Evaluating Alternative Strategies for Central-City Distribution

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Central-city distribution is an essential element in the hierarchy of a regional transportation network. It is the total system that the user views, and consequently both collection and distribution systems require separate evaluation.

A central-city distributor system can be composed of pedestrian ways, bus systems on existing streets, or mechanized loops on exclusive rights-of-way. The distributor system technology is influenced by the nature and configuration of the regional system. If the regional system penetrates the core area, then both delivery and distribution must be accomplished within one set of criteria. If two or more technologies are considered, then a greater variety of alternatives is possible because the regional system is freed of its role as a CBD distributor and the distributor system is freed of the restraints dictated by the location of the regional lines. The selection of alternative strategies is based on a variety of factors including facility cost, level of service, environment, and community impact.

Travel time, including waiting, walking, station dwell, transfer, and riding, is utilized in this study to evaluate a variety of single-technology and small-vehicle systems developed for the Pittsburgh central business district. The model developed calculates all appropriate paths between each cordon point and the zone centroid for a convenience (minimum time) rule and for an accessibility (minimum walk) rule.

•CENTRAL-CITY distribution is one element in the hierarchy of a regional transportation network. For corridor-oriented systems, transportation service is normally between low-density residential areas and high-density commercial activities in the central business district or other urban cores.

A regional network comprises facilities consisting of three basic elements: (a) the collection of persons located in relatively scattered residential areas by the use of facilities such as feeder bus systems or park-and-ride; (b) the delivery between residential areas and the downtown core by the use of line-haul rapid transit systems, either bus or rail; and (c) the distribution to ultimate destinations by the use of a variety of distribution systems, including walking. It is the total system that the user views when he compares alternative modes, and consequently both collection and distribution systems are essential elements of a regional network and require separate evaluation.

The technologies that are appropriate to the function of delivery and central-city distribution can influence the resulting system configuration. For example, if a single technology is maintained throughout the system, then both delivery of high volumes to the core area and distribution within the core must be accomplished within one set of criteria (1). If, however, two or more technologies are incorporated, then each can be tailored to serve the specific requirements set by travel demands.

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ALTERNATIVE DISTRIBUTOR SYSTEMS

If the regional system, which may be either rail transit line or bus on a separate right-of-way, is to act also as the central-city distributor, then the regional lines must penetrate the core area. This conventional approach, illustrated in Figure 1, requires that stations be located in the core area along the regional lines.

On the other hand, if two or more technologies are considered, then a greater variety of alternatives are possible because the regional system is freed of its role as a CBD distributor and the distributor system is freed of the restraints dictated by the location of the regional lines. Consequently, each can be designed to its individual capacity requirements rather than to that of the entire system. This more novel approach, illustrated in Figure 2, relies upon the development of small-vehicle systems tailored specifically for the purpose of central-city distribution.

If the regional system does not penetrate the core, a transfer to the distributor system will be required to a greater extent than that for the single technology system, although transfers are unavoidable in either system. The transfer is generally considered to be highly undesirable under most present-day systems, as it represents an inconvenience in both time, energy, and comfort, quite intolerable in our affluent motorized society. Careful design of the transfer point from the viewpoint of a pleasurable environmental experience and coordinated operation between both systems is required to minimize the delay at the interface and thus enhance the public's acceptance.

REQUIREMENTS OF SMALL-VEHICLE SYSTEMS

The central-city distributor system can take a variety of forms, ranging from simple pedestrian paths or bus systems on existing streets to mechanized loops on exclusive

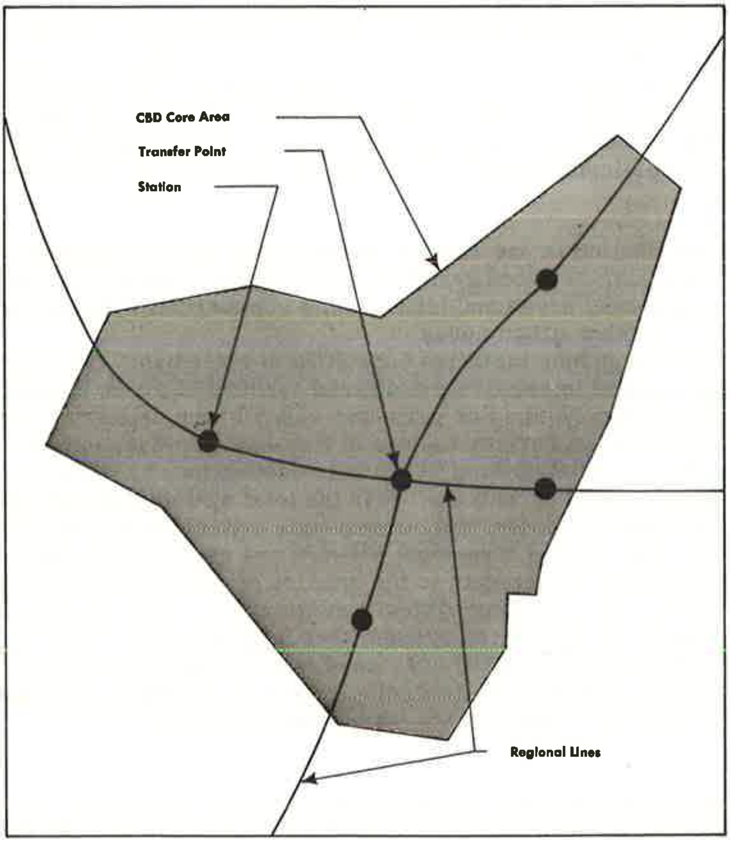


Figure 1. Regional system acting as central-city distributor.

