 9 minutes (peak) and 11 minutes (off-peak).

For through transfer, SMART gives a transfer wait of 0 minutes.

In Westside's actual timed transfer system, transfers are not perfectly coordinated. Buses arrive 2-4 minutes apart and wait at the transfer point for 2-3 minutes. The total wait/transfer is 4-7 minutes. As each SMART trip consists of two transfers, the equivalent wait/transfer time would be 8-14 minutes—spanning the SMART estimate. The maximum wait for timed transfers is comparable to the minimum wait for random transfers, so there should be tangible time savings with a timed schedule. In fact, the saving for timed transfer may be understated. Timed transfer offers the passenger the psychological advantage of seeing the outbound bus as he/she arrives at the transfer point. It is also likely that timed transfer points will improve bus-scheduled performance and therefore reduce the transfer delays. Exhibit 5.8 shows SMART transfer wait-time results for the three different kinds of transfers.

Fixed Guideway

Three fixed guideway options were run with SMART: an exclusive (diamond) lane bus service, a light-rail line, and a heavy-rail line. The corridor selected for fixed-guideway analysis extended from downtown Portland south along I-5 to Beaverton-Hillsdale Boulevard and then west to Beaverton.

EXHIBIT 5.8

TRANSFER WAIT TIMES FROM SMART*

	Time/Trip	
Transfer	Peak Period	Off-Peak Period
Random	55	53
Timed	52	48
Through	43	37
Transfer Wait	Minutes	
Random	12	16
Timed	9	11
Through	0	0

---

*Transit mode share = 0.04.

Exhibit 5.9 illustrates the relationships among exclusive bus, light rail, and heavy rail for different service parameters. Both light rail and heavy rail are penalized by the high costs of fixed guideway and more expensive vehicles. In fact, heavy rail is not in contention over the range of mode shares studied.[3] Light rail is appreciably more costly per passenger than heavy rail up to 20 percent mode share. At 30 percent mode share, light rail is substantially cheaper than bus ($0.25 vs. $0.40 per ride). Twenty percent mode share sounds high when compared to a systemwide average of 4 percent, but only 20 percent of the passengers in the light-rail corridor need to be attracted to the new service. This amounts to just over 5,000 passengers per hour during the peak period, or almost 60,000 passengers per day. This is a lot of traffic, but certainly an attainable patronage.

Both light rail and heavy rail offer shorter mean trip times than the bus. Bus trip times increase with increasing mode share up to about 5 percent when buses are essentially filled during the peak period. At higher mode shares, trip time decreases because the demand requires more frequent service, with the result that waiting times are shorter. Light rail trip times increase with increasing mode shares because vehicles make more stops and longer stops to accommodate increased demand. Rush period light-rail vehicles are not filled until the transit mode share exceeds 20 percent mode share. Heavy-rail vehicles can board and discharge passengers quickly so that there is little change in trip time for increasing mode share.

Because of their efficiency, both light rail and heavy rail permit reductions in the total transit vehicle fleet. Light rail supports a greater reduction in fleet size because it offers more frequent stops and thereby serves the corridor more thoroughly.

Light and heavy rail also offer substantial reductions in mean fuel consumption per passenger, which relates directly to total fuel consumption. At 20 percent mode share, light rail offers a 25 percent reduction in fuel consumption for the study area.

Several SMART runs were made to compare the fixed- and flexible-route systems for a range of vehicle sizes. The analysis focused on two zones with very different characteristics:

- Zone 26, a small zone of 3.3 square miles and relatively high trip densities, located just south of the downtown Portland area
- Zone 43, a large zone of 7.4 square miles with relatively low trip density, located in the Aloha area in the Westside

