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Foreword

Highway administrators, highway and transportation system planners, and urban specialists will find the six papers in this RECORD of special interest. Several travel modes are dealt with in the papers, ranging from pedestrians in Toronto's CBD to "jitney" taxis in Caracas.

In the first paper, Kudlick reports his analysis of the unusual transit mode of "jitney" taxis, or shared taxicabs, in Caracas, Venezuela. While nearly a half-million passengers are served each day by this system, the future is apt to be limited by the system's inherently low profit, and by competition with other forms of public transportation.

The next paper, by Ness, Worrall, and Hutchinson, examined patterns of pedestrian circulation in the CBD of Toronto for two types of pedestrian trips—transportation terminal to offices, and lunch hour circulation. The authors developed a model of the pedestrian demands for the former, and developed a simulation of lunch hour pedestrian circulation patterns of the CBD office workers for the latter. Friction factors are given for both developments.

In the third paper, Horton and Wagner analyzed the urban travel behavior of individuals grouped into categories of similar socioeconomic occupational class. Three travel behavior sets were developed and analyzed using trip linkage distributions generated by Markov chain analysis; significant differences between travel patterns for the three groups were defined.

The travel time factor is considered constant over time, as used in gravity model studies. In this paper, Ashford and Covault question the constancy over time by attempting to express the curves in parametric form, relating the parameters to variables known to change over time. Their work showed significant relationships between curve parameters and such variables as number of trips made, trip-making rates, car ownership, and ratios of trips made for various purposes. Two discussions and a closure add to this significant paper.

Travel mode splits are the concern of the final two papers. Wynn describes a "shortcut modal split formula" with which to measure the number of drivers who would be diverted to public transit by fare reductions or transit travel time reductions. Stopher has derived a model of travel mode choice for the work journey in terms of differences in costs and times between the modes. Limited tests of the models have reproduced existing mode choice to a high degree of accuracy.

Contents

Carros Por Puesto—The "Jitney" Taxi System of Caracas, Venezuela

WALTER KUDLICK, Project Manager, Parsons, Brinckerhoff, Quade & Douglas, Inc., and Alan M. Voorhees & Associates, Inc.

•THIS paper discusses the findings of a study of one of the component modes of transportation in Caracas, the "por puesto" or "jitney" taxi service. Por puesto operation consists of shared taxicabs that pick up and drop off passengers anywhere along prescribed routes and normally charge each passenger carried a fixed fare on a zone basis. The system is a common one in South and Central America and in some countries it is known as "Colectivo" or "Publico" service. Jitney taxis were also utilized at one time, generally on a much smaller scale, in such North American cities as Miami Beach and St. Louis. San Francisco and Atlantic City are thought to be the only cities in the United States that still have a jitney service.

It is believed that the por puesto system has a number of characteristics, such as frequent service and speeds comparable to the private automobile, that are similar to the characteristics of various proposed small car and minibus public transportation systems being studied by others. It is hoped that the Caracas example of a large-scale application of these characteristics will be of interest to transportation planners considering various types of systems in an attempt to develop the mixture of facilities and services needed to meet the variety of transportation problems found in urban areas.

The por puesto study was undertaken by the Oficina Ministerial del Transporte (OMT) to determine what the future role of this mode of travel might be within a balanced transportation system for Caracas. This paper is based on data collected in 1966 by an origin-destination home interview survey, vehicle-counting programs, travel time studies, and other traffic surveys.

The OMT was established in 1965 as a part of the Ministry of Public Works of Venezuela and was given responsibility for conducting studies and developing comprehensive, integral plans for transportation facilities in urban areas. The first area selected for study was Caracas, the capital of the country and its most important urban center. In 1966 the joint venture of Parsons, Brinckerhoff, Quade & Douglas, Inc., and Alan M. Voorhees & Associates, Inc., was selected to furnish technical advice and assistance to the OMT.

THE CITY OF CARACAS

Caracas is located approximately seven miles south of the coast of Venezuela in an east-west valley 3,000 feet above sea level. It lies behind a mountain range that rises to over 9,000 feet in places and separates the city from the Caribbean Sea. The axis of the valley is about 15 miles long and coincides with the Guaire River. The valley floor at its widest point is 2.5 miles and is traversed by a number of deep drainage ravines running roughly north-south from the mountains into the river. Mountainous topography south of the city forms several secondary valleys which lead into the main valley.

Although the city was founded as a Spanish settlement over 400 years ago, its period of greatest growth has been during the past thirty years. In 1936 Caracas had a little more than 263,000 inhabitants and occupied scarcely 5,000 acres of land. The remainder of the fertile valley consisted of woodlands, coffee and sugar plantations, and a few

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small country villages. By 1966 the population of the city had grown to 1,760,000 and urbanization had spread throughout virtually all of the main and secondary valleys. The population is expected to exceed 4,000,000 by 1990.

The structure of urban development is greatly influenced by the topography that shapes and restrains the built-up area and limits the lines of communication. The original colonial settlement is now the central business district (CBD) of the city where most of the economic activity is concentrated. As the city grew, new developments seeking to avoid the congestion in the center and uneven terrain elsewhere spread out along the east-west axis of the valley. The result is that the city today has a distinctly linear form with important focal points of commercial, retailing, residential, and other activities located at intervals between Catia at the west end of the valley and Petare at the east end.

Caracas is the principal employment center in the country and its 522,000 job opportunities in 1966 made up 21 percent of the national employment. Government and service activities account for 44 percent of the city's employment. It is estimated that there will be between 1.2 and 1.4 million employment opportunities in Caracas by 1990. The average family income in Caracas at present is about $5,000 per year and this is forecasted to reach $8,800 per year by 1990.

THE TRANSPORTATION FRAMEWORK

Based on the origin-destination home interview survey carried out by the OMT in 1966, the 1,760,000 inhabitants make approximately 2,700,000 trips on a typical working day.

Public transportation is provided by buses, por puestos, and taxis which provide 1,324,000 trips a day, or 48.9 percent of the total daily person trips. The private automobile serves 1,234,000 trips or 45.6 percent of the daily total, and the remaining trips are made by various minor modes such as motorcycles and school buses. During the peak hour, public transportation is used for 52.3 percent of the trips, the private automobile for 35.3 percent, and minor modes, because of the high number of school bus trips, account for 12.4 percent. The existing street and highway system, which is used by all modes of transportation, presently totals about 650 miles and consists of approximately 22 miles of freeways and limited-access highways, 58 miles of major arterial streets, 120 miles of important collector streets, and 450 miles of local streets. Presently under construction or scheduled for construction in the near future are 32 additional miles of freeways, 27 more of major arterials, and 20 miles of collector streets.

Approximately 150,000 private automobiles circulate daily in Caracas, along with about 1,200 buses operating over some 70 different lines, and 12,000 taxis and por puestos. As could be expected from the form of the urban structure, traffic volumes and congestion are greatest on the east-west facilities running parallel to the axis of the valley. The CBD attracts 27 percent of trips made by all modes during the peak hour, and during 24 hours, 34 percent of all trips have either their origin or their destination in the CBD.

Traffic volumes are normally heavy during almost all hours of the day because inadequate street and highway capacity tends to spread the peak arrival and departure times; there is a certain amount of staggering of working hours according to industry and job classification, and because almost half the labor force returns home to eat lunch on a typical day. Another notable travel characteristic is the absence of severe tidal flows, with traffic normally heavy in both directions during most

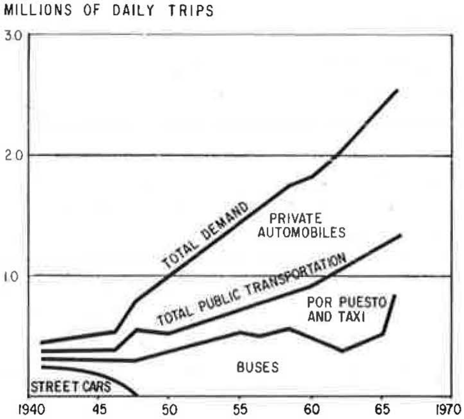

Figure 1. Transportation demand by mode.

hours. This relative absence of directional flows is attributable to the dispersion of secondary traffic generators and attractors along the length of the valley outside the CBD.

HISTORICAL DEVELOPMENT OF THE POR PUESTO SYSTEM

The relative roles of various means of transportation over the years can be seen in Figure 1. As the population of Caracas grew and the city began to spread throughout the valley, there was a lag in provision of public transportation services. Generally speaking, service to the newly developing areas was provided by one or more new private bus companies, rather than by a logical extension or expansion of existing service. The quality of new service varied greatly but was often very poor. In a short time, the haphazard and inadequate expansion of the bus system resulted in unnecessary duplication of services in some areas and virtual absence of service in others. Bus operators, sometimes completely inexperienced before they went into business, often did not follow accepted operation principles. Expanding use of the automobile soon congested the existing narrow streets, and bus schedules and speeds became highly erratic and unreliable. Consequently, the use of taxicabs was very attractive to those who could afford them and the number of taxis soon increased greatly.

A 1948 report (1) on traffic and transit in Caracas states that in that year there were approximately 37,000 vehicles registered (as compared with about 10,000 in 1937) and that there were more than 6,400 taxicabs registered in the Caracas metropolitan area—more than in the city of Chicago at that time. This unusually high number of taxicabs was directly attributed to the poor service available on the bus system. No mention is made of por puestos and it is probable that they did not exist at that time in any significant numbers.

A 1961 report (2) on transportation in Caracas, although it cautions several times that the statistical data available were limited and often unverifiable, is again critical of the bus system. It states that the routes of the lines were confused, poorly advertised and unposted, and suffered from considerable overlapping in some areas. No provision for the comfort of waiting passengers was made and long lines of passengers standing in the hot sun or rain were commonly seen. The report indicates that por puestos made their appearance sometime after 1948 and that by 1960 there were 9,600 taxicabs and 6,400 por puestos or a total of 16,000 "for hire" vehicles on the streets of Caracas. The report mentions keen competition between taxicabs, por puestos, and buses and states that there seemed to be a total lack of coordination and regulation with near anarchy in public transportation.

The maximum limitation on taxi fares imposed by governmental regulation was one of the principal factors encouraging the growth of the por puesto system. Rather than make one trip for a maximum fare of 5.00 bolivars (about $1.10) with time lost because of the need to leave the major travel corridors in order to bring the passenger to his door, it was economically attractive to taxi drivers to operate a shuttle service along the major arterials and charge each passenger carried a fare of 0.50 to 1.00 bolivar ($0.11 to $0.22). The poor bus service created a ready market for por puestos because many people were willing to pay somewhat more than bus fares for better service but could not afford the taxi fares.

PRESENT POR PUESTO SYSTEM CHARACTERISTICS

Route Coverage

The area coverage of the approximately sixty routes used by the 6,000 por puestos operating in Caracas in 1966 is shown in Figure 2. The coverage is extensive, with at least one route penetrating into virtually all the medium- and high-density areas of the city. Most routes eventually converge on the principal east-west streets and highways and there are 34 routes on the four main east-west approaches to the CBD.

A partial inventory made of these routes indicates that about 44 percent of them are less than 6 miles long (one-way), another 44 percent measure between 6 and 10 miles long, and the remaining 12 percent are between 10 and 15 miles.

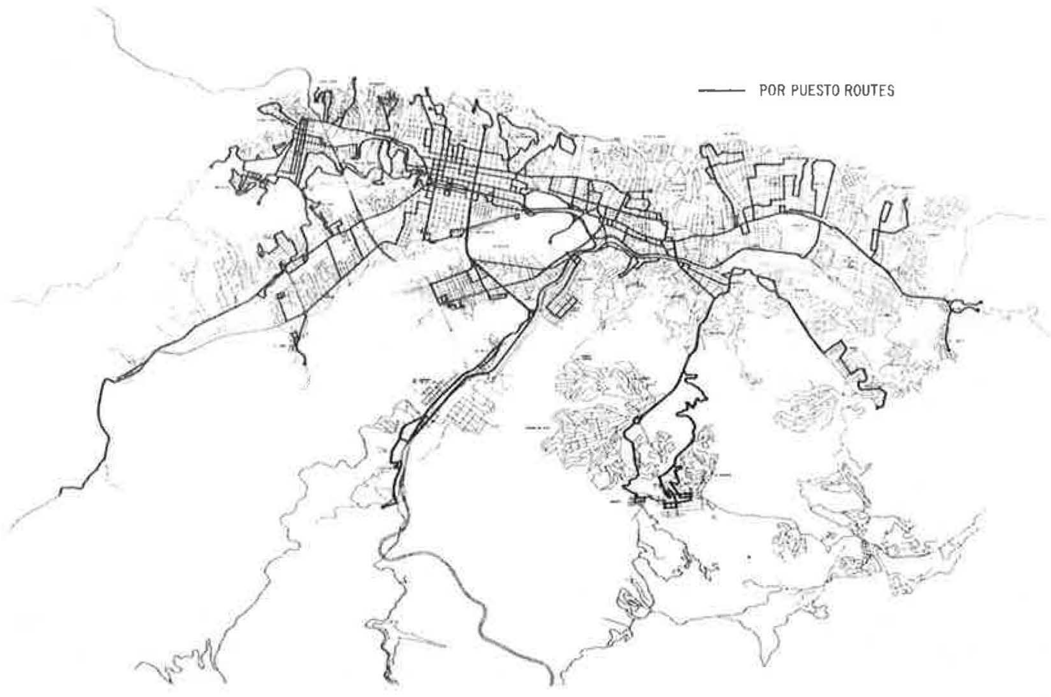

Figure 2. Por Puesto Routes.

In addition to the established por puesto services, it is estimated that about half of the 6,000 taxicabs in Caracas operate as "pirate" por puestos during peak periods. They do this by simply placing a destination signboard on the front windshield and following any of the established routes, generally one of the major east-west trunk lines. Although illegal, this practice is tolerated. It is attractive to taxi drivers because of the limit on his normal fare charges and the heavy competition for taxi passengers. When the demand for taxis is great, as during rainy periods, few convert to por puestos and most continue to operate as taxicabs.

Although por puestos drivers normally follow their designated routes, it is not unusual for them to seek out alternative streets to avoid traffic congestion, especially when all seats are taken, but only if passengers have no objection.

Operating Hours, Service Frequency, Speeds

There is considerable variation in the operating hours of the various por puesto routes. Service begins on most lines at 6:30 a.m. (although some start as early as 4:30 a.m.) and continues until 8:00 p.m. Reduced service is offered on many routes until 11:30 p.m. or midnight, and some, particularly those operating on the main east-west trunk lines, provide limited service on a 24-hour basis. A few lines operate only during peak periods in the morning and evening and at lunch time.

The frequency of service also varies significantly throughout the city, and traffic counts at key points on major arterial streets have recorded volumes ranging from about 200 to 800 por puestos per hour at different locations. Because the occupancy at maximum load points on most routes during peak periods averages from 80 to 100 percent of capacity, the effective service frequency (one or more seats available) is substantially less than the number of vehicles recorded past a point. It was found that the effective frequency on 70 percent of the lines is at least 20 vehicles per hour. Stated another way, effective headways range from 3 min down to 36 sec over 70 percent of the system during peak periods.

TABLE 1

NUMBER OF TRIPS BY MODE ACCORDING TO PURPOSE OF TRAVEL*

Mode	Purpose								
	Work	Personal Business	Social Recreation	School	Shopping	Other Home Based	Non-Home Based	Totals	Percent
Auto driver	268,026	178,861	34,650	11,875	56,562	14,772	157,874	718,620	27.3
Auto passenger	63,965	157,124	57,983	62,200	39,368	37,981	61,914	480,535	18.3
Bus passenger	287,811	245,398	15,502	132,900	52,479	33,534	37,400	805,024	30.6
Por puesto passenger	248,959	78,990	3,074	47,525	20,923	7,033	24,514	431,023	16.4
Taxi passenger	18,836	14,420	2,064	900	4,176	2,352	6,536	49,284	1.9
School bus	625	75	175	127,050	25	175	650	128,775	4.9
Truck passenger	1,415	250	0	0	0	0	250	1,975	0.1
Other minor modes	11,525	175	75	500	25	100	925	13,325	0.5
Totals	901,222	675,293	113,523	382,950	169,563	95,947	290,063	2,628,561	100.0
Percentages	34.3	25.7	4.3	14.6	6.4	3.6	11.1	100.0	–

*Note: 24-hour "linked" trips are shown. "Unlinked" trips are somewhat greater in number.

Travel time studies indicate that average por puesto speeds are virtually identical to average speeds obtained by private automobiles. Por puestos stop to discharge passengers only as requested to do so and stop to pick up passengers only when signaled from the sidewalk. The time lost during passenger boarding and alighting is compensated for by more aggressive driving habits and a tendency to take greater chances to save time than are risked by the drivers of private automobiles. Consequently, por puesto speeds are only limited by the existing congestion and during peak periods average from 10 to 30 mph on limited-access highways, 10 to 15 mph on major arterial streets, and about 5 to 10 mph in the CBD. Because por puestos do not always travel the fastest or shortest route, this does not imply that zone-to-zone travel times by por puesto are necessarily the same as those for private cars.

Trip Characteristics

Approximately 460,000 trips a day are made with por puesto passengers. This represents more than one-third of the trips made by public transportation on a typical working day. Bus passenger trips amount to approximately 810,000, whereas about 50,000 trips a day are made by taxi passengers.

The distribution of reported trip purposes for the por puesto and other modes of travel is given in Table 1. Work is by far the predominant purpose of por puesto travel. This is probably because of both the increased por puesto service available during peak periods and a greater value placed on time saved when traveling for this purpose; therefore, a greater willingness to pay the extra cost of por puesto service.

The average por puesto trip is about 3.3 miles and takes about 23 minutes, whereas the average bus trip is approximately 3.0 miles and takes over 30 minutes. These times include an allowance for walking and waiting and indicate that in Caracas use of por puestos can reduce public transportation travel times by almost one-third, on the average.

Most of the persons making por puesto trips come from families who do not own automobiles. It is interesting to note, however,

TABLE 2

DAILY TRIPS GENERATED BY DWELLING UNIT ACCORDING TO AUTOMOBILE OWNERSHIP

Type of Trip	Number of Automobiles Per Dwelling Unit				
	0	1	2	3 or more	all
Auto driver	0.13	4.48	9.60	15.35	2.49
Auto passenger	0.48	2.65	5.08	8.50	1.68
Bus passenger	3.84	1.54	0.90	0.56	2.80
Por puesto passenger	1.71	1.24	1.05	1.11	1.49
Other	0.37	1.00	0.50	1.75	0.71
Totals	6.53	10.91	18.13	27.27	9.17

as indicated in Table 2, that while the rate of bus trip production per family decreases sharply as auto ownership increases (the rate for one-car families is 40 percent of that for families without a car), por puesto trip generation is not as sensitive (the rate for one-car families is 72 percent of that for families without a car). The cause for this is probably that as family income rises, people are more willing and able to pay the costs involved in return for greater speed and comfort. Por puesto passengers come from a broader variety of educational and income levels, in contrast with much of the bus system patronage that is made up of lower income families. Por puestos have an acceptable "status" level and are used as public transportation by many people who refuse to ride the cheaper but less comfortable buses.

The CBD attracts and produces over 26 percent of the total trip ends of por puesto travel on a typical weekday. About 75 percent of por puesto travel is concentrated in the densely developed, high transportation demand corridor running along the axis of the main east-west valley and the remaining 25 percent of total por puesto trip ends are scattered throughout the remaining portions of the city.

Terminals and Boarding and Alighting Procedures

Por puestos normally pick up and discharge passengers on request anywhere along their route. There are, however, a number of terminals that have come into existence either because they are at locations where numerous lines come together and hence transfers are possible on payment of an extra fare, or because one or more major lines terminate at these locations. These terminals are all located on city streets and generally people line up during peak periods to board the por puestos.

The fact that por puestos stop whenever requested, not only on city streets but on freeways and access ramps as well, causes considerable interference to the smooth flow of traffic. Although most drivers attempt to pull into the curb, it is not unusual for them to stop in the middle of the street or to block intersections. An additional traffic hazard is caused by passengers who sometimes leave by the doors on the street side (rather than curbside) when vehicles are crowded.

Interurban and Miscellaneous Services

In addition to intracity service in Caracas, there are also por puesto lines carrying passengers to almost all major cities in Venezuela. There are three major interurban terminals, but the off-street location near the CBD is by far the major one, serving more than 80 percent of all intercity trips. Approximately 70 percent of interurban por puesto service is for trips less than two hours from Caracas. This high percentage of relatively short-haul service is caused by the fact that nearly 4,000,000 people (almost half the population of Venezuela) are concentrated within two hours' driving time of the capital. Although no statistics are available, the consensus seems to be that the number of intracity por puesto trips has been declining over the past several years while intercity trips have been increasing. On a typical working day in 1966, almost 31,000 people crossed the external cordon line around Caracas as bus passengers while por puesto passenger crossing numbered 26,600; automobile driver and passenger crossing amounted to about 58,700 trips daily.

It is possible to utilize intercity por puestos both for parcel post and messenger service. These services are unofficial, however, and are negotiated with drivers on an individual basis.

Vehicle Characteristics

Virtually all por puesto vehicles are four-door, six passenger (including driver) sedans. Normal capacity is a maximum of five fare-paying passengers but this sometimes increases to six when it is raining or small children are present. Almost all the different makes of automobiles assembled in Venezuela or imported into the country are represented in the por puesto fleet; they range from small economy compacts to luxurious hardtop convertibles.

The age of por puesto vehicles ranges from this year's latest model to vehicles 15 years old or older, with the estimated mean age for all official por puesto vehicles being nine years. This mean age would be somewhat lower if "pirate" por puestos were included because these are generally newer taxis. The physical condition of these cars varies considerably, ranging from excellent to poor. In general, the average condition might seem less than good in comparison with North American taxicab fleets but excellent in comparison with most of the local bus system or in comparison with por puesto fleets in some other countries. The care and maintenance of the por puesto is the responsibility of each individual owner. More often than not, the owner-driver also acts as his own mechanic and in most cases makes all minor repairs to his car.

ORGANIZATION AND GOVERNMENTAL REGULATION

Governmental regulation of por puestos became increasingly active after 1958 as one of a series of steps undertaken to improve public transportation and relieve traffic congestion. The por puesto industry (excluding pirates) is presently organized into about 50 "associations" or "societies" that have obtained a concession from the Ministry of Communications of the national government authorizing the associations to operate on a prescribed route with a controlled number of units. These associations vary in size from as few as 15 vehicles to more than 300 vehicles each, but most operate between 25 and 75 cars.

Most association drivers own their vehicle but some are employed on a commission basis. Drivers are required to obtain a permit and license from the Ministry of Communications and must also be approved by a municipal authority. At this time new permits are unobtainable and anyone wishing to be a por puesto operator must buy this permit from a previously licensed driver. Once a permit and license are obtained, the driver must be accepted by one of the associations.

All por puesto drivers also pay dues to a transportation union that, in return, acts as the bargaining agent for the societies with the Ministry of Communications and municipal authorities. The union also functions as a fraternal organization for its members, providing sickness, accident, and death benefits, and legal assistance in accident cases if needed.

The available accident records do not separate por puesto vehicles from others. Because of the slow operating speeds found on the congested streets, most accidents are of the property damage only type. Neither the por puesto associations nor individual drivers are required to provide insurance on their vehicle or for their passengers.

In addition to governmental control on routes and numbers of vehicles, the Ministry of Communications also regulates the fare structure of the industry and can limit the hours of operation. At present, each por puesto and taxicab is prohibited from operating on one workday during the week. This, in effect, removes 20 percent of all por puesto and taxis from streets on each working day. The intent of this regulation is not only to reduce the number of taxis and por puestos in circulation, and hence reduce traffic congestion, but also to insure that time is available for vehicle inspection, maintenance and repair.