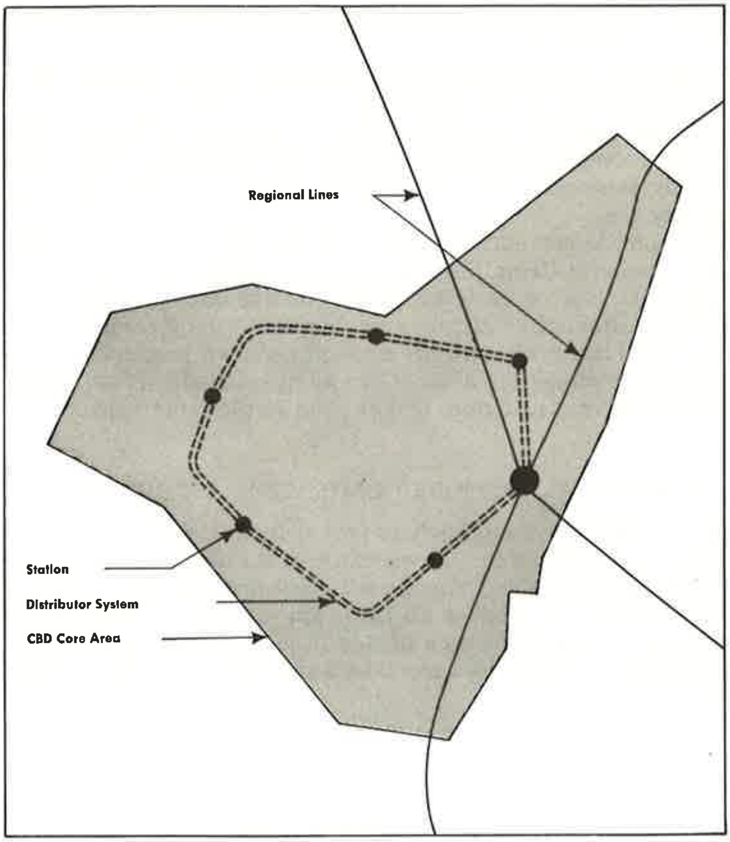


Figure 2. Small-vehicle systems for central-city distribution.

rights-of-way. Although small-scale systems have been proposed for central-city distribution, none has been tested in a full-scale urban setting (2). Basic requirements of such a system include ability to be integrated within an existing environment; easy accessibility and availability throughout the day and evening; minimum waiting; minimum fare; silent operation, free of fumes and noise; flexibility and capability of modification including complete removal; ability to adjust to changing capacity requirements; pleasurable riding experience; and moderate average speeds (3).

FACTORS AFFECTING SELECTION

This paper presents an evaluation of alternative central-city distribution systems using travel time as the measure of effectiveness. The model used compares both single-technology systems and small-vehicle systems, and results are presented based on data for the Pittsburgh central business district. The model tests all reasonable combinations of elements that form a complete trip between each origin and each destination and measures the relative service ability of each alternative. [For an evaluation of environmental and cost factors see Netsch (4) and the Allegheny Study (5).]

The selection of alternative strategies for central-city distribution is based upon a variety of factors, including facility cost, travel costs and benefits to the user (i.e., level of service), compatibility with the environment, impact upon the community, and other intangibles. This paper is primarily concerned with service-level aspects, but a brief look at cost factors and aesthetics is appropriate.

Transportation-facility costs are conveniently categorized as the capital cost for construction and right-of-way acquisition, and annual costs for maintenance, operation, and administration. Calculation of these costs is essential for the evaluation of each strategy.

Compatibility with the environment and community impact require an evaluation of the technology of each strategy with respect to items such as architectural effect, noise levels, effect upon abutting land uses, disruption of normal activities during construction, and the interrelationship with other community objectives. These items may be quantifiable or highly subjective, but information concerning these factors is essential in the evaluation process.

Level of service can be measured by several characteristics including user cost, safety, reliability, aesthetic (from the rider point of view), and time.

For central-city distribution systems, it may be assumed that the fare structure and accident cost for each alternative strategy are equal. Furthermore, factors related to rider identification with the system, while recognized as a positive attribute for aerial or surface systems, are subjective and not easily quantified. Thus, for evaluating the service level of alternative strategies, travel time is the most appropriate measure of effectiveness.

