CHOICE OF ROUTES ON URBAN NETWORKS FOR THE JOURNEY TO WORK

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About 13,000 drivers traveling from home to work were interviewed for their daily routes on the highway network and for their motivations for selecting these routes. The traffic conditions and characteristics of each route were also investigated. The results of these investigations and an analysis of the motivations showed that travel time, distance, number of possible stops, and maximum lane volume on a link between the points of choice are important for route selection. These 4 resistance factors were used to develop a trip-diversion model. It was found that the parameter values of this model depend on route distance or driving time and the type of town district traversed. Optimal routes in highway networks were found by determining a formula for link resistance. The formula contains travel time, length, and lane volume of the link as important factors, and it is shown that the parameters of this equation are a function of the link length. An application of the model showed good results.

•THE FACTORS AND REASONS that influence a driver to take a certain route in a road network, if he has a free choice among several routes, are numerous and are dependent on the driver's mentality, attitude, social status, age, sex, and other factors. Especially important, however, is the trip purpose. As in other problems of urban transportation planning, the easiest trip purpose to handle is the trip from home to work because its travel pattern is very homogeneous on all working days. Characteristics of this trip purpose are as follows:

1. The origins and destinations of commuter trips are well defined, as shown by all regression analyses and calibrations of trip-generation and trip-distribution models;
2. Commuters on their way to work from home drive in a very direct, straight, and purposive manner, and they take routes by which they reach their destinations promptly;
3. Commuters have a good knowledge of the area and know alternative routes; and
4. Traffic patterns and conditions (volumes, travel times, and waiting times) during morning peak hours are usually the same and have low variances compared with the variances of volumes and travel times during other hours of regular working days.

The route choice of trips for another purpose (e.g., shopping or social-recreational) is not so certain. These routes may not be so well defined because of the more leisurely nature of the trip or because the trip destination is often casual or unknown.

Many reasons for route choice for all trip purposes, however, can be classified into 2 groups—road characteristics and traffic conditions. Some of those belonging to the first group are route length, road width and number of lanes, pavement conditions, design, hills, sight distance, speed limits, right-of-way, traffic control, railroad crossings, road construction areas, and scenery. Some factors related to traffic conditions are travel time, waiting time, speed, volume, commercial traffic percentage, public transit

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in street, and pedestrian crossings. Not all of these factors are measurable by means of length, time, cost, and other quantities. Many of them can be evaluated only by psychometric methods and often describe primarily the convenience or strain of a route. These more subjective reasons of drivers can be obtained only from interviews.

Although the factors affecting travel patterns of the trips from home to work during the morning peak period are rather homogeneous, the drivers coming from the same residential area and going to the same industrial area do not all take the same route. The route 1 driver takes depends on the criteria of route resistance he uses for the evaluation of all possible routes for his trip to work. Every driver uses different criteria objectively or subjectively. Even if all drivers would choose the same criterion, they would not take the same route, because they cannot evaluate the route resistance of all possible alternates objectively. Another reason is that most of the route criteria are not constant or unchangeable; they alter during time and can only be estimated. The result is that in most cases there is more than 1 possible reasonable route between any 2 traffic zones.

The aim of this study was to determine the criteria drivers use in choosing for the routes for their trips to work, criteria that are practicable and applicable for a diversion assignment model. Other goals were to define a resistance criterion for locating optimal routes by computer analysis and to develop boundary conditions for a realistic evaluation of alternative routes.

DATA COLLECTION

The needed information was obtained by interviewing of 13,000 employees who drove every morning from home to work in their cars. The interviews were made in 1965 in the following 5 of the larger German cities:

City	Population	Residents per Vehicle
Aachen	178,000	6.1
Bochum	367,000	6.7
Düsseldorf	706,000	5.3
Frankfurt	696,000	4.2
Leverkusen	103,000	5.3

These values are for the area within the city limits. However, the total surrounding area of influence of these cities, relative to commuters, is much greater. For instance in Bochum, 4.1 million people can reach the core of the city within 30 min. In Düsseldorf and Frankfurt the figure is about 2.5 million people. The interviewed people were, in most cases, blue- and white-collar employees of manufacturing industries and, in some other cases, employees of the commercial or business industries.