Fare Structure

As was indicated earlier, the relationship between bus, por puesto, and taxicab fares is a significant factor in determining the patronage each mode attracts. Buses are normally the cheapest means of transportation and most buses have a basic zone fare of 0.25 bolivar (one bolivar is worth about $0.22). Long trips can involve as many as three fare zones and reach a cost of 0.75 bolivar.

Fare zones have been established on most por puesto routes and generally a charge of 0.50 bolivar is made for trips less than six miles long and 1.00 bolivar is charged for longer trips. As with all zone fare systems, short trips which cross the zone boundary are penalized by having to pay a greater fare while much longer trips that are made completely within the zone pay the lower fare. Fares are paid on boarding or on alighting or at any time in between at the whim of the passenger. No free transfers are provided and separate fares are paid when changing to another por puesto or to a bus line.

Taxicab fares normally range from a minimum charge of 3.00 bolivars to a maximum charge of 5.00 bolivars. They are, however, somewhat dependent on the negotiating ability of the passenger and such factors as time of day or night and whether or not it is raining. The same fare is charged between any two areas regardless of the number of passengers carried and regardless of the time needed to make the trip. The driver, therefore, pays the cost of congestion and lost time. Local practice is not to tip taxi drivers and consequently his only source of revenue is the fare collected.

Buses are generally used by the poorest people who of necessity are willing to put up with the slower speeds and less attractive ride. Taxicabs, and of course the privately owned automobile, provide transportation for those in higher-income brackets. Por puestos serve some poeple in both these extreme categories as well as middle-income families since they provide speed and comfort approaching that offered by the taxicab at prices only somewhat greater than bus fares.

Operating Revenues and Costs

It is difficult to compare por puesto operating revenues and costs precisely because of the wide variation among lines in such key items as working hours, patronage turnover, route miles of operation, and vehicle age and condition. Enough information is available, however, to permit drawing some general conclusions. It appears that most por puestos that are active for the entire day carry an average of from 60 to 90 passengers per day and that a probable range of revenue is from 70 to 75 bolivars per vehicle per day.

Unit por puesto operating costs have been estimated at about 1.00 bolivar per mile, including the driver's earnings or commission, which is estimated to be somewhere between 40 to 45 bolivars ($9 to $10) per day. The available inventory data indicate that the average por puesto travels about 60 to 70 miles per day, which results in a total operating cost of about 60 to 70 bolivars per vehicle per day.

It can be tentatively concluded that with the present fare structure por puesto revenues are just slightly in excess of operating costs and the return for most owner drivers consists of their daily pay rather than any real profit on their investment in the vehicle and license. Because economic factors are likely to play a major role in determining the future of the por puesto system, more refined economic analyses, including additional data gathering, are planned as part of the continuing transportation study.

FUTURE PROSPECTS

The por puesto system arose as a result of inadequate bus service; consequently, the evaluation of its future prospects should be made against the background of the planned improvements to the public transportation system. The national government has taken a variety of steps to regulate and control both the por puesto industry and to improve bus transportation. The most significant improvement to the bus sytem was the introduction of EMTSA service in 1966. The EMTSA system is owned and operated by the federal government and has a number of noticeable advantages over the previously existing private and municipally owned bus systems including newer, more comfortable equipment and 20 percent faster running times.

The EMTSA system was put into operation gradually during late 1966 and early 1967 and consisted at that time of 176 buses operating over seven routes. Since then, one more route has been added and an estimated 210 buses are now in service on a typical working day. It is planned to expand the EMTSA system as needed to meet growing transportation demand, and authorization for two additional routes is under consideration.

Based on screenline volume counts taken before and after the beginning of the EMTSA system, it is estimated that approximately 75,000 passengers per day or 14 percent of por puesto users were diverted from por puestos to EMTSA buses. Because a cheaper bus alternative existed previously, the switch in mode can be attributed primarily to the significant improvement in bus speed, cleanliness, and comfort rather than the cost advantage.

The final design for the first line of the Caracas Metro, or rail rapid-transit system, was begun in April 1968 and it is expected that the 12.4 mile Catia-Petare line will be in full service by 1975. The impact that this high-speed underground rapid-transit system will have on por puesto operation has been evaluated at two levels: (a) 1975 when just the east-west Catia-Petare line is in service and is basically in competition with existing bus and por puesto systems for public transportation passengers; and (b) 1990 when the entire 4-line, 30-mile rapid transit system is in operation and it is assumed that a coordinated network of surface public transportation has been integrated with the rapid transit lines.

The Catia-Petare line will serve the highest travel demand corridor in the city, where at present more than 30 percent of the population and almost 45 percent of total employment are located within easy walking distance of the line. It is estimated that by 1975 this line will attract 642,700 riders daily and that about 40 percent of those would be por puesto patrons if no Metro service were to be provided.

Forecasts indicate that by 1990 the population of Caracas will have grown to over 4 million inhabitants and that nearly 3,200,000 trips will be made by public transportation on a typical working day. About 2,160,000 of these trips will use the Metro system for at least a part of their journeys. It is expected that an integrated surface transit system will play a vital role in feeding and distributing patrons to and from the Metro stations.

CONCLUSIONS

It was concluded from the analysis of probable conditions in 1975 and 1990 that as a result of government policies toward limiting and controlling por puesto and taxi operations and as a result of the provision of improved bus service and a rail rapid-transit system, the por puesto will become progressively less important as a means of transportation in Caracas. There is evidence that the number of por puestos in operation has already declined. The future role of the system will probably be limited primarily to station feeder and distribution service, with perhaps some lines also providing complementary trunk service in the few remaining parts of the city with light- or medium-density development.

It is probable that boarding and alighting will be restricted to specified stop areas. The details of route coverage and probable number of vehicles needed for the future por puesto network are now being determined as part of the OMT's comprehensive transportation plan for Caracas.

Ultimately, the continued economic growth and development of the city may force the abandonment of the por puesto system on financial grounds as happened in the United States. As other employment opportunities grow, there will be fewer people willing to work the long hours at the low earnings needed to keep por puesto fares competitive with buses. Driver's income at present constitutes more than 60 percent of por puesto operating costs and the industry is barely able to recover operating costs from revenues. Any significant improvement in income levels is likely to hasten the replacement of por puestos by small- or medium-sized buses.

It should be recognized, however, that the use of por puestos as part of a public transportation system has several attractive aspects, including great flexibility in routing and scheduling, operating speeds equal to that of private automobiles, a seat for every passenger, and ability to provide frequent service at short headways. With transportation demand expected to grow to 2.5 times the existing level by 1990, it is the author's hope that a means can be found—perhaps through the use of nine-passenger limousines or government subsidy—to keep por puestos serving Caracas for many years to come.

True, the economic situation is not encouraging but public transportation systems are subsidized in many cities throughout the world today as a public service. Although the same number of people who now use por puestos could theoretically be carried by a much smaller number of buses, this could be done only with a significant decrease in frequency, speed, and other levels of service. These are the very characteristics that make the por puesto a much stronger competitor of the private car. Indeed, with the changed attitudes toward public transportation which have come about since jitney taxis were abandoned, a revival of a modified form of the system in North America is worth consideration. This could possibly be done as a first step toward a more sophisticated computer-controlled "dial-a-cab" system. Such a revival might also provide important social benefits such as creating jobs as drivers for the unskilled and improved transportation between slum areas and employment centers.

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An Analysis of Central Business District Pedestrian Circulation Patterns

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This paper examines the patterns of pedestrian circulation within the Toronto CBD for two pedestrian trip types. The first part of the paper develops a model of the pedestrian demands resulting from the location of the transportation system terminals and the configuration of office locations within Toronto. The model represents a standard application of the well-known gravity model formulation. The friction factors developed for the walking trips associated with each transportation mode are given.

The gravity model is also used to develop a simulation of the lunch hour pedestrian circulation patterns of the CBD office workers. However, a different approach is employed to calibrate the gravity model because the values of attraction were initially unknown. The iterative approach used is described in the paper. The friction factors used in the final calibration of the gravity model are given along with the generation and attraction rates for this type of CBD pedestrian trip. Finally, the paper presents information on the speed-volume-density characteristics of pedestrian flow.

•VERY little effort has been devoted to the analysis of patterns of pedestrain circulation within the central business districts of large urban areas. Although the amount of land consumed by pedestrian facilities in the CBD is insignificant when compared with the requirements of other transportation modes, the pedestrian circulation system is playing an increasingly important role in the articulation of CBD activities.

Morris (1), Benepe (2), and Stuart (3) have examined the role of the pedestrian in the CBD from the viewpoint of the city planner. All of these authors have noted the need for simple, quantitative models for predicting the pedestrian circulation patterns associated with CBD land-use plans. Morris (4) and Hill (5) have studied certain features of pedestrian circulation, but these studies were not sufficiently comprehensive to permit generalizations to be made for other urban areas.

The objective of this paper is to describe a study of pedestrian circulation in the Toronto CBD performed to develop predictive models for journey to work and lunch hour pedestrian circulation demands.

STUDY DESIGN

Information on pedestrian circulation characteristics was obtained by an office-based, questionnaire-type survey. Two distinct questionnaires were developed for distribution to selected office locations; one for the journey to work, and the other for the lunch hour circulation behavior of CBD office workers. Each type contained a series of questions and a street map of the CBD.

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There were 15,000 questionnaires distributed to 54 separate office buildings. Usable work trip questionnaires represented about 9 percent of the office work force, whereas the usable lunch hour circulation questionnaires represented about 5 percent of the work force.

JOURNEY TO WORK

The principal objective of this part of the study was to develop a model of the pedestrian demands resulting from the locations of the terminals of the metropolitan-wide transportation system and the configuration of office locations within the Toronto CBD. The model developed assumes a gross modal split and distributes trips from office locations to all the corridor transportation facility terminals within the CBD. The model developed represents a standard application of the well-known gravity model formulation.

The CBD street network and pedestrian ways were coded into a network consisting of 458 centroids arranged essentially in a grid configuration. Office zones were made up of facing pairs of block-faces with the centroid located at the midblock. The office zones were linked from block-face to block-face, and from block-faces to transportation centroids.

The inputs to the gravity model were the generation and attraction rates of office and transportation zones, a family of friction factors, and a set of minimum-path walking trees from all office centroids to all transportation zones. Office generation rates for each mode were based on employment figures for each office zone and the existing modal split proportions. Attraction rates for the transportation terminals were based on observed exit volumes associated with each transportation terminal. The attraction of a transportation terminal of a mode was assumed to be proportional to the fraction of all mode users exiting from that terminal, and to the total office employment. For example, the attraction of a subway zone was calculated from

$$A_j = \left(\frac{SV_j}{\sum_j SV_j} \right) \times 0.486 \text{ (total office employment)}$$

where

SV_j = subway volume observed exiting at j, and

j = number of subway stations.

The constant 0.486 is the existing proportion of CBD office workers traveling by subway.

A comparison of the trip length distribution curves from the final calibration of the gravity model with the actual trip length distributions indicated generally good agreement between the two for the walking trips associated with the four corridor transportation modes. Figure 1 shows the friction factors used in the final calibration of the gravity model, as well as the exponents of the linear portions of the curves.

Trips were assigned to the network using an all-or-nothing procedure and compared with the survey ground-count volumes. Generally good agreement was obtained between the assigned and observed volumes. A completely objective comparison was not possible as the ground counts included pedestrians involved in walking trips other than completing the journey to work.

LUNCH HOUR CIRCULATION PATTERNS

The gravity model was also used to develop a simulation of the lunch hour pedestrian circulation patterns of the CBD office workers. However, it was necessary to alter the usual approach to calibrating the gravity model because the values of attraction (A_j's) were unknown initially. Assuming that the gravity model is an accurate representation of the way in which people actually choose the destination of a trip, all trips in any survey sample will have already been through a real life gravity type distribution. The number of trips in a sample attracted to any destination is not a value of the attraction but the value of attraction discounted by the separation of the destination from the origin where the sample was taken.

The gravity model formulation may be expressed in the following alternate manner:

$$A_j = \frac{A_j^*}{\left(\frac{\sum_{i=1}^{n} P_i \cdot F_{ij}}{\sum_{j=1}^{n} A_j \cdot F_{ij}}\right)}$$

where

A_j = unknown attraction of zone j,

A_j^* = known attraction force from the survey,

P_i = known trip production of zone i from survey, and

F_{ij} = friction factor for distance i - j.

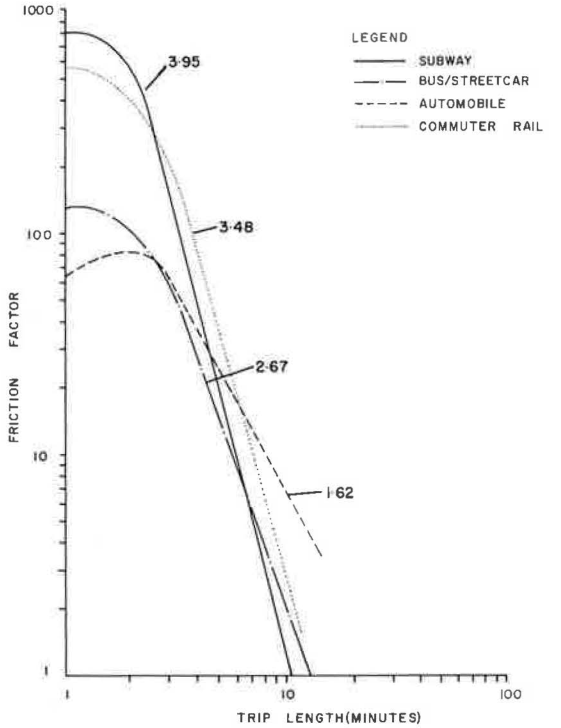

Figure 1. Terminal walking time friction factors.

This equation in A_j may be solved by an iterative process. A value of A_j may be estimated and inserted in the right-hand side of the equation and a new value of A_j generated, and the process continued until the A_j's are identical. The friction factors are also unknown and the iterative process must also generate these. It is possible to iterate the model successfully on two unknowns because the model is very much more sensitive to a change in F_{ij} than to a change in A_j and therefore tends to converge to a stable solution fairly rapidly.

The magnitudes of A_j were obtained by iterating several runs of the gravity model on the survey data. Then these A_j values were used with areawide employment and land-use data to obtain a full-scale simulation of pedestrian movements. The gravity model was calibrated to the survey data for three trip stages; (a) office to shop, (b) shop to shop, and (c) shop to office. Trip productions and attractions and trip length frequency distributions for each stage were tabulated from the survey data for use as inputs to the calibration.

The minimum-path measure of separation used in the calibration incorporated walking time, waiting time at street intersections, street attractiveness, and a turn penalty. This was necessary because it was found that minimum time paths were not followed by pedestrians for this trip type. The particular measure used was developed from the walking paths indicated on a random sample of the questionnaires and had the form

$$d_{ij} = T + 0.5W + 0.4(T - A) + T_u$$

where

d_{ij} = measure of separation used in gravity model,

T = walking time (minutes),

W = waiting time (minutes),

A = attractiveness factor (F) times walking time in minutes,

F = length of attractive features on both sides of a link divided by twice the length of a link, and

T_u = turn penalty of 0.01 minutes for each turn made.

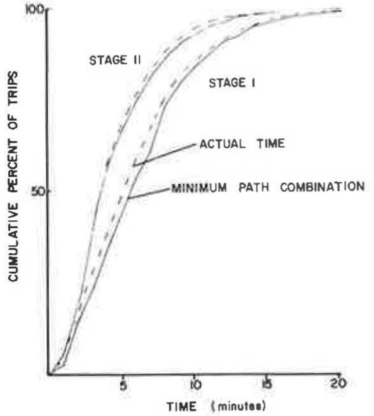

Figure 2. Walking time distributions for actual and minimum path measure.

Figure 2 shows the walking time frequency distributions for actual walking times and for the minimum-path measure of separation for the first and second stages of the lunch hour trip. The third stage distribution was identical with the first stage distribution. Table 1 provides a comparison of the actual time distributions and the minimum path distributions.

The questionnaire survey revealed that employees leaving their offices at lunch hour made an average of 1.7 visits to shops, restaurants, etc. Table 2 shows a breakdown of these rates by purpose of shopping. No direct measurements of attraction were made because of the difficulties of obtaining a large enough sample of door counts.

Table 3 provides estimates of the gross trip attraction rates for the first three trip purposes of Table 2. These rates were determined by aggregating land-use and employment data and trip-end information from the survey. The employment information for the department stores is inflated because it includes workers in mail order sections and offices as well as sales clerks. The employment figure for retail shops is low because the available land-use information does not include all stores with employment of less than 10 persons.

Attraction rates for personal business trips to banks, trust companies, and the City Hall could not be estimated because the land-use data available included all workers at these locations, the majority of whom were not employed in customer service. It has been pointed out that since it was not possible to define completely the attractions in terms of land use and employment, the gravity model was calibrated to the survey data and the calibrated model was then used for the full-scale simulation.

A minimum path assignment was included in the final iteration of the gravity model calibrated on the survey data, and the assigned volume on each link matched the minimum path assignment to a high degree as indicated by the following correlation: Gravity model volume = 0.97 + 1.036 × minimum path assignment volume, $R^2 = 0.987$. The number of trips attracted to each zone in the model was identical with the number of trips in the sample.

The output of the final run of the gravity model calibrated to the survey data was (a) a set of values of the attraction of each zone for each stage of the trip, (b) a set of friction factors for each stage, and (c) a value of accessibility of each zone for each stage. The accessibility measure is the denominator of the gravity model and is a measure of the relative strength of all the attractors surrounding a zone of trip generation.

Figure 3 shows the proportion of employees leaving a building as a function of the first stage accessibility and it illustrates the nonlinear nature of this relationship.

TABLE 1

COMPARISON OF TRIP TIME DISTRIBUTIONS

Stage		Mean Trip Length	Median Trip Length
Stage 1 (office to shop)	Actual	6.0	5.2
	Minimum path	6.4	5.6
Stage 2 (shop to shop)	Actual	4.4	3.5
	Minimum path	4.5	3.5
Stage 3 (shop to office)	Actual	6.9	6.3
	Minimum path	7.0	6.6
Total trip	Actual	15.9	15.0
	Minimum path	16.5	15.5

TABLE 2

TRIP PURPOSE BREAKDOWN

Activity	Visits Per Head
Department store	0.57
Retail shop	0.36
Restaurant	0.36
Personal business	0.29
Recreational stop	0.06
Recreational walk	0.05
Transportation	0.01
Total	1.70

TABLE 3

TRIP ATTRACTION RATES

Trip Goal	Trips Attracted	Gross Floor Area	Employment	Trips Attracted (per 1000 sq ft)	Trips Attracted (per employee)
Department store	39,000	2,173,000	16,500	13.3	1.8
Retail shop	18,000	1,273,000	3,650	14.1	4.9
Restaurant	18,500	1,522,000		12.1	

Although the accessibility measure is an arbitrary value, the saturation value at which maximum generation is reached may change from place to place, but the shape of the curve will remain the same.

The implications of Figure 3 are more clearly understood by drawing isopleths representing the generating intensity of each part of the CBD. Figure 4 shows the contours of this primary generation rate for the CBD area. Figure 4 also shows that the area of maximum generation is centered around the major department stores with an extension north and south along Yonge Street which has the principal concentration of retail trade establishments.

An attempt was made to relate the value of the attraction (A_j) generated by the gravity model for each trip purpose to the land-use and employment characteristics of each zone by multiple regression analysis. This analysis failed to produce a meaningful result for the majority of zones with a low value of attraction because the standard error of estimate was of the same order of magnitude as the value of attraction. The principal reason for this failure is that the land-use and employment data available were not sufficiently accurate, particularly for those zones containing a large number of small establishments and mixed land uses.

Figure 5 shows the friction factors developed for each stage of the lunch hour trip with the exponents of the linear portion of each curve. The tangent gradients on the first and third stages of the trip are virtually identical showing that these trip stages may be interchanged, the outward distribution being the same as the inward distribution. The friction factors for the intermediate stage have a flatter tangent which shows that people are more indifferent to walking between shops than leaving the office. However, the curve steepens considerably after the 12-min interval showing that they will not walk much further than this distance between shops.

The final test of the simulation model was a full-scale run using the total office employment in the study area as an input. Using the primary generation rate curve of Figure 3 and the total office employment, the number of people making trips from each zone was determined. The trip attraction of each zone was the value of A_j determined from the final run of the survey gravity model, and the friction factors used were those for this run. A simple gravity model distribution yielded the number of trips to each

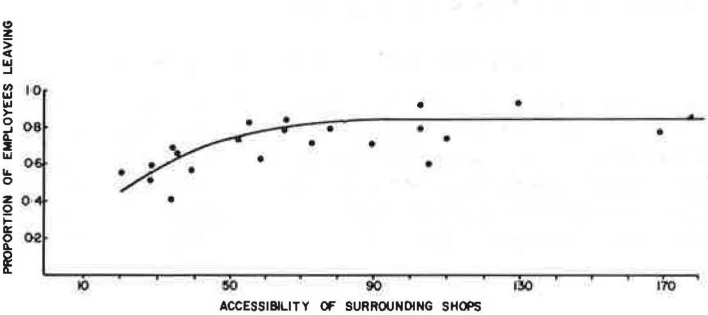

Figure 3. Primary generation rate from office buildings.

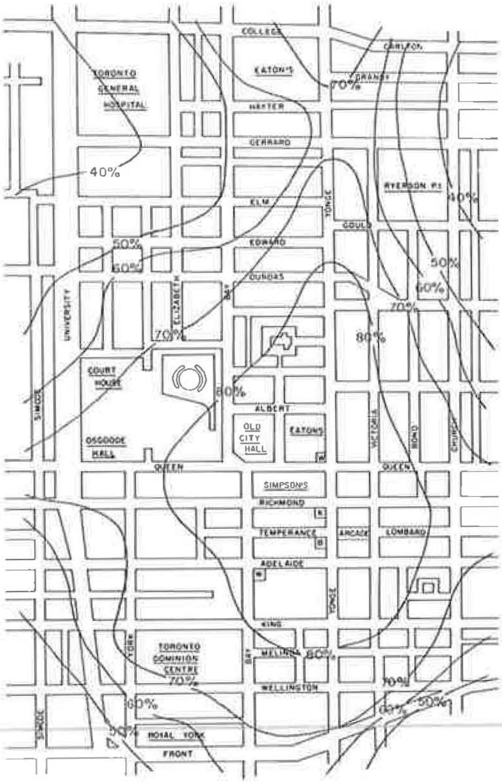

Figure 4. Primary generation rate contours.

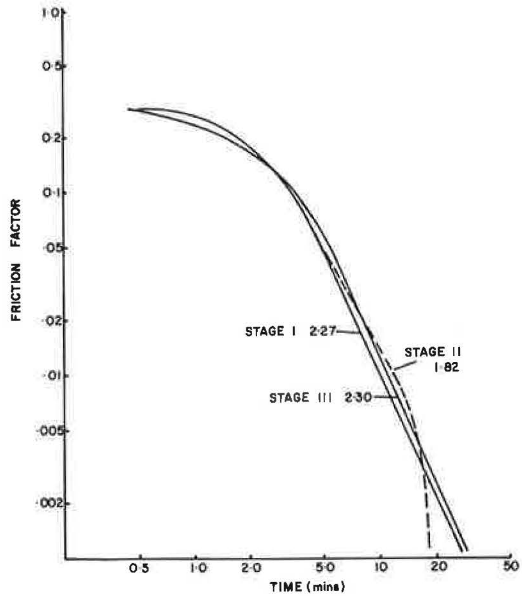

Figure 5. Friction factors for lunch-hour trips.

zone and an assignment of the trips to each zone.

A second distribution between shops was made by taking the first stage arrivals at each zone and applying the uniform secondary generation rate (0.7) to give the second stage generation. This was then used as the input for a second stage gravity distribution, that yielded another assignment and number of trips attracted. Because the survey had shown that the final stage was similar to the initial stage, no further distribution was made and the final link volumes were obtained by doubling the first stage volumes and by adding the second stage volumes. There was good agreement between the assigned volumes and the control counts suggesting that the calibrated gravity model was a reasonable approximation of the lunch hour circulation patterns of office workers.