ELEMENTAL ACTIONS COMPRISING A CBD TRIP

The elements of a trip may be defined as travel from a cordon point to a zone centroid. (The cordon is defined as the intersection of the regional system with the core-area boundary. This definition provides an efficient and equitable means of comparison between alternative strategies because all trips are considered to originate at a common boundary.) A trip can be described by a series of elemental actions, such as those illustrated in Figures 3 and 4. The model considers the time involved in each of these

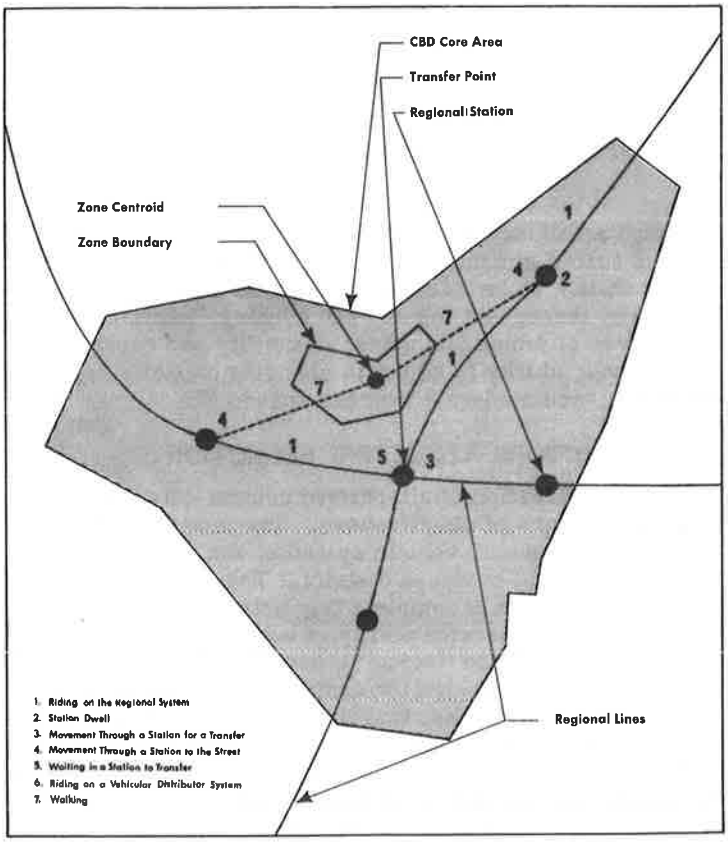


Figure 3. Elemental actions comprising total trip on regional system distributor line.

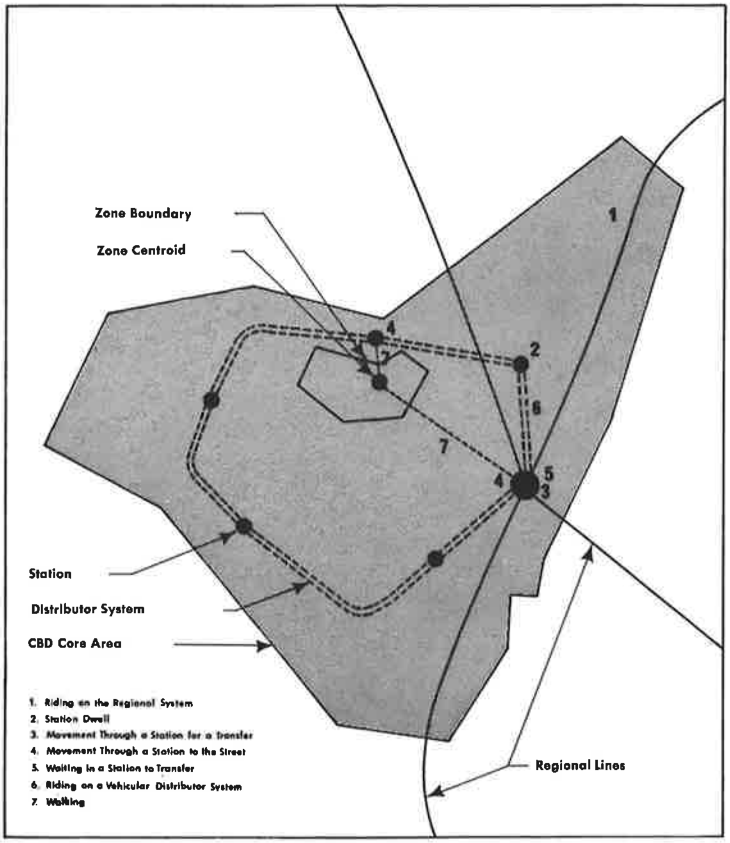


Figure 4. Elemental actions comprising total trip on small-vehicle system distributor line.

actions when measuring the total time through the system. These elemental actions are:

1. Riding on the regional system;
2. Dwelling in the station (i.e., time spent on a vehicle in the station when the passenger is neither embarking nor debarking);
3. Moving through a station for a transfer to another vehicular mode;
4. Moving through a station to the street;
5. Waiting in a station to transfer;
6. Riding on a vehicular distributor system other than the regional system; and
7. Walking.

For example, in Figure 3, a trip originating at the northern cordon point has two possible paths to the zone centroid, one composed of elemental actions 1, 4, 7 and the other of 1, 2, 1, 3, 5, 1, 4, 7. In Figure 4, two possible paths are 1, 4, 7 or 1, 3, 5, 6, 2, 6, 4, 7. One of these paths involves less time than the other. However, the user might select the longer time path if it involves less walking.

Two sets of information are required to reduce the ride on a regional or distributor line to a time interval. First is the spatial arrangement of the guideway and the stations, and second is the equations relating the motion of the vehicular system to space and time. Solving the equations of motion for each particular alignment yields the ride time between two stations.