The interview form used was distributed in most cases by the employer's personnel office. It had on its front page a short information section and instructions on how to complete the form. The questions were easy and quick to answer without the help of an interviewer. As expected, many people refused to answer. The return rates ranged from 25 to 62 percent; however, about 13,000 completed questionnaires were returned.

The respondents were required to answer the following questions:

1. Where do you live (address and city)?
2. Describe the route you take every morning from home to work by giving 3 or 4 names of streets, bridges, and buildings located along the route. (The route description on almost all returned forms were precise enough for the route to be drawn accurately on a map. This method of route description was chosen because pilot interviews had shown that many people could not describe their path on a map.)
3. Why do you take this route? From the following 9 given motivations, check the 2 (but only two) most important to you: (a) only 1 route exists; (b) I drive it out of habit;

(c) it is the fastest route; (d) it is the shortest route; (e) it has good road design and pleasant scenery; (f) it has greater safety because of traffic control; (g) it has right-of-way at most intersections; (h) it has less congestion for the longest part of the route; (i) it is less hilly; and (j) there are other reasons not stated here.

4. When do you start from home each morning? This question was asked to obtain the peak period of the investigated home to work trips.

5. What is the travel time from home to work you usually require?

6. Where do you park your car while at work? From this question, the exact destination in the industrial area could be located.

7. Do you take the same route back to your home (answer yes or no)? A detailed description of this route was not asked. However, a special investigation in Frankfurt showed that 85 percent of the drivers took the same route on their way home.

The origins and destinations and routes obtained from this interview were located and analyzed with the help of a map. The most important interchanges and their given routes were used for a very intensive survey of the existing road characteristics and traffic conditions. For each road section or each intersection of the considered route, the following factors describing the road characteristics were determined: length, effective roadwidth, number of lanes in the considered direction, streetcars without separate tracks, grade, traffic control at intersections, cycle and phases of signalized intersections, coordination of signalized intersections, speed limitation, and location within the urban area. Factors concerning the traffic conditions that were obtained were mean speed, travel time, waiting time, volume per lane and direction, and truck percentage. These factors were gathered by local measurements and traffic observations during the morning period in the direction of the considered traffic flow and were checked by direct travel time measurements from origin to destination by test trips. The analysis of the interviews later showed that the average travel time stated by the drivers was almost always higher by 5 to 10 min than the measured travel time average and was independent of the trip length. The probable reason is that drivers include their walking time to and from the parking lot.

ANALYSIS OF INTERVIEWS

Number of Chosen Routes

The 5 investigated cities have somewhat different characteristics. Düsseldorf and Frankfurt are typically metropolitan in their residential areas and have very active central business districts and large industrial districts that sometimes reach to the city core. Bochum has a similar land use; however, it has 2 big neighbors, Essen and Dortmund, where many of the interviewed drivers came from. It also has a very efficient highway and freeway system. Aachen has major industries in the northern and eastern fringe area, and, because many employees come from neighboring communities to the north or east by using rural highways or the autobahn, its traffic pattern is different from that of the other cities. Leverkusen is located at a very important autobahn intersection and has a good highway network to its neighborhoods, where most of its employees live.

These short descriptions of the investigated cities, their highway networks, and relationships to their surrounding neighborhoods are made to explain the following findings. It was found that the number of routes between origin and destination is dependent on the following:

1. The trip length measured by the airline distance. With increasing distance, the number of selected routes increases, having a maximum of 3 to 5 routes at a 2- to 6-mile distance. Then, with increasing distance, the number of alternatives decreases to 1 or 2 routes because the drivers for longer trips apparently prefer freeways or fast highways and stay on them to the exit nearest their destination.

