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Development of a transit policy analysis tool for small urban areas

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DEVELOPMENT OF A TRANSIT POLICY ANALYSIS TOOL FOR SMALL URBAN AREAS

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Development of a transit policy analysis tool for small urban areas

by

Richard Yun-Hao Woo

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
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Department: Civil Engineering
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For the Graduate College

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CHAPTER I. INTRODUCTION

Background of Study

A continuing problem for transportation providers in the 1980s will be the development of strategies to maintain mobility for all segments of the population in the face of increasing costs and increasing uncertainty about fuel supplies and financial resources. Transit operators in particular will need to consider what adjustments can be made in route coverage, service frequency, labor arrangements and other areas in order to optimize their operation.

Fortunately, there have been several studies which provide estimates of demand changes for corresponding changes in fare and service. Also, large scale planning and analysis models such as the Urban Transportation Planning System (UTPS) provided by the U.S. Department of Transportation (DOT) have been developed to assist transit planners with network analysis problems. Unfortunately, these large scale analysis procedures require substantial data, time, dollars and professional expertise. Small and medium size cities have not usually had the capability to use these planning tools. Even at the state level in Iowa, the transportation planners have been unable to justify the expenditure of resources necessary to get the UTPS on-line. The UTPS does not provide the urban transit planner a hands-on capability appropriate for short-run policy analysis on specific routes of a transit system. The need to make the planning tools more accessible and understandable to the local planner has been recognized.

With the advent of microcomputer technology, new applications are arising daily as more and more organizations seek the advantages of increased productivity, reduced cost, greater responsiveness and improved ease of use. In the local planning field, work is underway to combine microcomputer systems and simplified procedures to place more directly in the hands of the planner, the tools which he/she can use to examine local conditions. The Urban Mass Transportation Administration (UMTA) of the U.S. DOT has begun sponsorship of projects to develop their programs which could be run on microcomputer systems. However, these programs are often directed to operations with extensive data sets and major networks. Planners need to develop simplified procedures to examine and optimize transit service using basic operating and demographic data which are more readily available to the smaller transit agencies.

Objectives and Scope

The purpose of this research was to develop a short-range transit planning technique to help local planners evaluate the impacts of transit routing and scheduling options. It was intended to provide a framework for selecting the best service policies to undertake when considering a reallocation of system resources. A transit route evaluation procedure was developed to establish route potential on the basis of demographic and transit service factors. An optimization strategy to maximize the ridership subject to energy and budget constraints was defined. Policy issues related to factors such as fares, vehicle size, and labor policies were not considered in the scope of the research. The research will be of primary benefit for short range analysis in small and medium-size cities.

There was a parallel objective of demonstrating the applicability of the approach. To achieve this goal, the approach was applied to a case study of Des Moines Metropolitan Transit Authority (MTA) fixed routes. The purposes of the case study were several:

1. It demonstrated the data needs of the methodology.
2. It provided an indication of the potential of each transit route in the corridor.
3. It showed how the analysis techniques can be applied to a real city.
4. It permited a look at the impacts of several alternatives which have been formulated on travel demand in the corridor.

5. It optimized the ridership in the corridors subject to constraints.

CHAPTER II. RESEARCH APPROACH

Literature Review

The need for simplified techniques for estimating bus route-level demand and optimizing transit systems is partially reflected by the funding philosophy dictated by the policies of the 'New Federalism'. These policies are directed to reducing the role of the federal government in the control and financial support and placing more of this responsibility with the local governments. In addition, the 1980 census data and the advancement of microcomputer technology provide extra strength to the local planner. These resources provide the planner an opportunity to analyze more completely alternatives which can enhance the transit operation. Some of the state-of-the-art methods and applications are reviewed here to show the development of transit policy analysis tools.

Demand model

A report summarizing the route-level ridership prediction techniques which currently are used by the transit industry was prepared by Multisystems, Inc. (1). These techniques include judgemental methods, noncommittal surveys, similar routes methods, rule of thumb procedures, trip rate models, regresssion models, elasticity methods and trend analysis. It is important to judge the value of any technique by its accuracy. However, that is clearly not the only criterion. Other criteria such as sensitivity to decision variables, range of application, analyst dependence, cost of the application, technical sophistication and transferability should be taken into the evaluation process.

The Urban Mass Transportation Administration (UMTA) supported-research by Turnquist, et al. has major objectives which are parallel to the objectives of this research in that maximum use of available data was desired and the analysis program was prepared for a microcomputer (2). However, within the framework of the demand model, the researchers used a multinomial logit (MNL) model borrowed from a large metropolitan area, the Twin Cities area of Minneapolis and St. Paul. In transportation choice models, probability models have been given considerable attention because they can be applied to discrete choices and can be calibrated with small data sets based upon the assumption of independence of individual choices. Unlike other principal techniques such as discriminant and probit, a logit model is a model structure without the specification of any distributional assumptions. Although the logit model has many conceptual advantages, the use of this demand approach in this research would not be considered acceptable because of the disparity between the characteristics of cities considered here and the cities where the behavioral modeling have typically been completed.

Yuratovac used the route-segment as an observation unit to develop route-level demand models for local radial bus routes in Cleveland, Ohio (3). A working example was provided to demonstrate the application. Trip generation and distribution steps were applied to predict ridership for each route-segment. In the trip generation step, equations were used to generate a home-based transit trip rate. The development of the trip rate equations relied heavily on the local data bases, especially origin-destination data. Yuratovac assumed that no passengers will travel beyond the central business district (CBD) and also that passengers will transfer from crosstown routes to radial routes only and not from a radial to a radial. However, these assumptions may not be appropriate for some cities.

Optimization technique

A model for determining the general dimension of an optimal mass transit system for an idealized urban area was developed by Black (4). The model was based on a circular city with a definite center and with density declining uniformly from the center in all directions according to the negative exponential function. By use of integral calculus, a model was derived that represented the total community costs of building and using such a system. By use of differential calculus, a procedure was developed to optimize the principal design variables in the system: the number of radial routes, their length, and the number and spacing of stops on each route. Unfortunately, it is unrealistic to apply such an abstract model to the irregular pattern of a real city.

Furth and Wilson have demonstrated one technique based on Kuhn-Tucker optimality conditions and found that under inelastic demand conditions, the allocation of resources was quite insensitive to the specific set of parameters and objectives (5). The authors noted that an important limitation of the model used in their study was the assumption of independence among the routes.

General Motors Transportation Systems Center has developed the Interactive Graphic Transit Design System (IGTDS). The IGTDS is a set of computer programs which enables the user to design and evaluate alternative transit plans through the use of computer graphics. Especially, IGTDS deals with those transit systems providing trips from multiple origin to a single destination. IGTDS has been used as a valuable tool for both research and instruction at many universities, such as Cornell, Michigan State and University of Washington. However, from Cornell's experience, it took approximately a year to implement IGTDS.

Model variables

It has been shown that socioeconomic characteristics are indicators of potential transit ridership. In the Paducah Urban Area Transportation Study, socioeconomic factors were used to define transit use areas (6). The variables included passenger cars per dwelling unit, average income, females age 16 to 24 years, persons age 62 or over, and dwelling units per acre. In the Cleveland study, service frequency was used to estimate the home-based trip rate (3). Trip distribution was based on the number of employees and travel time.

A large number of studies have discussed fare and service impacts on ridership. A study reported by Weisman evaluated statistical data to test the relationship of six transit system variables (7). The variables included speed, frequency, express bus service, route coverage, noncentral business area service and the need to transfer. It would appear that frequency of service has been shown in a number of examples to have a prime influence on transit use. Lutin emphasized that access distance and service area conditions should be among the system evaluation criteria as these are among the most basic indicators of transit availability (8).

In evaluating transit performance, U.S. transit authorities have primarily been concerned with establishing minimum tolerable standards for justifying expenditures on transit projects. Talley and Becker demonstrated that deficit per passenger may be used to evaluate performance with respect to the objective of maximizing ridership subject to a maximum allowable deficit (9).

Census data

The 1980 census provides current demographic data and travel information. The summary tape files are available at Iowa census services at Iowa State University. The Census Software Package (CENSPAC) is a generalized data retrieval system that the Census Bureau developed for use with its public use statistical data files (10). Although these data can be accessed and combined with other network data files through geographic base/dual independent map encoding (GBF/DIME) files, the capability is somewhat meaningless unless substantial familiarity with the computer operating system is available. The UTPS package has simplified the interface problem with census data, but since only major metropolitan areas have typically developed a first-hand dialogue with the UTPS package, very little advantage is seen here.

The 1980 census Urban Transportation Planning Package (UTPP) is a special tabulation of census data for individual standard metropolitan statistical areas (SMSAs) tailored to geographic areas that are used in transportation planning. In addition to its special, user-oriented cross-tabulations of social, demographic, and economic data items, the primary advantage of the UTPP is that it provides place-of-work data tabulated at geographic levels (i.e., census tract and block group) that are much finer than any shown on the standard summary tape files (STF).

Microcomputer developments

Several transportation planning programs are currently being developed to operate on microcomputers to improve the responsiveness of analysis techniques to the needs of local officials. However, it is difficult to know exactly where to look for information in the new and rapidly changing area of transportation applications of microcomputers.

In August 1982, the first 'UTPS Microcomputer in Transportation Information Source Book' was published by Urban Mass Transportation Administration (UMTA) and Federal Highway Administration (FHWA) (11). At UMTA and FHWA, they have tried to keep up with the developments and to maintain up-to-date microcomputer references for transit operators, transportation planners and traffic engineers. They sponsor individual research in these areas and have funded clearinghouses for evaluating and preparing information related to transportation developments. Rensselaer Polytechnic Institute was chosen to operate the user support center which is also known as the Transit Industry Microcomputer Exchange (TIME).

There are a number of transportation planning software packages in the market. MicroTRIPS, by PRC Voorhees, is a comprehensive package paralleling the Urban Transportation Planning System (UTPS) in functional capability for systems up to 150 zones, and 2000 links. It allows interactive demand estimation and network assignment for highway and transit systems.

Methodology

The method used in this research to estimate route ridership under varying supply conditions is the use of a stiffness concept applied in structural analysis. The stiffness of a structural member is represented by the material strength, cross-sectional properties, and the length of the member. The load which a member takes is proportional to the stiffness of the member.

In a similar way, it is hypothesized that the stiffness along a transit route can be represented by population characteristics, employment or other activity along a route and the transit service levels. Since ridership along a transit route is not uniformly distributed, one would like to divide the route into segments. The stiffness of each route-segment can, therefore, be distinguished. The higher the stiffness, the more demand potential on the route-segment. However, unlike a structural member, the stiffness is not always a constant. Service level changes will change the route-segment strength. Resources should be allocated in recognition of these variations.

This research to estimate stiffness parameters to examine relative route-segment potential in a radial system will focus on a single city's fixed-routes for development purposes. The methodology is intended to define basic route parameters for the specific community using existing ridership, service, employment and population characteristics of each city rather than attempting to transfer parameters among cities.

Study City

The City of Des Moines, Iowa has been selected for building the route demand model. Des Moines is a city of approximately 200,000 population in a metropolitan area of approximately 290,000 population. It is the state's capital and also called the 'insurance center of the West'. Des Moines has more than 160 home and divisional offices of insurance firms. With other types of business, approximately 40,000 persons are employed in the central core.

Drake University, a private liberal arts four-year college with full-time enrollment exceeding 6,000, is located in Des Moines. Other colleges in the city have fewer than 1,000 students each. There are seven hospitals and thirty-two shopping centers in the Greater Des Moines Area. Merle Hay Mall, Valley West Mall, and Southridge Mall are the largest shopping centers in the region with 1,148,000 square feet, 900,000 square feet, and 705,700 square feet, respectively.

The Metropolitan Transit Authority (MTA) operates nine fixed routes, radially oriented to the central business district. Each route has two interlocked legs which extend into separate areas of town. Three routes serve Merle Hay Mall, two serve Valley West Mall, and three serve Southridge Mall. Each of these three shopping malls is located at the terminating point of the routes.

Seven express routes provide service from the suburban areas to the central business district and the capital complex. These operate during the peak periods.

Ridership on all weekday and weekend routes was estimated to be 5,600,000 in 1981. The total fleet consists of 100 vehicles ranging in capacity from 37 to 51 seated passengers.

Data Sources

Ridership data

The ridership data were based on a complete on-board passenger count in 1981. The MTA is establishing a regular program for conducting these passenger studies which can be directly processed by the computer, using the EZDATA^{TM} program developed by a consultant. Although previous summaries have focused on total route usage, it is possible to examine the ridership in segments of the route through a manual process.

Socioeconomic data

Socioeconomic characteristics were obtained from the 1980 census summary tape files by using the CENSPAC program. Population and number of households were retrieved for each census block, but median household income was available only for each census blockgroup.

Employment data

The primary source of employment data comes from the employment map by census tract subarea in the City of Des Moines. This information is based on a survey taken by the Des Moines Plan and Zoning Commission staff for the year 1980. However, the suburban communities of West Des Moines, Windsor Heights, Clive, and Urbandale were not included in the survey. Supplemental information was obtained from the '1981-82 Directory of Iowa Manufacturers' published by the Iowa Development Commission and the '1981 Greater Des Moines Area Major Employers Listing' compiled by the Greater Des Moines Chamber of Commerce.

Shopping center data

Data such as floor area, number of stores, and number of employees for each shopping center are desired. However, most of the data are not readily accessible at this time. Compliments of the Des Moines Register and Tribune, square footage data were obtained from the 'Shopping Center Map of the Greater Des Moines Area'.

Hospital data

The '1981 American Hospital Association Guide to the Health Care Field', which is available at public and university libraries in the state, provide the size of hospitals. Size can be expressed in terms of beds, admissions, and staffs. This research relied on number of beds as the explanatory variable.

School data

Enrollment data for colleges and universities were obtained from the '1982-83 Yearbook of Higher Education' which is also available at public and university libraries in the state. A 1981 high school enrollment summary was provided by the Office of Pupil Accounting and Records, Educational Service Division, Des Moines public schools.

Stiffness Parameter

The stiffness parameter was developed to reflect route demand potential using regression techniques. Since ridership along a transit route is not uniformly distributed, one would like to divide the route into segments. In this way the variation within the analysis unit can be reduced. On-off-passengers per route-mile will be used as the primary dependent variable. On-off-passengers is the sum of on-passengers and off-passengers within a route-segment during the day. The use of on-off-passengers, rather than on-passengers or off-passengers, was based on the fact that the number of on-passengers is not equal to the number of off-passengers. The inbalanced data resulted mainly because on-board passenger counts were not taken in the same day and there are one-way passengers. However, it is usually assumed that a person who travels from segment i to segment j will make a return trip later in the day, boarding in segment j and alighting in segment i. The demographic and service parameters were used as independent variables.

The stiffness is more than a trip generation equation from an area. Its function is to simultaneously measure a trip generation and distribution effect by incorporating both production and attraction capabilities along a route. Further, the potential for distribution through the network will be dependent upon the strength of the other routes with which it connects. As in a building structure, if the other structural members do not have sufficient strength, the integrity of the system will be reduced. A weak route-segment can not carry much of the load and possibly could be removed so the resources could be used to strengthen other route-segments. However, continuity of the route-segments should be maintained.

The Statistical Analysis System (SAS) was used for demand model development (12). The application of the commercial multiple regression programs for microcomputer was also examined. Having developed the route-segment stiffness, the route stiffness was calculated as the weighted average of the route-segment stiffnesses of the transit route.

Optimization Strategy

The objective of this task was to optimize the transit route on the basis of the demand and system constraints. A general mathematical statement of the linear programming model will demonstrate the attempts as follows:

Find X_1, $X_2, \ldots,$ X_n, which optimize the linear equation

$$\text{Max } Z = C_1X_1+C_2X_2+\ldots+C_nX_n \qquad \text{Eq. (1)}$$

subject to the constraints

$$A_{i1}X_1+A_{i2}X_2+\ldots+A_{in}X_n\leq B_i \quad (i=1,m) \qquad \text{Eq. (2)}$$

where $X_1\geq 0$, $X_2\geq 0,\ldots,$ $X_n\geq 0$, and A_{ij}, B_i, C_j are given constants.

The above model, interpreted in terms of transit planning, indicates that one has n transit lines which will be the nine fixed routes in the Des Moines MTA. The decision variables X_j ($j = 1,\ldots,n$) represent the supply of the transit system for each route (bus-mile or trip). C_j is the stiffness of each route (passengers per bus-mile) which is developed indirectly from the demand model. The number of relevant sources is m, and each of the m linear inequalities express a constraint (such as available fuel and money, performance standards) on one of these resources. Each B_i is the total amount of resource i consumed by the transit lines, and A_{ij} is the amount of resource i consumed by each unit of transit line j. The total usage of the respective resources is given by the left side of these inequalities. The non-negativity constraints X_j express the fact that a negative quantity of a transit line can not exist. However, a lower bound can be set for X_j which represents the minimum services on a transit lines. The objective is to optimize the ridership in the system.

The IBM^{TM} Mathematical Programming System (MPSX) was used to maximize the ridership subject to the constraints. MPSX is capable of giving the user all the options of linear programming computations, such as sensitivity analysis and range analysis. But other user-developed linear programming programs are available. Furthermore, commercial software programs used on a microcomputer system were also examined.

Evaluation of Supply and Usage

The objective of this phase was to evaluate the possible change of usage due to the change of supply. In the previous phase, transit services provided for each route were determined. However, these services were expected to be changed because the available resources were changed. This then induced the change of usage. Therefore, a new set of route stiffness needed to be determined according to the adjusted transit services. An iteration process was then executed until the transit services provided and the usage were balanced. Because of the lesser number of alternatives in the smaller communities the solution was expected converge quickly.

CHAPTER III. DEMAND MODEL DEVELOPMENT

A first stage in the analysis of the Des Moines transit system was to develop transit ridership estimates. Multiple linear regression techniques were used for the development of the stiffness parameter. The observation unit was route-segment. Passenger density, the stiffness, was used as a dependent variable. Independent variables included the demographic and service parameters. In this chapter, three major sections undertaken to accomplish the demand model development are discussed. These are preliminary work, model calibration, and model results.

Preliminary Work

The sources of ridership data, socioeconomic data, employment data, shopping center data, hospital data, and school data were discussed in Chapter II. Several tasks were undertaken before actual model development. Data were compiled and quantified for the numerical values of dependent and independent variables. This preliminary work was divided into six tasks as follows:

Task 1. Divide route into segments.