The station dwell (i.e., in-station time for a vehicle) can be fixed for a particular system, or it can be determined for each station but varied from station to station depending on the time to load or unload a vehicle.

Movement through a fixed-guideway system station either to another vehicle or to the street requires knowledge of the spatial arrangement of the station interior and the various modes employed to move passengers. Time intervals can be derived by knowing walking distances, pedestrian speeds, and travel rates of escalators, elevators, and moving walkways. The level of sophistication can vary from crude approximations of in-station movements to simulated transfer analysis that accounts for queuing at escalator points and for other factors. For surface bus systems, the in-station time is usually negligible as the passenger debarks directly onto the street.

The wait for a transfer is dependent upon the regularity of schedules and system capacity. Expected waiting time is proportional to the headway between successive vehicles, but could be increased if capacity is exceeded.

COMPUTING TRIP TIMES: CONVENIENCE VS ACCESSIBILITY

The rule for computing trip times involves knowledge of the behavioral characteristics of the system user in order that the correct route choice and combination of links be determined for each origin and destination pair. To date, there are no definitive answers to this behavioral question and, consequently, two route-choice rules are assumed, one based on convenience and the other on accessibility.

The convenience rule is based on the hypothesis that all users will choose the absolute minimum-time path from origin to destination. This route-choice rule assumes that the user places equal weight on all elements of the trip (i.e., it is immaterial if the user is riding, waiting, or walking provided that the total trip time is minimized).

The accessibility rule is based on the hypothesis that all users will choose the minimum-time path that provides delivery nearest to the ultimate destination. This rule assumes that the user places greatest weight upon the walking element of the trip, (i.e., it is immaterial that the user rides or transfers provided that the walk time is minimized).

The weighted averages of all travel times obtained by applying these rules are the measures of effectiveness and are termed the convenience measure or the accessibility measure.

These rules represent extremes, but the model is flexible and allows for computing values between these measures. In operation, the accessibility measure is computed by heavily weighting the street walk time. To obtain results between these extremes, it is only necessary to change the weight assigned to the walk element.

The convenience and accessibility measures are obtained by computing the weighted average total trip time for the system. The expression for the weighted average total trip time for the system is:

$$t^{T}_{AVE} = \sum_{j=1}^{m} \sum_{i=1}^{n} \rho_{ij} t_{ij} \tag{1}$$

where

t^{T}_{AVE} = weighted average system trip time,
i = index of origins,
n = total number of origins,
j = index of destinations,
m = total number of destinations,
ρ_{ij} = weight placed on trips from i to j,
t_{ij} = total minimum trip time from i to j under a measure,

and

$$\sum_{j=1}^{m} \sum_{i=1}^{n} \rho_{ij} = 1 \tag{2}$$

The weight, ρ_{ij}, is that proportion of the total passengers going from i to j. This relates to the distribution of originations and terminations by

$$D_j = \sum_{i=1}^{n} O_i \rho_{ij} \tag{3}$$

or

$$O_i = \sum_{j=1}^{m} \rho_{ij} D_j \tag{4}$$

where D_j is the proportion of total passengers traveling to destination j, and O_i is the proportion of total passengers originating at i.

As an indicator of dispersion, the standard deviation can be calculated using the following expression:

$$\sigma_T = \sqrt{\sum_{j=1}^{m} \sum_{i=1}^{n} \rho_{ij} t_{ij}^2 - \left(t_{AVE}^T\right)^2} \tag{5}$$

These formulas consider only the total trip time. Under each hypothesis the mean and standard deviation of each primary trip element can also be similarly computed.

Other service statistics are available from the model that can provide more detailed information about all elements of the trip. Furthermore, as a result of constructing a general model for testing the level of service, other relevant statistics, such as the number of passengers that transfer or terminate at a given station, can be generated. These are useful for comparing alternative strategies, and with the model as posed this is simply a matter of bookkeeping.

THE PITTSBURGH CBD: A CASE STUDY

The present and future land use plan for the central city is a primary determinant in selecting a transportation alternative. The density configuration of trip destinations based on the land use plan is a reflection of the alignment and location of the core area distribution system. Ideally, station locations are selected to be coincident with the centers of trip density but also to be consistent with minimum station spacing requirements, geometrical constraints on route alignments, and site availability.

The Pittsburgh central business district, for example, illustrates a strong focus of employment and commercial activity. Although eighth in population (as of the 1960 census), the city ranks third in the location of the largest industrial corporations and serves as a regional hub for the tri-state area. Constrained by two rivers and unusually rugged topography, this compact area of approximately two-thirds of a square mile is bounded on the east by an elevated highway and railroad tracks. This area, known as the Golden Triangle, is the focal point of almost 30 million square feet of office space and has a daily influx of 100,000 commuters.

The Golden Triangle defines the central-city cordon and is shown in Figure 5. The proposed regional lines, designated as north, south, east, and west, are depicted as they would enter the central area. The alternative strategies for central-city distribution are considered as the distribution systems that serve trips between these four regional lines at the cordon points and the land use activity in the CBD.

The points of destination within the Pittsburgh CBD are defined by partitioning this area into zones and placing centroids within each of the zones. The centroids are then considered, for analytical purposes, as destinations. Figure 6 illustrates the selection of zones and the placing of centroids for this analysis. The zones generally are city blocks or multiple blocks in areas where streets are presently developed. In other more irregular areas, zones are selected such that available land space is covered.