2. The type of highway network the drivers mainly used. The number of accepted routes is lower in a rural highway network than in a typical urban network. Autobahns or other freeways are generally preferred and reduce the number of chosen routes in an area more than when no freeways are available.

3. The district of the town that is traversed. In central business districts, the number of alternative routes is higher than in fringe and suburban areas, depending on the arterial network density.

4. The traffic load of the arterial road network.

One may note close interrelationships among the last 3 items. However, the combinations of them in the 5 investigated cities were quite different and had an effect on the number of chosen alternative routes. For instance, Frankfurt has a higher number of alternative routes than Aachen does because the characteristics previously described are different (Fig. 1). Bochum's widely spread distribution is a good indication for its location in an intensely urbanized neighborhood.

Alternative routes were considered as only those that were used by more than 3 drivers in the sample during the morning peak hour. If one included the routes taken by only 1 driver, the alternatives would have been 2 to 3 times as high (white bars in Fig. 1). Such routes were regarded in further considerations as not indicating the behavior of a significant number of drivers, even if they were logical routes.

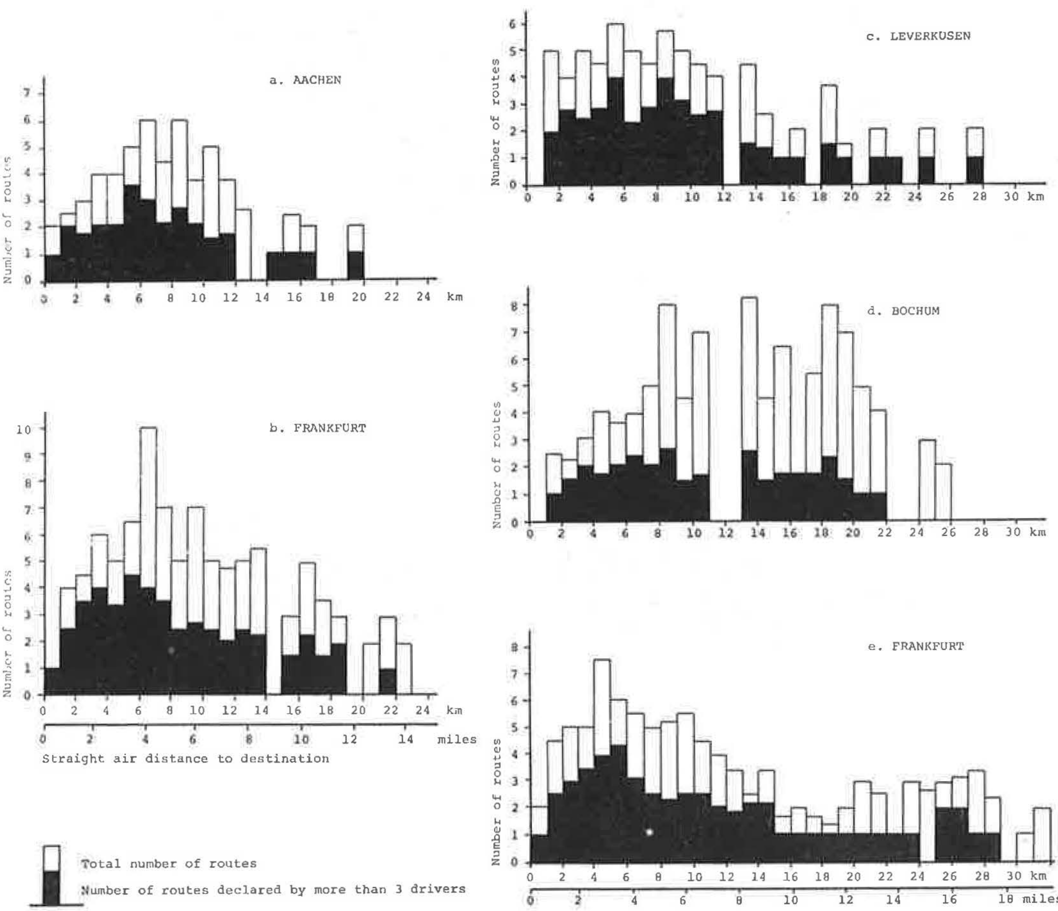


Figure 1. Alternative routes versus length of trip (air distance).