Task 2. Determine service area.

Task 3. Determine population characteristics.

Task 4. Determine employment characteristics.

Task 5. Determine route-segment ridership.

Task 6. Determine transit service level.

Task 1. Divide route into segments

The initial effort examined the Des Moines transit routes to identify homogeneous sections of routes. Homogeneous segments were needed so the general population characteristics along the route could be examined for potential to explain ridership variations. Census data by block, the lowest census summary level, were used to define population characteristics. Each census block has its unique number and the transit routes were located on the 1980 census map.

The route was divided into segments based on major intersections, geographical boundaries, and census blockgroup. The reason for selecting the census blockgroup, the first digit of the block number, was that median household income information was summarized in this level by the Bureau of the Census. Income summaries were not provided in smaller areas in order to assure anonymity.

The central business district (CBD) was assigned as route segment 1 for each transit route with a segment length of approximately one mile. However, the CBD was treated as a whole unit instead of each route individually. This was because the CBD has little residential land use, high employment density, and high level of transit service. All of the transit routes were running parallel with each other in either an east-west or a south-north direction. An attempt to associate these common characteristics of this area with each of the routes would distort the significance of potential explanatory variables on portions of the route outside the CBD. MTA fixed routes were divided into 110 segments which are shown in Figure 1.

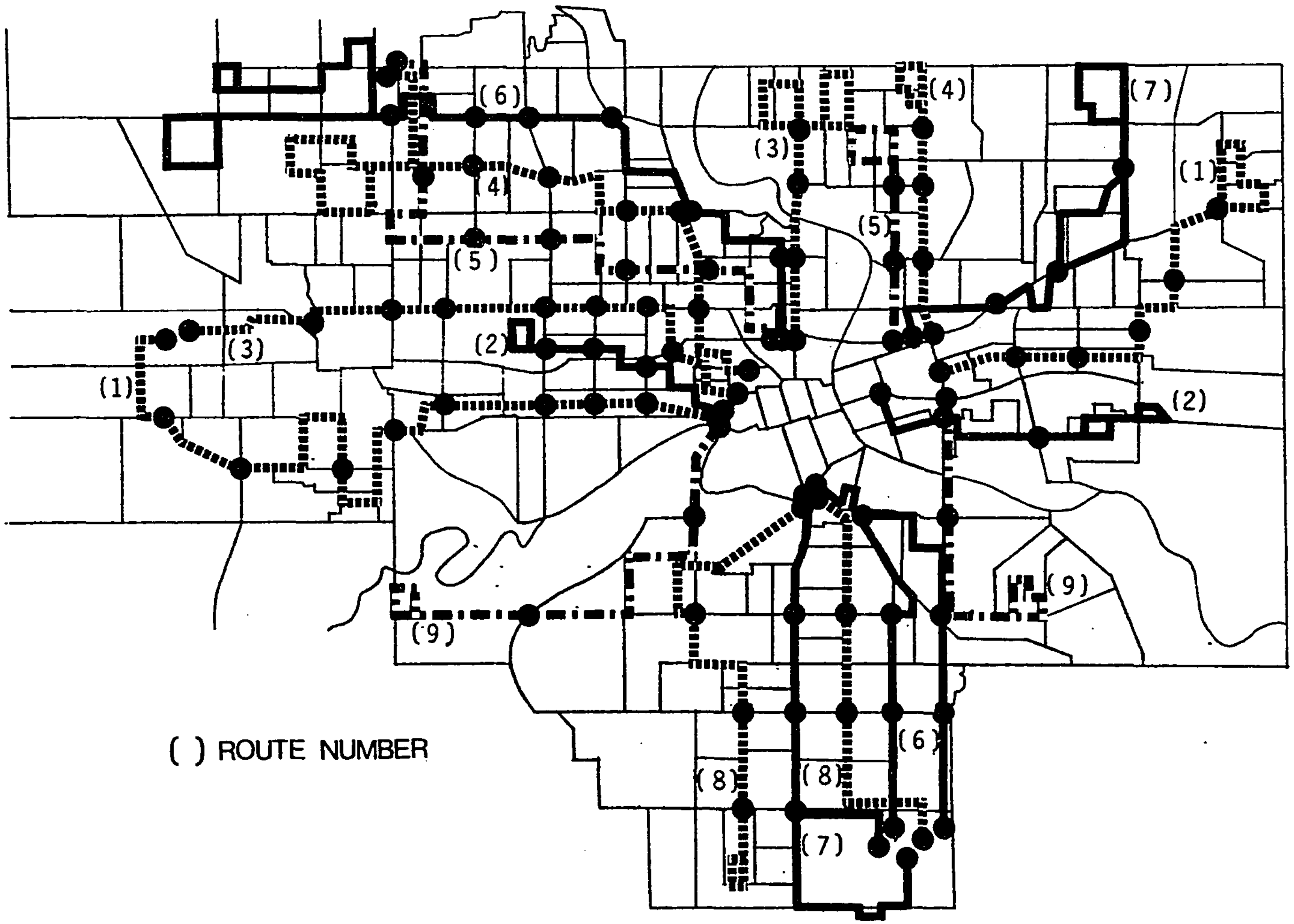


FIGURE 1. Des Moines MTA fixed routes and segments

Task 2. Determine service area

The service area for the bus route was defined as the area within 0.25 mile of the route. Using the 1980 census map, census blocks within that area were identified for each route-segment.

If a census block was partially in the service area, it was or was not included depending upon the percentage of the census block within the service area. The decision rule was that more than 50 percent had to be in. Major barriers such as rivers, railroads, and interstate highways were taken into account as to how they affected accessibility.

The CBD service area was served by 18 transit routes; six of them go eastward, four go southward, five go westward, and three go northward. This covered an area of approximately two square miles.

Task 3. Determine population characteristics

Population, the number of households, the number of persons over age 62, and the number of females between the age of 16 and 24 were determined for each route-segment. The selection of females between the age of 16 and 24 was based on the fact that a large segment of transit markets in many urban areas has been composed of this young female group. Data for these four variables were retrieved from the 1980 census summary tape file for each census block. The route-segment data were then summarized through a manual process.

Income level for each route-segment was determined by taking the weighted average of median household income for each corresponding census blockgroup within the service area. The 1979 median household income in the Greater Des Moines Area was approximately 17,500 dollars as shown in Table 1. By using upper and lower quartile incomes, household income above 25,000 dollars can be considered as high income and below 10,000 dollars as low income.

Task 4. Determine employment characteristics

Data obtained from the Des Moines Plan and Zoning Commission, the Iowa Development Commission, and the Greater Des Moines Chamber of Commerce were used for determining the number of employees as described in the previous chapter. The number of employees were expected to relate to the potential work trips. However, major trip generators such as shopping centers, hospitals and schools also attract trips other than work trips. These non-work trips are generated by shoppers, patients or students.

Instead of using several variables to represent the attraction of a route-segment, one single variable, employment equivalence, was used. The idea was to convert other factors such as students and square feet of shopping area to an equivalent employment factor which would relate to transit trip potential.

For example, referring to the ITE Trip Generation report (13), a shopping center with 250,000 square feet gross floor area (GFA) has a trip rate of 50 vehicle trips to and from the area per day per 1,000 square feet GFA and 3 percent of these are transit trips. This means that this shopping center generates 1.5 transit trips, to and from, per day per 1,000 square feet GFA. On the other hand, an employee, having a trip rate of 3 vehicle trips per day and a 5 percent transit trip rate, generates 0.15 transit trips per day. Using these comparative rates,

TABLE 1. 1979 median household income in Greater Des Moines Area[a]

Household income	Number of households					
	Des Moines	West Des Moines	Urbandale	Clive	Windsor Heights	Total
Less than $2,500	2566	135	75	30	33	2839
$2,500 to $4,999	6452	301	108	51	62	6974
$5,000 to $7,499	6386	367	200	73	78	7104
$7,500 to $9,999	6098	475	352	94	78	7097
$10,000 to $12,499	6279	526	362	152	104	7423
$12,500 to $14,999	5571	464	347	156	80	6618
$15,000 to $17,499	6074	598	468	169	190	7499
$17,500 to $19,999	5296	497	403	140	105	6441
$20,000 to $22,499	5800	600	481	145	177	7203
$22,500 to $24,999	4417	451	482	122	134	5606
$25,000 to $27,499	3986	556	505	134	117	5298
$27,500 to $29,999	3102	405	324	146	145	4122
$30,000 to $34,999	4527	740	752	229	196	6444
$35,000 to $39,999	2882	604	535	163	144	4328
$40,000 to $49,999	2857	776	560	212	171	4576
$50,000 to $74,999	1824	580	377	163	207	3151
$75,000 or more	1299	239	120	70	127	1855
Total	75416	8314	6451	2249	2148	94578

[a] Source: 1980 census summary tape file three (STF 3).

the employment equivalent factor is 10 (1.5 divided by 0.15) per 1,000 square feet GFA for a 250,000 square feet shopping center. This means that a 250,000 square feet shopping center is equivalent to an employer having an additional 2,500 (250x10) employees. The employment equivalent factors for major generators are shown in Table 2.

These equivalent factors which are based on the ITE report are subject to the reliability of the base data of that report. One recognized that there are variations but these are the best available sources. For instance, hospital data were collected from hospitals located primarily on the West Coast; some hospitals were situated within major cities while others were located in the outlying suburban areas. Studies of 210 different type shopping centers were obtained for the ITE study and included centers as small as 6,900 to as large as 1,600,000 gross square feet of leasable area.

Task 5. Determine route-segment ridership

As mentioned in the previous chapter, the ridership data were processed by an EZDATA^{TM} program prepared by consultants to the Des Moines Metropolitan Transit Authority (MTA). A copy of the computer printouts was available in the planning office of MTA. Before using the data, an estimate of possible measurement errors in the on-board passenger counts was desired.

Ideally, the number of on-board passengers at origin point i plus the number of on-passengers equaled the number of off-passengers plus the number of on-board passengers at terminating point j. As shown in Table 3, it was found that the equilibrium condition did not hold.

TABLE 2. Employment equivalent factor

Generator	Employment equivalent factor[a]
Shopping center	
0- 49,999 GFA	23/1,000 GFA
50,000- 99,999 GFA	16/1,000 GFA
100,000- 199,999 GFA	12/1,000 GFA
200,000- 299,999 GFA	10/1,000 GFA
300,000- 399,999 GFA	9/1,000 GFA
400,000- 499,999 GFA	8/1,000 GFA
500,000- 999,999 GFA	7/1,000 GFA
1,000,000-1,249,999 GFA	6/1,000 GFA
School	
High school	0.3/student
Junior/Community college	1.3/student
University	2.0/student
Hospital	10/bed
Governmental office	4/employee

[a] This is based on 3.0 vehicle trips to and from per day per employee and 5 percent transit of total person trips. Equivalent factors based on data from ITE Trip Generation, 13.

TABLE 3. Weekday on-board passenger count at Des Moines MTA fixed routes[a]

Route	Outbound				Inbound			
	No. of trips	Onboard	On	Off	No. of trips	Onboard	On	Off
1 West Des Moines	39	563	691	1223	41	15	1383	847
1 Fairgrounds	37	575	419	938	40	51	958	414
2 Crocker	9	59	109	154	9	10	208	132
2 Scott	11	78	54	97	10	-	74	41
3 University	41	545	771	1303	42	24	1384	789
3 Highland - Oak Park	43	649	367	899	40	119	962	523
4 East 14th	40	369	193	522	38	45	593	246
4 Urbandale	40	365	535	891	37	33	817	475
5 East 6th & 9th	38	323	302	545	38	80	476	221
5 Clark	36	337	398	739	38	22	829	506
6 West 9th - Douglas	41	377	654	1028	40	40	1059	760
6 Indianola - Lacona	36	365	163	510	36	22	536	195
7 Fort Des Moines	46	525	430	884	43	65	939	595
7 Walker	41	474	440	825	43	95	1266	817
8 SW 14th - Havens	13	126	81	211	13	2	244	183
8 South Union	13	71	103	191	12	2	226	118
9 Park Ave. West	12	63	77	138	9	3	98	67
9 Park Ave. East	10	38	36	74	10	15	87	37

[a] Source: EZDATA, Des Moines Metropolitan Transit Authority (MTA), 1979.

Possible reasons for the errors include that some passengers travel beyond the CBD from an inbound trip, and on-board passenger counts were not completed all in one day but over several days. However, the error, which was in the neighborhood of 5 percent, was considered to be acceptable. The total number of on-passengers was approximately equal to the total number of off-passengers for each route as shown in Table 4.

The number of on-passengers and the number of off-passengers for each direction of travel (inbound, outbound) and time of day (AM, mid-day, PM, evening) were summed for each route-segment. However, this set of data was only a single point in the whole sampling distribution.

The sampling distribution of an estimate is the theoretical distribution of all possible values of the estimate, each with its probability of occurrence. Commonly, instead of specifying desired precision, the researcher(s) must work from reasonable allowed funds.

To check the adequacy of the original data, another small sample set of data was collected to examine the ridership variations for this research. The results and the analysis of that data set are presented later in this subsection.

The potential of using statistical methods in the collection of individual bus-line data was investigated by Phifer (14). The results demonstrated that sampling gave the necessary precision while permitting more efficient use of manpower and allowed the flexibility needed to focus on data of interest. It was concluded that, with the establishment of appropriate guidelines for its use, sampling provided a

TABLE 4. Weekday total on-off passengers at Des Moines MTA fixed routes

Route	On (total)	Off (total)
1 West Des Moines/ Fairgrounds	3,390	3,292
2 Crocker/ Scott	445	424
3 University/ Highland - Oak Park	3,484	3,514
4 East 14th/ Urbandale	2,131	2,112
5 East 6th & 9th/ Clark	2,005	2,011
6 West 9th - Douglas/ Indianola - Lacona	2,408	2,494
7 Fort Des Moines/ Walker	3,009	3,121
8 SW 14th - Havens/ South Union	654	703
9 Park Ave. West/ Park Ave. East	298	316
Total	17,824	17,987

valuable tool to bus transit.

In this research, two survey sampling techniques were considered for obtaining the long-term ridership data. These were random sampling and rotation sampling.

Random sampling is intuitively fair and free from distortion. Every route-segment is equally likely to appear in the sample. Its weakness is that it does not use any relevant information or judgement that we have about the transit system. For example, route-segments in one part of a city have more consistent ridership patterns than those in another. Rotation sampling selects one or more transit routes at a time where individual bus runs of a route would be randomly selected and the bus trips within the bus runs would compose the sample. Another cluster sample is used for the next data collection where repetition of route(s) can be considered. A complete on-board passenger count is used for control. Every route-segment is included in the sample. The weakness of rotation sampling is that it takes time to complete a round (all routes) and additional information is needed to adjust for seasonal effect. A statistician should be consulted for the experimental design whenever possible.

The rotation sampling technique was chosen for this research. The validation sample consisted of three peak-hours on-board passenger counts on two buses (71 and 73) for the Fort Des Moines/Walker route on Tuesday and Wednesday during March and April. The results are presented in Table 5.

Note that the number of on-off-passengers on the third day was

TABLE 5. Peak-hours on-board passenger counts on two buses

Day[b]	Route segment[a] (number of on-off-passengers)										
	1	2	3	4	5	6	7	8	9	10	11
1	59	65	35	59	102	273	26	50	22	47	91
2	71	72	41	58	71	285	29	41	22	51	87
3	90	78	50	101	137	286	61	131	34	70	119

[a] Segment 5 and segment 6 are in CBD.

[b] Day 1 and day 2 are on spring break (no student).

higher than the first two counts. This was mainly because the first two counts were taken during the spring break of Drake University and the Des Moines schools. Students who ride the bus to and from school were not shown on those counts. Using the data in Table 5, an analysis of variance has been done to examine the among route-segment variation and the within route-segment variation. The sum of squares among (or between) samples measures the variability among the sample means; that is, the variability of the sample means about the overall mean. The within sample sum of squares is a measure of the within sample variability; that is, the variability of an observation about its sample mean. The percentages of variation are shown in Table 6.

From Tables 5 and 6, several conclusions are evident. In Table 5, the CBD segment had a higher passenger density than the other segments. This substantially influenced the magnitude of the among segment sum of

TABLE 6. An analysis of variance of transit ridership

Variation	Dataset A[a] Include CBD (N=33)	Dataset A[a] Exclude CBD (N=27)	Dataset B Include CBD (N=22)	Dataset B Exclude CBD (N=18)
Segment	91.7[b]	52.3	97.7	97.1
Day	3.7	33.3	0.1[c]	0.5[c]
Error	4.6	14.4	2.2	2.4

[a] Dataset A includes all three days data; Dataset B includes only two days (spring break) data.

[b] All values represent the percentage of corrected total sum of squares.

[c] The variable was not significant at the 0.05 level.

squares. The combined CBD and student effects reduced the among segment sum of squares to 52 percent of the corrected total sum of squares as shown in Table 6. Otherwise, the data demonstrated more than 90 percent of the variation was among the route-segments. In other words, the ridership pattern was rather consistent under a similar environment. There was almost no variation between days when only days 1 and 2 were examined. Therefore, it can be concluded that the data obtained for the MTA were not distorted because of any widespread variability in day-to-day trip activity.

Task 6. Determine transit service level

In demand analysis for the radial transit system, level of service was represented by frequency of service and travel time from the middle point of a route-segment to the central core. Frequency of service was measured in terms of number of trips provided for each route throughout the day. Travel time was measured in terms of scheduled bus time or auto travel time. Auto travel time was measured in terms of distance from the middle point of the route-segment to the central core under the assumption of constant travel speed. The distance was estimated by the researcher on the basis of distance using the arterial facilities rather than the airline distance. A distance contour map was prepared as shown in Figure 2.