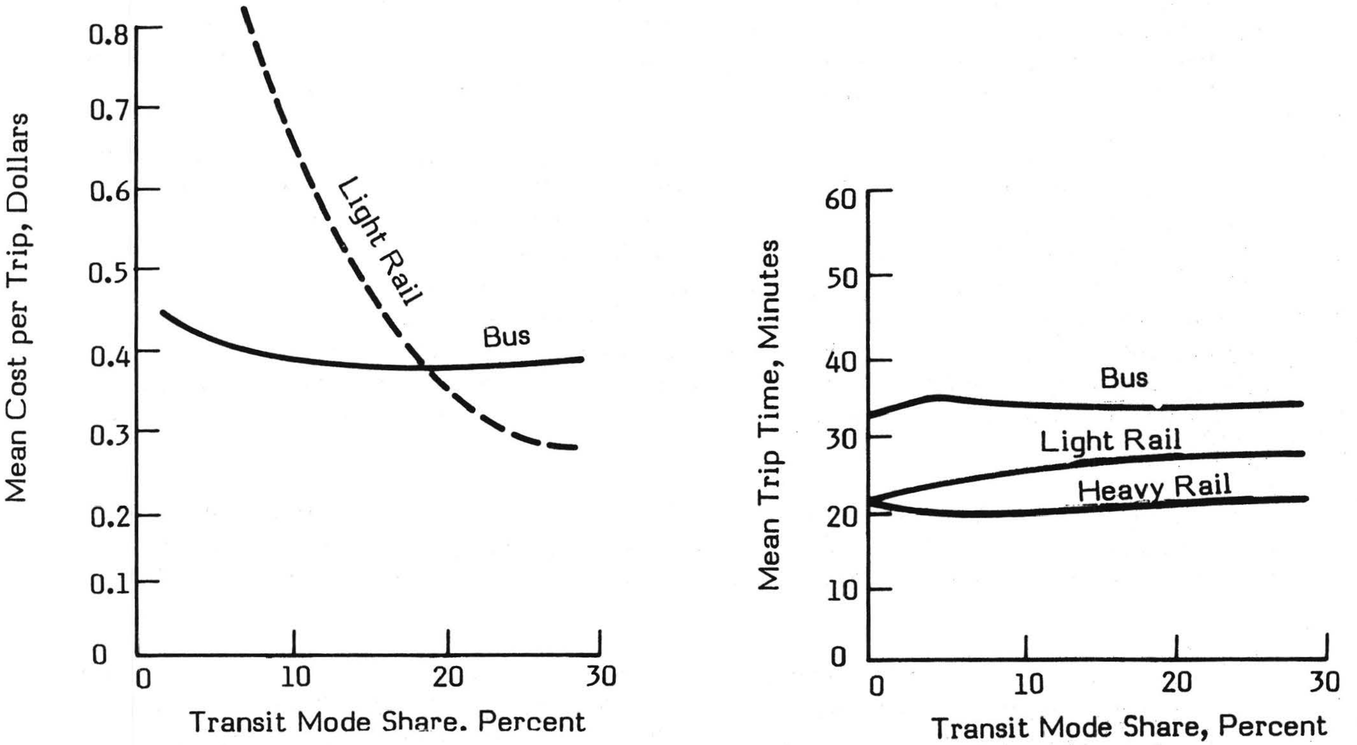
Fixed/Flexible Route Tradeoff

Except at very low mode share (less than 1 percent) fixed-route service is less expensive than flexible service (Exhibit 5.10). The fixed-route cost curve has a very sharp elbow where buses become essentially filled. This elbow would occur at

---

[3] Cost per passenger at 30 percent mode share is $1.49.