Motives for Route Choice

The questionnaire was simplified for the respondents in that it had 9 allowed statements about route-choice reasons. The one or two that seemed to be most important to the driver in his preference of route were to be checked. These statements were chosen from pilot studies conducted previously. Item 10 gave an option to the respondent to name another reason not listed in the other items, but it was not used very often. When it was used, only special reasons (no railroad crossings or better access to a freeway) were named, or else it was used for complaints about very bad traffic situations at special points in the network.

Most commuters in all 5 cities took their chosen route because they believed it to be the shortest in time; the second most important reason was that it was the shortest route in distance. The next important reasons, but not nearly as important as the first two, were "less congestion" and "good road design." The order was the same in all 5

a. BOCHUM

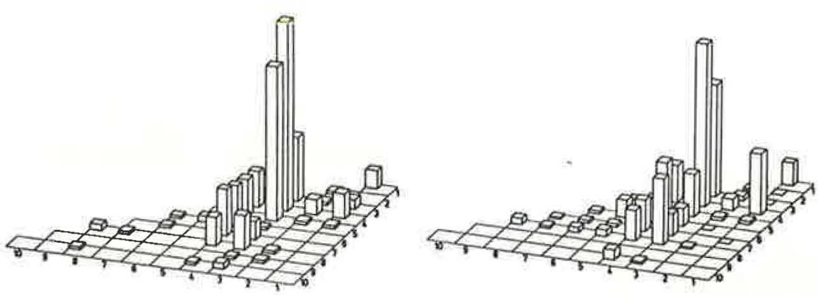
	1	2	3	4	5	6	7	8	9	10
10			7 / 0.8	4 / 0.4				3 / 0.4		
9		4 / 0.4	4 / 0.4							
8		3 / 0.4	40 / 4.5	33 / 3.7			4 / 0.4	7 / 0.8		
7			22 / 2.4	55 / 6.1		3 / 0.4				
6			4 / 0.4	48 / 5.3	7 / 0.8	3 / 0.4				
5	4 / 0.4	4 / 0.4	181 / 20.0	44 / 4.9						
4	30 / 3.3	18 / 2.0	221 / 24.5	33 / 3.7						
3	11 / 1.2	4 / 0.4	73 / 8.1							
2		4 / 0.4								
1	22 / 2.4									

b. FRANKFURT

	1	2	3	4	5	6	7	8	9	10
10			7 / 0.3	29 / 1.3						
9										
8		4 / 0.2	194 / 8.6	90 / 4.0	20 / 0.9	16 / 0.7	7 / 0.3	18 / 0.8		
7	2 / 0.1		65 / 2.9	92 / 4.1	11 / 0.5	9 / 0.4	4 / 0.2			
6		2 / 0.1	52 / 2.3	70 / 3.1	51 / 2.3	9 / 0.4				
5	8 / 0.4	9 / 0.4	126 / 5.5	141 / 9.6	25 / 1.1					
4	177 / 7.9	34 / 1.5	463 / 17.0	105 / 4.7						
3	2 / 0.1	13 / 0.6	318 / 14.2							
2	2 / 0.1	5 / 0.2								
1	65 / 2.9									

Above: Absolute frequency

Below: Per cent frequency



Columns show relative frequency

Motives for route choice:

1. There exists only one route
2. Route is driven by habit
3. Fastest route
4. Shortest route
5. Good road design
6. More safety by traffic control
7. Right-of-way at most intersections
8. Less congestion
9. Less hilly
10. Other reasons

Figure 2. Route-choice motivation.

