

that is zoned for single and two-family dwelling units will experience more rapid change than an area that is zoned for medium and high-density development.

CONCLUSIONS

The mathematical model for the city of Quincy illustrates the following:

1. Residential land development will be stimulated by the construction of the new extension line of the rapid transit system;
2. Land developers will begin construction of new housing units when construction of the new transit line is initiated and will not wait until the line is open for service;
3. Zoning regulation is a significant mechanism for controlling the location and type of land development;
4. Neighborhoods that are primarily zoned for single and two-family dwelling units are particularly vulnerable to rapid change in neighborhood character, if a zoning regulation permits construction of medium and high-density units; and
5. Since transit service variables are not statistically significant variables, they have no quantifiable impact on land development.

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Abridgment

Evaluation of Alternative Station Spacings for Rapid Transit Lines

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The planning and design of both new rapid transit systems and extensions to existing systems are currently being undertaken in numerous cities. A basic part of this process is defining and evaluating the routes for the transit line. Usually, the stations associated with a proposed new line are located in an ad hoc manner that is based on surrounding land use, engineering and environmental factors, and a general concept of proper spacing. Once located, the stations are considered part of the line and are not evaluated independently of the line (3, 4, 6, 7).

This paper presents a case study in which two alternatives for station spacing for noncentral business district (non-CBD) sections of rapid transit lines are evaluated in terms of capital and operating costs, demand, and user benefits. The case study involves the use of either a long or a short station spacing for a proposed rapid transit line in Chicago.

PROPOSED NORTH LAKEFRONT LINE AND TWO ALTERNATIVE STATION SPACINGS

A high priority in the 1995 Transportation System Plan (2) for the Chicago area is a new rapid transit line that

would parallel the lakefront on the north side. The proposed line is 8.8 km (5.5 miles) long and would connect with an existing rapid transit line on its north end and a proposed subway at its southern terminus.

The North Lakefront corridor is a densely populated area with a large number of individuals who have high incomes and work in the CBD. The area is well served by the Chicago Transportation Authority (CTA) bus network with five express and six local bus routes that provide access to the CBD. The western fringe of the area is served by two rapid transit lines. The high quality of CTA service and the large number of CBD workers have resulted in high-intensity use of the transit system in this area. For the majority of trips made in this area, either the express or local bus services are used.

The two alternatives for station spacings were chosen because they represented realistic strategies for station locations on the line. The first strategy (short alternative) involves 10 stations that are approximately 0.8 km (0.5 mile) apart; the second strategy (long alternative) involves 5 stations that are approximately 1.6 km (1 mile) apart. The exact station locations are determined by complementary land use and engineering factors.

TRADE-OFFS

The basic trade-offs between the two alternatives are shown in cost and demand and user savings. Compared with the long alternative, the short alternative costs more to construct and operate, increases the user's in-vehicle time, but decreases the user's access times to stations. The impact on line-haul and access time indicates that the alternatives attract unequal numbers of riders as well as provide for differing user savings. Thus, while the cost of one alternative is clearly lower, the relative magnitude of both the ridership and user savings associated with each alternative is not easily determined.

The North Lakefront corridor is the testing area for the two alternatives because it is densely populated. It was also assumed that the short alternative would be more appropriate because the long alternative provides a higher quality of service in lower density areas. Thus, if the short alternative is not superior to the long alternative in this area, then the short alternative would not be appropriate for any other area that was densely populated.

Costs

A detailed evaluation was undertaken to provide a quantitative examination of the trade-offs between the two alternatives. This evaluation included an analysis of the costs, the ridership, and the user savings associated with the long and short alternatives. The costs of the two alternatives were divided into total capital and annual operating costs and are in 1975 dollars. The capital cost includes all expenses and contingencies incurred in constructing the right-of-way and the stations. Vehicle or support facility costs were not included in these costs.

The annual operating cost includes all expenses incurred in operating both the vehicles and the stations. Operating costs similar to those of a comparable high-volume CTA Line were used.

Demand and User Savings

Since the number of riders attracted to a facility is a monotonically increasing function of the user savings provided by the facility, the demand and user savings are related. However, due to the trade-offs between access and line-haul times, it was not inherently clear which alternative would provide the greatest savings and would also attract the largest ridership.

Demand and user savings were estimated only for daily trips between the North Lakefront corridor and the CBD and were classified by previous mode of travel. New trips by any mode of travel were not included in this analysis. Both demand and user savings were calculated as functions of the total factored user utilities, which include both travel times and costs. Total factored utilities (5, 9) are expressed in units of in-vehicle minutes and are equal to the sum of travel time (1 min of out-of-vehicle time equals 2 min of in-vehicle time) and travel cost (1 min of in-vehicle time equals 4 cents). Based on historical precedent, it was assumed that the Lake Shore Express service no longer operated.