EXHIBIT 5.9
COMPARISON OF FIXED GUIDEWAY ALTERNATIVES



I.a. Mean Cost per Trip

I.b. Mean Trip Time

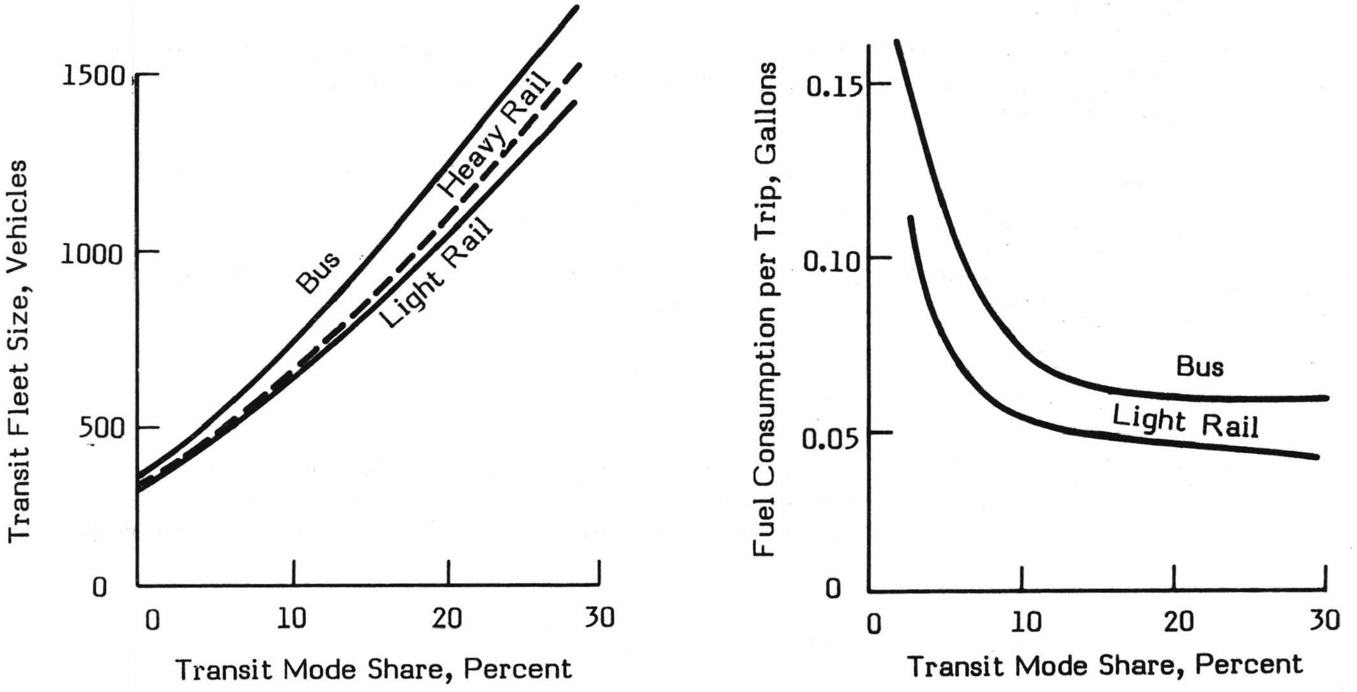
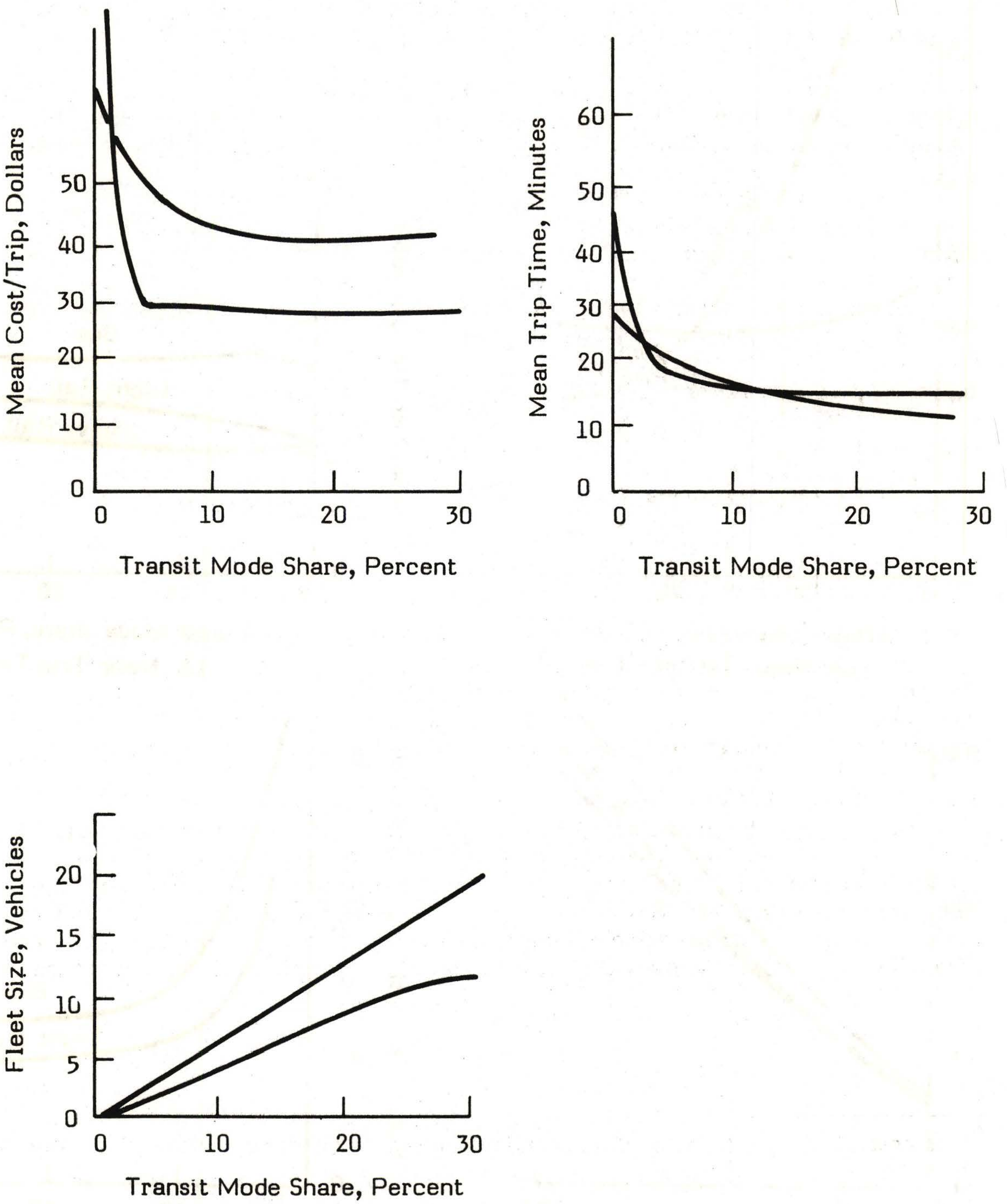