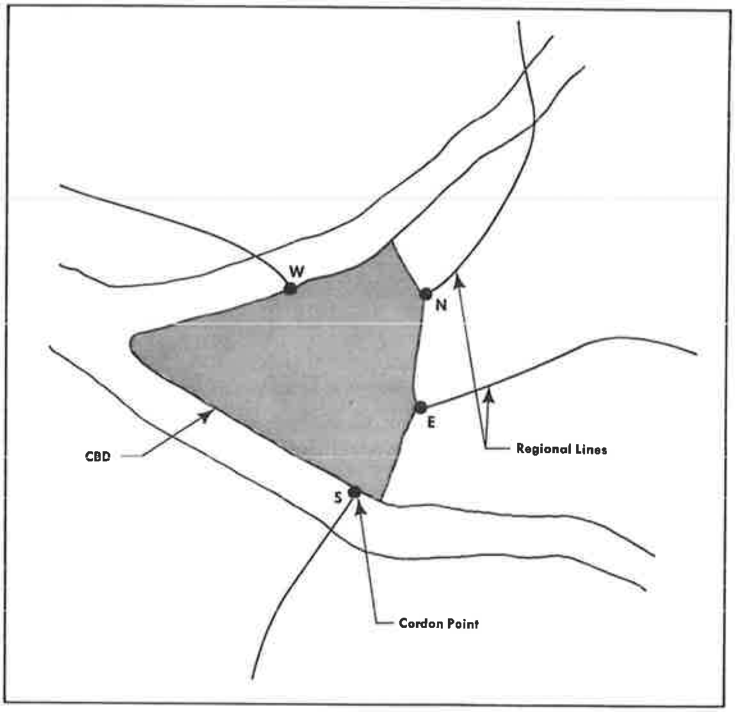


Figure 5. Pittsburgh's central business district, the Golden Triangle, and proposed regional lines.

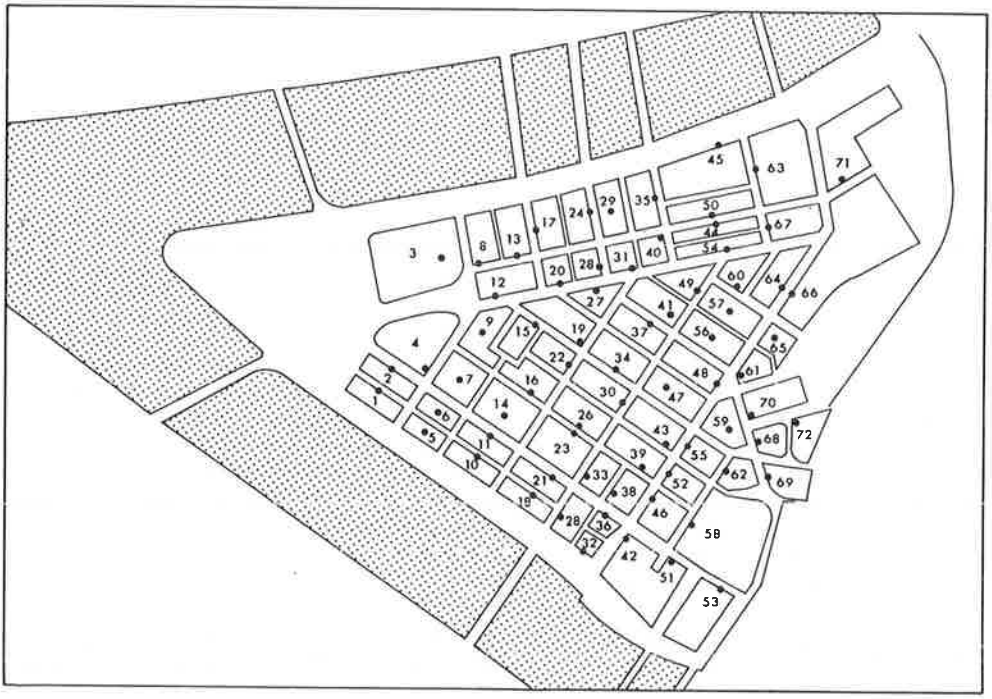


Figure 6. Analysis zones and centroids in Pittsburgh's Golden Triangle.