Diverted Trips

The number of previous transit users attracted to each alternative was estimated by using a disaggregate, minimum-path assignment process. For each existing transit user, the factored utility of the prior route (bus or rail) was compared to that of the proposed alternative. The user was then assigned to the route that had

the minimum disutility. If the current service was the Lake Shore Express, then the best remaining local bus service and the proposed alternative were compared.

This procedure was followed for all individual peak-period trips that were taken from the 1970 Home Interview Survey (1). The total number of individual sample trips attracted to the line was then adjusted by a series of factors that accounted for sampling size, return trips, and off-peak trips between the North Lakefront corridor and the CBD.

The number of automobile users diverted was estimated by using an existing model in a marginal manner (9). This involved determining the change in the factored utility of the transit mode resulting from the institution of the proposed alternative and calculating the corresponding number of automobile users who would divert to the transit mode because of this change. It was assumed that all of these automobile-diverted trips would use the proposed alternative.

For both transit and automobile-diverted trips, the user savings are expressed in in-vehicle minutes and include both times and costs. For each case, the estimations were made in conjunction with demand and under the same assumptions. For transit-diverted trips, user savings are calculated for the individual trips and factored in the same manner as transit demand to provide daily hours saved. For automobile-diverted trips, the number of daily hours saved is defined in terms of the consumer surplus function, estimated for each traffic zone, and then totaled. For each zone, the savings for previous automobile users are equal to the number of automobile-diverted trips multiplied by one-half the average savings of the automobile users.

QUANTITATIVE COMPARISON OF ALTERNATIVES

A comparison of the two alternatives is given in Table 1. The long alternative is superior to the short alternative in terms of three criteria:

1. It is less expensive to construct (31 percent) and operate (10 percent),
2. It attracts more riders (3 percent), and
3. It offers greater user savings (16 percent).

These results can be further interpreted by noting that (a) the short alternative would probably attract a greater percentage of local, intra-Lakefront corridor trips than would the long alternative; and (b) in terms of demand and user savings, the long alternative would probably increase once the Lakefront Line is joined on its northern end with either of the two existing lines. The probability of the latter is due to the fact that the long alternative would provide a superior level of service at the stations of the existing line. Thus, the long alternative would attract a greater demand, and this would result in greater user savings at these stations.

SENSITIVITY ANALYSIS

The sensitivity of the analytical results, to both the utility measurement and the discontinuation of express bus service, was analyzed. Both demand and user savings were calculated by using the procedures previously mentioned; however, travel decisions were based on unfactored utilities (1 min of in-vehicle time equals 1 min of out-of-vehicle time and 1 min of in-vehicle time equals 4 cents). It was also assumed that the Lake Shore Express service was discontinued.

Table 2 gives the results of these analyses under different sets of assumptions. With respect to the com-

Table 1. Quantitative comparison of alternatives.

Criterion	Alternatives			Percentage of Improvement With Long Alternative
	Long	Short	Difference	
Cost, 1975 \$				
Total capital ^a	161 000 000	232 000 000	71 000 000	31
Annual operating ^b	7 160 000	7 935 000	775 000	10
Demand, daily one-way trips				
Bus diverted	19 944	19 390	554	3
Rail diverted	8 547	8 547	0	0
Automobile diverted	1 656	1 336	320	24
Total	30 147	29 273	874	3
User savings, daily in-vehicle hours				
Bus diverted	1 487	1 071	416	39
Rail diverted	1 675	1 669	6	0
Automobile diverted	64	48	16	33
Total	3 226	2 788	428	16

^aCalculated by assuming construction costs of \$10 375 000/right-of-way km (\$16 600 000/right-of-way mile) and \$15 600 000/station (8).

^bCalculated by assuming operating costs of \$0.85/vehicle-km (\$1.36/vehicle-mile) and \$155 000/station year (8).

Table 2. Sensitivity analysis of alternatives under various assumptions.

Criterion	Factored Utilities ^a				Unfactored Utilities ^b			
	No Bus Service		Bus Service		No Bus Service		Bus Service	
	Long	Short	Long	Short	Long	Short	Long	Short
Demand, daily one-way trips								
Bus diverted	19 944	19 390	17 174	14 404	27 700	31 578	26 592	29 362
Rail diverted	8 547	8 547	8 547	8 547	6 919	6 919	6 919	6 919
Automobile diverted	1 656	1 336	1 774	1 610	1 566	1 064	1 578	1 226
Total	30 147	29 273	27 495	24 561	36 185	39 561	35 089	37 507
User savings, daily in-vehicle hours								
Bus diverted	1 487	1 071	1 773	1 579	2 622	2 004	2 649	2 226
Rail diverted	1 675	1 669	1 675	1 669	611	522	611	522
Automobile diverted	64	48	73	59	54	29	55	32
Total	3 226	2 788	3 521	3 307	3 287	2 555	3 315	2 780

^aThe value of out-of-vehicle time equals twice the value of in-vehicle time.