EXHIBIT 5.10

COMPARISON OF FIXED AND FLEXIBLE SERVICES



a larger mode share if the maximum headway were shorter than the 60 minutes allowed in this run. Even so, flexible service only has a cost advantage at very low mode shares.

Travel times are generally comparable between fixed-route and flexible services. Flexible service enjoys a slight advantage in the 2 to 10 percent mode share range, when route destination reduces walking time sufficiently to compensate for less frequent service. Fixed-route service is slightly faster at higher mode shares.

Fixed-route service requires a smaller fleet than flexible service because vehicles do not have to deviate to their passengers' doorsteps. At high mode shares, this advantage increases as fixed-route services take full advantage of vehicle capacity.

Vehicle size has a great impact on the cost and time performance of both fixed- and flexible-route systems (see Exhibit 5.11). For subscription service, time per ride increases linearly with vehicle capacity. A "plateau" occurs for fixed-route service, indicating a service-constrained operation. Cost per ride decreases with vehicle size to a minimum of about 55 passengers.

The analysis suggests that flexible vehicles should not be large, and that this service should be used only for mode shares of 10 percent of less. The information produced by the SMART model can be analyzed in greater detail to provide guidance on flexible service areas, maximum tour times, and other parameters that need to be carefully considered before a new service is inaugurated.

Carpool/Vanpool Diversion

The SMART model was used to investigate a major diversion from transit to carpools and vanpools. Exhibit 5.12 illustrates the general results that might be expected if three-fourths of the transit riders were to shift from transit to car- and vanpools. In this instance, the carpool fraction rose from 3.8 percent to 7 percent, and the transit mode share dropped from 4 percent to 1 percent.

The shift had virtually no impact on the cost or quality of either carpool or vanpool service. This is to be expected because pools operate as small, independent units that are not influenced by the existence of other pools.[4] The impact on transit service is devastating. Cost and fuel consumption per passenger increase threefold, while the bus fleet, constrained by maximum headways, can be reduced less than one-fourth. This situation is clearly unattractive to the transit operator, and may help to explain why many transit operators are suspicious of pooling programs.

---

[4] It is possible that a large pooling activity could command more attractive insurance rates than a small one.