TABLE 1

MOTIVATIONS OF DRIVERS WHO HAD THE CHOICE BETWEEN AN URBAN OR RURAL HIGHWAY AND A FREEWAY

Motivation	Motivations of Drivers Who Preferred Urban or Rural Highway When Measured Travel Time and Distance Showed This Route To Be								Motivations of Drivers Who Preferred Freeway When Measured Travel Time and Distance Showed This Route To Be							
	Not Shorter but Faster		Shorter and Faster		Not Shorter and Not Faster		Shorter and Not Faster		Not Shorter but Faster		Shorter and Faster		Not Shorter and Not Faster		Shorter but Not Faster	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1	9	1.5	23	1.5	5	0.9	9	3.0	8	0.8	11	1.9	1	1.4	12	2.9
2	11	1.9	40	2.6	10	1.8	6	2.0	17	1.7	16	2.8	1	1.4	28	6.7
3	187	32.0	469	30.0	164	29.0	94	31.0	446	45.3	145	25.5	37	52.8	87	20.8
4	157	26.8	468	30.0	139	24.6	96	31.6	111	11.3	218	38.4	2	2.9	174	41.4
5	91	15.6	198	12.6	86	15.2	32	10.5	251	25.4	66	11.6	24	34.3	29	7.0
6	43	7.4	100	6.4	39	6.9	11	3.6	49	5.0	58	10.2	2	2.9	36	8.6
7	43	7.4	123	7.9	47	8.3	23	7.6	52	5.3	44	7.7	1	1.4	30	7.1
8	43	7.4	138	8.8	65	11.5	33	10.8	45	4.6	9	1.6	2	2.9	23	5.5
9	1	0.2	6	0.4	9	1.6			6	0.7	1	0.2			1	0.2
10					1	0.2										
Total	585		1,565		565		304		985		568		70		420	

cities but with some differences in relative importance. The order of the stated motivations and the relative values the drivers attached to them in determining route preference gives a good indication of the existing highway network and traffic situation in these cities. For example, Figure 2 shows that the drivers take advantage of Bochum's good highway system, which offers them fast, short, and well-designed roads, and that drivers in Frankfurt, besides time and distance, prefer routes with low traffic densities and less congestion.

Although travel time and length of a route were those parameters that were evaluated most by drivers, comparison with measured values of travel time and length showed discrepancies in many cases. This indicates that the determination of the best route by drivers is rather subjective. Table 1 gives the comparison and evaluation of statements made by drivers who had the choice of taking an autobahn or freeway route for more than 50 percent of their trip length of origin to destination distances of more than 4 miles versus taking a typical rural or urban highway route with the actually measured values of time and length. The data show that the statements of those drivers who prefer the freeway are much more correct than the statements of the other group with regard to travel time and route length. The judgment of the nonfreeway group about advantages in time or distance on their rural or urban route are not very convincing. For this group, advantages in distance are also improvements in travel time because the difference in travel speeds on alternative routes is very small. Many freeway drivers stated they took the freeway route because of its better design, whereas drivers of the other group declared there was less congestion on their urban route. It may be, however, that the latter really assume they have a better possibility to drive around a point of congestion in front of them if one develops.

STUDY RESULTS

Frequency Distribution on Alternative Routes

For the case of only 2 available routes, the preference and choice of one of these routes by the drivers may range between the 2 extreme possibilities that (a) the assumed resistance of both routes is the same and accordingly there is an equilibrium in the route acceptance, or (b) the assumed route resistance of both differs very strongly and only one of them is accepted. This may be expressed by the following equations:

$$\frac{T_2}{T_1} = 1 \tag{1}$$

$$\frac{T_2}{T_1} = 0 \tag{2}$$

where $T_1 + T_2 = T_{ij}$, the total number of drivers traveling between zones i and j and taking route 1, T_1, or route 2, T_2.