Model Calibration

Among the state-of-the-art route-level patronage prediction techniques, the regression technique has 'better than average' characteristics in terms of sensitivity to decision variables, range of application, and analyst dependence (1). The primary objective of this research was to develop demand models to help local planners evaluate the impacts of transit routing and scheduling options. Several desirable characteristics of models were sought during the development process. The model should predict changes resulting from key modifications made by the system operator. The model should have no restrictions to certain parts of the urban area. All analysts should get the same results when applying the model; that is the predicted

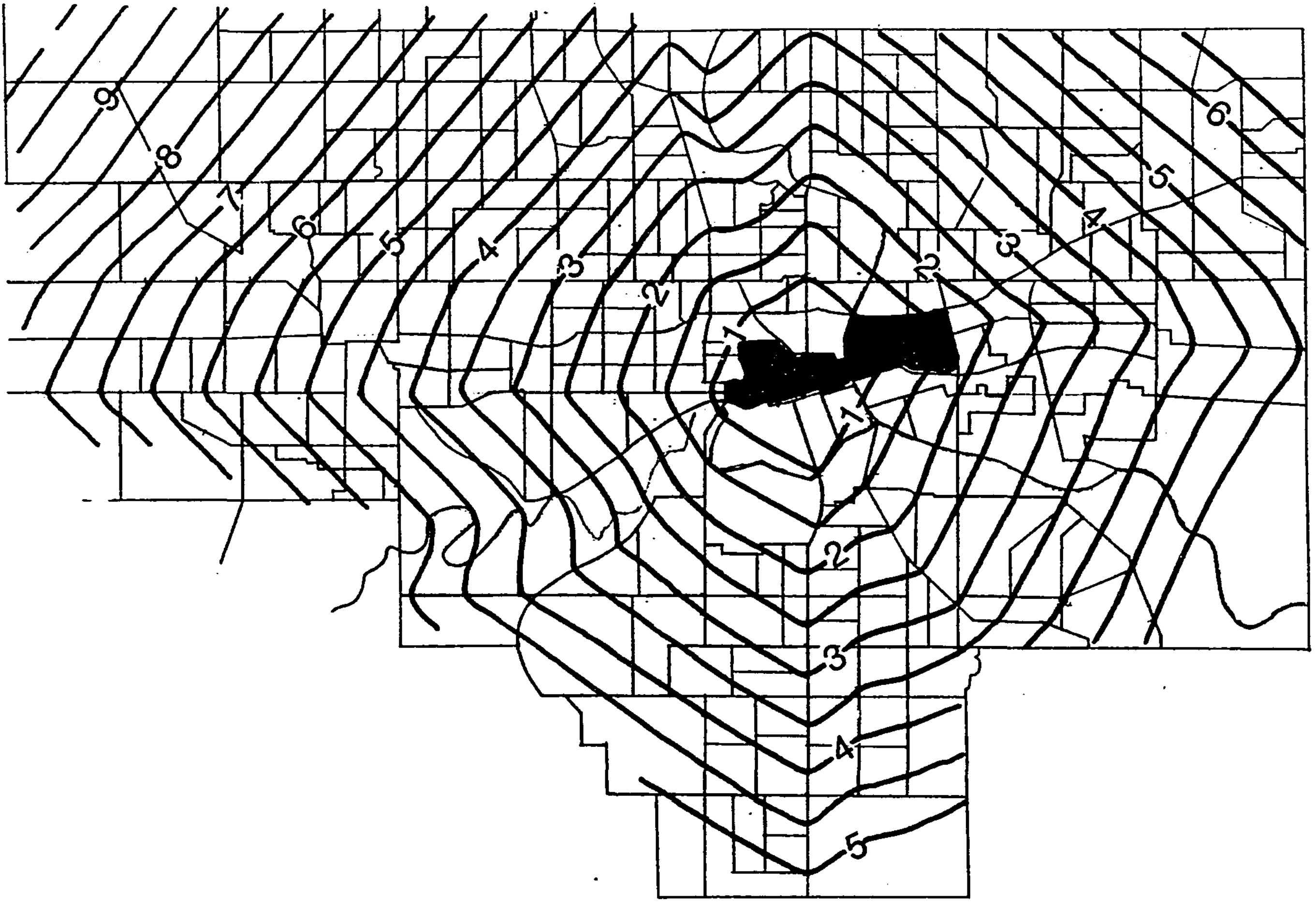


FIGURE 2. Auto travel distance (mile) to CBD

ridership should not depend on who is making the prediction. The analysis procedure should not require large new primary data sets.

Model variables

In trip generation analysis, trip rate was usually treated as a dependent variable. The trip rate was typically based on population for trip production or employment for trip attraction. However, the methodology used in this research to estimate route ridership was the use of a stiffness concept in structural analysis. The stiffness was more than a trip generation equation from an area. Its function was to simultaneously measure a trip generation and distribution effect by incorporating both production and attraction capabilities along a route.

The passenger density, stiffness, for each route-segment was used as a dependent variable. Since the service area for the bus route was defined as the area within 0.25 mile of the route, the passenger density can be represented by on-off-passengers per unit length (mile) of route-segment. Independent variables included population density, employment density, frequency of service, and travel time to the central core. However, it was difficult to identify the population density and the employment density for each CBD segment because of service area overlap. Also, service level for CBD segments was higher than that for non-CBD segments and most of the transfers occurred in the CBD. The sum of on-off-passengers at non-CBD segments for the route and the number of transfers to and from the route were used as independent variables for CBD segments. Table 7 provides a description of each of the variable acronyms and the unit of measurement.

TABLE 7. Variables considered in the models

Code	Variables
PASS	Passenger density, stiffness, for route i segment j; on-off-passengers per mile of route-segment
POP	Population density for route i segment j; number of persons per mile of route-segment
HS	Household density for route i segment j; number of households per mile of route-segment
SEN	Senior density for route i segment j; number of persons with age over 62 per mile of route-segment
FEM	Female density for route i segment j; number of females with age between 16 and 24 per mile of route-segment
EMP	Employment density for route i segment j; number of equivalent employees per mile of route-segment
TRIP	Frequency of service for route i segment j; number of trips per day (weekday)
TIME	Scheduled bus travel time from the middle point of route i segment j to the central core (minute)
DIS	Auto travel distance from the middle point of route i segment j to the central core (mile)
CBD[a]	On-off-passengers at CBD segment for route i
NON[a]	Sum of on-off-passengers at non-CBD segments
TRF[a]	Number of tranfers to and from the route

[a] Variables CBD, NON, and TRF were used for CBD segments; others for non-CBD segments.

Model forms

Multiple regression techniques were used to determine the best fit between a dependent variable (response variable) and one or more independent variables (predictor variables). The linear model (i.e. linear in the parameters to be estimated) is the form most commonly used. The first-order model with one predictor variable is the simplest linear model. Other linear models involve various orders in the predictor variables, and transformations on the predictor variables, or transformations on the response variable, or both.

Nonlinear models can be divided into two types, intrinsically linear and intrinsically nonlinear models (15). If a model is intrinsically linear it can be expressed, by suitable transformation of the variables, in the standard linear model form. If a nonlinear model can not be expressed in this form then it is intrinsically nonlinear, or simply 'nonlinear'.

The interest of this research was to develop demand models as simple as possible so that models can be used and also reproduced comfortably by transit planners. However, more complicated models such as the multiplicative model were also examined. The multiplicative model can be converted into linear form by taking logarithms. The logarithmic transformation allows planners to specify equations which can be better behaved (e.g. they can not predict negative ridership) and which may have more reasonable relationships than the simple linear form. Another advantage for the multiplicative model is that the exponent or power of each independent variable is the elasticity of that decision variable. For example, the coefficient 'x' on frequency indicates that a 1 percent increase in frequency will result in an 'x' percent increase in passenger density, the stiffness.

Demand models

As mentioned earlier in this chapter, the CBD segments were treated separately and three income levels were considered for model calibration. Table 8 provides a summary of the number of observations for each subgroup. It should be noted that there were only five route-segments in the high income level which was considered inadequate for multiple regression having more than three predictor variables. Middle income level and high income level were then combined as one income level. Two income levels, average household income less than $10,000 and average household income greater than $10,000, were used for regression models.

TABLE 8. Sample sizes for the statistical summaries

CBD	Income level Low (<10,000)	Middle (10,000-25,000)	High (>25,000)	Total
18[a]	11	76	5	110

[a] Number of route-segments.

In this section, a number of models are examined. However, only the R-square statistic was used for comparison at this stage. Other statistics are discussed in the succeeding sections for the preferred models.

Tables 9 and 10 present the variables and summary statistics for two income levels using the first-order linear model and the multiplicative model, respectively. Model I allowed all the variables to enter the model. Model II forced out the most significant population variable (HS) in order to show the second significant population variable. Models III and IV allowed consideration only of one population variable (HS), and one travel time variable (TIME or DIS), and employment density (EMP), and frequency of service (TRIP). The reason for using the variable DIS, auto travel distance, was that the scheduled bus travel time (TIME) is not available when new transit services are considered.

Second-order models were used to evaluate some unknown characteristics which may not be shown in the first-order models. Tables 11 and 12 present the variables and summary statistics using the second-order linear model for average household income greater than $10,000 and less than $10,000, respectively. Model I was a full second-order model with four independent variables. Model II left out the square terms from Model I. Model III left out the cross-product terms from model I. Model IV allowed all the second-order terms to enter the model. Models V through VII allowed only the first-order terms, or square terms, or cross-product terms to enter the model, respectively.

Table 13 presents the variables and summary statistics using both

TABLE 9. Summary of regression analysis using the first-order linear form[a]

	Income > 10,000 (N=81)				Income < 10,000 (N=11)			
Variables	Model I	Model II	Model III	Model IV	Model I	Model II	Model III	Model IV
POP	X[b]	X			X	X		
HS	X(3)[c]		X(3)	X(3)	X		X	X
SEN	X	X(3)			X	X		
FEM	X	X			X	X		
EMP	X(2)	X(2)	X(2)	X(2)	X(2)	X(2)	X(2)	X(2)
TRIP	X(1)	X(1)	X(1)	X(1)	X(1)	X(1)	X(1)	X(1)
TIME	X(4)	X(4)	X(4)		X	X	X	
DIS	X	X		X(4)	X	X		X
R-square	0.834	0.809	0.834	0.826	0.952	0.952	0.952	0.952

[a] Regression model $Y = a + b_1X_1 + b_2X_2 + \ldots + b_nX_n$.

[b] Each X identifies a variable allowed to enter the model.

[c] All numbered variables were significant at the .05 level. Numbers in parentheses represent the order of entry into the model using the STEPWISE procedure.

TABLE 10. Summary of regression analysis using the multiplicative model[a]

Variables	Income > 10,000 (N=81)				Income < 10,000 (N=11)			
	Model I	Model II	Model III	Model IV	Model I	Model II	Model III	Model IV
LOG(POP)	X[b]	X(4)			X	X		
LOG(HS)	X(4)[c]		X(3)	X(4)	X		X	X
LOG(SEN)	X	X			X	X		
LOG(FEM)	X	X			X	X		
LOG(EMP)	X(3)	X(3)	X(4)	X(3)	X	X	X	X
LOG(TRIP)	X(1)	X(1)	X(1)	X(1)	X(1)	X(1)	X(1)	X(1)
LOG(TIME)	X	X	X(2)		X	X	X	
LOG(DIS)	X(2)	X(2)		X(2)	X	X		X
R-square	0.875	0.870	0.877	0.875	0.672	0.672	0.672	0.672

---

[a] Regression model $Y = aX_1^{b1}X_2^{b2} \ldots X_n^{bn}$ or

$$\ln(Y) = \ln(a) + b_1\ln(X_1) + b_2\ln(X_2) + \ldots + b_n\ln(X_n)$$

[b] Each X identifies a variable allowed to enter the model.

[c] All numbered variables were significant at the .05 level. Numbers in parentheses represent the order of entry into the model using the STEPWISE procedure.

TABLE 11. Summary of regression analysis using the second-order linear form [a] (Income>10,000)

	Income > 10,000 (N=81)						
Variables	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
(TRIP)	X[b]	X	X(5)		X(1)		
(HS)	X	X	X		X(3)		
(EMP)	X	X	X(3)		X(2)		
(TIME)	X	X	X(4)		X(4)		
(TRIP)(TRIP)	X		X(1)	X			X(1)
(HS)(HS)	X		X(2)	X			X(2)
(EMP)(EMP)	X(4)[c]		X(6)	X(4)			X(3)
(TIME)(TIME)	X		X	X			X(4)
(TRIP)(HS)	X(1)	X(1)		X(1)		X(1)	
(TRIP)(EMP)	X(2)	X(2)		X(2)		X(2)	
(TRIP)(TIME)	X	X		X		X	
(HS)(EMP)	X	X		X		X	
(HS)(TIME)	X(3)	X(3)		X(3)		X(3)	
(EMP)(TIME)	X(5)	X		X(5)		X	
R-square	0.866	0.847	0.885	0.866	0.834	0.847	0.815

[a] Second-order model with four independent variables.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 +$$

$$b_{12}X_{12} + b_{13}X_{13} + b_{14}X_{14} + b_{23}X_{23} + b_{24}X_{24} + b_{34}X_{34}$$

[b] Each X identifies a variable allowed to enter the model.

[c] All numbered variables were significant at the .05 level. Numbers in parentheses represent the order of entry into the model using the STEPWISE procedure.

TABLE 12. Summary of regression analysis using the second-order linear form[a] (Income<10,000)

Variables	Income < 10,000 (N=11)						
	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
(TRIP)	X[b]	X	X(3)		X(1)		
(HS)	X	X	X		X		
(EMP)	X	X	X		X(2)		
(TIME)	X	X(2)	X		X		
(TRIP)(TRIP)	X		X(1)	X			X(1)
(HS)(HS)	X		X	X			X
(EMP)(EMP)	X		X(2)	X			X(2)
(TIME)(TIME)	X(2)[c]		X	X(2)			X
(TRIP)(HS)	X	X		X		X	
(TRIP)(EMP)	X(3)	X(3)		X(3)		X	
(TRIP)(TIME)	X(1)	X(1)		X(1)		X(1)	
(HS)(EMP)	X	X		X		X	
(HS)(TIME)	X	X		X		X(2)	
(EMP)(TIME)	X	X		X		X	
R-Square	0.986	0.987	0.986	0.986	0.952	0.946	0.969

[a] Second-order model with four independent variables.

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 +$$

$$b_{12}X_{12} + b_{13}X_{13} + b_{14}X_{14} + b_{23}X_{23} + b_{24}X_{24} + b_{34}X_{34}$$

[b] Each X identifies a variable allowed to enter the model.

[c] All numbered variables were significant at the .05 level. Numbers in parentheses represent the order of entry into the model using the STEPWISE procedure.

TABLE 13. Summary of regression analysis for CBD segments

Linear Model					Multiplicative model				
	N=18[a]		N=9			N=18		N=9	
Variables	Model I	Model II	Model III	Model IV	Variables	Model I	Model II	Model III	Model IV
TRF	X[b]	X**	X**		LOG(TRF)	X	X**	X**	
NON	X**[c]		X	X**	LOG(NON)	X**		X	X**
R-square	0.806	0.698	0.940	0.881	R-square	0.888	0.795	0.969	0.960

[a] The MTA operates nine (9) routes; each route has two interlocked legs which extend into separate areas of town (18 legs).

[b] Each X identifies a variable allowed to enter the model.

[c] The variable with asterisks was significant at the 0.05 level.

the first-order linear model and the multiplicative model for CBD segments. It should be noted that only two variables were considered here. Models I and II were developed by using data from the 'legs' of the MTA routes. The MTA operated nine fixed routes and each route had two interlocked legs which extended into separate areas of town. Some passengers who alight from one CBD leg may get on board a bus from the other CBD leg and vice versa. The between leg variation was expected to be higher than the between route (two interlocked legs) variation. Models III and IV were developed by using 'route' data (N=9) to show the differences.

Average household income greater than $10,000 As shown in Tables 9 and 10, frequency of service (TRIP) was the most important variable for both the first-order linear models and the multiplicative models. Model I indicated that household density (HS) appeared to be the most significant population variable and Model II showed that senior person density (SEN) and population density (POP) appeared to be the next significant 'population' variables for the first-order linear model and the multiplicative model, respectively. The correlation matrix obtained from the Statistical Analysis System (SAS) indicated high correlations among variables POP, HS, SEN, and FEM (females 16 to 24) as shown in Table 14. However, because of the high correlations, the potential problem of multicollinearity should be taken into account. Once variable HS entered the model, variables POP, SEN, and FEM have the least chance of entering the model. Employment density (EMP) and travel time (TIME or DIS) were the second variables of entry into the first-order linear models and the multiplicative models, respectively, as shown in Tables 9 and 10. This means that high employment density of the segment and short travel time from the segment to the CBD accounted for increased transit use in the segment. Note that Models III and IV that the use of scheduled bus travel time (TIME) or auto travel distance (DIS) were not significantly different. This allows the planner to evaluate existing as well as new transit services. The multiplicative model produced a somewhat higher R-square value (0.88) than the first-order linear model did (0.83).

TABLE 14. Correlation coefficients among population variables

Variables	POP	HS	SEN	FEM
POP	1.000	0.967	0.640	0.701
HS	0.967	1.000	0.727	0.627
SEN	0.640	0.727	1.000	0.268
FEM	0.701	0.627	0.268	1.000

Table 11 presents the variables and summary statistics using the second-order linear form. The cross-product terms (Models I, II, IV, and VI) appeared to be the most important variables. However, there were problems of collinearity. The combination of first-order terms and square terms (Model III) provided the highest R-square value (0.89). Model VII, square terms only, provided the lowest R-square value (0.82).

Average household income less than $10,000 From Tables 9 and 10, frequency of service (TRIP) was again the most important variable for both the first-order linear models and the multiplicative models. Employment density (EMP) was the only other significant variable for the first-order linear models (Models I through IV). In the multiplicative models, frequency of service (TRIP) was the only significant variable. Since the first-order linear model had two predictor variables, it produced a much higher R-square value (0.95) than the multiplicative model (0.67).

Table 12 presents the variables and summary statistics using the second-order linear form. The combination of any two of the first-order terms, square terms, and cross-product terms (Models I through IV) produced the same R-square value (0.99). Among Models V through VII, including only first-order terms, or square terms, or cross-product terms, Model VII had the highest R-square value (0.97). However, recall that this data set has only 11 observations.

Central Business District (CBD) As shown in Table 13, the multiplicative models provide better results than the linear models. The 'route' data (N=9) provided higher R-square values than the 'leg' data (N=18). In these CBD models the loading activity outside the CBD (NON) explained more variation than the transfer variable (TRF) using 'leg' data, whereas variable TRF explained more variation than variable NON using 'route' data. Therefore, the multiplicative model using the 'route' data and the transfer variable (TRF) was preferred. It produced an R-square value of 0.97.

Summary of models The regression models were valuable for sorting through the many eligible explanatory variables regarding transit ridership. Frequency of service (number of trips per day) was always found to be more useful in determining the passenger density than population, or employment, or travel variables.