North of Queen Street, the assigned volumes were lower than the control counts and much of the discrepancy could be explained by the nature of the land uses. There are large institutions such as Ryerson Polytechnic and the hospital complex on University Avenue that are generators of lunch hour trips although they are not offices and are therefore not included in the full-scale simulation.

SPEED-DENSITY FLOW RELATIONS

Figure 6 shows the relationships between walking speed and pedestrian density that have been established for various types of pedestrian components. Figure 7 is derived from Figure 6 and shows the relationship between speed and flow for the several types of facility. This relationship shows that the maximum capacity of all facilities is about the same. There are 1400 to 1500 persons per ft width per hour at approximately 2 to 2.5 ft per sec with a maximum density of approximately 0.2 persons per sq ft.

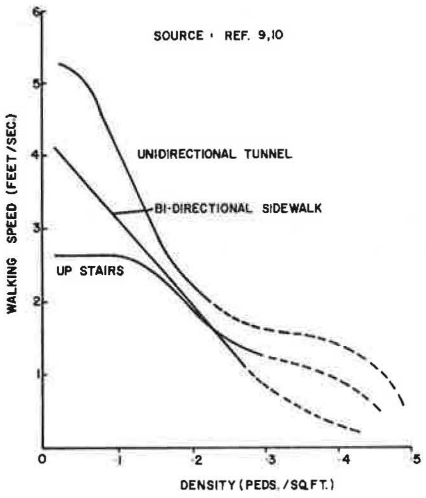

Figure 6. Pedestrian speed-density relations.

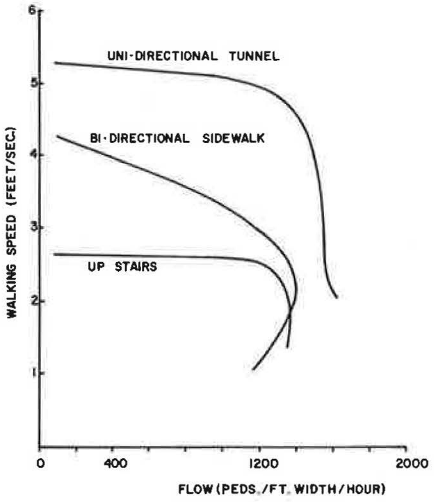

Figure 7. Pedestrian speed-flow relations.

SUMMARY

The central business districts of many medium and large urban areas are being modified to provide for the separation of pedestrian and vehicular traffic in order to improve pedestrian environment and to increase the efficiency of vehicular circulation. In addition, a number of urban centers are examining the feasibility of improving intra-CBD circulation of persons through the installation of mechanized transportation devices.

The investigation described in this paper demonstrates the validity of using a gravity model to simulate the patterns of pedestrian movement for two types of trips. Models such as these provide an objective basis for evaluating the usefulness of any proposals for improving pedestrian circulation within the CBD.

It is well known that the functions of many CBD's are becoming specialized and that the principal function in the future will be the office function. In addition, the other major CBD activity, retail trade, is becoming increasingly dependent on the CBD office work force for sales. The model developed for the lunch hour trip patterns of office workers provides a basis for examining the impact of various CBD land development proposals on pedestrian volumes, and consequently their probable impact on existing or proposed retail trade areas.

The generation rate-accessibility relation of Figure 3 and the friction factors shown in Figures 1 and 5 provide important information that could be employed in the CBD's of cities with a structure similar to that of Toronto. In other areas it would be a simple matter to conduct an office-based survey of the type described in this paper to generate data to calibrate a suitable model.

ACKNOWLEDGMENT

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A Markovian Analysis of Urban Travel Behavior: Pattern Response by Socioeconomic-Occupational Groups

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Knowledge concerning urban movement patterns is relevant in the expansion of planning principles that relate provision of transportation facilities to user demands. The purpose of this paper is to analyze the urban travel behavior of individuals grouped into categories of similar socioeconomic-occupational class. Socioeconomic neighborhood groups are formed vis-a-vis the application of a statistical grouping procedure to socioeconomic variables reflecting household status. Four types of residential areas are defined. However, it cannot be assumed that all people in a given census tract have the same class standing. Therefore, the occupation of the household head was used as a measure to isolate individual variation in socioeconomic status. Ten occupational groups are included. This resulted in 40 combinations of socioeconomic-occupation class groups based on neighborhood and occupation. Principal components analysis was applied to a matrix of trip linkages based on trip purpose for each of the groups. A modified Ward's grouping procedure was applied to a matrix of trip linkages based on trip purpose for each of the groups, resulting in three travel behavior sets.

Each travel behavior set was then analyzed using trip linkage distributions generated by Markov chain analysis. Equilibrium vectors for each of the three groups were examined to elicit the trip pattern differences. The resulting analysis defined significant differences between travel patterns of the three groups. Results indicate that the trip behavior varies significantly in purpose, linkages, and length. A similar analysis was applied to an examination of zonal interchanges for each socioeconomic-occupational group.

•OF major interest to urban transportation planners, urban planners, and transportation geographers is the study of urban travel flows. Knowledge concerning urban movement patterns is relevant to the expansion of planning principles that relate provision of transportation facilities to the user's demands. In recent years increasing attention has been placed on the analysis of individual urban travel behavior in an attempt to find ordering factors with which urban planners, transportation planners, and others can better understand and forecast travel patterns in the city.

The variations in trip movement of individuals may be considered to reflect personal preferences in their travel. Similar preferences arise for like groups of people, providing a basis for general models of intraurban travel patterns (5, chapters 4 and 5).

The purpose of this paper is to analyze the urban travel behavior of sets of individuals having similar socioeconomic characteristics. The first phase deals with the problem of defining socioeconomic groups. Those groups having similar trip structure are then defined. Using a time-dependent probabilistic model to describe trip movements of individuals within each group, differences and similarities between these

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groups are identified. This investigation deals with variation based on trip purposes, variation in CBD versus non-CBD trips, and variation in zonal interchange.

METHOD OF INVESTIGATION

It should be apparent that the first and most important step is to determine an accurate measure of space preferences, as reflected by socioeconomic status, because this is the delineating factor in grouping individuals with similar travel patterns. To accomplish this, socioeconomic data were gathered from the 1960 census for each census tract in Waco, Texas. After converting the data into percentage form, principal components analysis was applied to group those variables covarying; that is, those variables whose percentages varied in approximately the same manner for each of the census tracts. Based on this analysis, each census tract was classified as a particular type of residential neighborhood within the city. In order to link those census tracts of similar residential type, a modified Ward's grouping routine was applied to the component groups—the program utilized in this analysis was CONGROUP (4). Four groups of residential areas in Waco were identified.

The variables used in identifying socioeconomic groups included those measuring household, ethnic, occupational, and economic characteristics of each zone. The principal components analysis yielded four significant clusters of variables. The first was interpreted as representing upper socioeconomic characteristics, while the second exhibited lower socioeconomic characteristics. The third component identified middle class neighborhoods, and the fourth component strongly reflected ethnic characteristics.

Based on the grouping analysis, four groups of census tracts were identified. The first was characterized by high income, quality housing, and white collar occupations. The majority of the tracts were grouped into the middle class socioeconomic group, as might be expected. Two lower socioeconomic residential groups were recognized, differentiated by ethnic affiliation.

It cannot be assumed that all people in a given census tract have the same socioeconomic standing. Therefore, the occupation of the household head was used as a further measure of socioeconomic status to decrease within group variance. Thus, the combination of social area analysis and occupational position was used to measure socioeconomic status, which presumably reflects individual space preferences (6).

In the Waco Transportation Study (7), ten occupational groups were listed, including a miscellaneous category consisting primarily of housewives and students. Coupled with the four residential area types, there were 40 combinations of socioeconomic class groups based on neighborhood and occupation. In order to define those class groups with similar travel patterns, a matrix of trip linkages based on trip purpose for each of the groups was subjected to the modified Ward's grouping routine after being converted to percentages to reduce the influence of varying sample sizes. Table 1 defines the form of the data matrix that was operated on to delineate three classes of trip makers.

VARIATION IN TRIP PURPOSE

Preliminary Analysis

The grouping of the 40 socioeconomic-occupational groups according to similar trip purpose structure resulted in a reduction to three classes. The socioeconomic-occupational groups found in each class are given in Table 2. The first consisted of those people employed in professional and white collar occupations regardless of neighborhood, as well as middle-status workers from better residential areas. Also included were housewives living in upper socioeconomic neighborhoods.

Individuals with blue collar occupations, particularly those living in lower socioeconomic residential areas, made up the majority of the second class. Predominant were the service workers in all areas and the laborers in the low-status areas of the city.

The last class embodied the miscellaneous occupation category of all but the upper-status residential areas. This category consisted primarily of housewives and students, and therefore may be termed nonworkers.

TABLE 1

SOCIOECONOMIC-OCCUPATIONAL—TRIP LINKAGE INPUT MATRIX
SOCIOECONOMIC-OCCUPATIONAL CLASSES

Trip Linkages		S (1)	S (2)	S (3)	....	S (10)	S (11)	....	S (J)	....	S (40)	
		RA (1) OC (1)	RA (1) OC (2)	RA (1) OC (3)	....	RA (1) OC(10)	RA (2) OC (1)	....	RA (K) OC (L)	....	RA (4) OC(10)	$\sum_j X_{ij}$
T(1)	P (1) to P (1)	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$	....	$X_{1,10}$	$X_{1,11}$	....	$X_{1,j}$	....	$X_{1,40}$	$\sum_j X_{1j}$
T(2)	P (1) to P (2)	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$	....	$X_{2,10}$	$X_{2,11}$	....	$X_{2,j}$	....	$X_{2,40}$	$\sum_j X_{2j}$
T(3)	P (1) to P (3)	$X_{3,1}$	$X_{3,2}$	$X_{3,3}$	....	$X_{3,10}$	$X_{3,11}$	....	$X_{3,j}$	....	$X_{3,40}$	$\sum_j X_{3j}$
.	.	.	.	.		.	.		.		.	.
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.	.	.	.	.		.	.		.		.	.
T(11)	P (2) to P (1)	$X_{11,1}$	$X_{11,2}$	$X_{11,3}$	....	$X_{11,10}$	$X_{11,11}$	....	$X_{11,j}$	....	$X_{11,40}$	$\sum_j X_{11,j}$
.	.	.	.	.		.	.		.		.	.
.	.	.	.	.		.	.		.		.	.
.	.	.	.	.		.	.		.		.	.
T(I)	P(M) to P(N)	$X_{i,1}$	$X_{i,2}$	$X_{i,3}$	....	$X_{i,10}$	$X_{i,11}$	....	X_{ij}	....	$X_{i,40}$	$\sum_j X_{ij}$
.	.	.	.	.		.	.		.		.	.
.	.	.	.	.		.	.		.		.	.
.	.	.	.	.		.	.		.		.	.
T(100)	P(10) to P(10)	$X_{100,1}$	$X_{100,2}$	$X_{100,3}$	....	$X_{100,10}$	$X_{100,11}$	....	$X_{100,j}$	....	$X_{100,40}$	$\sum_j X_{100,j}$
	$\sum_i X_{ij}$	$\sum_i X_{i1}$	$\sum_i X_{12}$	$\sum_i 13$	....	$\sum_i i,10$	$\sum_i i,11$	....	$\sum_i X_{ij}$	....	$\sum_i X_{i,40}$	

RA - Residential Area

OC - Occupational Classification

P - Purpose of Trip

$\sum_{i=1}^{100} X_{ij}$ = Total number of trips by the j^{th} social class.

$\sum_{j=1}^{40} X_{ij}$ = Total number of trips in the i^{th} trip linkage.

$X_{ij} / \sum_{i=1}^{100} X_{ij}$ = Percentage of trips in the i^{th} trip link by the j^{th} social class group.

The original data matrices were transformed into transition probability matrices as shown in Tables 3, 4, and 5 (2, p. 24-42). That is, each entry represents the probability that a person within that group will move from an origin purpose (row) to a destination purpose (column) during some time period.

An examination of the three transition probability matrices revealed several class differences. In the high occupation class, people who began their trip at home had a probability of 0.38 that they were leaving for work. Other destinations from home with high probabilities were those serving passenger (0.16), social-recreation (0.15), and

TABLE 2

ELEMENTS OF TRIP CLASSES

Occupational Categories	Residential Area I by Group (lower white)	Residential Area II by Group (middle white)	Residential Area III by Group (lower Negro)	Residential Area IV by Group (upper white)
Professional	1	1	1	1
Administrative	1	1	1	1
Clerical	1	1	1	1
Sales	1	1	1	1
Skilled laborers	1	1	2	1
Semiskilled laborers	2	1	1	1
Unskilled laborers	2	1	2	1
Protective services	2	1	2	2
Personal services	2	2	2	2
Miscellaneous (housewives and students)	3	3	3	1

TABLE 3

CLASS 1—HIGH OCCUPATIONAL STATUS PREDOMINANT
9 × 9 TRIP PURPOSE MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5	6	7	8	9
Home	0.00[a]	0.38	0.09	0.01	0.06	0.15	0.02	0.12	0.16
Work	0.55	0.18	0.05	0.00[a]	0.00[a]	0.02	0.11	0.04	0.05
Personal business	0.44	0.12	0.18	0.01	0.01	0.06	0.03	0.11	0.04
Medical-dental	0.57	0.09	0.05	0.03	0.00	0.05	0.05	0.11	0.04
School	0.78	0.03	0.01	0.02	0.01	0.07	0.03	0.03	0.02
Social-recreation	0.68	0.03	0.03	0.00[a]	0.00[a]	0.14	0.02	0.05	0.04
Eat meal	0.23	0.56	0.04	0.00	0.01	0.04	0.01	0.05	0.05
Shop	0.64	0.03	0.05	0.00[a]	0.00[a]	0.05	0.02	0.18	0.03
Serve passenger	0.46	0.18	0.03	0.01	0.01	0.04	0.03	0.05	0.20

[a]Less than 0.005

TABLE 4

CLASS 2—LOW OCCUPATIONAL STATUS PREDOMINANT
9 × 9 TRIP PURPOSE MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5	6	7	8	9
Home	0.00	0.59	0.06	0.01	0.00[a]	0.08	0.01	0.09	0.15
Work	0.78	0.03	0.02	0.00[a]	0.00	0.01	0.04	0.05	0.06
Personal business	0.56	0.06	0.13	0.00	0.00	0.05	0.02	0.12	0.05
Medical-dental	0.69	0.00	0.13	0.00	0.00	0.00	0.00	0.06	0.12
School	0.67	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Social-recreation	0.69	0.01	0.05	0.00	0.00	0.10	0.02	0.07	0.05
Eat meal	0.20	0.56	0.02	0.00	0.00	0.04	0.04	0.08	0.06
Shop	0.68	0.07	0.05	0.01	0.00	0.04	0.02	0.13	0.02
Serve passenger	0.48	0.19	0.03	0.01	0.00	0.03	0.00[a]	0.03	0.23

[a]Less than 0.005

TABLE 5

CLASS 3—HOUSEWIVES AND STUDENTS
9 × 9 TRIP PURPOSE MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5	6	7	8	9
Home	0.00[a]	0.03	0.10	0.02	0.27	0.24	0.02	0.17	0.15
Work	0.74	0.02	0.03	0.00	0.03	0.04	0.08	0.02	0.04
Personal business	0.49	0.00[a]	0.21	0.01	0.01	0.07	0.02	0.16	0.04
Medical-dental	0.55	0.01	0.06	0.01	0.02	0.11	0.01	0.18	0.04
School	0.80	0.01	0.01	0.00[a]	0.02	0.07	0.03	0.04	0.02
Social-recreation	0.65	0.00[a]	0.03	0.01	0.02	0.17	0.02	0.07	0.04
Eat meal	0.51	0.04	0.06	0.00	0.10	0.15	0.01	0.09	0.04
Shop	0.62	0.01	0.05	0.00[a]	0.00[a]	0.07	0.02	0.19	0.04
Serve passenger	0.55	0.01	0.04	0.01	0.03	0.06	0.01	0.08	0.20

[a]Less than 0.005

shopping (0.12). The majority of trips have the home as a destination. An exception is the purpose of eat meal, which has only a 0.23 probability of going home but has a 0.56 probability of going to work. The other highly linked trip purposes for this class include (a) work with work and eat meal; (b) personal business with itself, work, and shop; (c) medical-dental with shop; (d) social-recreation with itself; (e) shop with shop; and (f) serve passenger with itself and with work.

The individuals in the blue collar-service occupation class (2) have a greater probability of leaving for work (0.59) than the first group. This group also has a higher probability of returning home than Class 1. This seems to imply more singularity in trip purpose when compared to Class 1. There is also a smaller proportion of trips for medical-dental purposes, possibly for economic reasons. Other important linkages include (a) personal business with itself and shop; (b) medical-dental with itself and serve passenger; (c) social-recreation with itself; (d) eat meal with work; (e) shop with shop; and (f) serve passenger with itself and work.

The third class, consisting mainly of housewives and students, has a unique trip structure in that the purpose to work is of little importance. The purpose of home continues to dominate as the primary destination, but from home trips are primarily for the purposes of school (0.27), social-recreation (0.24), and shopping (0.17), rather than for work (0.03). The purposes of shopping and social-recreation exhibit high linkages with most of the other purposes when compared to the other classes. The major linkages other than with home purpose are (a) personal business with itself and shop; (b) medical-dental with shop and social-recreation; (c) social-recreation with itself; (d) eat meal with social-recreation, school, and shop; (e) shop with shop; and (f) serve passenger with itself.

When examining all classes, it is clear that home and work purposes dominate for both origin and destination purposes. The averages for the three groups were 59, 69, and 41 percent, respectively, for both to and from home and work purposes. All three groups had over one-third of their origin and destination purposes related to the home, pointing out its significance as a base for the daily trips of the people regardless of their occupation.

Simple Markov Chain Analysis

To further examine the trip structure of the three groups, their urban travel movements were conceptualized as satisfying the conditions of a Markovian process. It may be assumed that the trip purposes within the urban system represent states that a tripmaker may choose as a trip goal. It is also logical to posit that given a tripmaker in a particular state i, there is an associated probability, P_{ij}, that he will move to another state j, in some time period t, and this movement is independent of where he was in any previous time period. Given these assumptions, the transition matrices may be used as a basic input to the Markov model, with the purposes viewed as states and the actual trip linkages as the associated probabilities of moving between states (1, 3).

The Markov chain model also yields the limiting matrix. This matrix may be interpreted as the percentage of trips that on the average have the given purpose as their destination. In other words, it gives the probability of being in a given state after many trips have taken place. Because all rows are similar in the limiting matrix, a row of the matrix is generally termed the equilibrium vector.

The equilibrium vectors for the three classes and the aggregate data are given in Table 6. All three have the home as the purpose state most likely to be occupied, but the high occupation class has a lower percentage than the others. It is also lower than Class 2 in the expected percentage at the work purpose, and higher for such purposes as personal business, social-recreation, eat meal, and shop. This suggests that individuals in the middle-to-high socioeconomic group have a more diverse trip pattern in relation to purpose than do those people in the lower socioeconomic groups, where the home and work states predominate. The people in the housewife-student class are found primarily in the school, social-recreation, personal business, and shop states, and have very few people in the work state.

TABLE 6

EQUILIBRIUM VECTORS FOR TRIP PURPOSE BY CLASS

Purpose	Class 1 High Occupation (percent)	Class 2 Low Occupation (percent)	Class 3 Housewives (percent)	Cumulative[a] (percent)
Home	34.7	38.7	38.2	37.3
Work	22.8	28.8	1.5	14.4
Personal business	6.7	4.6	6.9	6.7
Medical-dental	0.7	0.6	1.0	0.8
School	2.5	0.0[b]	11.5	6.3
Social-recreation	8.6	5.1	14.8	11.3
Eat meal	4.3	2.8	2.3	3.3
Shop	8.7	7.0	12.6	10.2
Serve passenger	10.0	11.0	9.4	9.5

[a]From Horton and Shuldiner (1). [b]Less than 0.05

Thus, the low socioeconomic class is more oriented towards the basic activities of home and work, whereas the medium-to-high occupation class is not only concerned with work, but also with activities such as shopping, personal business, and social-recreation. Another influencing factor might be that white collar and professional occupations often require more interpersonal or face-to-face contact, thus increasing the probability of the purposes of personal business and eat meal as related to their work. In the third class, housewives are more concerned with the purchasing of goods and services, whereas the students pursue their education.

It is interesting to note the consistency of the serve passenger state over all groups. This seems to indicate that approximately 10 percent of all trips, regardless of occupation or class, are concerned with serving the needs of other people. Also, the state of medical-dental is most frequented by members of the housewife-student group, probably because mothers often accompany their children to doctor's offices, and receive more regular medical attention themselves.

Absorbing Chain Analysis

Urban trip movements may be viewed as a closed-circuit system, with the trip-maker leaving home, making one or more stops, and then returning to the home base. By setting the probability of moving from the home state equal to unity (i.e., once a person returns home, he may not leave), an absorbing Markov chain is formed and it is possible to study the movements made before returning to the home (1).

Computation of the fundamental matrix yields the expected number of times the trip-maker will be in a particular transient state before returning to the absorbing state (home), provided that he starts in a given transient state. Tables 7, 8, and 9 give the

TABLE 7

CLASS 1—HIGH OCCUPATIONAL STATUS

EXPECTED NUMBER OF STOPS BY FIRST PURPOSE AND TYPE OF STOP

First Purpose \ Stops at	1	2	3	4	5	6	7	8
1. Work	1.37	0.10	0.01	0.01	0.06	0.16	0.10	0.11
2. Personal business	0.28	1.26	0.01	0.01	0.11	0.08	0.21	0.10
3. Medical-dental	0.22	0.10	1.04	0.00[a]	0.10	0.08	0.18	0.09
4. School	0.09	0.03	0.02	1.01	0.10	0.04	0.07	0.05
5. Social-recreation	0.10	0.05	0.01	0.01	1.18	0.05	0.09	0.08
6. Eat meal	0.82	0.12	0.01	0.02	0.10	1.11	0.14	0.14
7. Shop	0.10	0.09	0.00[a]	0.00[a]	0.09	0.04	1.25	0.07
8. Serve passenger	0.36	0.08	0.01	0.02	0.09	0.08	0.12	1.29

[a]Less than 0.005

TABLE 8

CLASS 2—LOW OCCUPATIONAL STATUS
EXPECTED NUMBER OF STOPS BY FIRST PURPOSE AND TYPE OF STOP

First Purpose \ Stops at	1	2	3	4	5	6	7	8
1. Work	1.09	0.03	0.00[a]	0.00	0.03	0.05	0.08	0.10
2. Personal business	0.13	1.17	0.00[a]	0.00	0.09	0.03	0.19	0.10
3. Medical-dental	0.06	0.16	1.00	0.00	0.02	0.01	0.11	0.18
4. School	0.04	0.39	0.00[a]	1.00	0.03	0.01	0.06	0.03
5. Social-recreation	0.06	0.07	0.00[a]	0.00	1.13	0.03	0.11	0.09
6. Eat meal	0.67	0.06	0.00[a]	0.00	0.07	1.08	0.16	0.15
7. Shop	0.11	0.07	0.01	0.00	0.06	0.03	1.18	0.04
8. Serve passenger	0.28	0.07	0.01	0.00	0.06	0.02	0.07	1.33

[a]Less than 0.005

mean number of times a person is in a transient state for each possible transient starting state for each of the three classes of tripmakers.

From a study of the two working class matrices, it appears that in general, Class 1 has a greater likelihood of stopping in the various states than Class 2. Some exceptions occur in the medical-dental and school trips, but they are probably caused by the small sample sizes for the blue collar-service occupation class. The other exception is that of serving passengers consecutively, implying that more individuals in the low occupation class depend upon rides from others.

In both classes, there is a high expected number of stops from eat meal to work, giving evidence that many workers go to their jobs after eating a meal somewhere other than home. The high occupation class also has a strong linkage of work with work, supporting an earlier contention that such occupations require more interpersonal contact with others in their work, resulting in a higher number of trips in the work category.