The attractivity or acceptance ratio T_2/T_1 is dependent on several factors that form the route resistance in the driver's mind. Some of them were mentioned previously, but many of them are not measurable objectively. Because the purpose of this study was for application in traffic assignment, only those factors were considered that were measurable. About 30 factors were considered. About 50 different model formulations were tested and evaluated by means of mathematical statistics. The findings were that the most important factors determining or influencing route choice by drivers on trips from home to work are travel time, distance, maximum traffic volume per lane, and number of possible stops. These factors coincide remarkably well with the most mentioned reasons of preference for route choice. Trip diversion can be most effectively described by the following equation:

$$\frac{T_2}{T_1} = (a + b)\left(\frac{t_1}{t_2}\right)^{\alpha} \left(\frac{l_1}{l_2}\right)^{\beta} \left(\frac{q_{max1}}{q_{max2}}\right)^{\gamma} \left(\frac{s_1}{s_2}\right)^{\delta} \tag{3}$$

where

t_1 = total travel time on route 1 (inclusive of any waiting time at the intersection at the first point of choice),

l_1 = total length of route 1,

q_{max1} = maximum peak-hour volume per lane that occurs on a road section or link of route 1, and

s_1 = number of possible stops on route 1 (intersections, railroad crossings, or pedestrian crosswalks).

These values are only between the 2 points of choice of alternate routes because tests showed that drivers consider only the gains and advantages of alternative routes between these points of choice. Because Eq. 3 is not a simple equation of proportionality because of its constants a and b, routes 1 and 2 must be defined. Tests showed that route 1 can usually be best defined as the route of shortest travel time. However, for $t_1/t_2 \geq 0.96$ and for $l_1/l_2 \leq 0.80$, route 1 should be defined as the shortest route.

The analysis of the observed values shows that the constants and exponents of the model are dependent on the length of route 1 (Fig. 3). For example, on short distances between the points of choice, the weighting exponents α and β are small because drivers cannot realize the gains in time and length of 1 route versus the other or do not attach much importance to it. However, as the distance becomes larger, both exponents increase; and, after the distance exceeds 4 miles, α is still rising slightly while β starts to decrease after a threshold is reached at 4 miles. The exponent γ is negative for short distances. An analysis of the reported and observed data sets shows that this occurs where the faster route 1 had a good road design with multiple lanes and higher maximum volumes per lane and usually bypassed the city core or fringe areas with high densities, whereas route 2 crossed these areas on roads with lower capacities. Thus, the higher volume q_{max} on route 1 expresses indirectly the attractiveness of this route. For longer distances, γ becomes positive. This means the route with the lower volume is then the more accepted. The exponent δ only exists on short distances and has its implication primarily in high-volume areas. Thus, on short distances the route choice is strongly influenced by the number of possible stops such as at intersections and railroad crossings.

Although the exponents weight the ratios of the factors of resistance that the model contains, the constants a and b can be assumed to consider all other factors of influence that are not in this equation. Because they vary more for short routes than for longer ones, it must be assumed that in this range factors other than t, l, q_{max} and s are important, too.

The coefficient of determination, R^2, for the model was 90.6 percent. The model was also tested without the constants a and b. The run of the exponent curves, however, did not change significantly. The coefficient of determination then was R^2 = 81.7 percent, still very good.

For further analysis, the data sets were stratified by the type of traversed town districts (city and core area, suburban and fringe area, and rural area, and freeway use). The parameter curves show typically that the drivers' behavior for their route choices when traversing these areas (Fig. 4) was as described before. The coefficient of determination, however, is much stronger for rural area data (R^2 = 94.2 percent) than for core area data (R^2 = 83.8 percent). On the core area trips, apparently factors other than those that the model considers have influence on the route choice also. The constants a and b vary considerably in this area.

The model was also applied to cases involving multiple splits, i.e. with 3 and 4 alternative routes, and showed a coefficient of determination R^2 = 86.7 percent. These multiple splits were also apportioned into double splits, and only the route sections between the relevant points of choice were considered (1).