Population density, employment density, frequency of service, and travel time were significant variables for non-CBD segments having an average household income greater than $10,000. Household density appeared to be the best among the 'population' variables. Either scheduled bus travel time or auto travel distance had nearly the same contribution to the regression models.

Although the second-order linear form provided the highest R-square value compared with the first-order linear form and the multiplicative model for all non-CBD segments, it was difficult to interpret when elasticity analysis is involved. The first-order linear models had slightly less capability in explaining variations than did the multiplicative models for average household income greater than $10,000. However, the first-order linear model has the simplest mathematical form for ridership estimation. In consideration of both elasticity analysis and variation explanation, the multiplicative model appeared to be the best and will be given more attention in the later discussion.

For non-CBD segments having an average household income less than $10,000, only one variable, frequency of service, was found to be significant in the multiplicative model with an R-square value of 0.67. One would definitely favor the first-order linear model which had two significant predictor variables, frequency of service and employment density, with an R-square value of 0.95.

Either variable TRF or variable NON was significant depending upon whether the analyst used 'route' data or 'leg' data for CBD-segments. The multiplicative models explained more variation than did the linear models. The best model was the multiplicative model using the 'route' data and the transfer variable (TRF) with an R-square value of 0.97. Table 15 presents the summary of regression models for ridership estimation.

TABLE 15. Summary of regression models for ridership estimation

Regression models	R-square
Average household income greater than \$10,000 (N=81)	
$Y = 0.217(\mathrm{TRIP})^{1.09}(\mathrm{HS})^{0.299}(\mathrm{EMP})^{0.126}(\mathrm{DIS})^{-0.456}$	0.875
$Y = 0.407(\mathrm{TRIP})^{1.09}(\mathrm{HS})^{0.324}(\mathrm{EMP})^{0.127}(\mathrm{TIME})^{-0.498}$	0.877
Average household income less than \$10,000 (N=11)	
$Y = -140.6+6.43(\mathrm{TRIP})+0.0328(\mathrm{EMP})$	0.952
Central Business District (N=9)	
$Y = 3.2\ (\mathrm{TRF})^{1.02}$	0.969
$Y = 2.5\ (\mathrm{NON})^{0.85}$	0.960

Examination of residuals

In the previous section, only the R-square statistic was used for model comparison. This section examines the residuals. The residuals are defined as the n differences $e_i=Y_i-\hat{Y}_i$, $i=1,2,\ldots,n$ where Y_i is an observation and $\hat{Y}_i$ is the corresponding fitted value obtained by use of the fitted regression equation. In performing the regression analysis, certain assumptions have been made about the residuals. The usual assumptions are that the residuals are independent, have zero mean, a constant variance and follow a normal distribution. If the fitted model is correct, the residuals should exhibit tendencies that tend to confirm the assumptions, or at least, should not exhibit a denial of the assumptions.

There are ways of examining the residuals in order to check the model. Most of these are graphic and are usually very revealing when the assumptions are violated. The principal ways of plotting the residuals are (1) overall plot, (2) plot against the fitted values, (3) plot against the independent variables, and (4) normal plot. On the basis of the data used for this research, an overall impression of a horizontal band of residuals was regarded as satisfactory. The unit normal deviate form and normal plot of the residuals were examined to check for outliers. The quantity e_i/s (e_i=residual, s=square root of residual mean square) is often called the unit normal deviate form of the residual e_i. The normal plot is often used to check on the normality. Figure 3 shows a normal plot of the residuals. The points fall, approximately, on a straight line. There were six data points

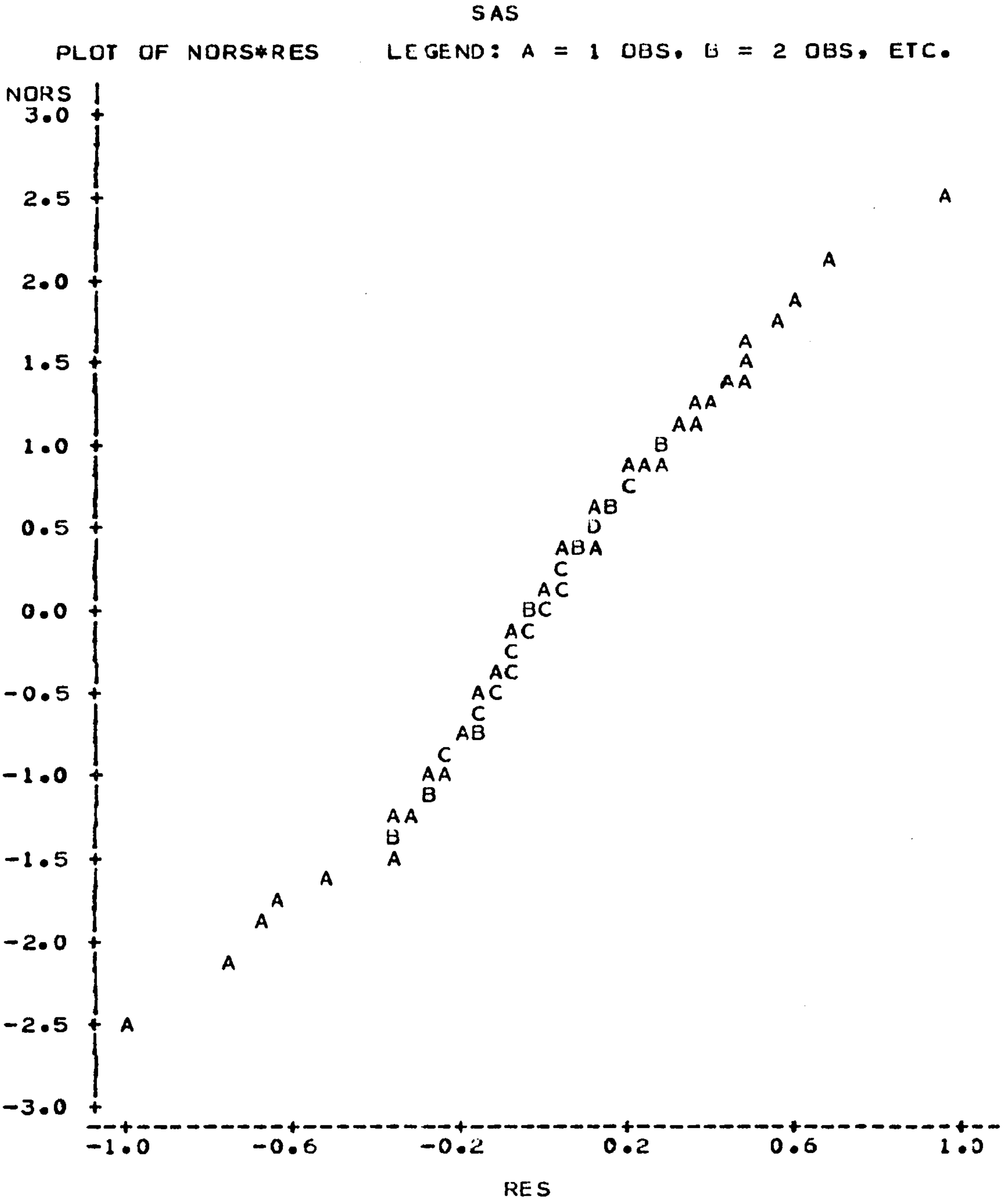


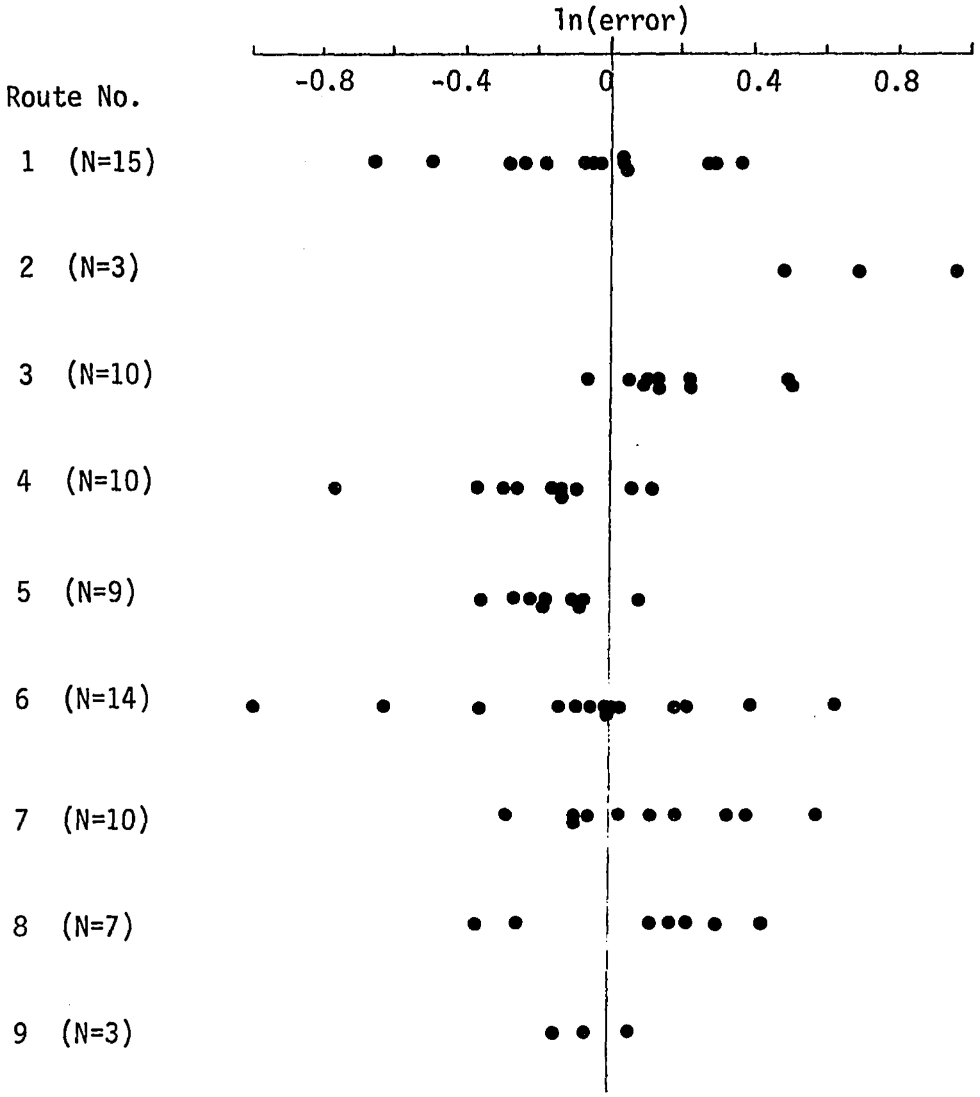
FIGURE 3. Normal plot of the residuals

which were not at all typical of the rest of the data. However, there was no strong reason to say that the assumptions were incorrect.

Figure 4 shows a residual plot against routes indicating block effects for average household income greater than $10,000. There was tendency to over or under estimate for some routes. This suggested that there was a basic difference in level of response. Routes 1, 6, 8, and 9, route 2, routes 3 and 7, and routes 4 and 5 were considered as distinct levels. The estimates for routes 1, 6, 8, and 9 were considered as satisfactory. Route 2 was considered to be underestimated drastically whereas routes 3 and 7 were considered to be underestimated moderately. Routes 4 and 5 were overestimated. Such a difference could be incorporated into the model by the introduction of dummy variables.

Dummy variables

The tendency to over or under estimate has not been explained by any of the variables being examined. Pivot-point method of adjustment has been used by others to improve prediction (16). It is a procedure for adjusting a forecast so that it does not contain the residual between the estimated and actual observation, which is contained in the calibrated model. The pivot-point adjustment factors which are determined from the base year data are then used to adjust forecast year estimates. In this research, the observation unit is route-segment and one is interested in estimating the transit demand in route level. Rather than using pivot-point analysis which would establish a fixed adjustment factor for each route-segment, dummy variables were used to adjust the route level. Calibration of a model incorporating dummy



Model $\ln(Y) = -0.898+1.09*\ln(TRIP)+0.324*\ln(HS)+0.127*\ln(EMP)$
$-0.498*\ln(TIME)+\ln(error)$

FIGURE 4. Residuals plot against routes indicating block effects

variables recognizes that there is a random error component in the adjustment, not just a fixed pivot-point constant for each route-segment. Dummy variables which adjust the residual in route level were used.

The variables considered in regression equations usually can take values over some continuous range. Occasionally, one must introduce a factor which has two or more distinct levels. One must assign to these variables some levels in order to take account of the fact that the various routes may have separate deterministic effects on the response.

In general, one can deal with (r) levels by the introduction of (r-1) dummy variables. However, there is no unique way of choosing dummy variables for a given regression situation and, in most situations, there are many possible representations. The dummy variable scheme for this research is shown in Table 16.

TABLE 16. Dummy variable scheme

Group	Route(s)	Dummy variables D1	D2	D3
1	1, 6, 8, 9	0	0	0
2	2	1	0	0
3	3, 7	0	1	0
4	4, 5	0	0	1

By using the dummy variables, regression models were developed for non-CBD segments having an average household income greater than $10,000 as shown in Table 17. In the regression models, KA and KB are the adjustment factors at route level. Either KA or KB is used depending upon whether the regression model includes variable DIS (auto travel distance) or variable TIME (scheduled bus travel time). Except for dummy variable D2 which indicates the block effects of routes 3 and 7, all other variables were significant at the 0.05 level. The significant levels of dummy variable D2 were 0.06 and 0.08 for regression models using variable DIS (auto travel distance) and variable TIME (scheduled bus travel time), respectively. The adjustment factors which indicate block effects for four route groups are shown in Table 18.

TABLE 17. Regression models including dummy variables

Regression models	R-square
Average household income greater than $10,000 (N=81)	
$Y = 0.166(KA)(TRIP)^{1.19}(HS)^{0.278}(EMP)^{0.113}(DIS)^{-0.423}$	0.913
where KA=EXP(0.773(D1)+0.16(D2)-0.172(D3)) D1, D2, D3 are dummy variables	
$Y = 0.310(KB)(TRIP)^{1.21}(HS)^{0.298}(EMP)^{0.112}(TIME)^{-0.485}$	0.920
where KB=EXP(0.859(D1)+0.142(D2)-D.184(D3)) D1, D2, D3 are dummy variables	

One can note that route 2 has an adjustment factor which is greater

TABLE 18. Adjustment factors for block effects

Group	Route(s)	Adjustment factors[a] KA	 KB
1	1, 6, 8, 9	1.00	1.00
2	2	2.17	2.36
3	3, 7	1.17	1.15
4	4, 5	0.84	0.83

[a] Either KA or KB is used depending upon whether the regression model includes variable DIS (auto travel distance) or variable TIME (scheduled bus travel time).

than 2.0. This means that the fitted models, without using dummy variables, estimated less than half of the actual ridership for route 2. Possible reasons for the errors include that route 2 has the lowest frequency of service and is the shortest route in the system. Although frequency and distance effects are allowed in the model, these variables alone could not account for the uniquely lower ridership on this route.

Model Results

In the previous section, regression models were developed for estimating weekday ridership on the fixed-routes of the Des Moines Metropolitan Transit Authority (MTA). Route-segment stiffness, the passenger density, was estimated for all route-segments outside the central business district (CBD). The non-CBD segments were divided into two groups based upon the average household income of the segment. Population density, employment density, frequency of service, and travel time or distance were used to estimate the route-segment stiffness for non-CBD segments having an average household income greater than \$10,000. When a new route was evaluated, the auto travel distance was used because there was no scheduled bus travel time. Adjustment factors were used to account for residuals at route level. For non-CBD segments having an average household income less than \$10,000, employment density and frequency of service were used to estimate the route-segment stiffness. The CBD ridership was then estimated by the correlation of either the non-CBD ridership of the route or the number of transfers to and from the route. In this section, graphic representations of the models and model testing are presented.

Graphic representation

In order to provide a quick response analysis tool, the mathematical models are presented in a graphic way. The advantage of the graphic representation is that, once the chart has been properly constructed, computations based upon its use can be made by a person having relatively little mathematical training. When an equation has more than three variables, a parallel-scale alignment chart has been constructed to satisfy the equation.

Average household income greater than \$10,000 The independent variables to estimate the passenger density for non-CBD segments having an average household income greater than \$10,000 were divided into three parts, e.g., $Y=[A][B][C] =[KA][0.166(DIS)^{-0.423}][(TRIP)^{1.19}(HS)^{0.278}$

$(EMP)^{0.113}]$. 'Y' is the passenger density for route-segment measured by the number of on-off-passengers per mile of route. 'A' is the adjustment factor, KA or KB, which accounted for route effects; it was developed by using the dummy variables for the existing routes. For new transit route services, the adjustment factor 1.0 was used. The adjustment factors are shown in Table 18 in the previous section. 'B' is the product of the constant term (or intercept) and the travel time factor and is dependent upon whether variable DIS (auto travel distance) or variable TIME (scheduled bus travel time) is used. The value of 'B' for each route-segment was obtained from Figure 5. 'C' is the product of three factors which are frequency of service (TRIP), population density (HS), and employment density (EMP). A parallel-scale alignment chart was constructed to obtain the value of 'C' as shown in Figure 6. The procedure for developing the chart may be found in a fundamental engineering graphic textbook (17).

Average household income less than $10,000 The regression model to estimate the passenger density for non-CBD segments having an average household income less than $10,000 was linear with two independent variables. The variables were frequency of service (TRIP) and employment density (EMP). A family of straight lines which represent various frequency of service was developed as shown in Figure 7.