As might be expected, the housewife and student group exhibits a higher mean number of stops in the social-recreation, shop, and personal business purposes than the working groups. Women usually make a series of stops when shopping for both goods and services, and are more likely to undertake such trips.

By summing across the rows of the matrix of the expected number of stops by first purpose, the average number of stops for each purpose as a starting state may be computed. In other words, the length of multipurpose trips, measured in frequency of stops,

TABLE 9

CLASS 3—HOUSEWIVES AND STUDENTS
EXPECTED NUMBER OF STOPS BY FIRST PURPOSE AND TYPE OF STOP

First Purpose \ Stops at	1	2	3	4	5	6	7	8
1. Work	1.02	0.05	0.00[a]	0.05	0.09	0.09	0.07	0.06
2. Personal business	0.01	1.29	0.01	0.03	0.15	0.04	0.28	0.09
3. Medical-dental	0.01	0.11	1.02	0.03	0.18	0.03	0.28	0.08
4. School	0.02	0.03	0.01	1.02	0.10	0.04	0.07	0.04
5. Social-recreation	0.01	0.06	0.01	0.03	1.24	0.03	0.13	0.07
6. Eat meal	0.05	0.11	0.00[a]	0.11	0.23	1.03	0.16	0.08
7. Shop	0.00[a]	0.10	0.01	0.01	0.13	0.03	1.27	0.08
8. Serve passenger	0.02	0.08	0.01	0.05	0.13	0.03	0.17	1.27

[a]Less than 0.005

TABLE 10

PREDICTED NUMBER OF STOPS FOR WACO PERSON TRIPS BY CLASS

First Purpose	High Occupation Class	Low Occupation Class	Housewife and Student Class	Cumulative Classes[a]
Work	1.92	1.38	1.44	1.8
Personal business	2.06	1.71	1.90	1.9
Medical-dental	1.80	1.54	1.74	1.8
School	1.41	1.57	1.33	1.3
Social-recreation	1.57	1.49	1.58	1.6
Eat meal	2.45	2.19	1.77	2.2
Shop	1.65	1.50	1.64	1.7
Serve passenger	2.04	1.84	1.76	1.9
System	1.84	1.50	1.58	1.7

[a]From Horton and Shuldiner (1).

TABLE 11

VARIANCE IN NUMBER OF STOPS FOR WACO PERSON TRIPS BY CLASS

First Purpose	High Occupation Class	Low Occupation Class	Housewife and Student Class	Cumulative Classes[a]
Work	1.89	0.75	0.82	1.4
Personal business	1.87	1.07	1.39	1.5
Medical-dental	1.60	0.98	1.18	1.3
School	0.94	1.01	0.64	0.7
Social-recreation	1.19	0.85	0.99	1.1
Eat meal	2.03	1.04	1.13	1.6
Shop	1.30	0.83	1.11	1.2
Serve passenger	1.90	1.19	1.22	1.5
System	1.71	0.90	1.03	1.3

[a]Horton and Shuldiner (1).

can be found for each non-home starting state and for the system (Table 10). The variation in trip length can also be calculated (Table 11).

As suggested by previous results, the high occupation class has the highest expected number of stops in most of the starting states, and in the system as a whole, indicating that the majority of trips are multipurpose in nature. The low occupation class has a low frequency of trip stops in comparison with the other classes, implying that most trips are singular in purpose. There is a larger number of stops when starting at the eat meal and serve passenger states for both working classes. Surprisingly, the expected number of stops in the shopping state is small when starting from shopping, whereas personal business is relatively high.

VARIATION IN CBD VERSUS NON-CBD TRIPS

To further study the variation in the travel patterns of the three classes, trips were divided by CBD versus non-CBD origins and destinations. Initially, each category was

TABLE 12

CBD/NON-CBD TRIP BREAKDOWN BY CLASS

Trip End	Class 1		Class 2		Class 3	
	CBD	Non-CBD	CBD	Non-CBD	CBD	Non-CBD
CBD	417	1989	86	319	268	1146
Non-CBD	1932	14,491	331	2052	1169	11,342
CBD	0.173	0.827	0.212	0.788	0.190	0.810
Non-CBD	0.118	0.882	0.139	0.861	0.093	0.907

TABLE 13

HIGH OCCUPATIONAL CLASS (1)
5 × 5 ZONAL MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5
1. CBD	0.192	0.080	0.069	0.355	0.304
2. Northeast	0.156	0.498	0.038	0.144	0.164
3. Southeast	0.169	0.061	0.269	0.326	0.175
4. Southwest	0.125	0.029	0.055	0.529	0.262
5. Northwest	0.126	0.031	0.024	0.272	0.547

classified by trip purpose, but the resultant matrices had too few observations to warrant Markovian analysis.

However, some observations were possible. For trips leaving the CBD, approximately 60 percent were bound for home, regardless of group affiliation. Yet for trips starting and ending outside the CBD, the average was only 38 percent returning to home. The high percentage of the former can probably be attributed to the central function of the downtown area, with many specialized services and jobs drawing people who return home after their purpose has been accomplished. Also, the CBD has few trips from home to some other purpose in comparison with other areas.

For movements within non-CBD areas, 20 percent of the high occupation class trips were destined for work, whereas for the low occupation class, 29 percent of the trips had a similar destination. If the trip was to the CBD from the outer area, the percentage of trips for work for the high and low occupation groups was 54 and 46 percent, respectively. It therefore seems reasonable that a greater portion of high-status workers are employed in the CBD where higher order functions are located.

Work was the dominant trip purpose for within-CBD movements for both high and low occupation classes, with 40 and 31 percent, respectively. Both made approximately 19 percent of their trips for personal business purposes.

The housewife-student group made relatively fewer trips to the downtown area. Their first stop was divided with 20 percent of the trips for personal business, 19 percent for social-recreation, 15 percent for shopping, and 14 percent for school purposes. Once in the CBD, 35 percent of their trips within the CBD were for personal business, 20 percent for shopping, and 9 percent for social-recreation purposes.

By eliminating the trip purpose breakdown, three matrices of total trip ends were given based on the CBD versus non-CBD dichotomy. The totals and the corresponding percentages are shown in Table 12. A possible explanation for the higher percentage of CBD destinations for Class 2 may be the close proximity of low socioeconomic neighborhoods to the CBD, resulting in a greater potential interaction for various trip purposes.

VARIATION IN ZONAL INTERCHANGE

Because a better differentiation of zonal movements between the three classes was desired, the non-CBD area was subdivided into four sectors. Although the zones were chosen primarily on the criterion of dividing the city into quadrants of approximately equal area, it may be of interest to note the general socioeconomic composition of each. The southeast zone consists of poor whites and Mexicans with middle class whites in the outer tracts of the zone. But the southwest and northwest sectors are predominantly middle-to-upper income white households, although the latter includes some households in the lower socioeconomic group. The northeast quadrant is com-

TABLE 14

LOW OCCUPATIONAL CLASS (2)
5 × 5 ZONAL MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5
1. CBD	0.218	0.206	0.188	0.134	0.254
2. Northeast	0.131	0.483	0.052	0.155	0.179
3. Southeast	0.210	0.126	0.250	0.200	0.214
4. Southwest	0.118	0.227	0.134	0.261	0.261
5. Northwest	0.141	0.134	0.062	0.173	0.490

TABLE 15

HOUSEWIFE AND STUDENT CLASS (3)
5 × 5 ZONAL MATRIX OF TRANSITION PROBABILITIES

From \ To	1	2	3	4	5
1. CBD	0.196	0.083	0.127	0.309	0.285
2. Northeast	0.087	0.684	0.042	0.076	0.112
3. Southeast	0.121	0.052	0.423	0.243	0.162
4. Southwest	0.093	0.026	0.080	0.590	0.211
5. Northwest	0.116	0.029	0.030	0.234	0.591

TABLE 16

EQUILIBRIUM VECTORS FOR ZONAL INTERCHANGE

Zone	Class 1 High Occupation	Class 2 Low Occupation	Class 3 Housewife-Student
CBD	0.139	0.154	0.115
Northeast	0.073	0.247	0.106
Southeast	0.057	0.113	0.098
Southwest	0.373	0.182	0.352
Northwest	0.358	0.304	0.329

TABLE 17

HIGH OCCUPATIONAL CLASS (1)
EXPECTED NUMBER OF STOPS BY ORIGIN ZONE AND DESTINATIONS

Zone Origin \ Stops at	NE	SE	SW	NW
Northeast	2.31	0.37	2.29	2.30
Southeast	0.51	1.68	2.69	2.39
Southwest	0.46	0.42	4.12	2.71
Northwest	0.46	0.37	2.77	4.12

posed of Negro and white neighborhoods, mostly blue collar workers, with middle class whites residing in the eastern sections of the area. The northeast zone is separated from the rest of Waco by the Brazos River, making it subject to a barrier effect. The transition matrices for each class are displayed in Tables 13, 14, and 15.

Common to all three classes is a high intrazonal percentage of movement, except in the CBD area. The high occupational class has relatively little movement to the northeast and southeast sectors. Two possible factors contributing to this movement pattern are that both zones are primarily lower socioeconomic class neighborhoods, and that the northeast zone is separated from the city by the Brazos River. Greater interaction exists with those zones characterized by middle and high income residential areas.

The pattern in Class 2 (blue collar-service workers) is not as clear. It appears that they are more likely to move between zones regardless of neighborhood type. The zonal interchanges most likely represent flows to various low-skill employment centers within the sectors.

The housewife-student class shows an even greater tendency to restrict movement to within zones. Only a small percentage of trips from without are destined to the low income eastern sectors. Trips originating in the two upper socioeconomic neighborhood quadrants tend to remain in the same type of area. On the average, 10 percent of the housewife-student trips are destined for the CBD, whereas the working groups averaged nearer to 15 percent, illustrating the downtown area's strength as both a shopping and work center.

The equilibrium vectors (Table 16) give the probability of being in a given zone after a larger number of transitions have taken place. The blue collar-service occupation group differs from the other groups in that a greater proportion of trips end in the northeast sector while fewer travel to the southwest sector. One factor is the existence of a large number of laborer and semiskilled jobs in factories in the northeast sector, and another is that many of the neighborhoods in that sector are in the lower socioeconomic class. The high occupational class and housewife-student class trip distributions appear to be similar.

The CBD is of primary importance in that it is the focal point for a large number of trips for both work and non-work purposes. Hence, it was used as the absorbing state

TABLE 18

LOW OCCUPATIONAL CLASS (2)
EXPECTED NUMBER OF STOPS BY ORIGIN ZONE AND DESTINATIONS

Zone Origin \ Stops at	NE	SE	SW	NW
Northeast	3.21	0.63	1.33	2.07
Southeast	1.50	1.82	1.26	1.94
Southwest	1.84	0.75	2.46	2.22
Northwest	1.65	0.64	1.34	3.50

TABLE 19

HOUSEWIFE AND STUDENT CLASS (3)
EXPECTED NUMBER OF STOPS BY ORIGIN ZONE AND DESTINATIONS

Zone Origin \ Stops at	NE	SE	SW	NW
Northeast	3.78	0.79	2.74	2.76
Southeast	0.92	2.39	3.22	2.86
Southwest	0.84	0.90	4.90	3.11
Northwest	0.82	0.75	3.24	4.63

TABLE 20

PREDICTED NUMBER OF STOPS FOR WACO INTERZONAL TRIPS BY CLASS

Origin Zone	Class 1 High Occupation	Class 2 Low Occupation	Class 3 Housewife-Student
Northeast	7.28	7.24	10.06
Southeast	7.26	6.53	9.39
Southwest	7.71	7.27	9.75
Northwest	7.72	7.13	9.43
System	6.17	5.50	7.73

in an absorbing Markov chain analysis to study the movements made before arriving there. Tables 17, 18, and 19 display the fundamental matrices of the three classes. Each entry represents the probable number of times that a tripmaker will be in a certain zone before traveling to the CBD, given that he begins in a particular non-CBD zone.

For the professional-white collar worker, the majority of the trips are destined to the high socioeconomic neighborhoods in the western sectors of the city, even if they start their trip in the eastern sectors. The same is true to a lesser extent for the blue collar-service workers, although they also have regular stops in the northeast sector. For both groups, there are few stops in the southeast sector. This is most likely caused by the lack of employment opportunities in this area.

The non-working class of housewives and students has a pattern comparable to the professional and white collar workers, but with a greater frequency of stops at all zones. This appears reasonable because tripmakers in this class do not travel to the CBD for work trips, but rather for occasional shopping and business trips. The majority of their trips are local. The frequency of stops in the southeast zone is increased, possibly because of the presence of Baylor University.

The expected number of stops in non-CBD zones before stopping downtown is given for each starting zone in Table 20. Class 2 has the fewest stops before entering the CBD, especially if the origin zone is the southeast sector. The housewife-student group visits the CBD the least often, in that at least 9 non-CBD trips are made, on the average, before a downtown trip is undertaken.

CONCLUSIONS

The results indicate that the travel behavior of various socioeconomic-occupational groups varies considerably in trip purpose, linkages, and length. These groups also appear to differ in their spatial distribution of trip ends within the city. As a result, research in the development of trip generation and distribution models utilizing this information would appear worthwhile. Also of importance is the application of the Markovian process and models in analyzing the travel behavior of urban households. Research is currently being undertaken to utilize the probability matrices generated in the analyses discussed in this paper as basic input to a simulation model of urban travel behavior which will define movement behavior of the three groups under different environmental conditions.

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The Mathematical Form of Travel Time Factors

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The travel time factor represents the effect of travel time on trip interchanges. In its use in gravity model studies, the travel time factor is an empirical hand-down curve that is considered constant over time. This paper questions constancy over time by attempting to express travel time curves in parametric form and relating the parameters to variables within the study area that are known to change over time. Driving time curves for three trip purposes were selected from ten widely scattered transportation study areas of different sizes. By curve moment techniques, the travel time factors were closely modeled by Pearson Type I and Pearson Type III curves. The travel time curves of home-based work and non-home-based trips were best modeled by Pearson I curves, whereas the factors for shorter length shopping trips were better modeled by Pearson III curves. Using factor analysis and correlation analysis for the selection of independent variables, regression equations of acceptable statistical significance were derived relating the parameters of the Pearson models to variables calculated on a citywide basis. The study found significant relations between curve parameters and such ephemeral variables as numbers of trips made, trip-making rates, car ownership, and ratios of trips made for various purposes.

•THE CURRENT use of the gravity model in the trip distribution phase of transportation planning has evoked interest in the form of the effect of distance or travel time on travel. Traditionally, research was into the effect of separation function suggested by calibrations of the form with respect to available data. This work sought to further that research, still in an empirical manner, by an examination of the travel time factors as used in various transportation studies. After observations of the form of existing travel time curves, conclusions concerning the general form of such curves could be drawn. From these conclusions, suitable parametric curves were derived and fitted to the travel time curves.

Having achieved suitable parametric fits, the parameters derived were themselves subjected to examination to determine whether relationships existed between these parameters and characteristics of the study area and its population. It appeared reasonable that if relationships between curve parameters and areawide variables could be found, then changes in parameters (and changes in the travel time curves themselves) could be predicted from changes in the areawide variables. Another area of application would arise in the generation of a travel time curve for a study at the start of the calibration phase. An initial curve could be obtained from the parameters obtained from the regression analysis on areawide variables. Current methods of estimating the travel time factor curve for the first calibration cycle generally evolve on a guess based on past experience in other study areas. An improvement of this technique would result

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from a modeling approach. Such an approach would decrease the number of cycles needed to calibrate the gravity model within required limits of accuracy, with an ensuing decrease in computer and technical time involved in the calibration process.

GENERAL DISCUSSION OF THE GRAVITY MODEL

The use of the theory of gravity to describe the interaction of human populations dates back to the early nineteenth century.

Voorhees (1) utilized a gravity formulation in his "General Theory of Traffic Movement." His work used a constant exponent for the influence of distance, but Voorhees also indicated that travel time rather than physical spatial separation was a realistic measure of impedance to travel. This is reflected in current practice which uses the following form of gravity model:

$$T_{ij} = \frac{P_i F_{ij} \cdot A_j}{\sum_{\text{all } k} F_{ij} A_k}$$

where

T_{ij} = the trip interchange from i to j,

P_i = the number of trips produced at zone i destined to all zones,

A_j = the number of trips attracted to zone j from all zones, and

F_{ij} = the friction factor derived from the travel time curve for a travel time equaling that time from i to j.

For clarity of presentation the model is shown without the often necessary social-economic adjustment factors. In early work in the Washington, D. C., area, Hansen (2) used travel time as a measure of spatial separation, and found that a constant exponent was not usable. The negative exponent appeared to increase with increasing separation. This was highly apparent in the case of the work trip. The need for a variable exponent in the use of a gravity model has been found necessary in many city studies carried out since Hansen's work. The San Mateo study, for example, used travel time exponents that varied with time, ranging from 0 to 1.2. More common practice is the use of ordinates from an empirical hand-drawn "friction factor curve," equivalent to using an exponent of time that varies over the whole time range. Tanner (3) investigated the question of a constant exponential of spatial separation from a mathematical approach. It was found that it was not mathematically possible for the distance exponent to remain constant with the distance. This work indicated that short trips required, under assumptions of uniform population density, an exponent between 2 and 3, which was theoretically impossible in the case of long trips, and which led to a ridiculously high vehicle-mileage of travel in an area. Rather than a constant exponent where

$$f(d) = d^n$$

Tanner suggested a more general form of curve, the gamma function,

$$f(d) = e^{-\lambda d} d^n$$

where

$f(d)$ = the functional form of the effect of distance as it would appear in a gravity model formulation,

λ = some nonnegative constant,

d = the measure of spatial separation,

n = some constant, and

e = the base of natural logarithms.

Such a form would permit a sufficiently rapid decay of the function to prevent errors in long trip computations.

Voorhees (4) has suggested that the general gamma density function can be utilized as a parametric substitute for hand-fitted travel time factors.

CONSTANCY OF TRAVEL TIME FACTORS

An examination of range of travel time factors of various cities was made by Whitmore (5). This work found that the travel time factor could be represented by general polynomials, and that regional friction factors are similar from region to region, but vary considerably from city to city. Whitmore indicated that the best fit to travel time factors could be found with a polynomial of the form

$$f(t) = A_0 + A_1 t + A_2 \cdot \frac{1}{t-3}$$

where A_0, A_1, and A_2 are constants, and t is the travel time including terminal time. An examination of the form of function indicates that as t tends to infinity, the function itself becomes infinite. Although it gives an apparently adequate fit over certain ranges, it cannot be held as a completely rational form of the travel time factor. Possible forms should certainly have characteristics similar to that of the function suggested in Tanner's work, in which the value of the function decreases at an increasing rate with time.

It is felt that a great deal of information on the behavior of the travel time factor is being lost by current use of hand-fitted travel time factors. This problem has been recognized for some time by the Bureau of Public Roads which states:

> It is important to keep the "line of best fit" smooth and as straight as possible for the following reasons:
>
> a. Smooth curves can be approximately defined in a mathematical expression; possibly, one that is not complex.
> b. If these curves can be approximated by a mathematical expression, meaningful comparisons can be made between these expressions for different urban areas with various population and density characteristics.
> c. These comparisons would eventually help quantify, with a mathematical function, the effect of spatial separation between zones on trip interchange.

If nonparametric curves continue to be used in the gravity models of transportation studies, little advance can be made with respect to the assumption of constancy. Such an assumption is not likely to be greatly in error in a slowly developing community. In an area of considerable development, and significant social change, the assumption may well be unjustified. It is precisely within areas of radical change that the transportation modeling process is of greatest value. The use of parametric travel time curves is recommended so that information relating the form of the curve to the character of study area can be retrieved by statistical relationships. Statistical modeling is in widespread use throughout the remainder of the transportation planning process, and it is felt that it can well be extended into the modeling of the travel time factor itself. Any model used to describe the form of the travel time factor must be sufficiently flexible to fit the various shapes of the factors.

The Pearson system of curves, a highly flexible system derivable from a basic differential equation appears to have adequate variety of form to permit its adaptation for use as a travel time factor curve. Pearson curves have as many as three shape parameters and one shift parameter. All curves are derivable from the basic formula

$$f(x) = \frac{x-a}{b_1 + b_2 x + b_3 x^2}$$

where a, b_1, b_2, b_3 are constants.

PURPOSE OF RESEARCH

It was decided that this research would serve three main purposes:

1. To determine how satisfactorily this curve system could serve as travel time factors.
2. To establish relationships between the parameters of fitted curves and the characteristics of the study area and its population; and to derive suitable regression equations.
3. To indicate how well parameters derived from regression relationships would serve for initial estimates of the travel time factor.

Further advantages from the use of parametric curves occur from the fact that the calibration cycle itself can be completely computerized, thus eliminating the present methods of hand-fitting empirical curves at each stage of calibration of the gravity model. The modeling method indicated in this work is directly applicable to the fitting of a parametric curve to points, rather than to the hand-fitting method recommended by the Bureau of Public Roads.

Curve fitting was carried out by the method of moment, found to give excellent results with Pearson I and Pearson III distributions (6).

The Pearson system of curves may be derived from the basic differential equation

$$\frac{dy}{dt} = \frac{y\,(t + a)}{b_0 + b_1 t + b_2 t^2}$$

where

$y = F(t)$, the functional form,
t = the time separation, and
$a = b_0,\ b_1,\ b_2$ = constants.

This is a very general form of curve, which by proper choice of constants can insure that $y = 0$ as t tends to infinity, that $dy/dt = 0$, and that y can have a local maximum at low values of t. The equation therefore conforms with observed properties of the travel time factor.

Depending on the values of the constants in the basic differential equation, a variety of curve types are obtainable. If the roots of the denominator are real and of different sign, then the differential equation gives the Pearson I curve of the form

$$F(t) = \frac{C_1}{A^{m_1 + m_2 + 1}} \cdot B(m_1,\ m_2) \cdot (t - c)^{m_1} \cdot (A - (t - c))^{m_2}$$

where

$m_1,\ m_2,\ A$ = shape parameters;
c = a shift parameter;
C_1 = a constant, affecting only the magnitude of the curve;
t = the time separation; and
$B(m_1,\ m_2)$ = the value of the beta function with parameters $m_1,\ m_2$.

When $b = 0$, the solution to the differential equation is the Pearson III curve:

$$F(t) = C \cdot \frac{p}{A} \cdot \frac{(p+1)^p}{e^{p+1}\,\Gamma(p+1)} \cdot \left(1 + \frac{t - \mu}{A}\right) \cdot e^{-p/A(t-\mu)}$$

where

$p,\ A$ = the shape parameters;
μ = a shift parameter;
C = a constant, affecting only the magnitude of the curve;
t = the time separation; and
$F(t)$ = the functional form.

Depending on the value of the differential equation constants, eleven different types of curves result. These are examples of the Pearson system of curves. For the purposes of this work, it was found that satisfactory fit could be obtained using Pearson I for work trips and non-home-based trips, and Pearson III for shopping trips. It is of interest at this point to compare this approach from the differential equation basis with Tanner's earlier observation that the time factor could not be constant, but was probably of the form

$$f(d) = e^{-\lambda d} d^{n}$$

Tanner's suggested form of the travel time curve, derived mathematically, is a special case of the Pearson III distribution, which is itself a special case of the solution to the basic differential equation. The work undertaken here was therefore considered an examination of Tanner's generalized hypothesis.

DISCUSSION OF DATA

For this study, extensive use was made of data compiled in Whitmore's work, including additional data. In order that the data should be compatible for the rational application of regression equations to similar data, the studies selected were those using driving time curves with no inclusion of terminal times. Compatible data were available for ten cities for the home-based work trip, nine cities for non-home-based trips, and five cities for shopping trips. Because of the small sample for shopping trips, caution should be used in accepting results found in this limited study. Other trip purposes such as school trips and social-recreational trips could not be investigated because of the variety of ways in which these trips were treated in the available studies.