EXHIBIT 5.11

VEHICLE CAPACITY FOR LARGE ZONE, PEAK HOUR

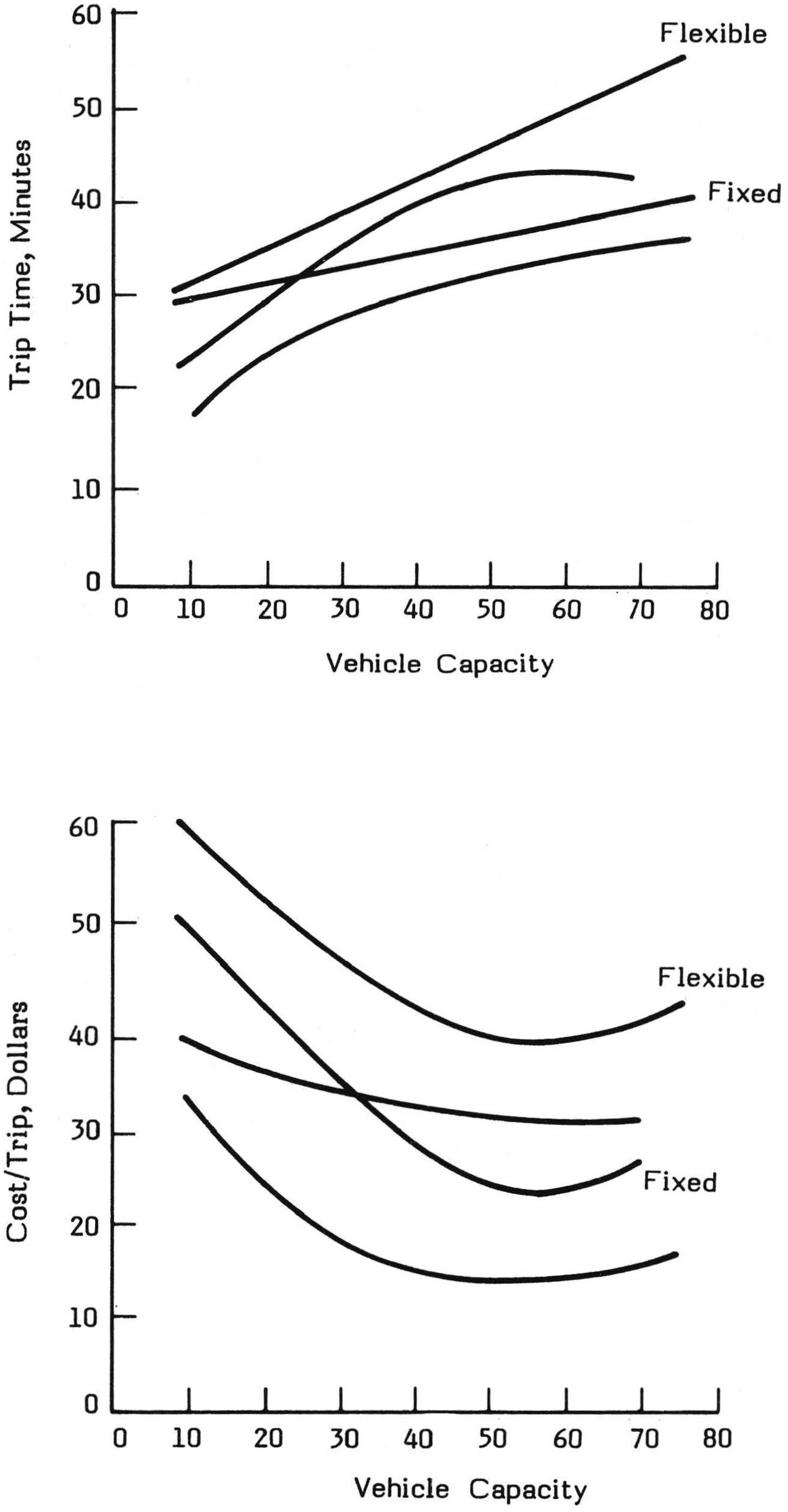


EXHIBIT 5.12

EFFECT OF CARPOOL/VANPOOL DIVERSION OF TRANSIT RIDERS

	Carpool	Transit	Vanpool	Transit
Car/Vanpool Fraction = 0.38 Transit Mode Share = 4%				
Peak:				
Cost/trip ($)	1.00	0.90	1.84	0.89
Time/trip (minutes)	19.1	50.9	25.1	50.5
Fuel/trip (gallons)	0.23	0.099	0.063	0.099
Fleet		413	411	
Off-Peak:				
Cost/trip ($)	0.95	1.02	1.89	1.02
Time/trip (minutes)	16.0	47.3	22.2	47.0
Fuel/trip (gallons)	0.22	0.15	0.064	0.15
Car/Vanpool Fraction = 0.7 Transit Mode Share = 1%				
Peak:				
Cost/trip ($)	1.00	2.74	1.84	2.73
Time/trip (minutes)	19.6	51.9	24.9	51.4
Fuel/trip (gallons)	0.23	0.34	0.062	0.34
Fleet		320		319
Off-Peak:				
Cost/trip ($)	0.95	3.85	1.88	3.84
Time/trip (minutes)	16.0	46.7	22.0	46.1
Fuel/trip (gallons)	0.22	0.57	0.064	0.15

5.6 REFERENCES

The data sources used to develop the SMART representation of Westside Portland are listed below, along with the basis for some assumptions and calculations.