Central Business District (CBD) Figure 8 shows the correlation among the non-CBD ridership, the CBD ridership, and the transfers. One should note that the unit of all variables here was not passenger density, rather, it was the number of on-off-passengers or number of

DIS = auto travel distance from the middle point of the route segment to the central core

TIME = scheduled bus travel time from the middle point of the route segment to the central core

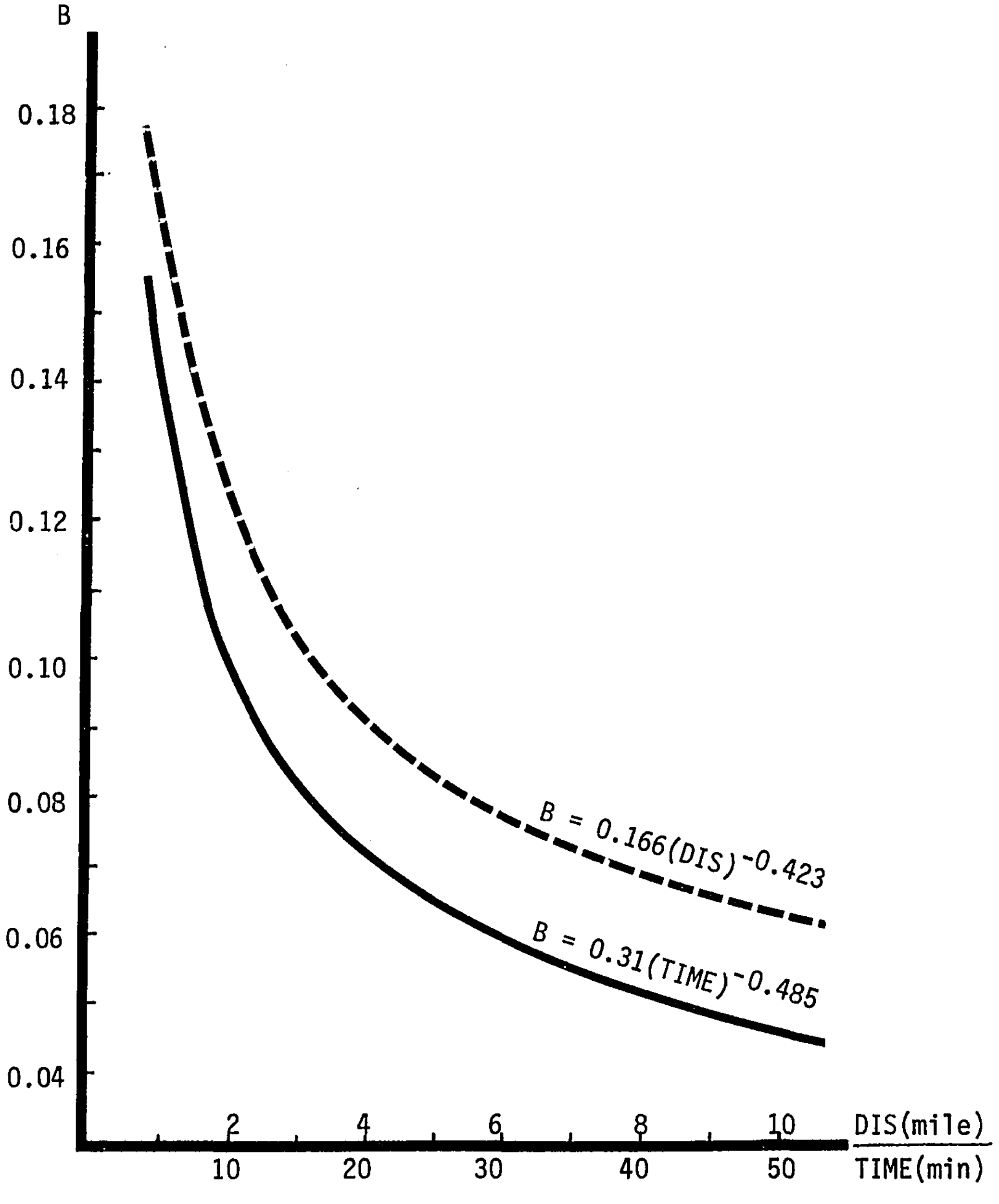


FIGURE 5. Travel time factor

$$C = (TRIP)^{1.2}(HS)^{0.29}(EMP)^{0.11}$$

TRIP = frequency of service (number of trips)
HS = population density (number of households per mile of route)
EMP = employment density (number of employees per mile of route)

Steps in solution :

(1) Draw a line from EMP value to HS value intersecting Turning Line.
(2) Draw a line from Step 1 intersection of Turning Line to TRIP value. The intersection point of this line with the Solution Line is "C" value.

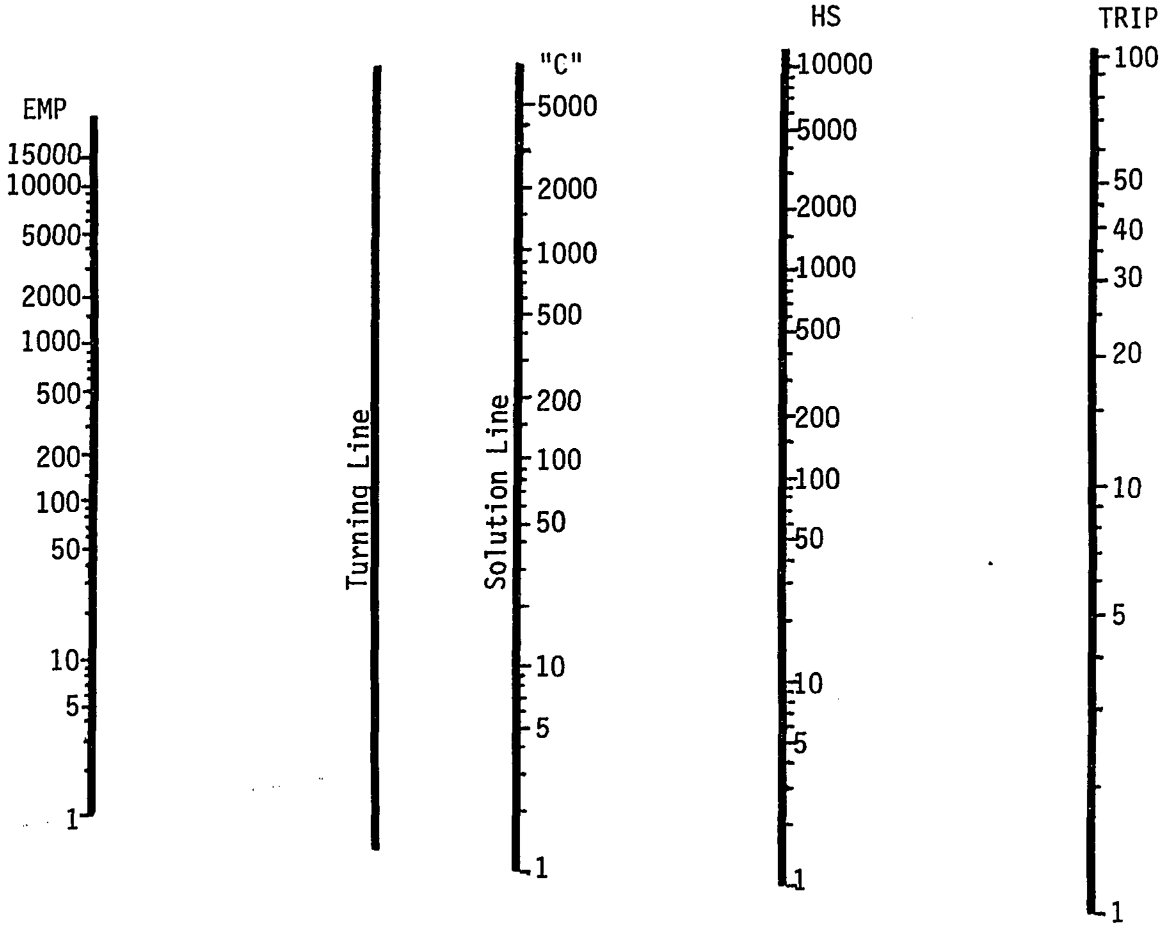


FIGURE 6. A parallel-scale alignment chart for variables TRIP, HS, and EMP

$Y = -140.6+6.63(TRIP)+0.0328(EMP)$

Y = passenger density
(number of on-off-passengers per mile of route)
TRIP = frequency of service
(number of trips)
EMP = employment density
(number of employees per mile of route)

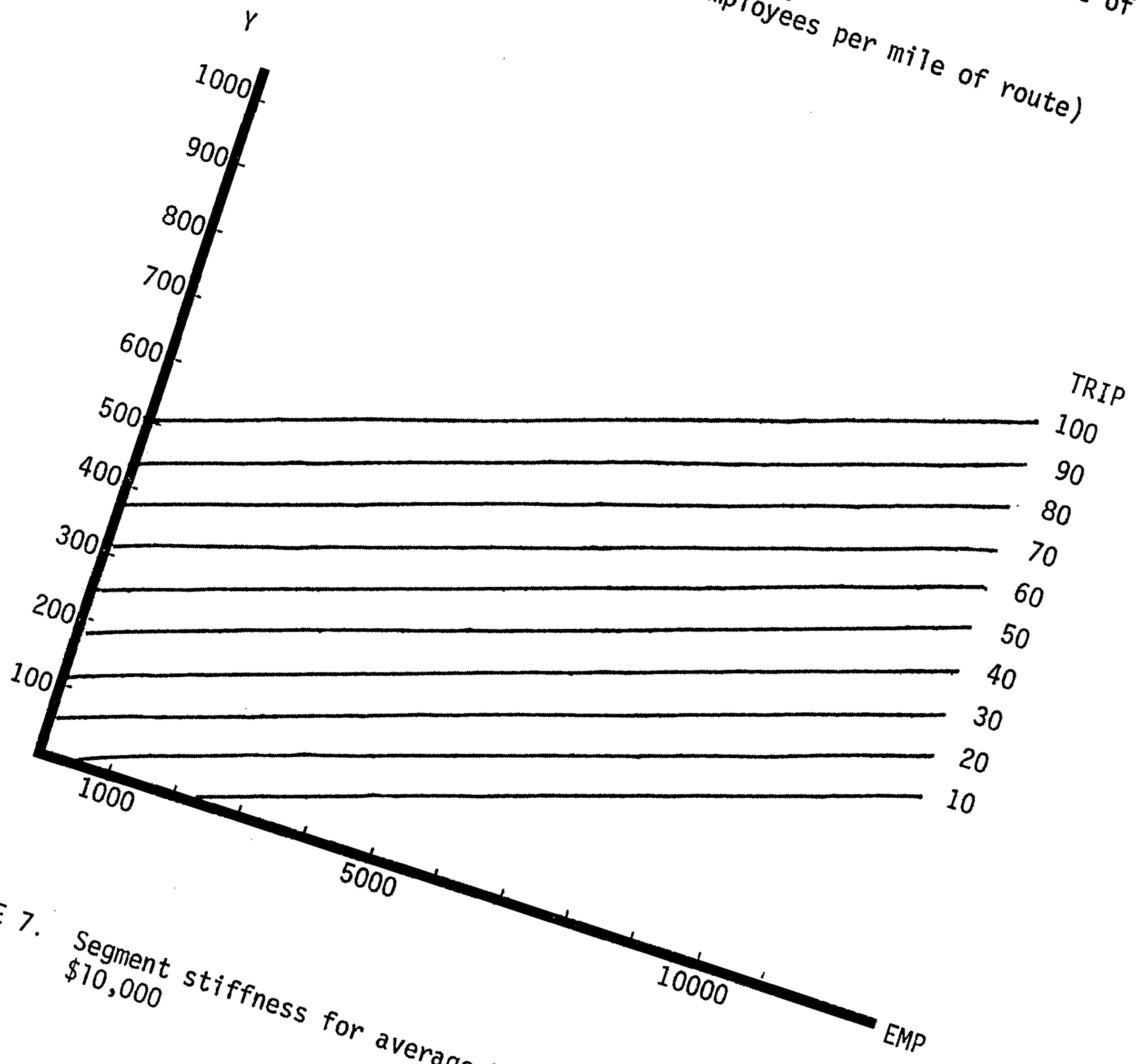


FIGURE 7. Segment stiffness for average household income less than $10,000

CBD = number of on-off-passengers in the CBD
NON = total number of on-off-passengers in the
non-CBD segments
TRF = number of transfers to and from the route

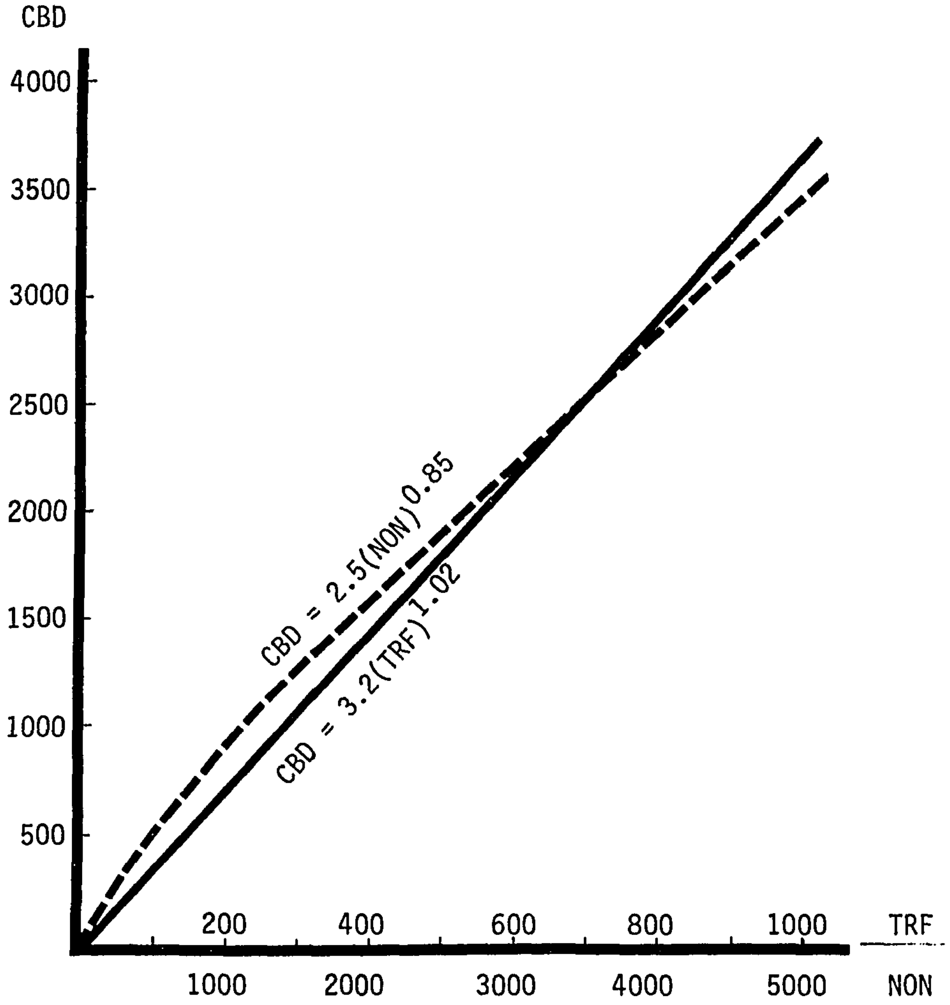


FIGURE 8. Correlation among non-CBD ridership, CBD ridership and transfers

transfers. Once the non-CBD ridership had been estimated, the CBD ridership and the transfers were predicted by using Figure 8. For example, one estimated that there were 5,000 on-off-passengers in the non-CBD segments for route 'x'. One would predict that there were 3,500 on-off-passengers in the CBD segment for route 'x' and 950 transfers from and to route 'x'. This also shows that the CBD ridership was approximately 70 percent of the non-CBD ridership and the transfers were approximately 11 (950/(5000+3500)) percent of the total ridership for MTA fixed-routes on weekdays.

Model testing

Recall that the observation unit used for regression analysis was route-segment and the number of observations is 110. The unit normal deviate form and normal plot of the residuals were examined to check for outliers in the previous section. There were six data points which were not at all typical of the rest of the data. However, there was no strong reason to say that the fitted models were incorrect.

For the route-level, Table 19 indicates the actual and the model predicted weekday on-off-passengers for MTA fixed-routes. Except for route 2 which had an error of 16.5 percent, all other routes have produced predictions for an error of 10 percent or less. Four (routes 3, 4, 7, and 8) of a total of nine routes had an error of 3 percent or less.

This level of accuracy for the aggregation of the routes was felt to be satisfactory. It was recognized that part of the reason for the close fit was due to the adjustments made using the dummy variables.

TABLE 19. Actual and predicted weekday on-off-passengers for MTA fixed routes

Route	Income > 10,000		Income < 10,000		CBD		Total	
	Actual	Predict	Actual	Predict	Actual	Predict	Actual	Predict
West Des Moines/	3,363	3,483	---	---	3,319	2,505	6,682	5,988
Fairgrounds	(N=15)		(N=0)		(N=1)		(N=16)	
Crocker/	215	211	190	100	464	414	869	725
Scott	(N=3)		(N=4)		(N=1)		(N=8)	
University/	2,885	2,797	1,347	1,221	2,766	3,046	6,998	7,064
Highland - Oak Park	(N=10)		(N=3)		(N=1)		(N=14)	
East 14th/	1,916	1,873	239	307	2,088	1,715	4,243	3,895
Urbandale	(N-10)		(N=1)		(N=1)		(N=12)	
East 6th & 9th/	2,314	2,253	---	---	1,702	1,822	4,016	4,075
Clark	(N=9)		(N=0)		(N=1)		(N=10)	
West 9th - Douglas/	2,711	2,683	299	367	1,892	2,279	4,902	5,329
Indianola - Lacona	(N=14)		(N=1)		(N=1)		(N=16)	
Fort Des Moines/	3,548	3,540	---	---	2,582	2,621	6,130	6,161
Walker	(N=10)		(N=0)		(N=1)		(N=11)	
SW 14th - Havens	789	672	---	---	568	729	1,357	1,401
South Union	(N=7)		(N=0)		(N=1)		(N=8)	
Park Ave. West/	271	263	22	77	321	324	614	664
Park Ave. East	(N=3)		(N=2)		(N=1)		(N=6)	
Total	18,012	17,775	2,097	2,072	15,702	15,455	35,811	35,302
	(N=81)		(N=11)		(N=9)		(N=101)	

The dummy variables were used to adjust for differences in route ridership that could not be explained by the various models. Perhaps if more information on travel pattern were available the ridership behavior of the residents could be modeled better. However, by using this dummy variable we recognized that in certain routes we were over or under-predicting in the base data and if we made short-run changes we would expect this same type of over or under-prediction to occur if we did not make an effort to adjust. The purpose of the dummy variable was to consider these basic model deficiencies and adjust for them.

In this chapter, the models discussed were used for evaluating total day route performance. They were provided to show the general development. It was recognized that there was a time of day variation which will be discussed in the later chapter.