^bThe value of out-of-vehicle time equals the value of in-vehicle time.

parison between the long and short alternatives, the most important results are (a) in terms of relative magnitude for the alternatives, only demand (not user savings) is sensitive to the analytical assumptions and (b) only the method of utility measurement (not the existence versus nonexistence assumptions of the Lake Shore Express service) has an impact.

Thus, the comparison between the alternatives is sensitive to only one of the analytical assumptions. In terms of theoretical validity, the assumption for travel decisions based on factored utilities is more precise than that based on unfactored utilities (5). Although the impact of the method of utility measurement should be noted, it is the first analysis that is better than the second analysis. Thus, the long alternative is again superior to the short alternative.

CONCLUSION

This report analyzed two alternatives for station location on a rapid transit line. The evaluation shows that, in terms of cost and demand and user savings, the long alternative is superior to the short alternative for the non-CBD section of a rapid transit line in Chicago.

The transferability of these results to other areas in Chicago as well as to other cities in general must be used with caution. Before determining station locations, factors such as local trip-making characteristics, detailed land uses, and competing bus, rapid transit, and commuter rail services must be examined. However, the evaluation approach used in this paper can be

applied to comparing alternative strategies for station locations as well as to individual station locations in various circumstances. The use of such a systematic method should significantly improve the planning and designing of rapid transit systems.

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Discussion

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Permut has authored several interesting reports on various aspects of transit planning; however, I want to dispute both the methodology used in and results derived from Permut's work presented here.

It has been shown in literature (10, 11, 12, 13) that spacing of stations on the line should vary depending on the density of population along the line and on the number of passengers traveling through the area. It is too simplistic to take two sets of uniform spacings and compare them based on the assumption that one of them must be optimal.

The basic trade-off in determining station spacings is between the operating speed of the line and the area it covers. The higher the operating speed is, the more the line will attract long trips, but fewer people along the corridor will be attracted to it. It is this trade-off that must be considered in searching for the optimum.

The author makes an assumption that the number of passengers who use the line will be constant regardless of the station spacings. But Permut assumes that the long spacings will attract more passengers from the outlying areas because the travel time is shorter by 4 to 5 min. Thus, the author arrives at the conclusion that 1.6-km (1-mile) spacings would attract more passengers than 0.8-km (0.5-mile) spacings! This is not only unrealistic for the conditions in the corridor studied, but it also leads to a basic deficiency of the model: One side of the trade-off that affects the station spacings is eliminated. Thus, by definition, the optimization problem has one extreme as the solution: All elements become better as the station spacings increase. The conceptual error in the model can be proved very clearly: If one takes 3.2-km (2-mile) spacings rather than 1.6-km (1-mile) spacings, i.e., reduce the number of stations by one-half, the model would show that this further reduction of the number of stations is optimal. Proceeding in the same manner, one would come to the obviously absurd result that the line has only one station (i.e., the outer terminal) and that all the passengers from the corridor would walk to that terminal!

Approaching this problem from the empirical side leads to the same type of comments. Most rapid transit systems have station spacings that average about 0.8 km (0.5 mile). In high-density areas, the spacings are only 0.5 to 0.6 km (0.3 to 0.4 mile); only on regional lines that depend mostly on park-and-ride do the average spacings approach 1.5 to 1.6 km (0.9 to 1.0 mile). There is simply no way that 1.6-km (1-mile) spacings would be optimal in a dense corridor such as the one analyzed in this case. The number of passengers who would not be attracted to such a line because of this long spacing would not be negligible; it would be extremely high. Another item that should be considered is the possibility

of using a skip-stop operation. This operation would allow a greater number of stations without reducing the operating speed, at least during the periods of high-frequency service or the peak hours.

In conclusion, the analysis of two sets of approximately uniform station spacings is an overly simplistic approach. Moreover, the model used in this study is incorrect because it omits the impact of a greater number of stations on passenger attraction from the corridor served and thus incorrectly finds that longer spacings are always better than shorter spacings. It should also be mentioned that, if errors are made in determining the number of stations, it is better to err on the high side since a station can be closed for some periods of the day more easily than it can be constructed on a line that is in operation. Permut's analysis errs on the low side of stations, and this error could lead to a situation that would require an extremely expensive correction after the line has been constructed. Several of our recently built rapid transit systems suffer from such errors in their initial planning, and the planners find that the building of additional stations is extremely difficult. Let us learn from previous errors.

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Author's Closure

In response to Vuchic's comments, I would like to review the purpose of the paper, the problem that the analysis addressed, the methodology used, and the empirical aspect of the station spacing problem.