WORK TRIP TRAVEL TIME CURVES

It was found that the travel time factor for work trips could be modeled satisfactorily by the use of the Pearson I curve, which has three shape parameters and one shift parameter. The summary of the results is given in Table 1. The Pearson I curve was found to model adequately a full range of travel times that included at least 90 percent of all travel for that purpose. The range of times varied from a low value of 2 minutes to a high value of 50 minutes. In all classes the percentage of trips falling outside the upper limit of the model was sufficiently small that it could be ignored without affecting the validity of the model. No attempt was made to fit parameters at very low travel times.

TABLE 1

SUMMARY OF PEARSON I SHAPE PARAMETERS FOR HOME-BASED WORK TRIPS

Location	m_1	m_2	A	c Shift Parameter	Index of Multiple Correlation	F-Ratio of Regression
Cedar Rapids	-0.27	1.48	55.9	0.72	0.997	13,861
Waterbury	-0.72	4.16	74.2	1.71	0.995	2,593
Erie	-0.37	1.89	40.9	1.21	0.999	26,733
New Orleans	-0.73	2.84	70.7	1.93	0.997	6,288
Providence	-0.66	5.40	104.6	2.25	0.992	2,434
Sioux Falls	-0.35	0.48	15.8	0.97	0.979	831
Hartford	-0.63	3.01	60.6	1.10	0.997	5,776
Fort Worth	-0.83	3.89	54.8	2.23	0.993	1,379
Baltimore	-0.65	2.19	57.3	1.87	0.988	1,702
Los Angeles	-0.77	6.87	128.3	11.37	0.991	1,825

It is apparent that a high degree of fit has been obtained by the use of the Pearson I curve. Figure 1 shows examples of the excellent fits obtained using the Pearson I curve.

Relationships Between Curve Parameters and Area Characteristics

The second stage of the research dealt with attempting to find statistical relationships between the parameters of the model for travel time factors, and various citywide variables. Such a relationship would indicate possible predictability of the travel time factor curve under varying conditions, and would shed light on the assumption that travel time factors are constant with time.

Statistically significant trends were found to exist between the shape parameters of the model and citywide variables determined in the O-D studies. The selection of the variables used in the regression was based on correlation analysis, factor analysis, and the suitability of the variable for predictive purposes. Where it was possible variables involving the study area size were avoided. For predictive purposes, such variables would in general be unreliable because the inclusion of large peripheral rural areas could radically affect the value of such variables without a remarkable change on the trip characteristics. Final selection of the regression equation was also selected by minimizing the significance level of both the regression coefficients of the independent variables and the regression equation itself. This procedure was followed for all trip purposes. Table 2 and Figures 2 through 5 summarize the findings of the regression analysis for home-based work trips.

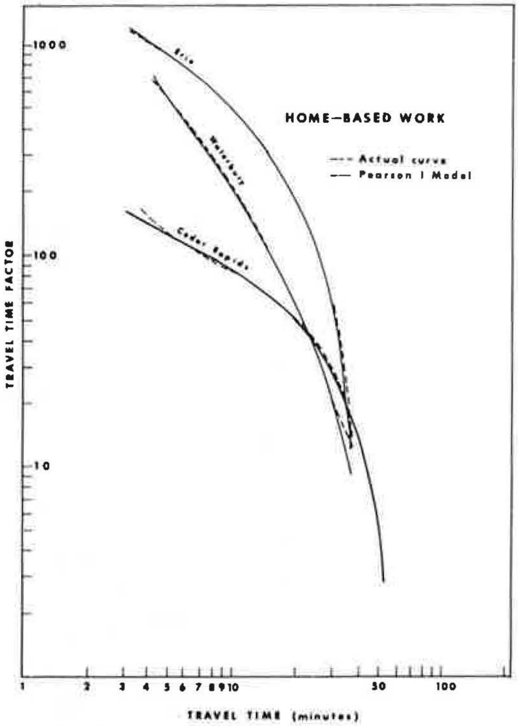

Figure 1. Examples of adequacy of Pearson I fit for home-based work travel time factors.

A summary of the statistical findings concerning the home-based work trip travel time factors would indicate that (a) travel time factors curves can be satisfactorily modeled with Pearson Type I distribution curves and that (b) the parameters of the

TABLE 2

SUMMARY OF REGRESSION EQUATIONS FOR CURVE PARAMETERS—WORK TRIPS

Regression Equation	Level of Significance of Regression Coefficients (percent)	Level of Significance of Variables (percent)	Correlation Coefficient of Equation
$m_1 = -0.993 + 0.000933 \times$ home-based work trips per 1,000 population	2	2	0.75
$\ln(m_2) = 3.51 - 1.74 \times \ln$ (total trips per car)	1	1	0.79
$\ln A = -4.995 \times 10^4 \times$ (total home-based work trips)$^{-1}$ + 4.52	0.1	1	0.87
$c = 2.63 - 0.0025 \times$ home-based work trips per 1,000 population	2	2	0.77

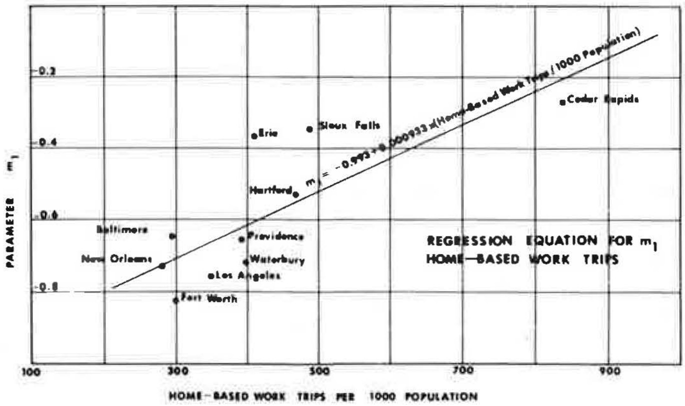

Figure 2. Regression equation for m_1, home-based work trips.

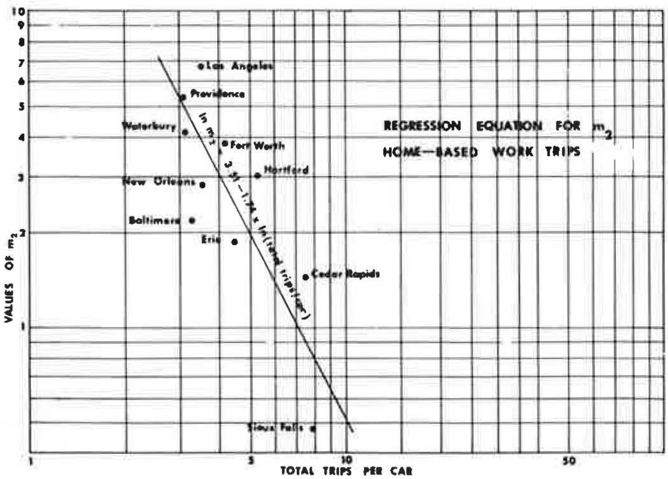

Figure 3. Regression equation for m_2, home-based work trips.

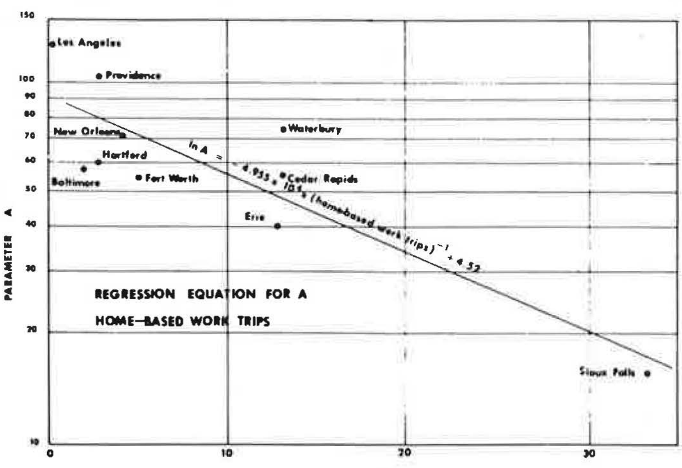

Figure 4. Regression equation for A, home-based work trips.

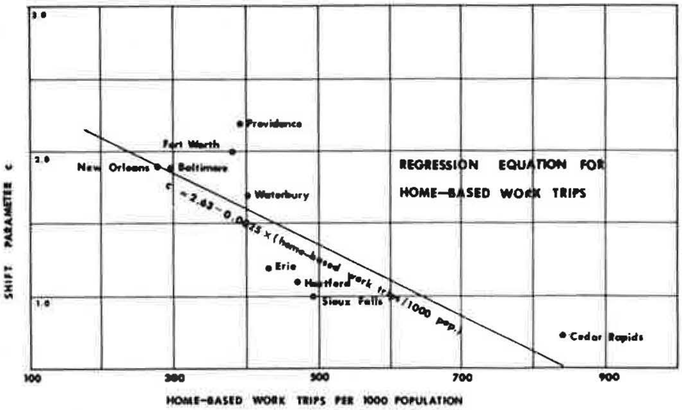

Figure 5. Regression equation for c, home-based work trips.

Pearson I models are found to be statistically related to overall citywide variables. These variables were found to be the number of home-based work trips per thousand population, the total number of home-based work trips, and the number of trips per car. From the statistical relationships found for home-based work travel time factors, it would appear that these factors may not be constant over time as is currently assumed in the calibration of the gravity models for transportation studies. Constancy over time for a particular urban area would indicate an independence of the parameters of the curve from any relationship with city variables, and any change in the trip-making patterns would be assumed to have no effect on the form of the travel time curve.

NON-HOME-BASED TRIP TRAVEL TIME CURVES

In the case of non-home-based trips, homogeneous data were available for nine cities for analysis of the travel time factor curves. It was found that the most satisfactory model for the non-home-based trip curves was the Pearson Type I distribution. Table 3 summarizes the results. This curve was an accurate model over the range of travel times that included at least 90 percent of non-home-based trips. A full range of travel times was therefore considered. In all cases, the percentage of trips falling

TABLE 3

SUMMARY OF PEARSON I SHAPE PARAMETERS FOR NON-HOME-BASED TRIPS

Location	m_1	m_2	A	c Shift Parameter	Index of Multiple Correlation	F-Ratio of Regression
Cedar Rapids	-0.42	1.95	38.7	1.02	0.999	17,097
Waterbury	-0.18	7.02	46.7	0.90	0.997	4,098
Erie	-0.58	2.89	42.6	1.42	0.994	2,135
Providence	-0.61	11.48	78.3	1.20	0.997	2,380
Sioux Falls	-0.54	0.62	16.6	1.10	0.996	3,133
Hartford	-0.91	8.05	68.2	1.07	0.990	791
Fort Worth	-0.68	3.11	48.0	1.68	0.996	2,560
Baltimore	-0.86	9.92	109.0	1.52	0.985	2,380
Los Angeles	-0.64	1.05	57.9	11.37	0.987	2,359

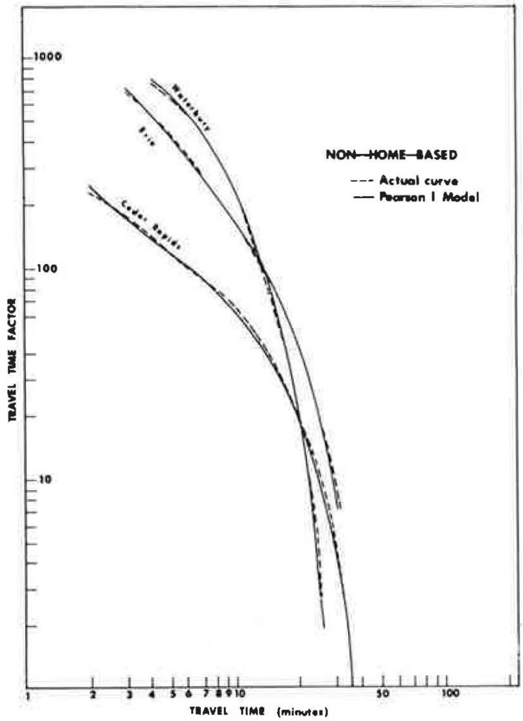

Figure 6. Examples of adequacy of Pearson fit for non-home-based trip travel time curves.

outside the range of applicability of the model was sufficiently small that the model was considered valid.

It is immediately apparent from a comparison of the model values and the actual values that a high degree of fit has been achieved with the use of the Pearson I curve. Examples of the fits obtained are shown in Figure 6.

Relationships Between Curve Parameters and Area Characteristics

The second stage of statistical modeling indicated that significant relationships could be developed between the parameters of the Pearson I models and various citywide variables. The results of the regression analysis are shown in Table 4 and in Figures 7 through 10.

The findings on the travel time factors for the non-home-based trips can be summarized as (a) travel time factor curves can be satisfactorily modeled by the use of Pearson Type I distribution curves; and (b) the parameters of Pearson I models are found to be statistically related to the following overall citywide variables: all-purpose trips per car, non-home-based trips; all trips, total number of trips, non-home-based trips per car, and non-home-based trips; study area.

The dependency of the curve parameters on independent variables would indicate that these parameters may not be constant under conditions where the independent variables noted above are projected to change during the planning period.

Caution must be exercised in the use of the regression equations developed here. The sample size of this study was relatively small, and further research would appear to be necessary to determine whether the findings can be generally applied.

TABLE 4

SUMMARY OF REGRESSION EQUATIONS FOR CURVE PARAMETERS—NON-HOME-BASED TRIPS

Regression Equation	Level of Significance of Regression Coefficients (percent)	Level of Significance of Variables (percent)	Multiple Correlation Coefficient
$m_1 = 0.479 + 0.169 \times$ (total trips per car) $- 1.56 \times \frac{\text{(non-home-based trips)}}{\text{all trips}}$	2	2	0.87
$m_2 = 6.56 + 5.86 \times 10^{6} \times$ (total trips) $- 0.207 \times$ (non-home-based trips $\div$ total trips)	2, 5	2, 5	0.89
$\ln A = 6.55 - 0.417 \ln$ (non-home-based trips $\div$ study area in sq mi)	1	2	0.79
$c = 1.51 - 0.71 \times$ (non-home-based trips, trips per car)	7	7	0.71

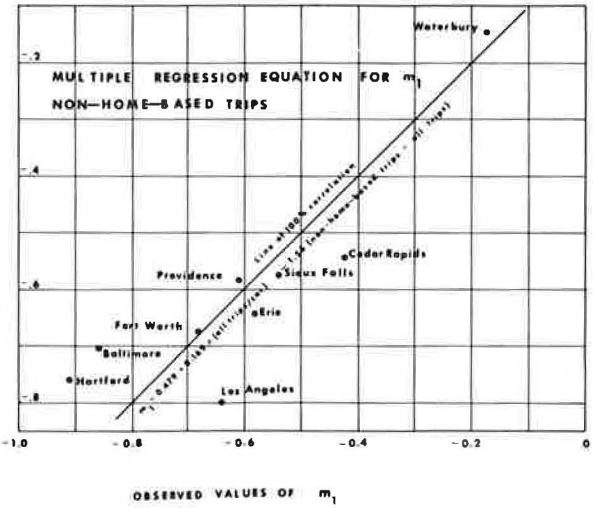

Figure 7. Regression equation for m_1, non-home-based trips.

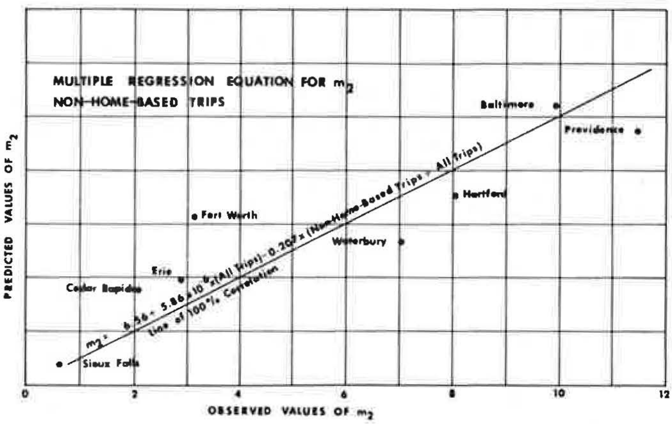

Figure 8. Regression equation for m_2, non-home-based trips.

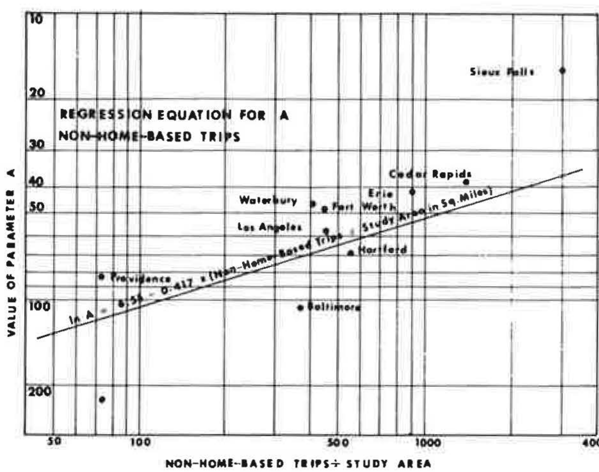

Figure 9. Regression equation for A, non-home-based trips.

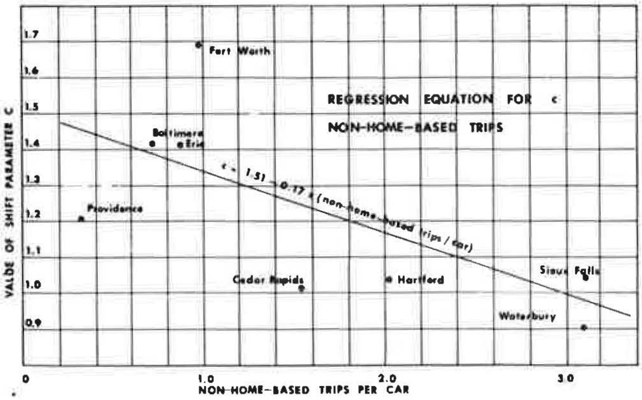

Figure 10. Regression equation for c, non-home-based trips.

SHOPPING TRIP TRAVEL TIME CURVES

The final set of travel time curves analyzed was for shopping trips. Because of the various ways in which shopping trips can be classified for study purposes, this group of travel time factors presented the smallest homogeneous sample of the set. Only five travel time curves were analyzed.

At the time of analysis, an immediate difference became obvious between the shopping trip and the two other types of trips. The median shopping trip length was 7.5 This compared with 12.2 for the work trip. It was found that the best fit to the shopping trip curves was obtained with the Pearson III curve. This distribution curve was found to satisfactorily model at least 90 percent of all trips.

TABLE 5

SUMMARY OF PEARSON III SHAPE PARAMETERS FOR HOME-BASED SHOPPING TRIPS

Location	p	A	Shift Parameter μ	Index of Multiple Correlation	F-Ratio of Regression
Waterbury	-0.35	-1.12	2.85	0.997	2,913
Erie	-0.45	-1.90	3.16	0.991	824
Providence	-0.49	-2.33	3.32	0.996	2,226
Hartford	-0.79	-4.27	1.91	0.997	1,951
Fort Worth	-0.39	-0.97	2.54	0.990	760

TABLE 6

SUMMARY OF REGRESSION EQUATIONS FOR CURVE PARAMETERS—HOME-BASED SHOPPING TRIPS

Regression Equation	Level of Significance of Regression Coefficients (percent)	Level of Significance of Variables (percent)	Correlation Coefficient of Equation
$\ln(A) = 1.37 + 1.28 \times 10^{-3} \times$ total trips per 1000 population	10	10	0.82
$\ln(p) = 1.11 + 5.10 \times 10^{-7} \times$ total trips	5	10	0.87
$= 8.06 - 15.79 \times$ (cars per person)	1	1	0.97

Table 5 compares the Pearson III model with the actual travel time factors used in the transportation studies. Excellent fit has been obtained using this form of curve. The F-ratios are high, and the index of multiple correlation is also high (Fig. 11).

The Pearson III curve used for this type of trip is a curve discontinuous at its lower end only. The curve is continuous to infinite travel times. The number of parameters needed to describe it is one less than for the Pearson I curve, which is discontinuous at both ends. The second stage of correlation for the shopping trip curves therefore amounts to the relation of the two shape parameters p and A, and the shift parameter μ to the citywide variables and the curve parameters. The results of the regression analysis are shown in Table 6 and Figures 12 through 14.

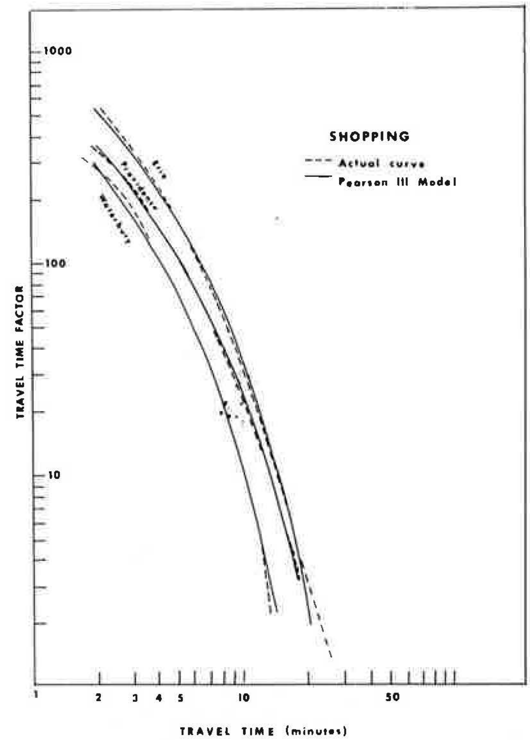

Figure 11. Examples of adequacy of Pearson III fit for shopping trip travel time factors.

Relationship Between Curve Parameters and Area Characteristics

A summary of the statistical findings concerning shopping trip travel time factor curves would indicate that (a) travel time factor curves can be satisfactorily modeled using Pearson III distribution curves, and (b) the parameters of the Pearson III curves that best fit the actual curves were found to be statistically related to the following citywide variables: total trips per thousand population, total trips, and car ownership per person. The regression equations developed indicate a method whereby the change in travel time curve parameter for a given change in travel behavior can be predicted.

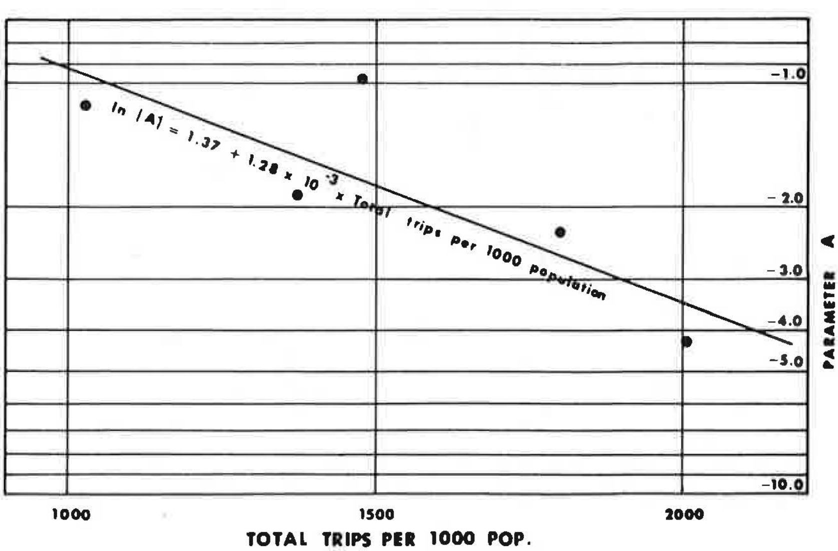

Figure 12. Regression equation for A, shopping trips.