CHAPTER IV. SYSTEM OPTIMIZATION

Route-segment stiffness and route stiffness were developed in the last chapter. The model demonstrated the capability of predicting the ridership for each transit route. In this chapter, a linear programming model is used to optimize the transit route on the basis of the demand and system constraints. The objective is to maximize the ridership in the system. The constraints include budget restriction, fuel supply, service policy, performance standards, and others. The stiffness parameter, which indicates the route demand potential, is used as a prime factor to allocate the limited resources among competing transit routes in the optimal way. By establishing a uniform procedure, it would be possible to evaluate the transit service and to assess the impacts of alternative constraints or policies.

Linear Programming Model

A linear programming (LP) mathematical model was used to describe the general problem of allocating resources to activities. The standard LP form consists of two major parts. They are the objective function and constraints which were described as shown in Table 20. The function being optimized is called the objective function. The restrictions are referred to as constraints.

Objective function

The objective function is the weighted sum of the decision variables. In this research, the weight was the route stiffness, which

TABLE 20. Linear programming model for system optimization

Objective function

$$\text{Max. } Z = \sum_{i=1}^{n} (K_{ip}X_{ip}+K_{im}X_{im}+K_{ie}X_{ie})$$

Constraints

$$\sum_{i=1}^{n} (C_{ip}X_{ip}+C_{im}X_{im}+C_{ie}X_{ie}) \leq C$$

$$\sum_{i=1}^{n} (F_{ip}X_{ip}+F_{im}X_{im}+F_{ie}X_{ie}) \leq F$$

$$X_{ip} \geq L_{ip};\ X_{im} \geq L_{im};\ X_{ie} \geq L_{ie}$$

$$X_{ip} \leq U_{ip};\ X_{im} \leq U_{ip};\ X_{ie} \leq U_{ie}$$

$$\sum_{i=1}^{n} (R_{ip}K_{ip}X_{ip}+R_{im}K_{im}X_{im}+R_{ie}K_{ie}X_{ie}) \geq R$$

Description of the variables

Z = ridership (on-off-passengers)
n = number of transit lines
K_{ip},K_{im},K_{ie} = route stiffness (on-off-passengers per bus mile) for line i and time of day (p = peak, m = midday, e = evening)
X_{ip},X_{im},X_{ie} = bus-miles of service provided for line i and time of day
C_{ip},C_{im},C_{ie} = costs (dollars per bus-mile) for line i and time of day
F_{ip},F_{im},F_{ie} = fuel consumption rate (gallons per bus-mile) for line i and time of day
L_{ip},L_{im},L_{ie} = minimum service level (bus-miles) for line i and time of day
U_{ip},U_{im},U_{ie} = maximum service level (bus-miles) for line i and time of day
R_{ip},R_{im},R_{ie} = fare revenue (dollars per on-off-passenger) for line i and time of day
C = total costs (dollars)
F = fuel supply (gallons)
R = total fare revenue (dollars)

was the number of on-off-passengers per bus-mile. The decision variables were the route service levels, which were measured by the number of bus-miles. The objective was to maximize the ridership in the system.

Constraints

There are functional constraints and nonnegativity constraints. In a LP problem, the functional constraints may be either equalities or inequalities. The constraints included budget restriction, fuel supply, minimum and maximun service levels, performance standards, and others.

Budget restriction This constraint ensured that capital and operating costs were held to a specific level. Generally, operating costs were sensitive to the number of crews required by time of day, the number of peak vehicles required, and the distance traveled in revenue service and deadhead operation. The relationship between operating costs and service level of the transit route was, therefore, not necessarily linear. Unfortunately, the operating cost data were not provided in sufficient detail to uniquely identify the cost per peak vehicle or driver on each route. The relationship between costs and service level was considered as linear when a small range of service level was defined. The range was bounded by the minimum and maximum service levels of the transit route. These service level bounds will be discussed later in this section.

The cost data available were in a monthly summary which shows the actual expenses in the previous month. The cost per bus-mile was equal to the total costs divided by the bus-miles of service provided for the month. When a large amount of fuel was purchased during the month, a high cost per bus-mile was shown. There was no breakdown on cost for each route. In this research, the operating cost per bus-mile used was the average operating cost. Based on three years of cost data (1980-1982) from the MTA, the average operating cost for MTA fixed routes was estimated to be approximately 2.00 dollars per bus-mile for 1980 with a 15-cent increase in each of the next two years. Total operating cost was equal to the average operating cost times total bus-miles.

In 1982, the MTA covered 51.5 percent of its own cost through passenger fares, charter fees, grants, advertising and other sources. The remaining 48.5 percent of the MTA funding came from local (20.2%), state(2.8%), and federal (25.5%) governments. The Reagan administration has called for cutting federal operating funds to local transit systems by 33 percent a year until 1985. In 1986, federal operating funds will be eliminated. For fiscal year 1986, the projected annual deficit after local subsidies is 2.5 millions of dollars.

Fuel supply In response to the possible shortage of fuel supply, this constraint was introduced. The fuel consumption rate of Des Moines MTA buses was estimated to be approximately 0.25 gallons per bus-mile by using three year (1980-1982) data. Total fuel consumption was equal to the fuel consumption rate times total bus-miles. Note that this constraint was similar to the budget restriction. Both constraints controlled the allowable bus-miles of service. Either budget or fuel supply constraint was redundant depending upon which constraint governs.

Minimum and maximum service levels   Policy headways were usually used as minimum provision of service. Although a route may have had low ridership potential it may not have been feasible to remove the low productivity service because of social and political needs. Therefore, minimum levels of services may have been established by the community. To address this in the mathematical model, minimum headways, established by policy, were used to assure minimum service levels. The transit system performance evaluation and service change manual indicated that there was general agreement by transit planners on minimum policy headways for regular route service (18). Policy headways for peak and off-peak regular service are 30 minutes and 60 minutes, respectively.

For allocating the limited resources among competing transit routes in the optimal way, all transit services were assigned to the route having the highest stiffness. Although this assignment was mathematically optimal, it was unrealistic. Any transit route, no matter what its stiffness was, would reach a yield point. The yield point was the point where the ridership per additional bus trip leveled off as shown in Figure 9. Beyond the yield point, additional services were considered as inappropriate. Maximum service level, the service level at the yield point, was estimated from the existing relationship between ridership and frequency of service. The yield point was determined from a plot of cumulative ridership by frequency where the ridership was first sorted in descending order. The plot was developed from a regression fit.

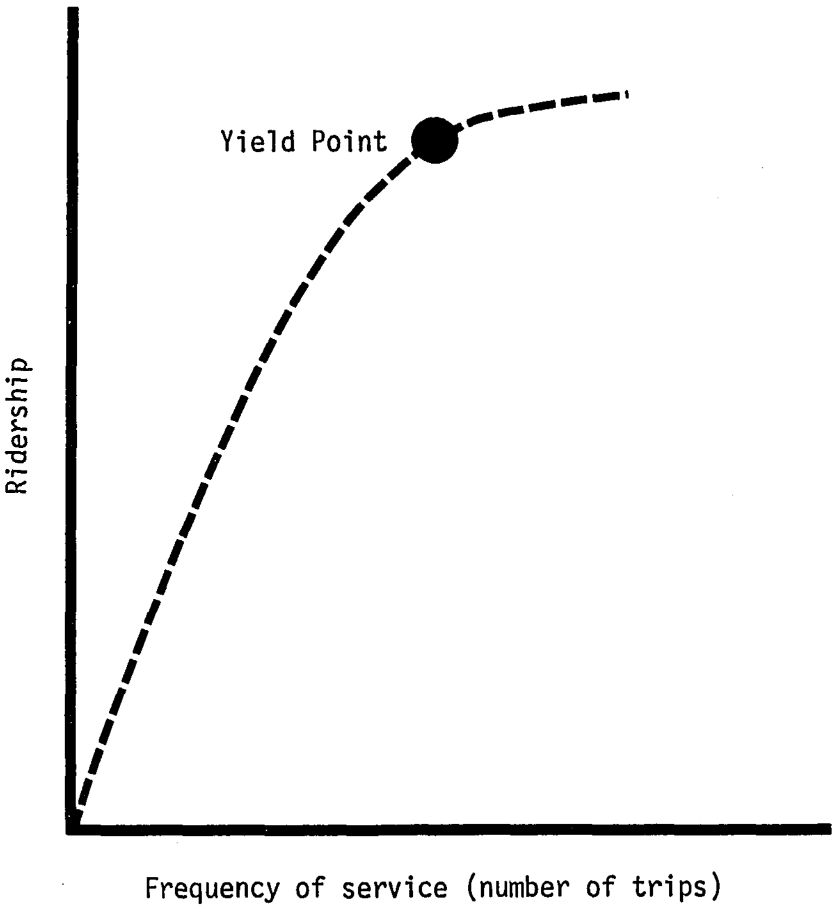


FIGURE 9. Transit service yield point

Performance standards The performance standards for the Des Moines MTA included minimum average speed, maximum load standard, schedule adherency, transfers, miles between accidents, level of pay hour productivity, passengers per revenue miles, percentage of breakeven (revenue/cost ratio), and minimum passengers per hour (19). Among these standards, the percentage of breakeven was considered as the most important measure by the MTA board (19). Other measures could be evaluated in a similar way.

The estimate of fare revenue was based upon the average fare for each route. The weekday average fare for Des Moines MTA fixed-routes is shown in Table 21. For an adult rate of 60 cents, the mean of the average fares was approximately 50 cents and the standard deviation was approximately 2 cents. The fare revenue was estimated by the average fare times the number of passengers for each route. The number of passengers was estimated by the route stiffness (on-off-passengers per bus-mile) and the decision variable, service level measured in bus-miles.

Analysis Approach

Simplex method

The simplex method, a general procedure for solving linear programming (LP) problems, was applied to identify an optimal solution for the LP model (20). This is a remarkably efficient method that is routinely used to solve huge problems on modern computers. Computer codes for the simplex method now are widely available for essentially

TABLE 21. Weekday average fare for Des Moines MTA fixed routes[a]

ROUTE	FAREBOX CASH	MONTHLY PASS	WEEKLY PASS	.60 TOKEN	.30 TOKEN	.60 TICKET	.30 TICKET	TOTAL REVENUE	PASSENGERS	AVERAGE FARE
1	629	428	450	188	34	113	17	1,859	3,784	.49
2	88	52	99	28	3	17	1	288	654	.44
3	508	425	263	155	25	93	13	1,482	2,940	.50
4	419	257	168	124	24	74	12	1,078	2,134	.51
5	298	256	144	88	17	53	9	865	1,831	.47
6	505	342	126	146	25	86	14	1,244	2,571	.48
7	485	332	347	148	24	88	12	1,436	2,740	.52
8	134	111	33	42	4	25	2	351	666	.53
9	49	49	21	18	0	11	0	148	261	.57

[a] Source: Des Moines Metropolitan Transit Authority (MTA).

all modern computer systems. In fact, major computer manufacturers, such as IBM^{TM}, usually supply their customers with a rather sophisticated linear programming software package, such as Mathematical Programming System (MPSX). However, some very good LP programs also have been developed by the users for relatively small LP problems.

Both the MPSX program and a user-written FORTRAN program, SIMPLEX, were used for this research. Program SIMPLEX provided not only the optimal solution for the decision variables and the value of the objective function but also the option of printing out the simplex tableau for each iteration step. The last simplex tableau is usually used for sensitivity analysis. The advantage of using a user-written program is that the user can easily make the necessary changes to cope with the needs so that the program is used in the most efficient way.

Sensitivity analysis

One assumption of linear programming is that all the parameters of the models are known constants. In this research, the parameters included route stiffness, operating cost, fare revenue, fuel supply and budget constraints. Actually, the parameter values used in the model usually were just estimates based on a prediction of future condition. Furthermore, an 'optimal' solution was optimal only in respect to the specific model being used to represent the real problem, and such a solution became a reliable guide for action only after it had been verified as performing well for other reasonable representations of the problem as well. The constraint parameters sometimes were set as a result of policy decisions. Therefore, it was important to perform a sensitivity analysis to investigate the effect on the optimal solution provided by the simplex method if the parameters take on other feasible values.

Iteration process

The iteration process discussed here is not the iterations involved in the simplex method. Rather, this was a process to evaluate the possible change of transit usage due to the change of transit supply. The decision variable in the LP problem was the service level of each transit route, which was expressed in terms of bus-mile. Recall that the stiffness parameter was a function of frequency of service, which was affected by the optimal solution of the LP model. A causal relationship existed such that the optimal solution determines the stiffness parameter, and the stiffness parameter decides the optimal solution as well. An iteration process was executed until the transit services provided and the usage are balanced.

Data file management

Since the optimal solution of the LP model determines the stiffness parameter, a new set of stiffness parameters was calculated after the changes of service level. It was, therefore, helpful to develop a procedure to obtain the new stiffness in response to the changes of service level and/or other factors in the demand model. A data file management program, STIFFNESS, was written by the author in APPLE PASCAL^{TM} language. This program was used to create a new data file, to add and delete observed data, to change data values, to calculate the stiffness, and to print the output file. Program STIFFNESS was run on an APPLE II^{TM} computer in an interactive mode.

Performance measure

In Chapter III, the stiffness parameter was developed to reflect route demand potential using regression techniques. The number of on-off-passengers per mile of route-segment was considered as the dependent variable. Population density, employment density, frequency of service, and travel time were used for independent variables.

The current all-day route performance was measured by the number of on-off-passengers per bus-mile, the route stiffness. However, the strength of a route was affected by peak and off-peak period schedules. Generally, one would expect that the route stiffness at the peak period was higher than that at the off-peak period. For allocating the limited resources among the competing transit route in the optimal way, it was important to identify the route stiffness by time of day. Three time periods, peak, mid-day, and evening, were considered. The peak period included AM peak (6:00 A.M. to 9:00 A.M.) and PM peak (3:00 P.M. to 6:00 P.M.). The mid-day period was from 9:00 A.M. to 3:00 P.M. The evening period included the rest of the day.

By using the same procedures and variables as described in Chapter III, regression models were also developed for estimating the route-segment stiffness at peak, mid-day, and evening as shown in Table 22. Model results also demonstrated the capability of predicting the ridership for each transit route by time of day. Table 23 indicates the actual and model predicted weekday on-off-passengers for non-CBD

TABLE 22. Regression models for ridership estimation by time of day

Regression models	R-square
Average household income greater than \$10,000	
Peak	
$Y = 0.226(KA)(TRIP)^{1.11}(HS)^{0.337}(EMP)^{0.09}(DIS)^{-0.452}$ where $KA=EXP(0.362(D1)+0.237(D2))$	0.849
$Y = 0.343(KB)(TRIP)^{1.16}(HS)^{0.38}(EMP)^{0.092}(TIME)^{-0.514}$ where $KB=EXP(0.419(D1)+0.16(D2)-0.158(D3))$	0.863
Midday	
$Y = 0.475(KA)(TRIP)^{1.42}(EMP)^{0.161}(DIS)^{-0.49}$ where $KA=EXP(1.42(D1)+0.239(D2))$	0.862
$Y = 1.037(KB)(TRIP)^{1.45}(EMP)^{0.163}(TIME)^{-0.538}$ where $KB=EXP(1.57(D1)+0.219(D2))$	0.863
Evening	
$Y = 1.411(KA)(TRIP)^{1.08}(DIS)^{-0.395}$ where $KA=EXP(0.257(D2)-0.282(D3))$	0.725
$Y = 2.758(KB)(TRIP)^{1.11}(TIME)^{-0.435}$ where $KB=EXP(0.239(D2)-0.296(D3))$	0.728
Average household income less than \$10,000	
Peak	
$Y = -123.4+7.74(TRIP)+0.0195(EMP)$	0.937
Midday	
$Y = -33.4+6.56(TRIP)+0.0118(EMP)$	0.939
Evening	
$Y = -2.28+2.01(TRIP)+0.00236(EMP)$	0.963

TABLE 23. Non-CBD on-off-passengers by time of day

Route	Peak		Midday		Evening		Total	
	Actual	Predict	Actual	Predict	Actual	Predict	Actual	Predict
West Des Moines/ Fairgrounds	2177	2279	1031	899	155	152	3363	3330
Crocker/ Scott	336	234	69	67	0	0	405	301
University/ Highland--Oak Park	2508	2386	1516	1397	208	198	4232	3981
East 14th/ Urbandale	1402	1451	665	647	88	90	2155	2188
East 6th & 9th/ Clark	1586	1526	605	601	123	101	2314	2228
West 9th--Douglas/ Indianola--Lacona	1940	1944	909	929	161	133	3010	3006
Fort Des Moines/ Walker	2212	2326	1196	1200	140	135	3548	3661
SW 14th--Havens/ South Union	533	407	254	284	2	5	789	696
Park Ave. West/ Park Ave. East	283	407	3	0	6	12	292	419

segments by time of day for the MTA fixed routes.

The route stiffness was calculated as the weighted average of the route-segment stiffnesses of the transit route. The number of bus-miles (frequency times segment length) was used as the weight. Table 24 shows the route stiffness and frequency of service by time of day for the MTA fixed routes. One can note that the route stiffness is sensitive to the time of day. Most of the routes had the greatest route stiffness at the peak period. Note that there was a large variation between the two ends of the Crocker/Scott route.

Operation strategy

The purpose of this research was not to do a planning study for Des Moines MTA. Instead the effort was to test the interaction of the demand and optimization phases by selecting strategies to test on selected routes. The stiffness parameter was used to reflect the route performance. An optimization tool, linear programming, was evaluated to test the sensitivity of different operating policies and to establish the bounds in which service must be operated.