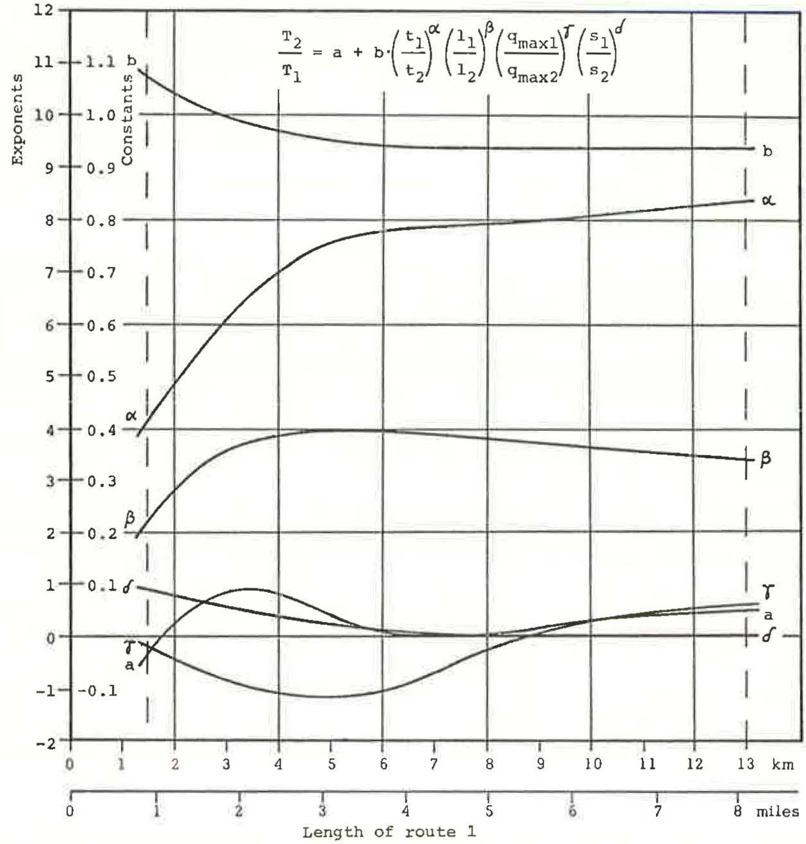


Figure 3. Parameter values for the trip-diversion model.

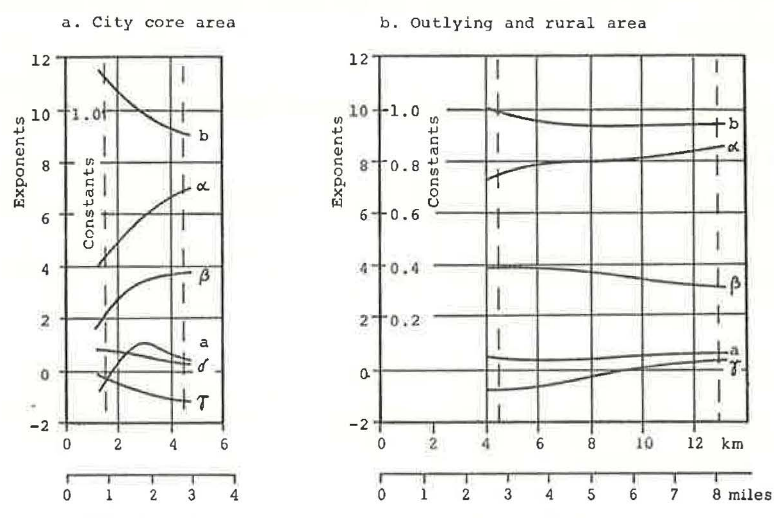


Figure 4. Parameter values for the trip-diversion model by type of urban area.