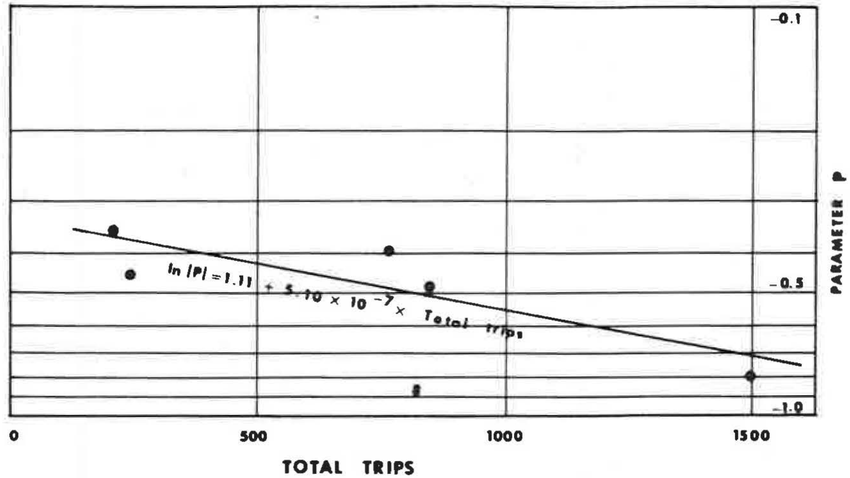

Figure 13. Regression equation for p, shopping trips.

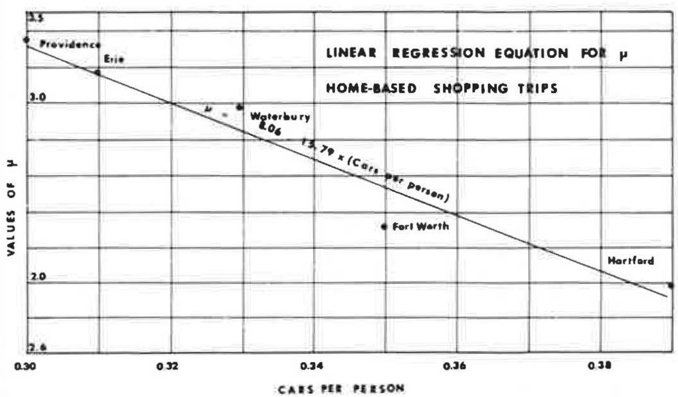

Figure 14. Regression equation for μ, shopping trips.

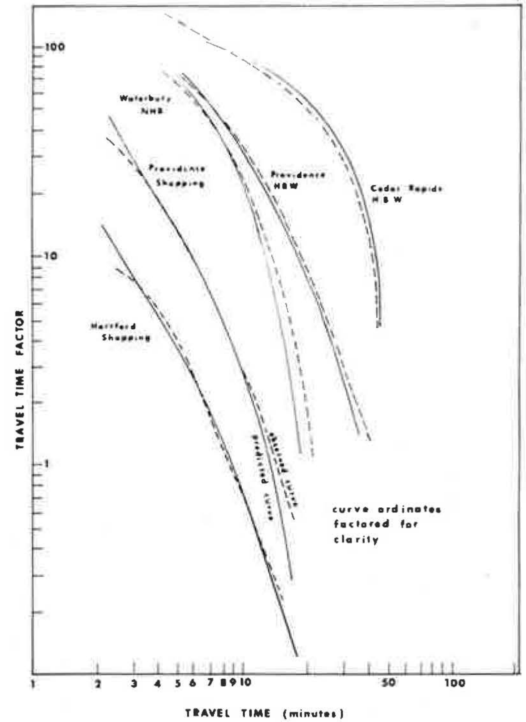

Figure 15. Predictive ability of regression equation parameters.

PREDICTIVE ABILITY OF REGRESSION EQUATION

To determine how well the derived regression equations could be used for predicting travel time curves, an analysis was made comparing curves from regression-derived parameters with actual travel time curves. The results of the analysis for the three trip purposes are shown in Figure 15. For clarity the curves are standardized on convenient ordinates. It is apparent that the regression-derived parameters in some cases gave curves that would have been adequate for final gravity model calibrations, whereas in other cases the curves would have sufficed only for initial estimates of the curves. It would appear that the derived regression equations in Tables 2, 4, and 6 are likely to give good first estimates of travel time curves.

CONCLUSIONS

1. Empirical travel time factor curves for transportation studies can be closely approximated by parametric curves of the Pearson system. The parameters are best estimated by curve moment procedures.
2. Home-based work and non-home-based travel time curves are best modeled by Pearson I curves. Pearson III curves were found to provide a better model for the shopping trip that has a lower mean trip time than home-based work or non-home-based trips. It would appear that the Pearson I distribution provides a better fit to those travel time curves in which the change of time exponent with time is most apparent.
3. Statistical relationships were found between the parameters of the Pearson models and pertinent citywide variables. Among those variables related to model parameters were home-based work trips per thousand population, total trips per car, total home-based trips, ratio of non-home-based trips to all trips, total trips in the study area, non-home-based trips per car, cars per person, and total trips per thousand population.
4. Significant regression equations between study area variables and model parameters can be calculated, indicating that there is statistical probability that these parameters are not constant, but are likely to change as the character of the area itself is modified. Such modification would be reflected in a change in the areawide variables.
5. The regression equations can be used without serious error for a first approximation of the travel time factors. Modification of the initial estimate of travel time curves can be effected in a manner similar to the method suggested in the Bureau of Public Roads Manuals, except that the new curves should be computed by moments rather than by the hand-fitting method currently recommended. This would enable the formation of a data bank of mathematical expressions for travel time curves and study area characteristics so that "meaningful comparisons can be made between these expressions for different urban areas with various population and density characteristics." This curve-fitting technique is easily programmed for high-speed computers, and will speed the present gravity model iterative fitting techniques.
6. The Pearson I and III shape parameters were not found to be highly sensitive. Small errors or small changes in parameters did not give radically different curves.

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Discussion

SALVATORE J. BELLOMO, Alan M. Voorhees and Associates, Inc.—In reviewing the work of Covault and Ashford, certain findings and implications were made regarding use of Pearson I and III statistical relationships for estimating travel time factors for urban transportation planning studies. This discussion will be related to certain of their major conclusions and what I see as shortcomings that would require a limited use of their work, and as applications of their research that will definitely improve our ability to do travel forecasting at a lower cost in our small- and medium-sized urban areas.

It appears that the statistical measures given, such as the index of multiple correlation and F-ratio, are based on a comparison of actual versus estimated travel time curves rather than on a comparison of the actual versus estimated distribution of trips. Research done as part of Factors and Trends in Trip Lengths (4) indicates that any procedure to estimate travel time factors must be sensitive to the first 10 to 15 minutes of travel, the time period in which most trips are made. Figure 15 of the authors' paper shows this comparison of travel time factors and indicates that the Pearson distribution does not fit this critical part of the curve, especially in the first 10 minutes. Because Alan M. Voorhees and Associates, Inc., conducted half the studies mentioned, it well recalls the sensitivity of these travel time factors in this critical area on the synthesis of the trip length distribution.

The applicability of the Pearson distribution formulas based on the areawide characteristics mentioned would be quite dubious in larger metropolitan areas where mode choice and mass public transportation are currently being evaluated. In these studies, person travel time factors are usually developed, and current research on trip lengths has indicated that these travel time factors may be affected by mode as well as route choice. Furthermore, the areawide characteristics, such as car ownership in urban areas with potential mass transit use, would not be applicable to synthesizing travel time factors for people who have no car. Does their travel time curve really depend on areawide characteristics? In conducting research for Factors and Trends in Trip Lengths, it was found that travel time factors within our metropolitan area may be influenced by the spatial arrangement of trip opportunities. This is illustrated in Figure 16 which shows variations in travel time factor curves based on the mean opportunity length and in Figure 17 which indicates the relationship found between the shape parameter of the gamma distribution used to synthesize travel time factors in that research project and the mean opportunity length for several selected zones in the Washington area.

Concerning the sensitivity of the parameters of the Pearson distribution and their effect on the synthesis of the travel time curve, no analysis was conducted by the authors. Varying the areawide characteristics, based on reasonable changes that might occur, should be made to see their effect on travel time factors and on the trip length distribution. In addition, the results of this research should be checked for their applicability over time using historical rather than cross-sectional data. It should be noted that these tests were conducted over time for Washington and Baltimore. No appreciable change in travel time factors was found for these metropolitan areas. Studies are currently being made in Detroit to see if the travel time factors for that metropolitan area change over time. If they do, the effect of these changes on the actual trip length distribution will be determined.

From a practical standpoint, the recommendation to use Pearson distribution parameters and a computer because of cost savings seems unsupported and unwarranted. A recycle of a gravity model costs less than a Pearson III statistical calculation does when one considers staff time, programming, and the cost of turnaround on calibrating gravity models. (To run a gravity model for a 180-zone system costs about \$50.) Furthermore, a program is currently available that calculates unsmoothed travel time factors and plots actual and estimated trip length distribution given the O-D trip table and zone to zone travel time or costs as inputs. The computer running time with this program is low.

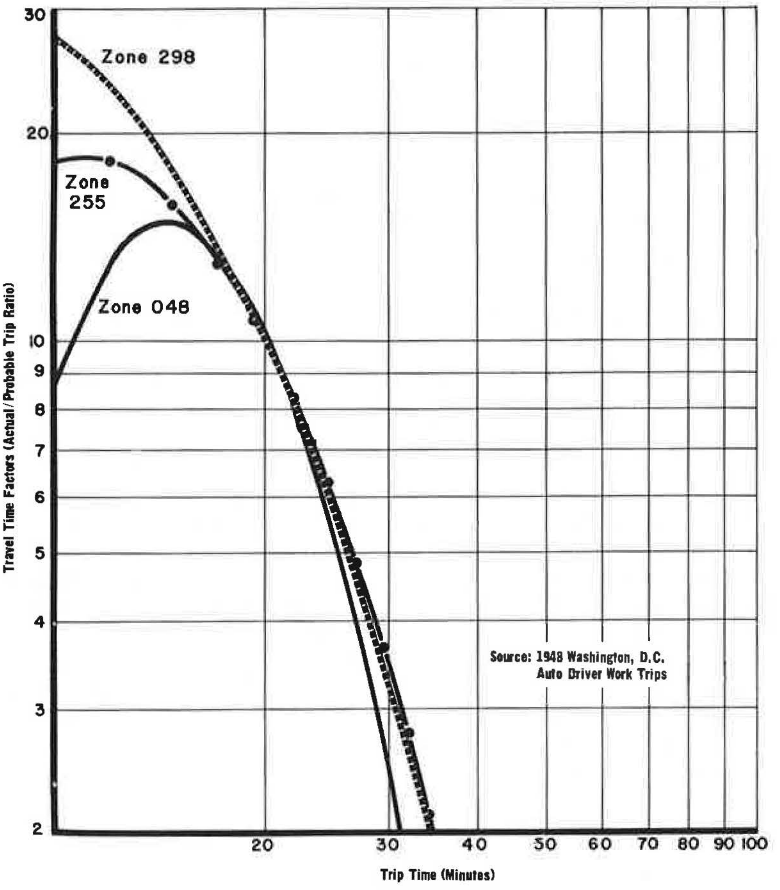

Figure 16. Travel time factors vs trip time for three selected zones in Washington, D.C.

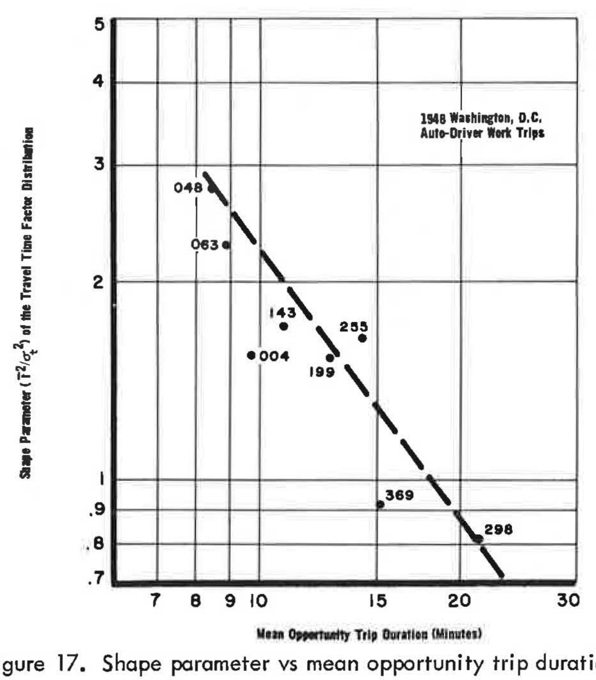

Figure 17. Shape parameter vs mean opportunity trip duration.

The idea of collecting parameters for the Pearson distribution for research purposes is unwarranted, and it would not be applicable to be undertaken by operating transportation agencies. More research and support are required before this work is required by the DOT of on-going studies.

The applicability of these research findings, as I see it, would probably be in our small- and medium-sized cities with small modal split where data collection of costly O-D data could be reduced in lieu of a travel time factor simulation based on areawide characteristics. What could be done is as follows:

1. Covault and Ashford's technique might be used in estimating travel time factors based on areawide characteristics.
2. A small sample O-D survey could be used to establish trip generation rates, and the trip length distribution.
3. A thorough land use and land activity survey could be applied to the trip rates to establish trip productions and attractions.
4. A gravity model run could then be made and the mean and standard deviation of the resulting trip length could be checked against the small sample O-D trip length.

These steps could reduce the cost of data collection and could produce a model more quickly while the transportation and land-use issues are being faced by the community. However, before this is applied, it should be rigorously tested in pilot studies by a transportation study agency working closely with the Department of Transportation. These studies should be conducted for an area of about 50,000 population and for one of about 150,000 population; they should compare alternative ways of developing transportation models in less time and at a lesser cost.

In conclusion, I have attempted to pinpoint what I felt to be areas which needed additional support while at the same time reporting what I thought would be an area of application for their findings in our transportation planning studies. I commend the authors on their work and hope they find this discussion constructive to their research effort.

DONALD E. CLEVELAND, University of Michigan—Ashford and Covault have appropriately directed their efforts toward a problem of some concern to those who use the gravity trip distribution model, the problem of the time stability of the relative attractiveness of destinations at varying distances from the trip origin. Until now little direct evidence has been presented to support or refute the contention that this function is constant over time.

The main thrust of their paper is that (a) there is value in determining a relatively simple mathematical function that can be used to express the relative attractiveness of destinations as a function of travel time; (b) parameters for the appropriate mathematical function can be easily determined; (c) the extent of correlation of these parameters with other study area variables for a cross-sectional sample of data from several cities can be determined, and the existence of a causal relationship inferred; and (d) the time stability of the correlated study area variables is apparent. If they are not stable over time, neither are the travel time factors. If they are stable, so are the travel time factors.

The authors worked with 24 sets of data classified by three trip purposes and developed in several cities. They concluded that the travel time function is not constant. My brief discussion raises certain questions of interest to those who wish to study the details of this procedure and concludes with a statement concerning the validity of the approach adopted by the authors.

1. In the statistical analysis it would be of interest to learn of the variables that did not correlate with the travel time factor parameters.

2. The way in which the authors resolved a number of difficult questions associated with fitting parameters to general Pearson types would be of particular interest to the student of curve fitting. Weighting procedures used would be of particular value.

3. The method of moments is not always an efficient method of obtaining parameters. Some comment on this is requested.

4. In discussing the development of an appropriate mathematical function for travel time factors, it is stated that the value of this function should decrease at an increasing rate with time. It is not clear to this reviewer why this should be the case. In fact, it would appear that this decline with separation would lessen at the larger separations.

5. It is well known that long trips contribute a disproportionate share of vehicle mileage on high-type facilities. What fraction of vehicle miles of travel is covered by the area of satisfactory fit of the Pearson I distribution?

6. It would appear to this reader that travel time factors would be particularly sensitive to spatial variables. If a region were to double in diameter, then it would be expected that there would be some travel between places separated by more than the original diameter of the area. Such a response would appear to require a spatial representation in the areawide variables used in the regressions. Previous studies bear this out.

Finally, it is my opinion that the approach used in this paper, one of inferring a causal relationship as a result of rather weak correlations of cross-sectional data, is weak and that those who believe in the variability of travel time factors will need stronger evidence than that presented here.

NORMAN ASHFORD and DONALD O. COVAULT, Closure—In closing the discussion, the authors wish to comment briefly on some of the important points brought out by Messrs. Bellomo and Cleveland.

The stability of travel time factors over time is an assumption that has been made with little supporting evidence. While the main thought of this paper was an examination of the form of the travel time factor, relationships were found to exist which should cause the planner to seriously question the traditionally accepted time stability.

Sensitivity analysis was carried out with respect to all shape parameters of both Pearson I and Pearson III curves. This analysis indicated that all shape parameters were insensitive, and the curve form was, therefore, applicable.

The method of moments is an efficient method of curve-fitting where the data points to be fitted closely identify with the curve form being used. The close agreement between actual curves and parametric curves lead the authors to believe that this method was justifiable for this work. The ability of the method to closely simulate the observed rapid increase in the logarithmic negative slope for smaller cities would indicate that the form selected was suitable.

The authors agree that some reworking of existing programs would be required to develop parametric curve fits. It is not felt that this is a major drawback which should discourage planners from adopting parametric forms in lieu of hand-drawn curves.

Shortcut Modal Split Formula

F. HOUSTON WYNN, Wilbur Smith and Associates

A shortcut modal split formula has been devised to measure the number of car drivers in large and middle-sized cities who would be diverted to travel on public transit if transit fares were reduced and/or if door-to-door travel times on transit were shortened by specified amounts. The shortcut formula applies only to car owners who work in central business districts since they often constitute the only significant concentration of tripmakers who can exercise a practical choice between driving and riding transit. The shortcut formula can be applied when two items of information are known: (a) the number of CBD workers who have their own cars, and (b) the proportion of car-owning workers who presently arrive at work on transit. Data may be evaluated for an entire city or for specific zones and zone clusters.

•IN the summer of 1965, Wilbur Smith and Associates was authorized by the U.S. Department of Transportation, Bureau of Public Roads, to undertake research entitled "Evaluation of Bus Transit Demand in Middle-Sized Urban Areas," with one aspect of this study to be the development of a "shortcut" method for quickly estimating the general magnitudes of change in the modal split when specific changes in cost or travel time requirements were introduced into a known situation. The "shortcut modal split formula" was prepared from data that represent trip-making behavior in large urban areas, but the formula is intended to indicate the general impact of trip cost or travel-time modifications in any community.

The shortcut formula relates only to travel performed by persons as they go to and from work and was developed from data on worker travel to the central business district (CBD) in the urbanized areas listed in Tables 1 and 2. (Although the shortcut formula has been prepared for a rather small and specialized segment of the traveling public, the principal reason for this restriction is based on the fact that there are very few transit riders in other trip-making populations who have regular access to a car, so that statistically stable information for analytical investigation is hard to find except for work trips to the CBD. There does not seem to be any basic reason, however, why the shortcut formula cannot be applied to workers traveling to any concentration of urban employment for which appropriate input data are available.)

The shortcut formula is designed to measure only the change in travel mode that can be expected to occur when the relative quality or cost of trip-making by car and public transit is modified, and is not intended to predict wholly new or induced trip-making that might result if the general level of mobility within an urban environment were improved. Because the formula relates only to the reapportionment of given amounts of travel, it is concerned with tripmakers who have the freedom to choose between private and public modes of travel.

Car owners will voluntarily travel by transit to very few employment centers in most urbanized areas. In searching for data to use in this study, it was soon found that the CBD is almost the only work place where a substantial number of car owners

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Paper sponsored by Committee on Origin and Destination and presented at the 48th Annual Meeting.

TABLE 1

SEVEN URBANIZED AREAS SELECTED FOR STUDY OF BUS TRANSIT DEMAND

Urbanized Area	Year of Survey	Population (thousands)	Dwellings (thousands)	No. of Cars (thousands)	Cars per Household	Thousands of Trips by Population		
						All	Transit	Percent Transit
Philadelphia, Pa.	1960	4,007	1,299	1,088	0.84	8,144	1,283	15.8
Boston, Mass.	1963	3,541	1,089	1,066	0.98	7,997	1,055	13.2
Baltimore, Md.	1962	1,608	481	446	0.93	2,675	322	12.4
Seattle, Wash.	1962	1,347	445	487	1.09	2,368	116	4.9
Milwaukee, Wis.	1963	1,221	366	373	1.02	2,555	268	10.5
Springfield, Mass.	1964	531	170	170	1.00	1,195	42	3.6
Columbia, S.C.	1964	196	62	69	1.12	581	14	2.5

TABLE 2

CBD WORKER POPULATIONS IN SEVEN URBANIZED AREAS (PERCENTAGES)

Urbanized Area	Population (thousands)	All CBD Trips (percent)	Percent Transit Riders	Percent Car Owners	Percent With Cars Ride Transit	Percent Transit Riders Have Cars	Transit Riders With Cars as Percent All Workers
Philadelphia	4,007	100	69.0	48.0	49.7	34.6	23.9
Boston	3,541	100	63.0	52.9	47.8	40.0	25.3
Baltimore	1,608	100	40.6	51.1	20.7	26.0	10.6
Seattle[a]	1,347	100	29.2	66.5	16.0	36.5	10.6
Milwaukee[b]	1,221	100	31.6	68.8	12.0	25.8	8.2
Springfield	531	100	21.8	65.2	7.6	22.8	5.0
Columbia	196	100	11.0	72.1	1.9	12.3	1.4

[a] Seattle data relate to only those portions of the Puget Sound Regional Transportation Study Area that lies east of Puget Sound.
[b] Milwaukee data have been compiled from the home interview survey conducted in the Milwaukee urbanized area, which is only a portion of the Southeastern Wisconsin Regional Planning Commission's Seven County Study Area.

regularly arrive at work by transit. Even in very large urban areas, such as Philadelphia and Boston, relatively few car owners use transit to get to work destinations that are not located in the CBD. Because this is the case, the basis for the shortcut formula is travel by car-owning workers who are employed in the CBD. While there are reasons to believe that the formula can probably be applied to workers at other large generators served by transit, empirical data are not available to prove it.

THE SHORTCUT MODAL SPLIT FORMULA

The shortcut formula is illustrated in Figure 1. The use of public transit for travel to work in the CBD is expressed as a percentage of any particular trip movement according to calculated cost differences for travel by transit and private car. When costs are equal (zero cost difference), half of the car-owning CBD workers would be expected to use their cars, while the other half would use transit. If transit costs are higher than those by car, less than half of the movement would take place in transit vehicles.

The following items cover most of the areas of cost subject to measurable manipulation:

1. Changes in transit fare structure;
2. Changes in toll charges and/or CBD parking rates; and
3. Changes in door-to-door travel time by car or transit (reduced to cost equivalents).