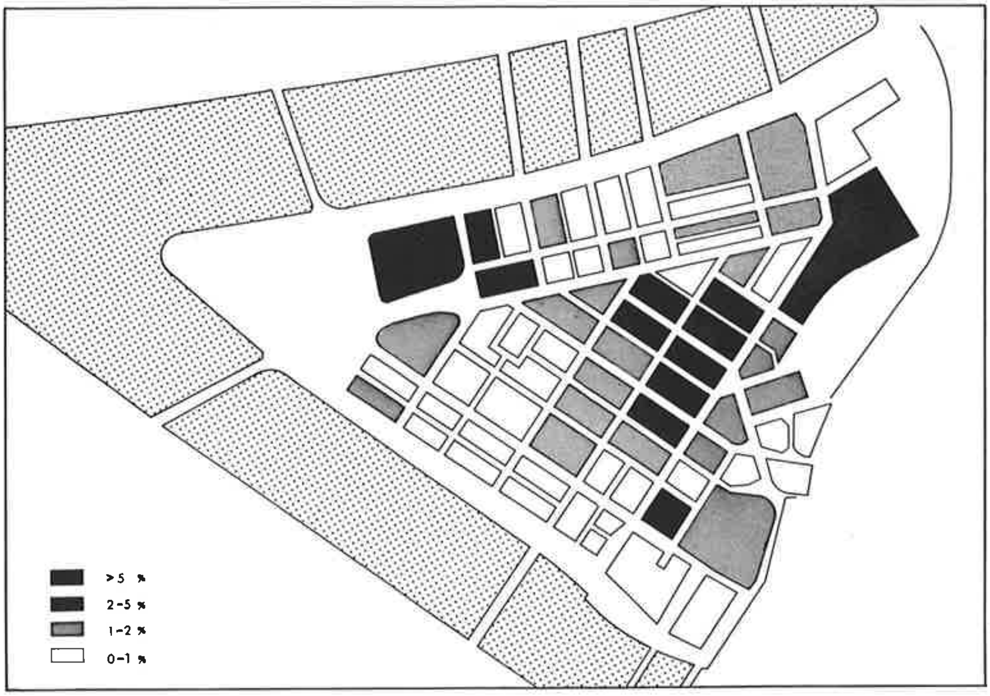


Figure 7. Density of trip destinations in Pittsburgh's Golden Triangle.

The centroids are located in logical positions in the zone depending on information available for the current and projected land use development of the area. The centroid of zone 3 illustrates a case where there are several large buildings in the zone, and the centroid is located at a common access point to these buildings. Zone 8 is a single building, and the centroid is placed at the main entrance. Placement of centroids is primarily based on present or projected knowledge of development in the core area. In many cases placement is quite realistic, and in other cases it represents an aggregation of known or projected destinations.

The employment density pattern for the Golden Triangle indicates that major concentrations of trip destinations occur along the base of the Triangle and in the vicinity of the Point. Analyses of these and similar trip-density patterns suggest several likely sites for downtown stations along the base of the Triangle and at its vertex. The distribution of destinations is illustrated in Figure 7.

CANDIDATE DISTRIBUTOR SYSTEMS

Figure 8 illustrates six candidate distribution systems that were tested. Systems I, II, and III are single-technology systems and involve penetration of the core area by the four regional lines. Systems IV, V, and VI are small-vehicle, closed-loop aerial distributor systems, contiguous with the regional lines at one or two key transfer points.

The single-technology systems differ with respect to both the location and the number of stations. Systems I and II have three stations located in the core area but on different alignments, whereas System III is along the same alignment as System I but has five downtown stations instead of three.

The small-vehicle systems also differ with respect to the location and number of stations. System IV utilizes one major interchange point between the regional lines and the distribution system. The location of this "transportation center" is at a site that is within a 5-min walk of approximately 50 percent of all destinations. System V utilizes two major interchange points between the regional lines and the distributor system.

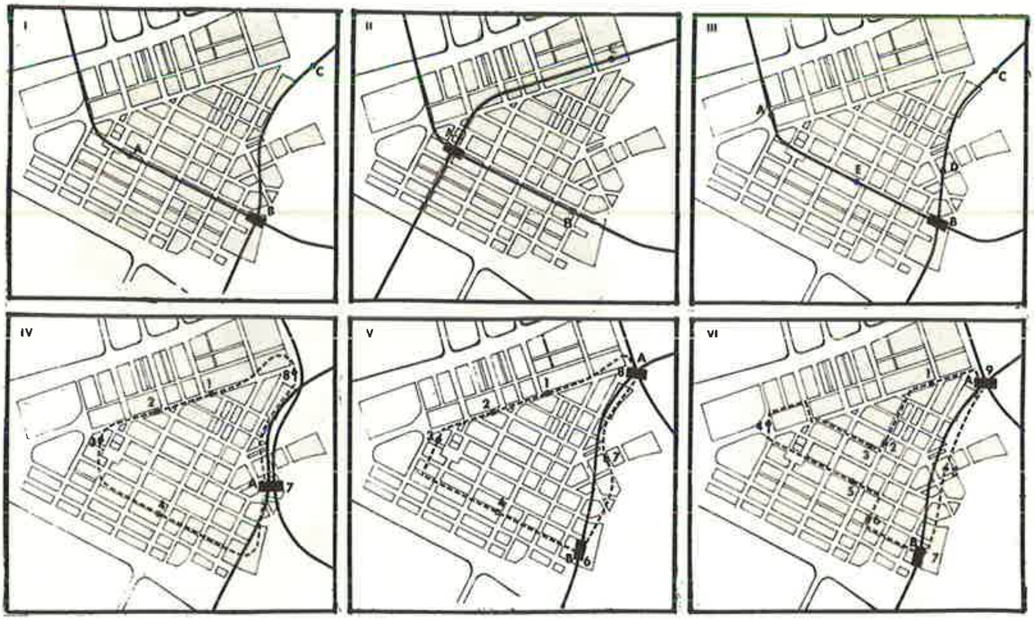


Figure 8. Candidate systems for Pittsburgh's central-city distribution.