SMART Input	Data Source/Comments
Zone size	Reference Guide to Travel, factors for various subareas, CRAG (former regional planning agency)
Link lengths	Portland's Highway Sketch Network and computer printouts sent by MSD (regional planning agency)
Link speeds	Same as for link lengths
Length of time periods	Tables 24-28 of CRAG Travel Behavior Survey
Trip distribution by time of day	Tables 24-28 of CRAG Travel Behavior Survey and MSDs Trip Data Sheets
Transit mode share	Computed from p. 30 of CRAG Travel Behavior Survey
Carpool fraction	Computed from p. 30 of CRAG Travel Behavior Survey auto occupancy data
Bus size	45 passengers per bus
Speeds	8-6 mph for CBD, 15 mph for FEEDER, 15-19 mph for LINKER
Maximum headway	25-30 minutes, match with Portland's bus schedules
Maximum route spacing	Four blocks/route (except in CBD = 2.5 blocks/route). These numbers are valid for a large number of cities.
Demand	From Portland's production-attraction trip matrix tape

6. PITFALLS

This report has presented general instructions on the use of the SMART model to analyze urban transportation problems. It has also presented examples of applications that have been made to test the model. Advice contained throughout the report is intended to help the user follow a logical path and to avoid pitfalls that have beset the project team. The purpose of this chapter is to collect the principal pitfalls in one place for easy reference, in the hope that future users will be able to avoid most, if not all, of them.

The most important single bit of advice that can be offered is the caution that SMART is a macro-analytic model. If adequately calibrated, it prepares estimates that are approximately correct. Its results are useful for making coarse comparisons among wide-ranging alternatives. However, the SMART model should not be used to identify small differences between similar services.

Other pitfalls can be broadly divided into two categories: data problems and model problems. The key pitfalls in each category are set forth below.

6.1 DATA PITFALLS

Transportation data are notoriously bad. Data are voluminous, expensive to collect and often biased. Quantitative data are influenced by the circumstances and attitudes that existed when they were collected. Survey data are suspect because they often record whims, and only rarely contain economic judgments. Nonetheless, transportation analysis requires data. It is generally better to do the best job that one can on the basis of the data that are available than to make a judgment that has no logical support.

All data have problems. The following pitfalls identify some of the more critical and disconcerting problems:

- Data must be consistent. SMART requires a variety of data: population, employment, area, mean trip length, transit headway, transit patronage, etc. When different items of data reflect different dates, different areas, or different categories, there can be serious compatibility problems. It will not be possible to eliminate all data discrepancies, but great care should be taken to minimize them.

- The assumptions underlying the data should be known. Knowledge of the data source, method of collection, and reason for collection is important. Many data sets are biased for one reason or other. Unless these biases are understood, the data may be misused.

- Regional shopping centers (e.g., the Dayton Mall) should be modeled with care. The three trip categories—home-based work, home-based other, and non-home-based—do not provide for regional shopping center travel very well. Travel to large shopping centers is out of proportion to the number of persons employed there. Artificial changes in residential population and employment should be made with great care because they affect the time distribution of trips in unexpected ways. It is possible to generate a trip table and modify this to account for a large shopping center.

- Great care should be taken with external zones. External zones funnel large volumes of traffic into the nodes to which their links connect. This influx can overload adjacent links and grossly distort traffic patterns. If external traffic is actually dispersed among many corridors, it may be desirable to establish a set of buffer zones that will diffuse the external trips.

- Care should be taken to establish network balance. The interzonal traffic on network links should approximate actual traffic on the arteries modeled. This means that each link should carry an amount of interzonal traffic that moves on non-modeled arterials that is just equal to the local traffic on the link. This requires careful selection of link spacing and links.