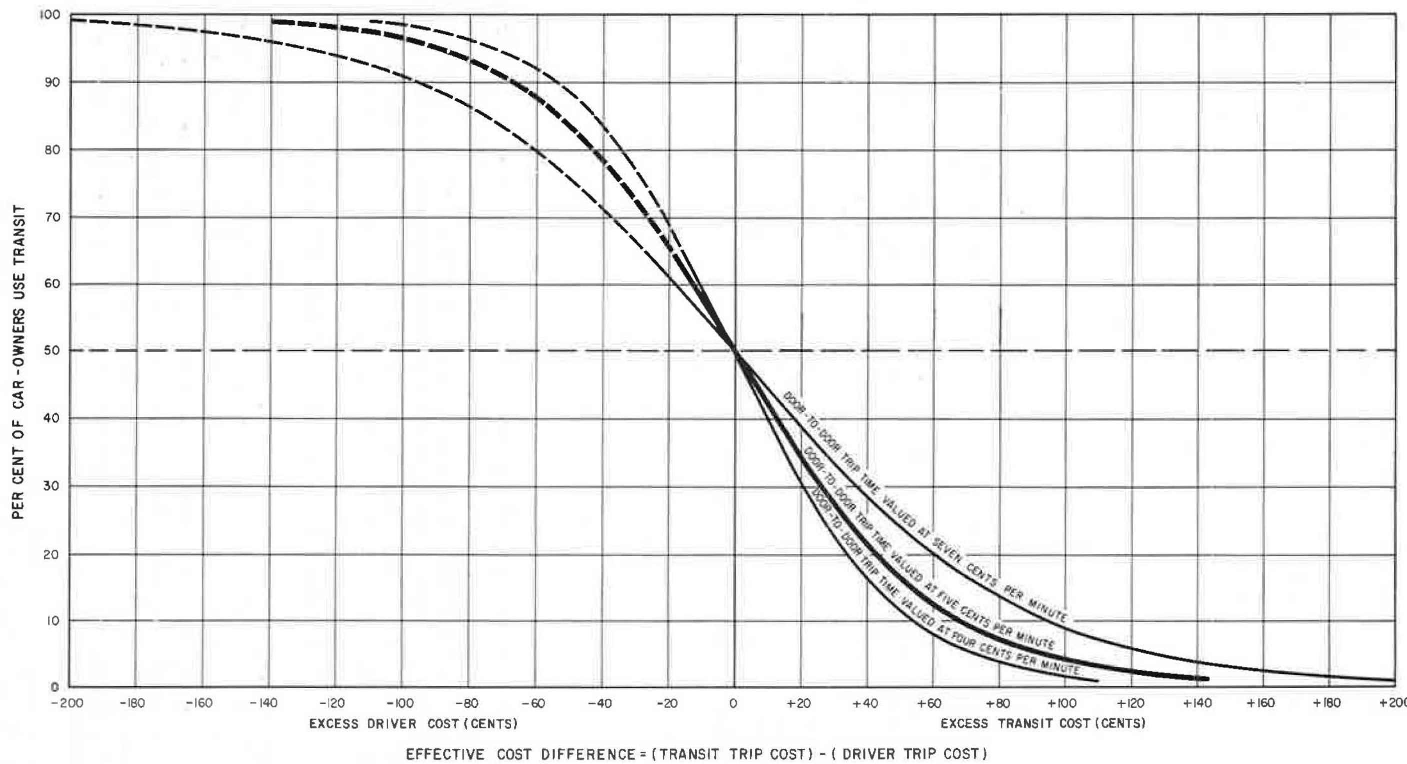

Figure 1. Shortcut formula to estimate effect of change in trip cost or travel time on the use of transit for CBD work trips by persons with cars.

Fares charged to transit riders may be modified by an overall increase or decrease in the cost of a ride; selective changes may be made, such as zone-fares, that affect only parts of the study area; or fares may be reduced or increased on some routes and not on others.

Average all-day parking costs tend to rise generally in most CBD's; it may be found feasible to accelerate an increase in rates, or even to reduce or eliminate charges. Toll charges usually apply to specific corridors (ferries, bridges, tunnels).

Travel-time may be modified for transit riders by increasing or decreasing service frequency (affects waiting time, or headway, between successive vehicles on a route); by adding or subtracting transit routes in a system that may change spacing between routes (affecting distance and walking time to bus stops); by reducing or increasing the number of loading and unloading stations (skip-stop technique may increase average running speed but also will result in longer waiting times at skipped stops); by introducing or abandoning express (nonstop) service between specific neighborhoods and the CBD; or by utilizing express highways, exclusive transit lanes, or exclusive transit rights-of-way for a portion of the trips. Driver trip time tends to become longer as traffic volumes (congestion) increase, but may be reduced when a new freeway or other street improvement is opened to use.

Some analyses of the value of travel time have differentiated between time spent in the vehicle and time spent waiting for the bus. These studies find that reduction of waiting time results in larger amounts of new transit travel than identical amounts of time saving achieved by improving vehicle speeds. The difference attributed to the value of a unit of time spent waiting, as opposed to time spent riding, would seem to be owing to the discomforts associated with waiting at transit stops, rather than to the time loss itself. These discomforts, such as adverse weather and fatigue of standing are among the "intangible" costs of travel that have not yet been defined and evaluated in mathematical terms. If it is proposed that time savings be achieved through reduction of waiting time, it would be appropriate to add the value of these intangibles, as found in controlled experiments and studies, to the cost savings attributed to the reduction in trip time.

APPLYING THE SHORTCUT FORMULA

The shortcut formula consists of a logarithmic growth curve which has been calibrated to show the proportion of CBD workers with cars who are likely to use public transit for their work trips under a complete range of relative cost conditions.

The following equation has been developed from the relationships shown in Figure 1 (this equation was developed by Herbert S. Levinson and Bruno Wildermuth, based on curves that had been hand-fitted to the data used in the study; earlier versions consisted of separate equations for each value of time-cost (2)):

$$P = \frac{1}{1 + \exp(16x/c)} \tag{1}$$

where

- P = percent of car owners who use public transit to travel to work in CBD;
- e = base of natural logarithms = 2.71828;
- c = cost of time in cents per minute; and
- x = net trip cost difference = (transit trip cost) - (driver trip cost).

Three curves have been calculated and drawn in Figure 1, based on different rates of cost for travel time. At present, a rate of 5 cents per minute provides an appropriate weighting for travel time when combined with other costs of travel. Rates of 4 cents and 7 cents per minute were used to develop the lightly drawn lines that flank the 5-cent curve and that are shown to illustrate a range within which an estimate might fall. The curves show how different assumptions on the worth of travel time affect estimates of transit use, ranging from low (7-cent curve) to high (4-cent curve) transit-use potentials. If the value of commuters' time continues to increase, the 7-cent curve should gradually become more suitable than the 5-cent curve, because per-mile direct costs will probably increase with the passage of time owing to the forces of inflation. Under conditions where differences in trip cost relate only to travel time, however, the equation will develop nearly identical estimates for any time value used (within the range shown).

To use the shortcut formula, it is necessary to know the number of car owners attracted to an employment center from each of the residential neighborhoods in an urban area, and to determine, either by direct measurement or informed estimate, the proportion of these car owners who arrive at work on a transit vehicle. Transit riders would include any persons who started their trips by car and transferred to transit, such as railroad commuters. When the percentage of transit riders has been found for a particular population of car-owning CBD workers, this information may be projected to the modal-split curves shown in Figure 1.

Figure 2 shows how the modal split curve can be used to estimate the effect of a reduction in transit trip costs relative to costs by car. In the example shown, it has been assumed that 15 percent of the car-owning CBD workers residing in a particular traffic zone are presently using transit for the trip to work. This value has been scaled on the vertical axis of the chart and carried horizontally (A) to intersect the 5-cent curve. The approximate value for excess transit cost has been noted on the scale at the bottom of the chart (B). It was next assumed that a saving of 10 cents in the average cost of the transit ride from the traffic zone of residence to the CBD can be anticipated; this reduction in the excess cost of transit has been subtracted from the "effective cost difference" by moving an appropriate distance to the left (C). A vertical projection (D) intersects the diversion curve again, and a new estimate of the proportion of car owners using transit has been obtained (E) from the vertical scale on the left margin of the chart. Under the revised condition, about 20 percent of the car-owning CBD workers in this residential zone would be expected to arrive at work by transit, or about a one-third increase in transit use by this particular sector of the traveling public.

The cost reduction assumed for transit can be realized in various ways. The 10-cent saving might result from a fare reduction, from introduction of express service that reduces trip time by two minutes, from an increase in service frequency that reduces average headways at the bus stop by four minutes, and thereby saves the average rider about 2 minutes per trip, by an increase in motorist parking costs, or by any combination of these. If the analyst believes that he can establish a realistic estimate of the value of such intangibles as air conditioning, protected bus stops, prohibition of standees, and other conditions that do not directly affect travel time or out-of-pocket costs, he can assume such savings and estimate the increased patronage resulting from such inducements.

The information needed to enter the shortcut formula consists of one item for each traffic zone; that is, the proportion of car-owning CBD workers who ride transit to work. When this is known or assumed for a base condition, the effect of trip cost savings or increases can be quantified for tripmakers in each traffic zone in the study area.

DEVELOPING THE SHORTCUT FORMULA

Only the CBD worker population was examined in this study, with special attention given to workers defined as car owners. This definition was applied only to CBD workers who had exclusive use of a car during the working day and, according to definition, the car was either used by the owner in making his trip to work or it remained idle throughout the time the worker was away at his job. In spite of this strict interpretation of car availability, almost half of all CBD workers interviewed in the Philadelphia survey, more than half of those in Boston and Baltimore, about two-thirds of the workers in Seattle, Milwaukee and Springfield, and nearly three-quarters of those in Columbia were classified as car owners.

Nearly half of the CBD car owners in Philadelphia and Boston arrived in the CBD on transit, but only a fifth came by bus in Baltimore, a sixth in Seattle, and an eighth in Milwaukee. The proportions were so small in Springfield and Columbia (less than 8

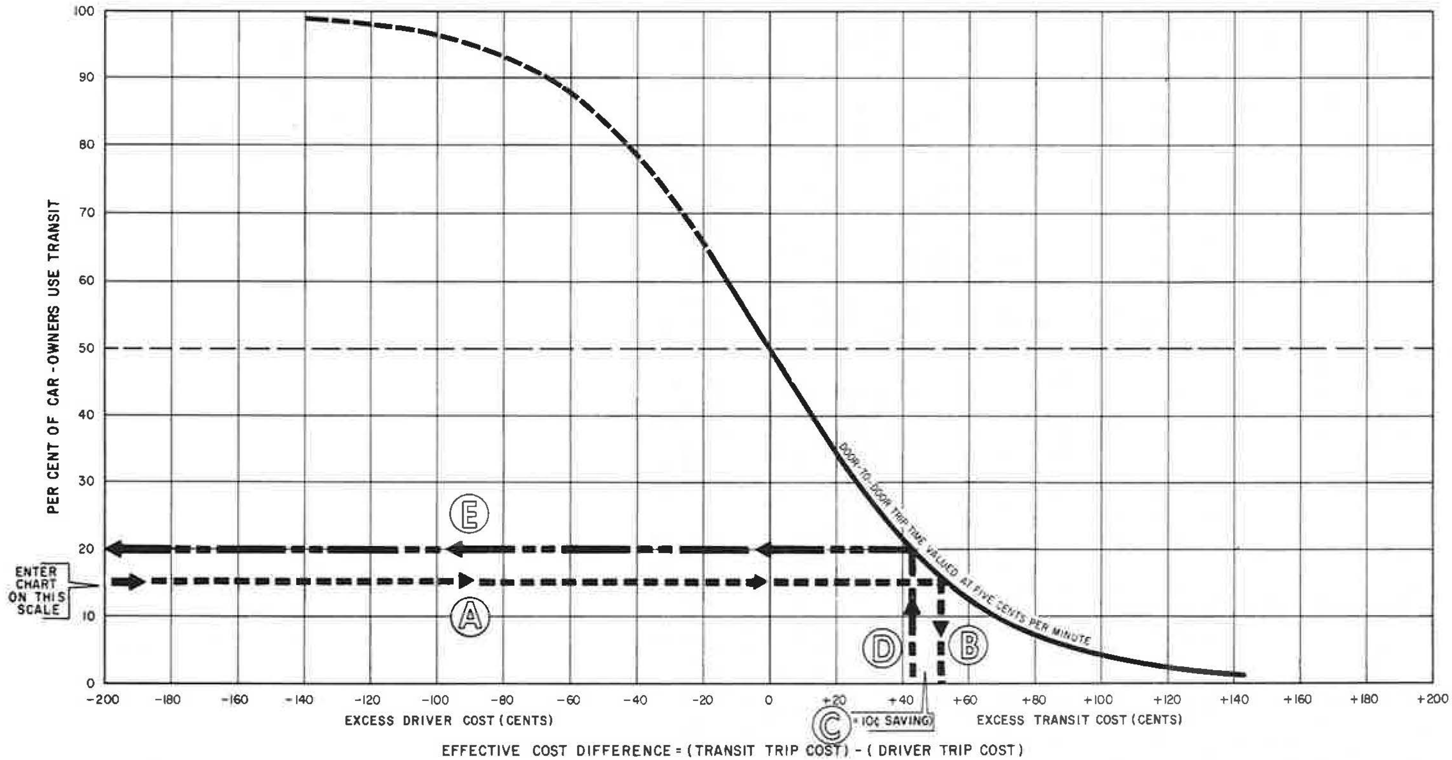

Figure 2. Shortcut formula: example of use to estimate effect of change in trip cost or travel time on the use of transit for CBD work trips by persons with cars.

and 2 percent, respectively) that data from these areas were dropped from further analyses. Both Boston and Philadelphia have extensive rail commuter services, with up to three-fourths of the car-owning CBD commuters in some outlying communities going to work by train each day.

Data for each study area were organized in a few concentric "rings" or "belts" of traffic zones centered on the CBD. All home-based worker trips to the CBD were assembled by rings and summarized by mode of arrival at work. Door-to-door elapsed trip times were compiled and average time values computed for travel from each ring according to mode.

The basis for the shortcut formula is the assumption that the use of transit by car owners who work in the CBD is a function of the relative costs of travel by car and transit. Although the cost of travel is an exceedingly complex subject, means were sought to simplify the situation and base the estimating formula on a few relatively uncontroversial cost items. Four categories of cost were defined for consideration:

1. Out-of-pocket costs of travel (fares on transit; vehicle operating costs for drivers);
2. Nonoperating costs to drivers (parking and tolls);
3. Travel time (minutes of trip-time, converted to appropriate cost values); and
4. Intangible costs (comfort, convenience, privacy, etc.).

Out-of-pocket costs are highly variable within each mode but, after careful consideration, it seems feasible to regard them as approximately equal, or near enough so that no reliable distinction could easily be developed. Intangible costs do not easily yield to quantification. After considering these points, estimated cost differences for travel by car and transit were prepared, based on door-to-door times (in cents per minute) and average all-day parking costs paid by drivers. Recent studies of the value of time to persons commuting to work suggest that a range of 4 to 5 cents per minute is appropriate (3, 4). It was convenient to apply these rates to the time-difference between car and transit trips.

Figure 3 was prepared to show the basic costs of all-day parking to those persons who pay for parking in the CBD, based on parking survey data for cities ranging widely in size. Curve B on the chart represents the actual rates paid by persons who had to

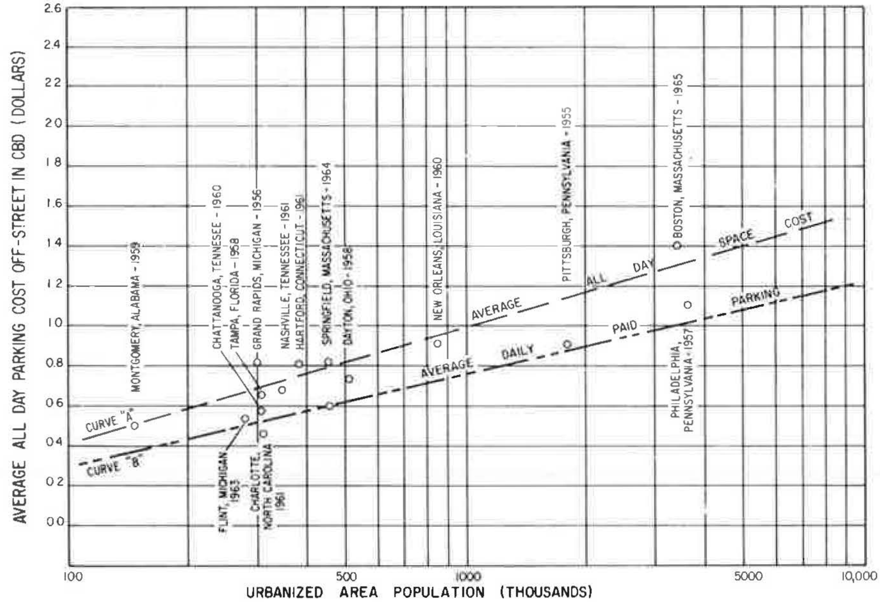

Figure 3. Average all-day, off-street parking rates in CBD.

bear the cost for storing their cars. Daily rates are shown to vary according to city size.

An amount equal to half of the daily parking cost represents a fair charge against the one-way trip to work; this value was factored by the percentage of drivers who paid to park to find an average parking cost for all CBD drivers. Parking costs were added to time cost of driver trips and the effective cost differences computed for car and transit travel to the CBD in each study area. Figure 4 shows these data, summarized by a ring, plotted against the proportion of car owners using transit. Figure 4 was plotted from data showing the percentage of car owners in each ring who use transit related to excess trip costs at 5 cents per minute. Points for the series of rings in each study area have been joined.

The logarithmic growth curve shown in Figures 1 and 2 has also been plotted in Figure 4. The general shape of the curve was worked out from inspection of the data-points, with consideration for the shape that the curve might be expected to take. The most evident relationship is the grouping of points for Philadelphia and Boston. A straight line drawn freehand to fit the Philadelphia points would cross the line of equal cost at a point where 50 percent of the CBD car owners use transit for the trip to work. Data for the most important rings in Boston, while dispersed more widely, tend to average out at about the same point. The data plotted in Figure 4 thus confirm the relationship that would be expected, assuming that all trip costs had been taken into account. It can be argued that this is true in the case of Philadelphia and Boston.

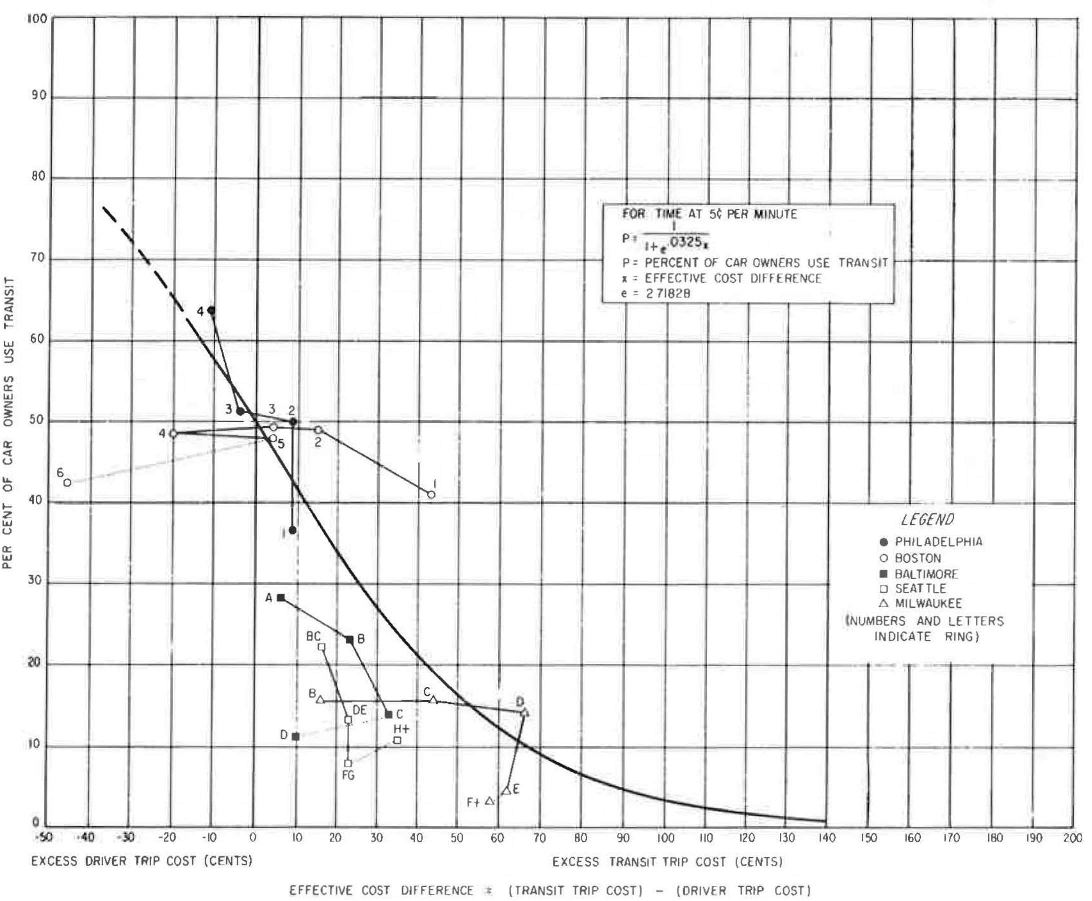

Figure 4. Transit use vs trip cost difference.

Data for the smaller cities do not lie on, or even near, the curve projected through the Philadelphia and Boston data. It is significant, though, that lines connecting the points representing rings in Baltimore and Seattle develop slopes that are generally similar to the curve. Thus, it could be argued that the lateral displacement of the curve represents cost differences that relate to intangible conditions. But, in any case, it is the slope of the curve that determines the added proportion of car owners affected when transit trip costs are reduced. The curve representing the shortcut formula has a reasonable slope in relation to these data.

TYPICAL APPLICATIONS

The shortcut formula pertains only to populations that have freedom of choice in the selection of a travel mode for work trips. These are the tripmakers who have their own cars and who are not likely to use transit for a trip unless it meets their needs better than the car.

In a typical situation, the shortcut formula might be used to estimate potential diversion of additional workers to transit because of an improvement in the effective cost-difference for transit travel between the CBD and a number of residential neighborhoods (zone clusters). The total of car-owning CBD workers in each neighborhood, and the percentage of them who presently use transit for the work trip, would be determined, and the effective cost-difference between car and transit would be established for each movement as illustrated in Figure 2. A 5-cent value of time can be expected to develop a good estimate of the cost-use relationships in most current situations, but the analyst may pick a cost value at his own discretion.

Taking this approach, the effect of a change in the relative costs or performance levels of car and transit work trips can be estimated. The average amount of cost change would be calculated for travel attracted to work places in CBD from each neighborhood and this amount would be subtracted from the effective cost-difference based on present levels of transit use. The new cost-difference value would be projected to the diversion curve to find the corresponding percentage of transit users.

A variety of costs can be considered in developing the estimate of change. Direct out-of-pocket cost-changes may relate to transit fares, parking charges, toll rates, and possibly other cost elements. Time changes, which must be converted to cost values according to a rate specific to the diversion curve used, can be realized in various ways, such as improved transit running speeds (owing to express service, skip-stop operation, exclusive bus lanes on freeways), more frequent headways (saving up to half of the difference in headway time-changes), closer spacing of transit routes (resulting in less walking time), and similar measures.

When a new percentage of transit riders is found, it may be applied to the base number of car-owning workers who travel to the CBD to derive an estimate of transit diversion and thus find the number of new riders. If these are estimates of 24-hour diversions of trips to work, an appropriate percentage factor may be used to estimate the number of new transit riders in peak-hour travel to work.

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A Probability Model of Travel Mode Choice For the Work Journey

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This paper describes the derivation of a probability model of travel mode choice for the work journey in terms of the differences in costs and times between the modes available for each individual's journey. The work is based on surveys carried out at two offices in central London, with some test data from a survey of workers in central Leeds. Regression techniques were used to establish simple linear relationships between the probability of using a car and the cost and time differences between a car and the best available public transport route. Reasonable correlation coefficients were obtained. Limited tests of the models have reproduced existing mode choices to a high degree of accuracy. Relationships were also established between the regression coefficients and income. A generalized model is derived from these relationships.

The basic model has a serious fault in that because it is linear, it permits values of probability to be obtained that exceed unity, or are less than zero. A logistic transformation is put forward to correct this and is used on the generalized model. The resulting model still appears to reproduce existing conditions to a similarly high degree of accuracy. The model appears to be reasonably behavioral, and could form the basis of a new and more accurate mode choice procedure.

•IN THE PAST, most models of travel mode choice have been developed as a stage in a traffic study for a particular area. To do this, the model devised has to conform to certain requirements. It must first fit into an existing forecasting package, or be able to be tailored to fit with existing trip distribution and assignment techniques. The model must then be able to be applied to a mass of people and to predict the volumes of travel on the various modes. Consequently, the model is often defined in terms of socioeconomic factors that serve to describe the population rather than the transport network available. Forecasting travel mode choice at a future date requires an assumption that people will change their socioeconomic classes, and that their travel desires and habits will conform with those of the class into which they have moved. This assumption is somewhat difficult to justify, particularly since it must depend on the ability of the transport network to accept an increased demand for travel.