This alternative has the advantage of reducing the volume on the most heavily used link and, consequently, requires shorter stations on the distributor system. System VI differs from System IV and V in the alignment of the distributor system. Rather than circling the Golden Triangle in a loop arrangement, the system follows a T-pattern, with the consequent advantages of improved environmental and architectural effects.

TRAVEL-TIME ELEMENTS

The computer program developed for this analysis is capable of calculating all appropriate paths between each cordon point and each centroid. In addition to a minimum-path algorithm for computing weighted-travel times for each trip pair, the program collects relevant statistics for comparison of alternative strategies. Computational efficiency is obtained through a dynamic-programming algorithm using only a minimal number of calculations to obtain the shortest time path. For each system analyzed, execution time is less than seven seconds using an ALGOL program run on the UNIVAC 1108.

Travel times between stations were determined with the aid of train performance simulators or equations of motion that assume constant acceleration and deceleration between the station midpoints. The average wait for a transfer is considered as one-half the headway, which is 120 sec on the east-west line, 90 sec on the north-south line, and 60 sec on the small-vehicle distributor system. The dwell time at regional stations is 20 sec and 10 sec on the small-vehicle distributor system. The travel time for walking from a station to a zone centroid was determined by scaling the actual walking distance and by computing the walking time based on an average pedestrian speed of 4 ft per sec.

Time spent moving through a station, either to transfer to another vehicle or to reach the street, was determined by a careful analysis of probable station designs including escalator locations, mezzanines, and platform designs. Based on these studies, the travel times given in Tables 1 and 2 were established for movement within each station.

The proportion of travelers arriving in the downtown area on each line was established from the results of home-interview origin-destination data and travel forecasts using standard modal-split and assignment techniques. These results indicated the following

TABLE 1

STATION-TO-STREET TIMES[a]

System	Line	Station A	B	C	D	E
I	E-W	110	136			
	N-S		103	122		
II	E-W	136	110			
	N-S	103		122		
III	E-W	110	136			110
	N-S		103	122	110	
IV	E-W	75				
	N-S	39				
V	E-W	61				
	N-S	107	108			
VI	E-W	61				
	N-S	107	108			

[a] In seconds. Station-to-street times for all small-vehicle systems are 50 sec except that at points contiguous with regional stations times are 107 sec.

TABLE 2

IN-STATION TRANSFER TIMES[a]

System	From	To	A	B
I	E-W	N-S		107
II	E-W	N-S		107
III	E-W	N-S		107
IV	E-W	Loop	39	
	N-S	Loop	75	
V	E-W	N-S	126	
	E-W	Loop	82	
	N-S	Loop	146	
VI	E-W	N-S	126	
	E-W	Loop	82	
			146	

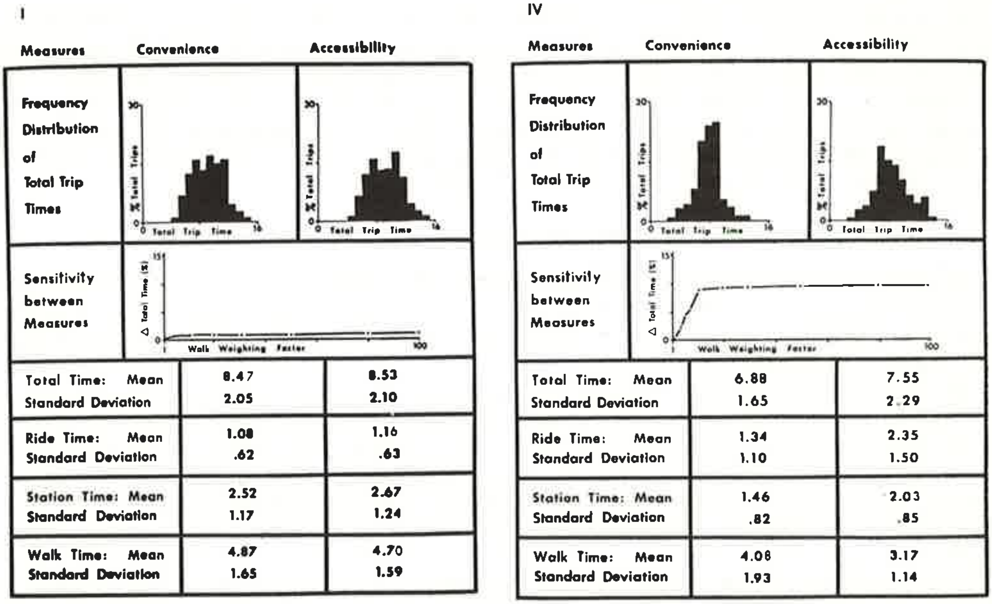
[a] In seconds. Does not include waiting time for transfer to another vehicle.

amounts from each direction: north, 38.6 percent; south, 30.8 percent; east, 14.2 percent; and west, 16.4 percent.

RESULTS

Figure 9 illustrates the results for System I and System IV, considering both the convenience and accessibility rule. Shown in this figure are the frequency distribution of total trips times, the sensitivity between measures, and the mean and standard deviation of the total time, ride time, station time, and walk time.