The work presented a case study in which two possible station placement strategies for a proposed rapid transit line in a high-density corridor were evaluated. In either case, the location of stations was not a direct function of a predetermined uniform spacing, but it was based on specific land use and engineering factors that were taken in conjunction with a general concept of station spacing.

The evaluation of the two alternative spacings included both service capabilities and cost (annual operating and total capital). With respect to service, the basic trade-off is between in-vehicle and out-of-vehicle time (or operating speed and line coverage as stated by Vuchic), and the service portion of the analysis directly addressed this point.

The analysis methodology did not assume that the number of passengers using the line would be constant for the two alternative spacings. The demand on each line was estimated for two different market groups (current transit and automobile users) by using a specific model for each market. The resultant number of riders attracted to the two lines varied because of the service characteristics of the line.

Furthermore, it is incorrect to assume that the overall evaluation process was of a linear nature, i.e., if 1.6-km (1-mile) spacing is superior to a 0.8-km (0.5-mile) one, then a 3.2-km (2-mile) spacing would be better than 1.6-km (1-mile) spacing and so on. Thus, the extreme solution was not a line with only one terminal station. This study identified only two points on the evaluation curve, and it is incorrect to extrapolate beyond this area by concluding that the longer the spacing is the better the line will be. In fact, it is extremely doubtful that, unless population densities at the terminal are inconceivably large and the densities along the line are correspondingly small, the demand and user savings associated with a line with a single terminal station would be greater than that of a line with 1.6-km (1-mile) or 0.8-km (0.5-mile) spacing.

From an empirical standpoint, the average station spacing on the rapid transit systems in cities such as Chicago, Boston, Cleveland, Washington, and Atlanta (including closely spaced downtown stations) is greater than 1.6 km (0.5 mile). Furthermore, in Chicago,

the closely spaced stations on the Congress Rapid Transit Line constructed in the late 1950s were recently closed because of low ridership levels. Since the capital cost of constructing a subway station is in the vicinity of \$15 000 000 to \$20 000 000 and the annual operating cost of the station is approximately \$200 000, it is questionable whether the number of stations on rapid transit lines should be overdesigned to minimize the possibility of adding stations in the future.

In summary, Vuchic has not shown that the evaluation methodology is deficient in any fashion. Furthermore, there is no indication that the analytical results are compromised. Finally, the basic conclusion of the paper is not to determine the optimal station spacing, but rather to systematically and empirically evaluate different station spacings on proposed rapid transit lines.

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Abridgment

Design of Elevated Guideway Structures for Light Rail Transit

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Currently, all levels of government in North America realize the need for making transit a real alternative to the personal use of the automobile in major urban centers. The innovative use of the diesel bus has proven effective in a number of cities, but there remain corridors with sufficient demand to justify a fixed-guideway system. The rail mode is the only system that uses widely proven technology, and it is most efficient when operating in an exclusive right-of-way. In many cases, full right-of-way does not exist in these corridors; therefore, it must be created. With new subway construction costing around \$32.5 million/km (\$50 million/mile) and the acquisition of surface property a time-consuming and unpopular process, it appears that the objections to the elevated guideway must be reviewed if the service and operating cost benefits of a fully (or largely) exclusive right-of-way are to be obtained at a reasonable capital cost.

The earlier generations of transit vehicles were noisy, and the unsightly three-quarter century old elevated guideway structures such as those of New York and Chicago amplified this noise. Thus, elevated guideways have a reputation as an undesirable urban neighbor. The modern transit vehicle is significantly quieter than its predecessors, and a growing understanding of the wheel-rail mechanisms that generate noise and of noise barrier design gives promise of noise reductions to come. Furthermore, modern structural design techniques in both steel and concrete can produce serviceable and elegant structures that might enhance the streetscape of commercial and industrial areas in cities of North America.

This paper outlines a rationale for designing an ele-

vated guideway for urban rail transit, and applies this rationale to a design of a double-track guideway for a proposed light rail transit (LRT) line.

DESIGN RATIONALE

The rationale for designing elevated guideway structures for LRT presented here organizes the thinking of the designer and his or her approach to the design problem. It superimposes the overall objective of the project on the guideway design effort and insists that all factors that affect the design, including those factors beyond the control of the designer, are recognized and understood. These factors are organized into three groups: (a) performance requirements that specify guideway function; (b) constraints that limit the choices available to the designer; and (c) design considerations that tell the designer how to choose among options, all of which satisfy the performance requirements and constraints. The priorities of factors in these groups may change with time. For instance, low cost may be a design consideration in the early stages of a project, but when capital budgets are allocated it becomes either a performance requirement or a constraint.

Performance Requirements

Performance requirements specify the function of the guideway and are quantifiable. An elevated guideway for LRT must provide safe and reliable support and guidance for trains and support for other system components in a secure right-of-way that facilitates the operator's