Generally, changes in services that are undertaken by small- to medium-sized transit systems include schedule, frequency, route changes, and new services. A scheduling change is identified as an action to improve service to permit coordination with major activity centers. For example, service to a major employment center could be scheduled to arrive at that center prior to 8:00 A.M. when the work-shift start time is also 8:00 A.M. However, scheduling changes were not evaluated in this research. The effort focused on changes in frequency of service

TABLE 24. Route stiffness by time of day for MTA fixed routes

Route	All-day	Peak	Mid-day	Evening
1 West Des Moines	3.00[a]	3.50	2.49	0.93
	(80)	(46)	(24)	(10)
Fairgrounds	3.02	3.56	2.55	1.10
	(77)	(41)	(25)	(11)
2 Crocker	4.36	3.91	3.86	----
	(18)	(15)	(3)	(0)
Scott	1.01	1.02	1.80	----
	(21)	(16)	(5)	(0)
3 University	3.99	4.40	4.35	1.57
	(83)	(43)	(28)	(12)
Highland - Oak Park	5.87	7.02	5.52	1.66
	(83)	(48)	(25)	(10)
4 East 14th	3.19	3.84	3.25	0.85
	(78)	(43)	(25)	(10)
Urbandale	2.75	3.27	2.59	0.87
	(77)	(43)	(23)	(11)
5 East 6th & 9th	3.80	4.63	3.47	0.90
	(76)	(44)	(20)	(12)
Clark	2.75	3.29	2.72	0.82
	(74)	(4)	(21)	(12)
6 West 9th - Douglas	3.39	3.67	3.55	1.16
	(81)	(45)	(26)	(10)
Indianola - Lacona	2.76	3.24	2.43	1.14
	(72)	(40)	(23)	(9)
7 Fort Des Moines	3.66	4.28	3.69	1.40
	(89)	(49)	(30)	(10)
Walker	3.62	4.22	3.66	1.30
	(84)	(48)	(28)	(8)
8 SW 14th - Havens	2.40	2.81	2.26	----
	(26)	(13)	(12)	(1)
South Union	2.76	3.35	2.36	----
	(25)	(13)	(12)	(0)
9 Park Ave. West	2.03	2.56	----	----
	(21)	(19)	(1)	(1)
Park Ave. East	1.72	2.48	----	----
	(20)	(18)	(1)	(1)

[a] Route stiffness was measured by number of on-off-passengers per bus-mile. Numbers in parentheses indicate the number of bus trips provided.

and routing. Types of routing changes considered were route cutbacks, route elimination, re-route or new routes.

Frequency of service The service change involved either an increase or decrease in the frequency of service of a route. Evaluation of poor performing routes from a revenue/cost ratio or route stiffness indicated need for an investigation to determine whether a headway increase was advantageous. On the other hand, excessive loads identified through an evaluation of load factor or route-segment stiffness needed to be assessed to determine whether a decrease in headway was possible. Recall that the stiffness parameter was a function of frequency of service and other factors.

Route cutback This type of service change involved shortening the length of a route or shortening certain trips on a particular route. If an evaluation of the route's revenue/cost ratio indicated that excessive cost and therefore too much service was the problem, and if increasing the headways was an insufficient solution, route cutbacks needed to be considered. If an evaluation of the route-segment stiffness indicated low performance in the route, and scheduling changes did not provide adequate solutions, route cutbacks needed to be considered.

Route elimination This type of service change involved the complete elimination of a particular route. Route elimination was generally considered for a very poor performing route after scheduling changes and route cutbacks had been evaluated, but where these did not provide an adequate solution. Both the low route stiffness and the low route-segment stiffnesses should have pointed to route elimination as a potential service change alternative.

Rerouting This service change involved minor route or alignment changes to an existing bus route generally within the same level of service resources. Reroutings may have been investigated due to a number of factors. One factor was underutilization of service on some route segments, with corresponding effects on the operating costs and route revenues. Other factors included route operating conditions, route on-time performance, need to service nearby generators or residential areas, and external factors such as requests for service to an unserved area.

New route This type of service change involved provision of bus services to areas not previously served, either through establishment of a new route or an extension of an existing route. New services may be warranted as a result of land use changes, social needs of special groups, public requests, and reallocation of resources from underutilized services.

System Evaluation

In 1981, the MTA provided approximately 6,000 bus-mile and 1,000 bus-mile weekday fixed-route services for non-CBD segments and CBD segments, respectively. The ridership was estimated at 20,000 on-off-passengers and 15,000 on-off-passengers for non-CBD segments and CBD segments, respectively. The system, as a whole, carried 2.5 passengers per bus-mile.

Recall that the CBD segments were treated separately for model calibration and the ridership of the CBD segments could be estimated by the ridership of the non-CBD segments. The focus of system evaluation was, therefore, on the non-CBD segments. The 1981 ridership and service levels of non-CBD segments were broken down by time of day as shown in Table 25.

TABLE 25. Non-CBD ridership and service level by time of day

	Peak	Midday	Evening	Total
Ridership (on-off-passengers)	13,000 (65%)	6,200 (31%)	800 (4%)	20,000 (100%)
Service level (bus-miles)	3,420 (57%)	1,860 (31%)	720 (12%)	6,000 (100%)

The MTA provided 12 percent of the services during the evening period, but the evening service generated only 4 percent of the ridership. As one would expect, the evening service is the most non-productive service in the system. However, the justification of the evening service was commonly based not only on the productivity but also on the social benefits.

Evaluation of route stiffness

The route stiffness, which indicated the route demand potential, was used as a prime factor to allocate the limited resources among competing transit routes in the optimal way. However, the change of frequency of the route changed the route stiffness. Figure 10 shows the relationship between the route stiffness and frequency of service for selected routes. The slope of the curves represents the sensitivity of the route stiffness.

The Highland - Oak Park route appeared to have the highest route stiffness, but was the most sensitive route to the change of frequency. Generally, one would have expected that the route stiffness at peak hours to be higher than that at midday and also that most of the trips that were made at midday were non-work trips. However, a higher route stiffness at midday was found on the University route. In Figure 10, it was also found that the slopes of the curves were more similar at peak than those at midday. This means that the ridership is more stable at peak than that at midday. The Urbandale route represented one of the routes which had low route stiffness that was less than one-half of the route stiffness of the Highland - Oak Park route. The low route stiffness indicated route elimination was a potential service change alternative.

Evaluation of route-segment stiffness

Route-segment stiffnesses were developed from demand models in Chapter III. Route-segment stiffnesses were measured by on-off-passengers per mile of route-segment and were used to reflect route-segment demand potential. In this section, the West 9th - Douglas route and the Scott route were selected to demonstrate the possible route cutback and rerouting alternatives.

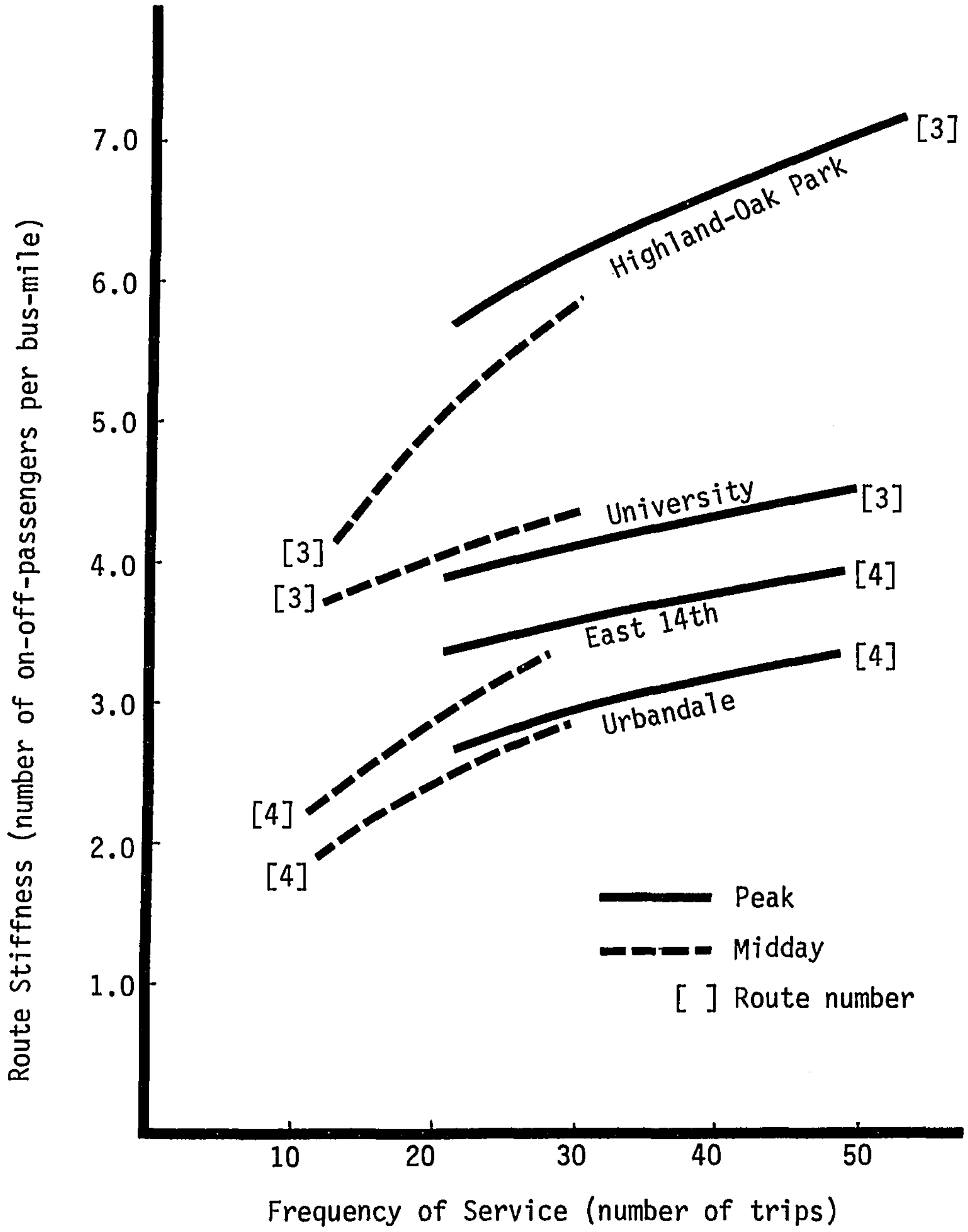


FIGURE 10. Sensitivity of route stiffness by time of day

The West 9th - Douglas route which operated along West 9th Street, Hickman Road, Harding Road, and Douglas Avenue provided service to northwest Des Moines and terminated at Merle Hay Mall. Beyond Merle Hay Mall, peak service was provided to residential areas in Urbandale, with trips alternated to 86th and Aurora and to Mary Lynn and Douglas. The Scott route served a predominantly lower income residential area and operated along Scott Street and Maury Street. There were railroad crossings along Maury Street which occasionally delayed traffic. Table 26 shows the route-segment stiffnesses for both the West 9th - Douglas route and the Scott route.

From Table 26, it was noted that the stiffnesses for route-segments 8 and 9 of the West 9th - Douglas route and route-segments 3 and 4 of the Scott route were extremely low. The low route-segment stiffness indicated route cutback or rerouting as a potential service change alternative. For the West 9th - Douglas route, it was recommended that service be terminated at the Merle Hay Mall, with trips through Urbandale eliminated as shown in Figure 11. By shortening the length of the West 9th - Douglas route, the route stiffness was expected to increase from 3.4 passengers per bus-mile to 3.6 passengers per bus-mile. This did not mean that ridership would increase, but rather the route performance would improve. By cutting back 36 bus-miles of service, the loss of ridership was expected to be 34 on-off-passengers, that is, 0.47 passengers per bus-mile which is well below the system average 2.5 passengers per bus-mile.

For the Scott route, a change in routing was recommended as shown

TABLE 26. West 9th - Douglas route and Scott route route-segment stiffnesses

Segment	Boundaries	Stiffness
West 9th - Douglas route		
2	9th and I-235 to 9th and College	470.6[a]
3	9th and College to Hickman and Harding	371.2
4	Hickman and Harding to Douglas and Lower Beaver	303.5
5	Douglas and Lower Beaver to Douglas and Beaver	203.2
6	Douglas and Beaver to Douglas and 50th	218.1
7	Douglas and 50th to Merle Hay Mall	189.3
8	Merle Hay Mall to Douglas and Mary Lynn	5.4
9	Merle Hay Mall to 86th and Aurora	5.8
Scott route		
2	East 6th and Market to Scott and Southeast 14th	67.5
3	Scott and Southeast 14th to Maury and Southeast 22nd	14.1
4	Maury and Southeast 22nd to Scott and Raccoon	0.4

[a] On-off-passengers per mile of route-segment.

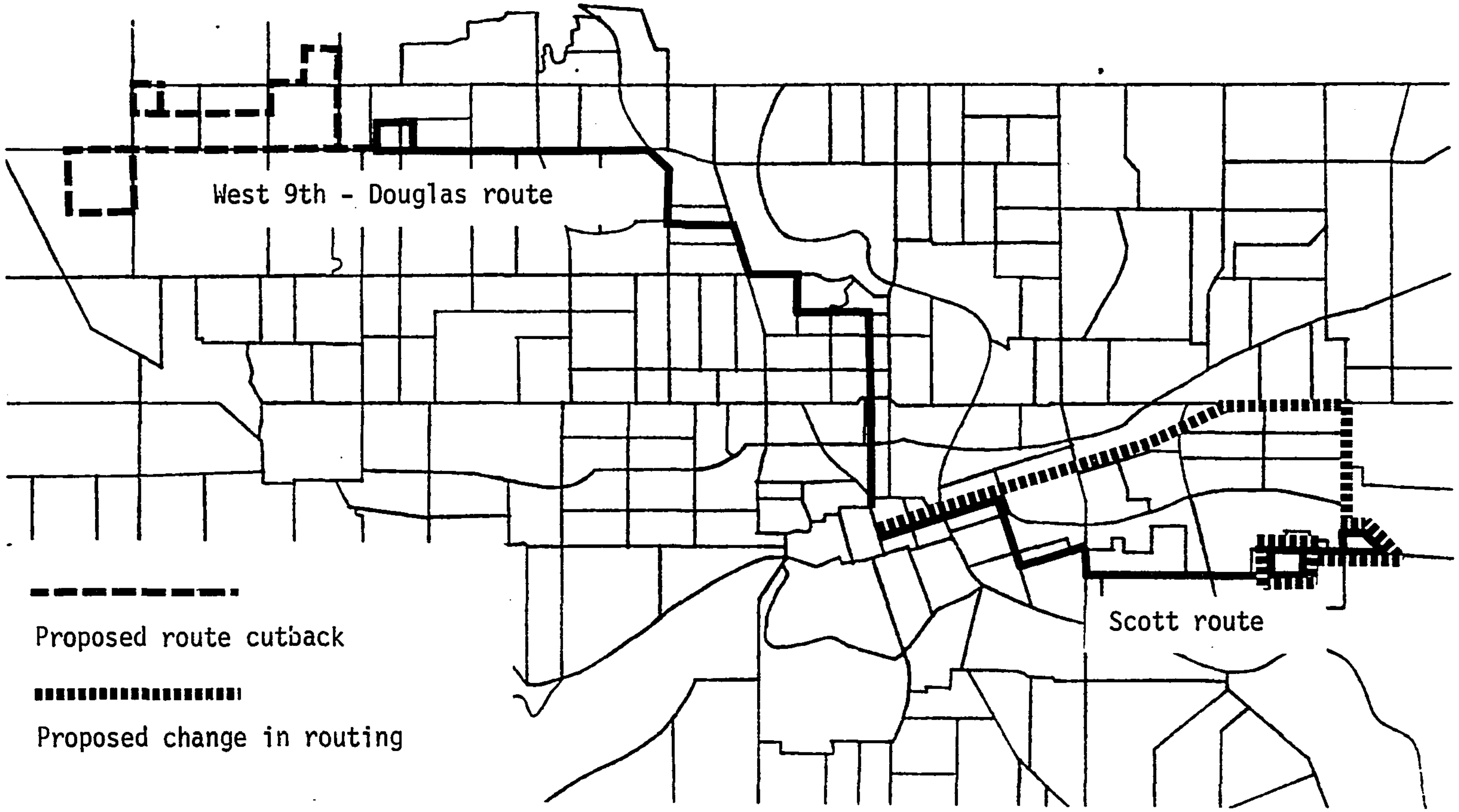


FIGURE 11. Proposed transit service changes for selected routes

in Figure 11. The residential area at the end of the Scott route was still served, in addition to the low-middle income area along University Avenue which was not served at the time. The rerouting creates access to a shopping area for the Scott residents. Other new places which were to be served were the Willard Elementary School, the Fairgrounds, the Wilson Community Education Center. Providing the same frequency of service as for the Scott route, the route-segment stiffnesses for the proposed route are shown in Table 27. Compared with the route-segment stiffnesses of the Scott route as shown in Table 26, the proposed route was expected to have increased in services by 25 percent, which was based on the same frequency and the new route length, and was expected to increase ridership by more than 100 percent.

TABLE 27. Proposed Scott route route-segment stiffnesses

Segment	Boundaries	Stiffness
2	Grand and East 14th to Hubbell and Claypool	81.2[a]
3	Hubbell and Claypool to University and East 25th	67.4
4	University and East 25th to East 30th and Capitol	54.4
5	East 30th and Capitol to Maury and Southeast 25th	36.1

[a] On-off-passengers per mile of route-segment.

The route-segment characteristics, which were used to derive the route-segment stiffness, are shown in Table 28. Using the census map, the proposed route was divided into segments based on major intersections, geographical boundaries, and census blockgroup. Census blocks within the service area were then identified for each route-segment. From the 1980 census, the number of households was determined for each route-segment. Income level for each route-segment was determined by taking the weighted average of median household income for each corresponding census blockgroup within the service area. The number of employees was determined from the employment map and employment equivalence was used to represent the attraction of a route-segment. Auto travel distance was measured from the distance contour map as shown in Figure 2. It took approximately an hour to develop the new estimates.

System impact evaluation

In the face of increasing costs and increasing uncertainty about fuel supplies and financial resources, transit operators need to consider what adjustments, especially for cutbacks, can be made in route coverage, service frequency and other areas in order to optimize their operations. In the previous sections, the stiffness parameters were used to reflect both route-segment and route performances in response to different service changes. In this section, system ridership is estimated for selected alternatives.

Two alternatives are presented here to show the impact on ridership. Based on the route performance by time of day, alternative A is to cutback the least productive route(s) to cope with the available

TABLE 28. Proposed Scott route route-segment characteristics

Segment	INCOME	TRIP	HS	EMP	DIS	Stiffness
2	11,125	21	1,182	722	2.1	81.2
3	14,767	21	1,225	730	3.2	67.4
4	18,991	21	1,167	320	4.0	54.4
5	11,490	21	358	205	4.0	36.1

$$\text{Stiffness} = 0.217(\text{TRIP})^{1.09}(\text{HS})^{0.299}(\text{EMP})^{0.126}(\text{DIS})^{-0.456}$$

Stiffness = on-off-passengers per mile of route-segment
INCOME = average household income
TRIP = frequency of service (number of trips)
HS = population density (household)
EMP = employment density
DIS = auto travel distance (mile)

resources. This alternative considers only the productivity of the route and provides the upper bound of the system ridership. Alternative B is to adopt the minimum service policy. Ultimately, all the routes would have at least the minimum services or policy headways for alternative B.