More recently, attempts have been made to devise models using parameters that are descriptive of the transport network, e.g., San Francisco Bay Area Transportation Study (1) and Twin Cities Transportation Study (2). These parameters have usually been an attempt at devising a measure of accessibility to apply to an area, or some form of time ratio. However, the derivation of a model that is descriptive of the transport system, but that is applied to a mass of people still leaves something to be desired in terms of a behavioral model, although the model developed by Traffic Research Corporation (3) goes far toward achieving this.

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The model attempts to describe mode choice in terms of each individual and the part of the transport system available to carry out the desired journey.

DESIGN OF THE MODEL

The first stage in the design of the model was to carry out a limited survey on a part of the population to which the model was intended to be applied. From the results of this survey, it was planned to choose the parameters to be used in the model and also possibly to make an initial tentative calibration of the model. For these reasons, the survey took the form of a questionnaire about the work journey, with a request for a number of socioeconomic factors required to define the sampled population that might be necessary to help explain mode choice. The survey also included two attitudinal questions about choice of mode. These were open-ended questions designed to elicit information on perceived reasons for choice of a particular mode.

This survey was designed as a questionnaire to be circulated without follow-up and with no time limit set on the returns. The location selected for the survey was University College London, and the questionnaires were circulated through the internal post system to all academic and administrative staff of the College. Apart from convenience, University College represented a useful location for this survey for two reasons. First, the model sought for at this stage was one that would predict the level of use of a car for the work journey. This required a fairly large number of car owners to be surveyed, but because it was not desirable to collect a large quantity of less useful information on non-car owners, a high proportion of car owners was desirable. This was expected to be the situation at University College. Second, the College is located within the Central Area of London as defined by the London Traffic Survey (4) and is well-served by public transport. It is also near the focus of the radial routes into London. The College also provides some free parking for staff, and although it is in an area of parking meters, it is less than a quarter-mile from the boundary of the controlled parking area (as of 1966, when this survey was carried out).

A total of 1308 questionnaires were distributed, of which 767 usable returns were received. This represents a response rate of 59 percent. Of the forms returned, 26 had to be rejected, representing only 2 percent of the dispatched questionnaires, or just over 3 percent of the returned questionnaires.

An analysis indicated a higher car ownership level and a higher average income than would be expected from a random sample in London. The comparative figures are given in Table 1, in which the London figures are from the London Traffic Survey (4). Analysis of the answers to the open-ended question on reasons for the choice of mode showed that the most important factors for people with a choice were speed, convenience, cost and comfort, in approximately that order. Speed was put forward by most people in all categories; i.e., non-car owners, car users, and car owners using public transport. Convenience came second to this and cheapness third for all public transport users, but fourth for car users. Comfort came third in importance to car users, but was mentioned by less than 10 percent of public transport users.

From this, it would appear that given a choice between any two modes, the most important factors that an individual perceives as influencing his choice are time, cost, and convenience, with the addition of comfort if the choice pair includes a car. Up to the present, it has not been possible to devise a quan-

TABLE 1

INCOME AND CAR OWNERSHIP DISTRIBUTIONS FOR UNIVERSITY COLLEGE IN 1966 AND THE LONDON TRAFFIC SURVEY AREA IN 1962

Income Range (pounds)	University College (%)	London Area (%)	Car Owners in Total Population (%)	
			University College	London Area
Under 500	2.0	14.0	0.2	0.5
500 to 999	21.0	39.5	3.1	10.3
1000 to 1499	18.0	27.5	6.8	13.0
1500 to 1999	16.0	10.5	10.8	7.2
2000 to 2999	23.0	5.5	16.7	4.3
3000 and over	20.0	3.0	15.0	2.7
Total	100.0	100.0	52.6	38.0

titative expression for comfort or convenience. It was therefore decided to concentrate on devising a model in terms of costs and times for the available modes only.

The basic model to be devised is one expressing the choice between car and public transport in terms of the time and cost for a particular journey by each mode. The form of model desired is one that allots a probability of using a car to each individual considered. In dealing with a given population, it is first necessary to exclude all those who have no car. Because the model is concerned with a real choice, it is then also necessary to exclude all captive car users, so that the public-private transport model is applied to the individuals in the remainder of the population.

The simplest form of the model would be a linear one between the probability of using the car and a function of costs and times. Both ratios and differences were considered for the functions of costs and times. To select one of these functions for the model, consideration was given to two factors: whether the function appeared to be well correlated with observed behavior, and whether the function appeared to reflect a person's attitude. The resulting data were grouped by total cost and time, in which an approximate probability was allotted to each group, based on the numbers of car and public transport users in each group. A very wide variation in probability occurred for any particular small range of cost and time ratios. It also seems more likely for relatively short journeys that cost and time savings are assessed in absolute terms not relative to the overall cost or time. For these reasons it was decided to use differences that show a much closer correlation with probability and that imply absolute valuation of any savings in costs and times.

The form of the model proposed is

$$p = a(c_2 - c_1) + b(t_2 - t_1) + d \qquad (1)$$

where d represents the probability of using the car when costs and times by public transport and car are the same. If choice depends on costs and times only, d would be 0.5. The departure of d from 0.5 gives an indication of a bias for or against car use on grounds other than cost and time. The value of b/a represents the implied value of travel time. The symbols c and t represent cost and time, respectively, and the subscripts 1 and 2 represent car and public transport, respectively. This model can be derived mathematically, and a possible derivation of it has been given previously (5).

An initial calibration was carried out on the sample of car owners from University College. The questionnaire had asked all respondents to give details of their usual work trip and details of the mode or modes that they considered to represent their best alternative. It was assumed, however, that all car owners would either use their car or specify car as their best alternative. For each car owner, costs and times were calculated for car and for the best public transport journey (i.e., either the public transport journey carried out or the one stated as alternative to using the car), and cost and time differences were calculated from these.

The car owning population was then grouped into a number of classes representing small ranges of cost and time differences. The total numbers of car users and public transport users within each class were counted, and the probability of using a car in each class was taken to be the number of car users in the class divided by the total population of that class. A regression technique was then used to find a relationship between this probability and the actual cost and time differences for each individual. The result of this process was the following model:

$$p = 0.00278(c_2 - c_1) + 0.00695(t_2 - t_1) + 0.394 \qquad (2)$$

for which the correlation coefficient R was 0.63 (R^2 = 39.7 percent). The implied value of time from this model is 2.5 pence per minute. The average wage rate of the sample was 2400 pounds a year, so that this value of time represents 0.42 of the wage rate. For salaries in a similar range to this, Beesley (6) found values of time between 0.42 and 0.50 of the wage rate; and in the Toronto survey (7), a value of 0.41 of the wage rate. However, it will be seen later that further analysis produced some lower time values, and it appears that the above estimates are somewhat inflated.

Resubstitution of the University College data in the model gave a prediction of 135 car journeys out of 311 car owners. The observed figure was 136 car journeys.

TEST OF THE BASIC MODEL

Having set up a basic model form and having carried out a tentative calibration of the model, it was decided to collect further data to test the model and to allow some recalibration if necessary. A second work trip survey was carried out, this time at County Hall London, the central office of the Greater London Council. This office block is situated on the south side of the Thames nearly opposite the Houses of Parliament and close to Waterloo Main Line Terminus station and Waterloo Underground station.

Approximately 6500 people work at County Hall and, as at University College, a questionnaire survey was designed to be circulated to all people working in the block. Again, no interviewing or personal follow-up was carried out. County Hall is not situated in a meter-controlled parking area, but practically no free parking is provided for employees. Cars must either be parked in side streets or at a pay car park adjacent to County Hall. It was hoped that the population of County Hall would exhibit much less bias than the University College sample, and that in terms of both income and car ownership it would much more closely resemble a random sample from the London area.

Because the model dealt with car owners only, the survey at County Hall was designed to eliminate non-car owners at an early stage and request journey details from car owners only. Information was collected from everybody on income, car-owning status of themselves and their household, and availability of a car for use for the work journey. Non-car owners were then eliminated. This allowed computation of statistics of car ownership and income, but avoided the collection and coding of a vast quantity of irrelevant information.

A total of 6395 questionnaires were sent out, with a time limit of $2\frac{1}{2}$ weeks set for the return of completed forms. Of these, 5166 forms were returned, from which 258 had to be rejected as incomplete. The 4908 usable replies represent a response rate of 77 percent that is exceptionally high.

Details of car ownership and income, compared with values from the 1962 London Traffic Survey, are given in Table 2. By applying an adjustment to the lower income groups recorded in the London Traffic Survey to allow for the $4\frac{1}{2}$-yr difference between the two surveys, so that the proportion in the lowest group is assumed to decrease while the next two groups increase, it can be seen that the distribution from County Hall is very close to what might be expected from a random sample from the London area. Thus, one of the aims in selecting County Hall for the second survey was achieved.

Of the 4908 replies, 2871 were from non-car owners, and 2037 from car owners. All the remaining analysis refers to these latter. Only 456 of the car owners used

TABLE 2

INCOME AND CAR OWNERSHIP DISTRIBUTIONS FOR COUNTY HALL IN 1966 AND THE LONDON TRAFFIC SURVEY AREA IN 1962

Income Range (pounds)	County Hall (%)	London Area (%)	Car Owners in Total Population (%)	
			County Hall	London Area
Under 500	6.5	14.0	0.5	0.5
500 to 999	46.5	39.5	10.5	10.3
1000 to 1499	26.5	27.5	14.0	13.0
1500 to 1999	11.5	10.5	8.8	7.2
2000 to 2999	7.0	5.5	6.0	4.3
3000 and over	2.0	3.0	1.7	2.7
Total	100.0	100.0	41.5	38.0

TABLE 3

RESULTS OF REGRESSION ANALYSIS BY INCOME GROUP FOR THE COUNTY HALL SAMPLE

Income Range (pounds)	Value of Time (pence per min)	Coefficient of Cost Difference	Constant Term	Correlation Coefficient	Sample Size
Under 1000	0.45	0.00998	0.357	0.77	415
1000 to 1499	0.65	0.00801	0.336	0.80	514
1500 to 1999	0.80	0.00698	0.308	0.77	321
2000 to 2999	1.10	0.00550	0.300	0.66	214
3000 and over	0.20	0.00376	0.218	0.49	73

their cars to travel to work, 1529 used public transport and the remaining 52 used a cycle, or walked to work, or traveled as a passenger in someone else's car.

The basic model calibrated at University College was then used on the County Hall data. The standard error of estimate of the model applied to the County Hall data is ±10 percent. The model predicted 554 car journeys by 1983 car owners compared with 456 who actually used their cars. The difference between prediction and observation is just under 5 percent. Considering the large differences in income and car ownership between University College and County Hall, this prediction error seems to be remarkably small. The County Hall data were split into ten groups based on income, and it was found that the University College model predicted too many trips in each group. All the misclassifications in these groups were additive.

MODIFICATION OF THE MODEL

It may be expected that valuation of time and probability of using the car will vary with income. The population of car owners obtained at University College was too small to allow any analysis to be carried out on variation of the model with income. However, the much larger population at County Hall does allow analysis of this sort. It may be anticipated that a very different value of time would be found for the whole population at County Hall, because the 2.5 pence per minute found at University College represents 0.74 of the average wage rate at County Hall.

The same technique was used on the County Hall data, which was split into five income groups, as was used on the University College data to perform a regression analysis. The results of the regression analyses are given in Table 3.

With the exception of the highest income group, the values of the coefficients appear to vary consistently. The constant term and the cost coefficient each decrease with increasing income, although the value of time increases. However, Table 4 shows that although the value of time increases with income, as a proportion of the wage rate it falls. Although the value of time found in the University College model does not correspond with that at County Hall for a comparable income level, the coefficients of time difference are similar, being 0.00695 for a mean income of 2400 pounds at University College and 0.00695 for the 2000- to 2999-pound income group at County Hall. Also, the values of time found here are very similar to values obtained by Quarmby (8) at Leeds.

The new models were again tested by re-substitution of the data used to calibrate them. The overall result was a prediction of 382 car journeys for a sample of 1537 car owners (some car owners had to be dropped from the analysis owing to insufficient data to calculate times and costs on an alternative mode), of whom 384 actually made car journeys. The total misclassification by income groups was 8 trips, the misclassifications having a tendency to be self-cancelling when the results for all income groups were summed up.

TABLE 4

VARIATION OF VALUE OF TIME WITH INCOME FOR THE COUNTY HALL SURVEY

Income Range (pounds)	Value of Time as a Proportion of the Wage Rate
Under 1000	0.32
1000 to 1499	0.26
1500 to 1999	0.23
2000 to 2999	0.21

GENERALIZED MODEL

It has already been observed that a consistent variation of model constants appears to occur with income group. An investigation was carried out to determine the mathematical form of the variation. The analysis of these variations must not be relied on to too great an extent, because the regressions carried out use only four or five observations. However, all the correlation coefficients are significant. The following relationships were established for the model constants:

$$a = 0.0337 - 0.0036 \log_e(I) \quad (3)$$

$$b = 0.00125 \log_e(I) - 0.00375 \quad (4)$$

$$d = 0.3825 - 0.000038\ I \quad (5)$$

where a, b, and d are the constants in Eq. 1, and I is the income in pounds a year. The correlation coefficients obtained for these equations gave R^2 values of 0.99, 0.98, and 0.90 respectively. From Eqs. 3 and 4 the value of time is found to be given by

$$v = \frac{0.00125 \log_e(I) - 0.00375}{0.0337 - 0.0036 \log_e(I)} \quad (6)$$

From these equations, overall models were computed for the County Hall and University College samples in terms of the mean incomes of the two samples:

$$\text{County Hall: } p = 0.0076(c_2 - c_1) + 0.00529(t_2 - t_1) + 0.331 \quad (7)$$

$$\text{University College: } p = 0.0057(c_2 - c_1) + 0.00599(t_2 - t_1) + 0.291 \quad (8)$$

The two sets of data were substituted in these models, and predictions of 383 and 105 car journeys, respectively, were obtained. The observed numbers of car journeys were 384 and 136. The relationships in Eqs. 3 to 6 do not appear to hold for incomes over 3000 pounds a year. Because this category represented only 4.5 percent of the County Hall sample, but 16 percent of the University College sample, this may account for the poorer result obtained at University College using the generalized model.

It was noted that the County Hall sample consisted of almost entirely car-train choices, there being only 92 car-bus choices for the 1537 car owners in this sample. It has been stated previously that the constant term of the model (d in Eq. 1) indicates a bias for or against car travel on grounds other than cost and time. It seems probable, on the basis of the replies to the attitude question in the University College survey, that much of this bias would be based on the grounds of comfort and convenience. If this is so, one would expect different values of the constant term according to whether one is considering car-bus or car-train choices. To investigate this, the general County Hall model was applied to the 92 car-bus choices with the result that a prediction of 40 car users was obtained. It was observed that 61 of the 92 people in this sample actually used their cars, so that the model is 22.8 percent in error. Without further data to check, it was then assumed that a correlation factor of 0.228 should be added to d for application to car-bus choices alone.

Data from Quarmby's survey at Leeds (8) were then used to test the model. These data consisted of trip details for 542 car owners, all of whom had a simple car-bus choice. The mean income of the car owners was 1400 pounds a year, which gives the following model for this population:

$$p = 0.0076(c_2 - c_1) + 0.00529(t_2 - t_1) + 0.559 \quad (9)$$

using the addition of 0.228 to d for car-bus choices. Of the 542 car owners, 112 were found to be captive to car or bus, so the model was applied to the remaining 430 car owners. The model predicted 270 car users, and the observed number was 264, an error of just less than 2 percent.

FURTHER MODIFICATIONS

In its present form the model is found to have one serious fault. Because it is a purely linear relationship, it is possible for very large positive or negative values of cost and time difference to yield probabilities in excess of 1 or less than 0, neither of which is permissible. This suggested that modifications should be made to prevent the occurrence of such values. The simplest method would be to define the model as a step function so that the linear form held true for values of cost and time differences that yield a probability between 0 and 1, but that for all other values of cost and time difference, the value of p becomes independent of cost and time differences, and tends to 0 or 1 according to whether the differences are negative or positive. However, this is not a particularly satisfactory treatment of the model.

A relatively simple mathematical form that would yield the desired form of relationship is the simple logistic where $p = e^y/(1 + e^y)$, and y is a linear function of various parameters. In this instance, y would be a linear function of cost and time differences, transformed directly from the original models. The logistic form can be written as

$$\log_e \frac{(p)}{(1 - p)} = y = a'(c_2 - c_1) + b'(t_2 - t_1) + d' \qquad (10)$$

It is convenient to assume that the value of time remains unaltered in this transformation, so that b'/a' retains the same value as b/a. In that case, it is found that a' equals $\log_e [d/(1 - d)]$. Thus, each of the models already produced can be altered into the logistic form by transforming the coefficients. This same transformation can also be applied to the generalized formulas for the model constants with the following results:

$$a' = 0.1348 - 0.0144 \log_e (I) \qquad (11)$$

$$d' = \log_e \frac{(0.3825 - 0.000038\ I)}{(0.6175 + 0.000038\ I)} \qquad (12)$$

where v is as in Eq. 4. Application of these transformed models to each income group in the County Hall data yielded a prediction of 397 car journeys instead of the 384 observed. Deriving a general model similar to that of Eq. 7, a prediction of 398 car journeys is obtained. Similarly, devising a logistic model for the University College sample, a prediction of 113 car journeys is obtained compared with 136 observed for the 311 car owners.

The effect of this logistic transformation can be seen in Figures 1 and 2, which show the original linear models and the new logistic models for the County Hall and University College samples. The main result of this exercise is to yield a model more behavioral and more mathematically satisfactory than the original simple linear model.

FUTURE DEVELOPMENTS

The model presented here represents the first stages in the development of a new mode choice procedure for work journeys. The survey at University College suggests that the same parameters used in this model may apply to the choices between public transport submodes for captive riders. If this is so, it should prove possible to build models for the choice between any pair of modes in an overall system containing more than two modes. This could lead to a modal split procedure involving the isolation of captive car users and captive public transport users. The captive public transport users could be split between available public transport modes by use of public transport submodels, and the remainder of the population could be split between available modes by a procedure involving either the use of certain submodels representing all the options available, or by a public-private model with submodels for the public transport users.

It is hoped that the development of such a procedure as that outlined above will be pursued. This could be allied to a new distribution and assignment procedure that in-

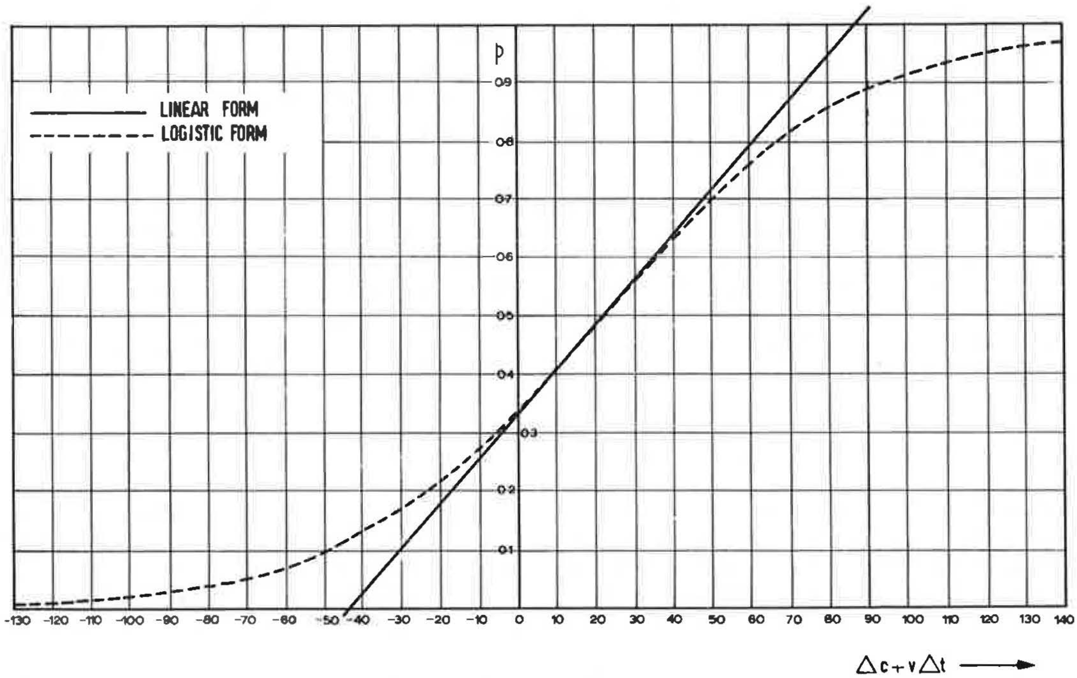

Figure 1. Comparison of linear and logistic model forms for the County Hall sample.

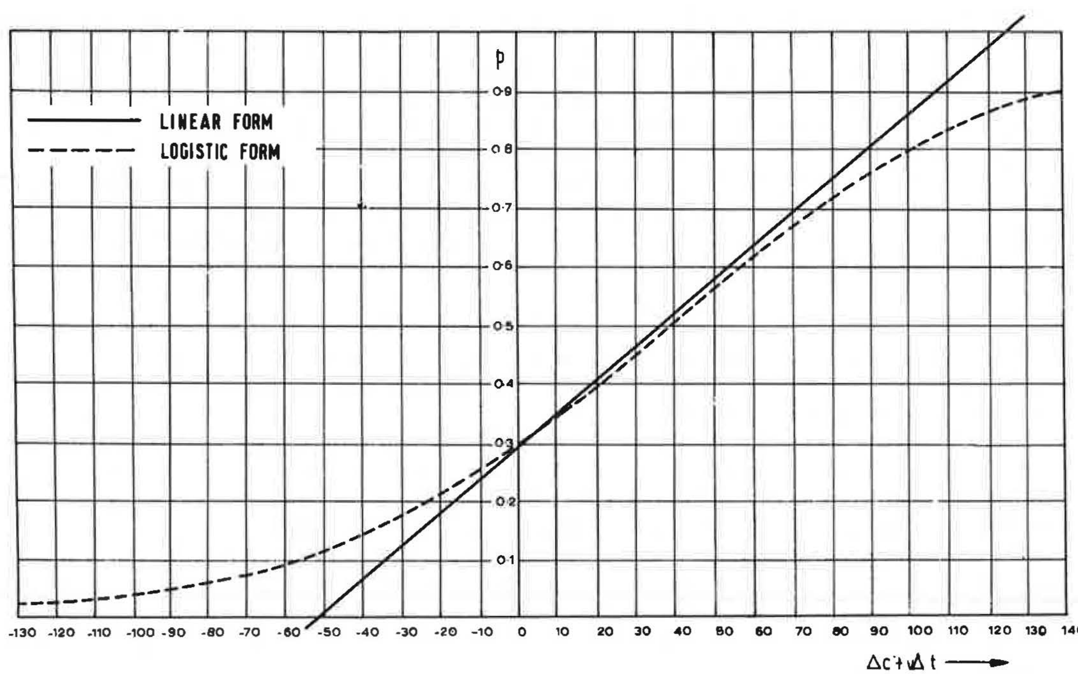

Figure 2. Comparison of linear and logistic model forms for the University College sample.

cludes allowances for congestion on the system, and uses times derived from the loaded network to produce input to the modal split phase and the assignment phase.

The existing model is at present being used at the College of Aeronautics, Cranfield, Bedford, to assist with the economic evaluation of alternative public transport systems for the projected new town of Milton Keynes in Buckinghamshire. The College is involved in examining a number of possible urban layouts and their implications in terms of trip distribution and modal split with various alternative transport systems. The proposed town will have a population of 250,000 by the year 2000, and it is necessary to decide upon the best transport system and layout for the town before development proceeds. No results are available yet from these tests.

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