Evaluation of Alternative Routes

In Frankfurt, for 1 origin and destination interchange, about 20 different routes were found. Most of them, however, were routes of single drivers. Apparently, the number of routes in gridiron networks with roads and intersections of nearly equivalent capacity are similar to the many choices for turn movements available to drivers. However, loops or other illogical routes were never observed. Based only on routes that were taken by more than 3 drivers of the sample from the same origin area, boundary values (minimum and maximum ratios of some factors of route resistance) were developed and show that nonlogical routes will not be accepted by drivers. These values were measured between the points of choice for 2 alternative routes. If the definition of routes 1 and 2, given previously, is used, the observed extreme ratios were $1.0 > t_1/t_2 > 0.62$, $1.6 > l_1/l_2 > 1.58$, $2.4 > q_{max1}/q_{max2} > 0.40$, and $2.3 > s_1/s_2 > 0.29$. One may assume that the range of these ratios also depends on the distance between the points of choice (for short route splits, these ratios will be more extreme than for longer ones), but the investigation showed no significant relationship to the route length. These ratios provide a method of developing logical alternative routes for a traffic assignment program.

The model was applied in a traffic assignment program (with capacity restraint) and compared with other assignment techniques in a transportation study for Muelheim/Ruhr. After 2 iterations, the model showed good results, while other methods needed 6 and more iterations to yield satisfying results (1).

A Proposal for a New Resistance Criterion

There exist some path-finding algorithms to find the best route in a network for any given criterion of route resistance. Most programs use shortest travel time or length as the criterion. However, the routes of shortest time are often those that follow expressways and major street arterials and that overload such routes during the assignment process. The shortest distance criterion, on the other hand, often overloads minor highways. Other studies attempted to eliminate these problems by combining time and length in a new and better criterion of route resistance, for instance by a linear combination W = a · (travel time) + b · (travel distance). The use of this equation gave results better and more realistic than the use of only time or length gave.

The fact is, as stated before, that there generally are alternative routes between 2 zones because drivers use different criteria for the evaluation of possible routes or they want to take the best route but cannot find it. However, between the 2 zones there is always 1 route that is used by a plurality of all drivers. This route could be used for the definition of the optimum route. Of course, this route may change during the day as the factors determining the criterion of resistance and the trip purposes change.

In his mind, the driver determines the total resistance of a route by weighting and summarizing the factors of resistance on particular sections and points of the highway network in the direction of his destination. Thus, every link on possible paths with its road and traffic characteristics is evaluated by the driver.

The previously mentioned definition for the optimal route was used in making several trials in this research to find a formula for link resistance that minimizes the route resistance of the most frequented route compared with the other less-frequented routes. The result for the resistance of a network link was

$$w_{link} = t^{\alpha} \cdot l^{\beta} \cdot q_{lane}^{\gamma} \tag{4}$$

where

t = travel time, driving time + waiting time (sec);
l = link length times 3.28 (ft); and
q_{lane} = volume per lane (vph).

The exponents are dependent on the link length. Table 2 gives data showing that drivers attach a greater importance to travel time, length, and volume on short links than on long links because the weighting exponents are then higher.

TABLE 2

PARAMETER VALUES FOR OPTIMAL ROUTE LINK RESISTANCE

Length of Street Section (ft)	α	β	γ
Less than 1,600	0.62	0.40	-0.05
1,600 to 3,200	0.60	0.40	-0.06
More than 3,200	0.56	0.35	-0.07

It was shown that in 95.7 percent of all data sets, the most frequented route was the minimum resistance route if the link resistance was defined as the model. Equation 4 gives the possibility of finding the best path between 2 zones by a computer route-choosing program. However, the collected data showed that travel time itself is a very good criterion for finding the optimum route because in 86.3 percent of all sets, the shortest route in time was the most frequented one. Where the trip length was used as the criterion, the percentage decreased to 65.0 percent; the percentage is higher, however, on short route splits than on longer route splits because distance and travel time then become equivalent.

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