6.2 SMART MODEL PITFALLS

This section is provided to sharpen the user's awareness of input aids that are available when SMART alternatives are run. Several guidelines are general in nature.

- Use the subtitle keyword. Subtitles can be printed with the input data. They are helpful in quickly identifying and describing the alternative that is being analyzed.

- All SMART input data are right justified. Put in an "o" to define location.

- Use GENDEM (WRITE). In the ring/corridor network, this command saves the full network demand and writes it out to an external file (demand output). This output can then be edited for many uses, such as a smaller transit service area and variable service areas. It can be edited to reflect the effects of regional shopping malls or to test "what if" development questions.

Network guidelines include the following:

- When adding a link or zone to the network (e.g., an external zone), a composite network vehicle is created that SMART can handle if the keyword COMNET is used. Otherwise, a disjoint network will occur, and the SMART run will terminate.

- When constructing external zones, in a ring/corridor network, a summation of the data for the external areas or an estimate of the population, employment, and zone size is required. Some sensitive juggling may be needed with the length of the links and number of lanes to be used to connect these zones to the network. The number of lanes can be estimated from traffic volume information for traffic flowing across the study-area boundaries. The length of the links should be kept sufficiently long to keep internal zone traffic off the links to the network.

- When no transit modes are to be treated within a zone (e.g., in external zones), the use of IGNORE with the ZONESET or ONEZONE input cards will accomplish this task. If an IGNORE zone has population and employment associated with it, the traffic to and from the zone will be included in the demand, but the internal traffic will not be included. IGNORE is convenient to use for

    - external zones
    - zones without population and employment (to remove default values assigned)
    - zones to be excluded from a sub-network that is treating only zones served by transit

- Default values exist like a shadow (secondary) data set, and the user should be aware of them. They will probably need to be replaced by real values or values to be tested to reflect local conditions. Default values for the modal parameters are shown in Exhibit 6.1. Other network defaults include values for radial link length, zone size, zone population, and employment densities.

- Dummy nodes. For zones attached to dummy nodes, set the population and employment density to "0," which ensures that no trips are destined to or originate in these zones (this operation replaces the default values).

The use of transit modes has some limitations:

- REGION — SMART allows only one transit mode per zone; thus the user may have to choose between using private auto transit (kiss-and-ride) and flexible-route service.

- FEEDER — Here, more than one transit mode in a zone can be modeled.

- Modes on links — Only one transit mode per link is possible. For example, light rail and fixed-route bus cannot be used on the same link.

- Exclusive busway (diamond) lane — A lane must be added to each link for the exclusive lane option to be run.

EXHIBIT 6.1

DEFAULT MODAL PARAMETERS

	Auto	Carpool	FRBUS	FLEXRTE	HRail	LRail	AGT	PvtAuto
$	0	0	0	0	0	0	0	0
$V	2.04	2.04	51.78	26.61	200.00	150.00	50.00	1.50
$/Vehicle-hour (min.)	0.012	0.012	0.16	0.145	0.40	0.30	0.17	0
$/Vehicle-mile	0.09	0.09	0.48	0.20	.01	.01	.01	.01
$/Route-mile	0	0	0	0	15,000.00	2,000.00	8,000.00	0
Speed (miles/min.)	.333	.333	.333	.333	1.00	.333	.333	.333
Minimal stop time/ stop (min.)	.5	.5	.2	.5	.17	.08	.17	.5
Incremental stop time/ passenger (min.)	0	0	.02	0	.13	.01	.05	0
Miles/gal.	15.0	15.0	5.2	9.0	0	0	0	15.0
Passengers/vehicle	1.2	3.0	50	10	185	220	100	1.2
Minimum headway (min.)							.05	
Maximum headway (min.)			60	60	30	30	3	
Maximum route spacing (miles)			1.0				.5	
Stops/mile			8	4	1	2		
Cars/vehicle	1	1	2	1				1
Fraction who park								1.00

Heavy Rail Train Size:

A.M. peak	10	cars
Off-peak	4	cars
P.M. peak	10	cars

Flex-Route Service:

A.M. peak	Subscription
Off-peak	Dial-a-ride
P.M. peak	Subscription

All transfer coordinations RANDOM

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-421-428/211

DOT-I-83-57

DOT-I-83-57

TECHNOLOGY SHARING

A PROGRAM OF THE U.S. DEPARTMENT OF TRANSPORTATION