In 1981, the MTA provided approximately 6,000 bus-mile weekday fixed-route services, which is equivalent to $3.35 millions, for non-CBD segments, and the operating cost was 2.15 dollars per bus-mile. Given the predicted operating budget of $3.0 millions in 1985 and the average operating cost of 2.60 dollars per bus-mile, 4,500 bus-miles of service can be provided for weekday non-CBD segments of fixed-routes. The weekday average fare for each route is shown in Table 21. The revenue/cost ratio of 0.5 was used as the system performance standard. However, some other cities might have different standards. The route stiffness by time of day is shown in Table 24. By using the LP program, the output provides the bus-miles of service allocated to each route and the system ridership.

For alternative A, the maximum service level was provided for each route and there was no limitation on the minimum service level. The LP output shows that no service is provided for all routes in the evening. The Scott route and the Park Avenue East route are eliminated. No service is provided for the SW 14th-Havens/South Union route, the West Des Moines/Fairgrounds route, the Indianola-Lacona route during the midday. The non-CBD ridership was estimated to be approximately 17,000 on-off-passengers. Compared with the 1981 non-CBD ridership and service level as shown in Table 25, 25 percent reduction in service would have 15 percent reduction in ridership by choosing alternative A.

Both the maximum and minimum service level constraints were provided for each route for alternative B. The LP output shows that all the routes have at least the policy headway in the whole day (peak, midday, evening). Maximum service is provided for the University/Highland-Oak Park route during the peak and the midday. The East 14th route, the East 6th & 9th route, the Fort Des Moines/Walker route have the maximum service levels during the peak period. The number of bus trips provided for the Fort Des Moines route during the midday is reduced from 30 trips to 28 trips. The non-CBD ridership was estimated to be approximately 14,000 on-off-passengers. Compared with the 1981 non-CBD ridership and service level as shown in Table 25, 25 percent reduction in service would have 30 percent reduction in ridership by choosing alternative B.

Table 29 shows the model output for alternative policy conditions. Figure 12 shows the sensitivity of ridership for alternatives A and B. The 100 percent marks in the figure represent the ridership and the services provided at the time of analysis. Providing a certain amount of services, the vertical distance between the two curves represents the ridership gain or loss by selecting the alternative. For example, if 60 percent of the existing services is provided, the ridership is estimated to be approximately 68 percent and 56 percent of the existing ridership for alternative A and alternative B, respectively.

Microcomputer Applications

In the past, only the largest agencies could have their own computer systems. This is no longer true. Now most small and middle-sized agencies can afford to own microcomputer(s). The new technological break-through allows smaller agencies to assess their own operations in a way never before possible. For routine and standardized applications, software packages can be purchased from software vendors. In this section, three commercial software packages which are relevant to this research are evaluated. They are two multiple regression packages and one linear programming package. However, several other packages are also available on the market, but they were not available

TABLE 29. Model output for alternative policy conditions

Route	Peak			Midday			Evening		
		Alternative			Alternative			Alternative	
	Base	A	B	Base	A	B	Base	A	B
West Des Moines	419.5[a]	420	210	218.9	0	110	91.2	0	90
Fairgrounds	227.6	230	115	138.8	0	70	61.1	0	60
Crocker	45.0	50	50	9.0	10	10	0	0	0
Scott	57.1	0	60	17.9	0	20	0	0	0
University	300.6	300	300	195.7	200	200	83.9	0	80
Highland--Oak Park	151.6	150	150	99.0	100	100	39.9	0	40
East 14th	132.9	130	130	77.3	80	40	30.9	0	30
Urbandale	287.7	290	145	152.9	150	75	73.2	0	70
East 6th and 9th	117.5	120	120	53.4	50	25	32.0	0	30
Clark	298.9	300	150	153.1	150	75	87.5	0	90
West 9th--Douglas	350.7	350	175	181.7	180	90	69.9	0	70
Indianola--Lacona	202.8	200	100	116.8	0	60	45.4	0	50
Fort Des Moines	283.3	280	280	172.8	170	160	55.6	0	60
Walker	263.6	260	260	153.7	150	75	44.0	0	40
SW 14th--Havens	74.9	70	70	69.1	0	70	5.8	0	5
South Union	58.9	60	60	54.4	0	50	0	0	0
Park Ave. West	95.8	50	100	5.0	0	0	5.0	0	5
Park Ave. East	65.3	0	70	3.6	0	0	3.6	0	5

[a] Number of bus-miles.

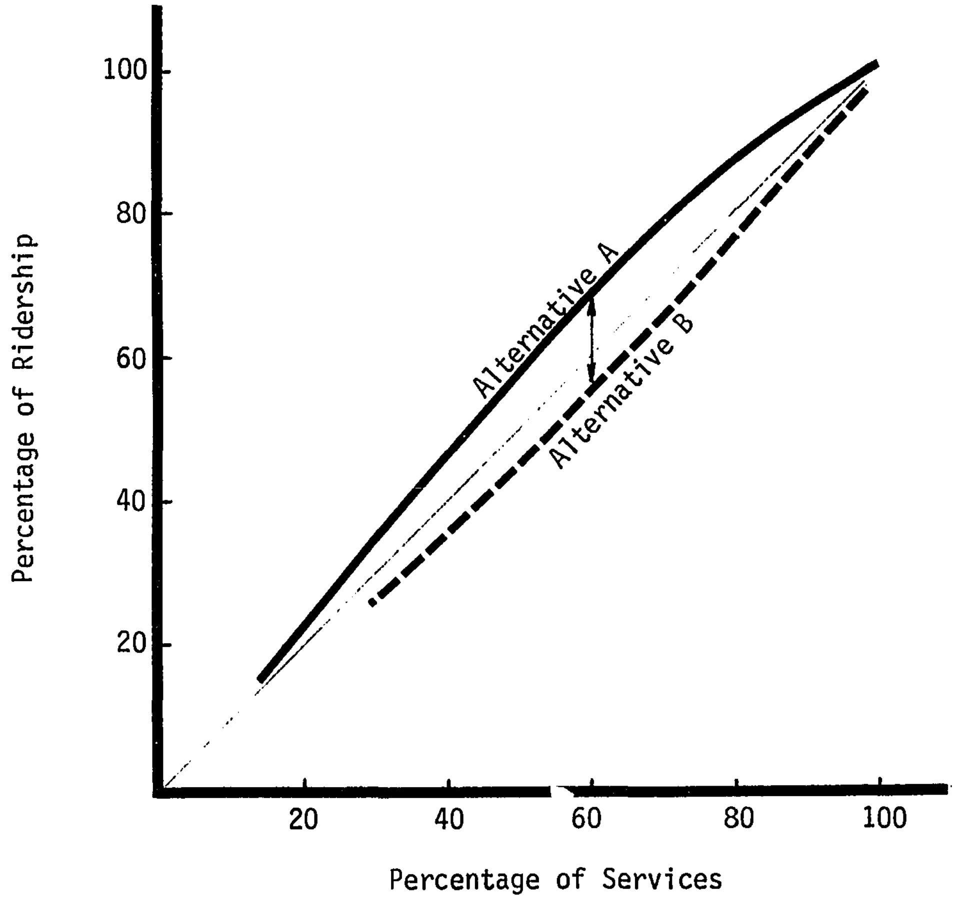


FIGURE 12. Sensitivity of ridership

to the author. The primary intent is to describe the type of computations that are available for the microcomputer.

Multiple regression package

Two multiple regression packages are evaluated in this section. The first package is mainly for the stepwise multiple regression analysis. It contains eleven programs. Four of the programs are used in the storage and updating of data maintained on diskettes. Four programs are used to calculate and display the results, and three additional programs support and integrate the system. By setting the statistical parameters, one of the three common stepwise methods, that is forward, backward, or hybrid, can be selected.

Up to 100 variables can be stored and up to 61 variables can be analyzed at one time. There is no limit to the number of observations. However, each variable diskette holds a maximum of 64 observations. If there were a large number of observations, several diskettes would be required. It is important that each diskette be filled with 64 observations before another one is begun, that is, only one partially filled diskette is allowed for a given set of data.

One disadvantage of this package is that one must enter the dependent variable last for each observation. Therefore, it does not allow the user to choose another variable, which is not the last variable, as dependent variable. Another disadvantage is that data transformation is not permitted. Unless the user knows exactly what the regression model form is, the data transformation process is generally almost unavoidable.

The output includes multiple correlation coefficient, standard error, regression coefficients, and F-value. Also included are the residuals, means, standard deviations, and correlations which are not included in the STEPWISE procedure in the Statistical Analysis System (SAS) which is a major statistical package running on large computers. The program has an option whether to print out the intermediate steps or not.

The second package contains the routines most useful in social science and survey research analysis. All functions are called as commands from within the main program. The statistics include description, correlation, frequency, one-way analysis of variance, multiple regression, crosstabulation, and others. However, a stepwise regression procedure is not included in the package.

The program provides space for about 11,000 data points (e.g. 500 cases by 22 variables). However, this limit applies only to the number of variables in memory at one time. The virtual memory system takes care of replacing unused variables with others saved on the disk, as one enters the new variable numbers. The program is capable of serious analytic work on large data sets (up to over 4,000 cases).

The data input routine is normally used to create a new data set from the keyboard, but may be called at any time to enter new variables. However, there is a limitation on data value. No more than five digits are permitted in the data, and the range must be from -32766 to 32767. The program allows one to transform data and to create new variable(s) by using the existing variables. When using a saved data file, the number of variables and the number of cases, in addition to the file name, have to match with the stored file in order to activate it.

The output can be directed to the screen, to a printer, or to the text file on the data disk. When sample problems were run and compared with the results from the Statistical Analysis System (SAS), the first three significant digits of the estimated regression coefficients were the same.

Linear programming package

A linear programming and computerized budgeting package for management decision making is evaluated in this section. The interactive instructions included on the program disk and the file problem examples found on the data disk facilitate use of the program. The program has options which permit choice of data output, storage of problem files, and override command options for ease of data entry and processing. The program accommodates problems with up to 50 constraints and 50 to 75 variables, depending on the types of constraints.

Data entry is provided for in four major blocks of the program. These blocks, which incorporate the standard components of linear programming formats, include number of rows (constraints) and number of columns (variables), type of constraint, row/column coefficients, and values assigned to the constraints. However, it is recommended that the data initially be coded on multicolumn LP model forms. All artificial coefficients are generated automatically by the program based on the type of constraint.

Comment

Numerical accuracy is crucial to any statistical and mathematical program. When choosing statistical and mathematical software packages, the main consideration should be ease of use and then test its accuracy. It was noted that the ease-of-use features are sometimes not found in microcomputer packages.

CHAPTER V. SUMMARY AND RECOMMENDATIONS

Summary

A state-of-the-art short-range transit planning technique was developed to help local planners evaluate the impacts of transit routing and scheduling options. A transit route evaluation procedure established route potential on the basis of demographic and transit service factors. A stiffness concept applied in structural analysis was used to estimate route ridership under varying supply conditions. The stiffness is more than a trip generation from an area. Its function is to simultaneously measure a trip generation and distribution effect by incorporating both production and attraction capabilities along a route. The Des Moines Metropolitan Transit Authority (MTA) fixed-route system, a radial transit system, was selected for evaluating the transit use potential at the route level.

Multiple regression techniques were valuable for sorting through the many eligible explanatory variables regarding transit ridership. The observation unit in regression analysis was route-segment. Passenger density, the stiffness for each route-segment, was used as a dependent variable. Passenger density was represented by on-off-passengers per unit length of route-segment. The number of on-off-passengers is the sum of the number of on-passengers and the number of the off-passengers. Frequency of service was always found to be the most significant independent variable. Other independent variables that are significant in explaining variations included population density, employment density, and travel time factor. Dummy variables were used to adjust the predicted value at route level. The model demonstrated the capability of predicting the ridership for each transit route.

A linear programming model was used to optimize the transit route on the basis of the demand and system constraints. The objective was to maximize the ridership in the corridor. The constraints included budget restriction, fuel supply, minimum and maximum service levels, and performance standards. The sensitivity analysis on the route stiffness provided a direction for allocating the limited resources among competing transit routes in an optimal way.

In a different radial transit network, community and transit data can be assembled and route potential can be developed to verify the demand concept by using the following procedure.

Step 1. Collect data

The analysis procedure does not use new primary data sets. The technique was formulated primarily with data already available or easily obtainable. Passenger count data, census data, employment data, travel time data, and transit service data provided basic information rather than major origin-destination studies or marketing surveys. A small sample set of passenger count data was used to examine the ridership variations.

Step 2. Divide routes into segments

The initial effort examined the transit routes to identify homogeneous sections of routes. The route was divided into segments based on major intersections, geographical boundaries, and census blockgroup. The reason for selecting the census blockgroup was that median household income information was summarized at this level by the Bureau of the Census. The Des Moines central business district (CBD) was treated as a whole unit instead of treating each CBD route-segment individually. This is because the CBD has little residential land use, high employment density, and a high level of transit service. An attempt to associate the common characteristics of the CBD with each of the routes would have distorted the significance of potential explanatory variables on portions of the routes outside the CBD.

Step 3. Determine service area

The service area for the bus route was defined as the area within 0.25 mile of the route. Using the census map, census blocks within that area were identified for each route-segment. If a census block was partially in the service area, it may or may not have been included, depending upon the percentage of the census block within the service area. The decision rule was that more than 50 percent of the block had to be within the service area to warrant inclusion. Major barriers were taken into account for inaccessibility.

Step 4. Determine population characteristics

Population, the number of households, the number of persons over age 62, and the number of females between the age of 16 and 24 were determined for each route-segment. Data for these four variables were obtained from the 1980 census for each census block.

Income level for each route-segment was determined by taking the weighted average of median household income for each corresponding census blockgroup within the service area. Three income levels were selected by using upper and lower quartile incomes. However, there were only five route-segments in the high income level. This sample size was considered to be too small and, therefore, inadequate for multiple regression having more than three predictor variables. The middle income group and the high income group were, therefore, combined into one income group. Average household income less than $10,000 was considered as low income.

Step 5. Determine employment characteristics

The number of employees were determined from data obtained from available sources. However, transit trips included not only trips that are made by employees but also non-work trips. Trip generators such as shopping centers, hospitals, and schools attract trips that are made by shoppers, patients or students. Instead of using several variables, one single variable, employment equivalence, was used to represent the attraction of a route-segment. The idea was to convert other factors, such as students and square feet of shopping area, to an equivalent employment factor which would relate to transit trip potential. The employment equivalence factors were based on the trip rates that are in the Institute of Transportation Engineers (ITE) Trip Generation report.

Step 6. Determine route-segment ridership

The ridership data were based on a complete on-board passenger count. The number of on-passengers and the number of off-passengers for time of day (AM, mid-day, PM, evening) were summed for each route-segment. Random sampling and rotation sampling in the collection of individual bus-line data were evaluated. An additional small sample set of data was used as a validation sample to examine the ridership variations. It was concluded that the ridership pattern was fairly consistent under a similar environment.

Step 7. Determine transit service level

Level of service was represented by frequency of service and travel time in demand analysis for the radial transit system. Frequency of service was measured in terms of number of trips provided for each route throughout the day. Travel time was measured in terms of scheduled bus travel time or auto travel distance. When a new route is evaluated and there is no scheduled bus travel time, auto travel distance should be used.

Step 8. Develop demand models

Demand models were developed for CBD segments and non-CBD segments by using the regression technique. The observation unit was route-segment. For non-CBD segments, the models were calibrated on the basis of income level and time of day. The passenger density, on-off-passengers per unit length, was used as a dependent variable. Independent variables included population density, employment density, frequency of service, and travel time to the central core. The linear model and the multiplicative model forms were used. For CBD segments, ridership estimation was based on the non-CBD ridership or the number of transfers, and the multiplicative models produced the correlations. Residual analysis was performed to check the adequacy of the model. By using the dummy variables, adjustment factors were developed to adjust the predicted values at route level.

Step 9. Determine route stiffness

Passenger density, the stiffness, was developed for each route-segment from Step 8. The route stiffness by time of day was calculated as the weighted average of the route-segment stiffnesses of the transit route. The number of bus-miles (frequency times segment length) was used as the weight.

Step 10. Evaluate system alternatives

The route stiffness, which indicates the route demand potential, was used as a prime factor to allocate the limited resources among competing transit routes in the optimal way. Route stiffness is measured by on-off-passengers per bus-mile of service. The sensitivity of route stiffness by time of day was evaluated. A low route stiffness points to route elimination as a potential service change alternative.

Route-segment stiffness is measured by on-off-passengers per mile of route-segment and is used to reflect route-segment demand potential. A low route-segment stiffness points to the possible route cutback or rerouting alternative. By setting up policy alternatives, the sensitivity of ridership was then evaluated. Route productivity, or minimum service level, or both can be used to determine policy alternatives.

Recommendations

This research was directed to small and medium size metropolitan areas of approximately 250,000 population or less. It was intended to evaluate short range operating policies which are proposed by the transit agency to meet energy, subsidy, or other management constraints. A case study on the Des Moines Metropolitan Transit Authority (MTA) radial fixed-routes was accomplished. The stiffness parameter was developed to reflect route demand potential. It is recommended that route potential will be developed to verify the demand concept in different transit networks.

One single variable, employment equivalence, was used to represent the attraction of route-segment in this research. By incorporating both production and attraction capabilities along a route, the stiffness of route-segment was developed to simultaneously measure a trip generation and distribution effect. The results demonstrate the stiffness of route-segment can be measured by a function of population density, employment density, frequency of service, and travel time factor.

In this study, the change of ridership on route j caused by a unit change of service on route j, K_{jj}, can be identified through the use of stiffness parameter. However, it is recognized that the change of service at one route may very likely affect the ridership on the other routes with which it connects. The potential for distribution through the network will be dependent upon the strength of all the routes. One can hypothesize that the change of ridership on route i caused by a unit change of service on route j, K_{ij}, is a function of K_{jj} and a distribution factor. Further, the distribution factor is hypothesized as a function of route stiffness and travel pattern. Unfortunately, there were no readily available data which could be used to verify the effect. To identify the variations within the route-segment and travel pattern, systematic data collection through the use of statistical sampling methods is also recommended.

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