The single-technology system shows little difference between travel times based on the convenience or accessibility criteria, whereas the values computed for small-vehicle systems change considerably. This result indicates that a specialized-distribution system can afford a wide range of user choice, whereas a single-technology system of few stations is quite insensitive to varying user demands. The total trip time



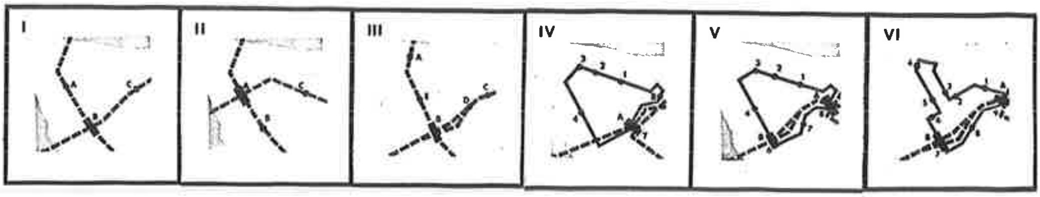
I

Measures	Convenience	Accessibility
Total Time: Mean Standard Deviation	8.47 2.05	8.53 2.10
Ride Time: Mean Standard Deviation	1.08 .62	1.16 .63
Station Time: Mean Standard Deviation	2.52 1.17	2.67 1.24
Walk Time: Mean Standard Deviation	4.87 1.65	4.70 1.59

IV

Measures	Convenience	Accessibility
Total Time: Mean Standard Deviation	6.88 1.65	7.55 2.29
Ride Time: Mean Standard Deviation	1.34 1.10	2.35 1.50
Station Time: Mean Standard Deviation	1.46 .82	2.03 .85
Walk Time: Mean Standard Deviation	4.08 1.93	3.17 1.14

Figure 9. Comparative data: regional system and small-vehicle systems for central-city distribution.



	I	II	III	IV	V	VI
CONVENIENCE						
TOTAL	8.47	7.10	8.07	6.88	8.10	8.20
RIDE	1.08	1.13	1.38	1.34	1.74	1.92
STATION	2.52	1.97	2.45	1.46	2.50	2.48
WALK	4.87	4.00	4.24	4.08	3.86	3.80
ACCESSIBILITY						
TOTAL	8.53	7.15	8.19	7.55	9.00	9.53
RIDE	1.16	1.21	1.64	2.35	3.09	3.86
STATION	2.67	2.06	2.75	2.03	2.82	3.03
WALK	4.70	3.88	3.80	3.17	3.09	2.64

Figure 10. Summary comparison of mean times (in minutes) for total trip and primary trip elements.

was 8.46 min for the single-technology distributor system and 6.88 min for the small-vehicle system. This saving of 1.58 min in average time results partly from the lower walking time and shorter time spent in moving through stations. This time saving could be reduced if station design were improved for System I or if a longer in-station time were required for System IV.

The frequency distribution of travel times indicated a wider spread for System I than for System IV. The average time for System I is 8.46 min, yet 63.9 percent of users are required to travel 9 min or longer; the comparable figure is 37.7 percent on System IV.

Figure 10 shows a comparison of total, ride, station, and walk times based on the convenience and accessibility rules.

The percent of users that are required to make a transfer, under the convenience and accessibility rule, was determined to range between approximately 21 and 33 percent for the single-technology system and between 42 and 88 percent for the small-vehicle system, depending on the route-choice rule and the particular system configuration. Station usage was also determined. For example, when the convenience rule was used approximately 58.4 percent debarked at the transportation center of System IV and 46 percent at the two regional stations of System V and VI.

SUMMARY

This paper has discussed alternative strategies for central-city distribution and their evaluation based on total travel time as the measure of effectiveness. Other relevant parameters useful in design and evaluation, such as percentage of transfers and station usage, were also developed.

Single-technology systems show little difference in travel time for either criterion, whereas values computed for small-vehicle systems change considerably. Total trip time for the single-technology system was 8.46 minutes, with 63.9 percent traveling 9 minutes or longer, and 6.88 minutes for the small-vehicle system, with 37.7 percent traveling 9 minutes or longer. However, only 21 to 33 percent must transfer on the single-technology system, whereas from 42 to 88 percent transfer on the small-vehicle system.

The final choice of either type system depends on a variety of economic, political, and environmental factors. From a level-of-service point of view, it would appear that small-vehicle systems for central city distribution present a viable alternative for system design. Aside from their inherent flexibility, these systems, which should be considered as adjuncts to larger networks and thus free of charge to users, have other advantages, including circulation for shoppers and workers throughout the central city at all times and at frequent intervals, and service to other regional bus lines, which are relieved of the necessity of circulating through the central district to distribute passengers.

The analysis presented was based upon results from a single city and a limited set of alternatives. Further study is required together with carefully designed test programs in order to develop improved circulation systems for areas of high concentration.

ACKNOWLEDGMENTS

The data for the central city analysis described in this paper were based on forecasts prepared by the Pittsburgh Area Transportation Study, and modal-split demand estimates were developed by the consulting firm of Parsons, Brinckerhoff, Quade and Douglas as part of a study of regional rapid transit for Allegheny County, Pennsylvania. The author also wishes to acknowledge the contribution of Frank DiCesare and James W. Hoag to the development of the model used in the analysis. Illustrations were prepared by Robert K. Moorhead.

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