peak hour per lane through at-grade crossings on semiexclusive LRT line-street intersections are given in Table 1 and are typical for the average motor vehicle, LRT tracks, and street lanes. This analysis is based on the Boeing articulated LRV. Optimum LRV operating speed for minimum traffic impact is obtained by substituting the values given in Table 1 into Equation 7. The optimum LRV operating speed is shown in Figure 1.

Case 1 Flow Estimates

Case 1 applies to the LRV that traverses intersections at its average operating speed. By substituting the values given in Table 1 into Equation 6 and by using G/C as defined in Equation 4, the vehicle flows (vehicles per peak hour per lane) through an at-grade crossing for a two-lane street, a four-lane arterial, and a six-lane divided highway were computed. A summary of the flow estimates and a comparison of the sensitivity of traffic flow per peak hour per lane to LRV consist size and operating speed are shown in Figure 2. The traffic flow per hour per lane with fewer movement restrictions (B, C, and D scales) is also shown in Figure 2.

Case 2 Flow Estimates

The flow estimates for case 2 deal with the special case described in Equation 5 in which the LRV consist accelerates through an at-grade crossing from a transit stop that is located at the intersection approaches. By substituting the values given in Table 1 into Equation 6 and by using g/C as defined in Equation 5, the estimated volumes of motor-vehicle flow per peak hour per lane through an at-grade crossing for a two-lane street, a four-lane arterial, and a six-lane divided highway for various LRT service frequencies and consist sizes were computed. A comparison of flows by both throughput and sensitivity to street width, consist size, and service frequency is shown in Figure 3. The flow estimates for case 2 are independent of LRV speed, since continuous acceleration through the crossing is assumed. Once the train clears the crossing, the peak speeds achieved by the crossing LRVs were found to be well within the operational limits.

SUMMARY AND CONCLUSIONS

The methodology and lane capacity estimate developed in this paper are designed to aid the transportation planner in the analysis of traffic impact due to the implementation of semiexclusive LRT lines. This type of analysis may provide the planner with the tool by which the grade separation requirement could be minimized or staged to some future year for the cases in which the motor-vehicle flow that was estimated at the time of the analysis would exceed the crossing capacity, the additional ROW for crossing improvement was unavailable or too costly, or totally grade-separated intersection must be considered.

The results of this analysis indicate that the deployment of LRT semiexclusive lines in fringe areas is a feasible alternative to transit lines that are totally grade-separated, fixed guideways. This analysis also indicates that, for LRT systems planned for multicar consist operation at high service frequencies, locating transit stops at grade-crossing approaches is desirable to reduce traffic impact.

However, this analysis considered only independent at-grade crossing situations, and additional considerations would be required to analyze the impact of at-grade crossings on adjacent intersections with signals. These intersections may require synchronization with the preempted crossing protection system.

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Abridgment

Impact of Transit Line Extension on Residential Land Use

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Land users can be defined as those members of society who continually weigh the characteristics of land sites to determine the suitability of each site for a particular social or economic need. If the characteristics are suitable, then one or more land users might exert pressure for changing or redeveloping a given site. To evaluate the impacts of new transportation systems on land development, transportation and land use planners must be able to identify the important physical, institutional, and transportation characteristics that are responsible for the change (2). One physical characteristic is the suitability of urban land for residential, recreational, industrial, or governmental uses. One transportation characteristic is the accessibility of a given site to employment, shopping, and recreation opportunities. A particular combination of physical and transportation characteristics will generate interest and action by certain land users to develop a given site. To control land development, society has used zoning ordinances as the primary political mechanism to regulate the type, quality, and magnitude of development. The purpose of this paper is to investigate the effectiveness of zoning regulations in controlling residential land development in a community that is served by a new extension line of a high-speed rail rapid transit system.

IMPACT OF TRANSIT LINE EXTENSION

The city of Quincy is a suburb of approximately 90 000 people and is located on the southern boundary of the city of Boston (1). Before 1971, the majority of residents commuted to the central business district (CBD) of Boston by automobile in about 25 min. Since the public bus service was primarily structured to serve Quincy Center, which is the CBD of Quincy, the public transportation service to downtown Boston was poor. By transferring from bus to rail rapid transit at either Fields Corner or Ashmont stations, a Quincy commuter could commute to the CBD of Boston by public transit. The average commuting time was 50 min or more. The rail transit line before 1971 is shown by the solid line in Figure 1.

In 1971, the South Shore Line of the rail rapid transit system was extended to Quincy Center, and intermediate stops were added at Wollaston and North Quincy stations. This line is shown by the broken line in Figure 1. In addition to the extension line, the bus lines were rerouted to serve as a collector system for the new transit line extension so that access from most Quincy neighborhoods to a transit station was 15 min or less. The commuting time via the new line from Quincy Center to the Boston CBD is approximately 22 min.

Since 1963, there has been an upward trend in the construction of residential dwelling units. Closer examination shows that the construction of residential dwelling units has generally been greater in areas where there is better access to transit stations. Since the opening of the new transit line, the number of dwelling units constructed per year in the area of Quincy Center has more than doubled. In 1971, the city of Quincy issued new zoning regulations. The primary purpose of these regulations was to maintain the low-density characteristic of neighborhoods in Quincy and to stimulate new development in the areas that are close to the new transit stations. A mathematical model was developed to explain the effectiveness of this measure.

Figure 1. Rail rapid transit service from Quincy to the Boston CBD.

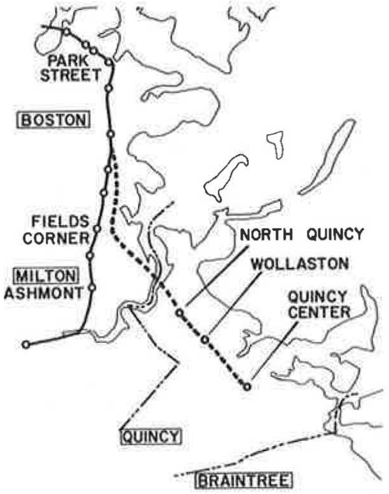
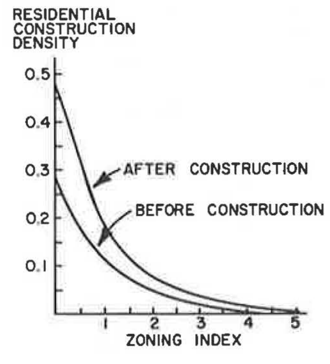


Figure 2. Density models for before and after residential construction.



MODEL DEVELOPMENT

The primary objective for establishing a mathematical model was to determine the significant variables that explained the development that took place in Quincy. Models can also be used to evaluate transportation and governmental policies for similar regions. Since the selection of model variables has an important bearing on the adequacy of the model as a planning tool, then the model should account for and be sensitive to all changes in the physical, institutional, and transportation characteristics of the area. However, many of these characteristics are not quantifiable measures. For example, the attitudes of the people and their political representatives toward land development are not quantifiable. As a result, some important information is not introduced into the model or is introduced by use of surrogate variables. Typically, travel time or speed is used to measure transportation service. Service characteristics such as comfort and convenience are not easily measured; therefore, they do not appear in most transportation planning models. Thus, travel time or speed is the best measurable quantity available, and it is used to measure the transportation service overall. In the transit impact study of Quincy, travel time as well as surrogate measures such as the zoning policy and public transportation service variables were used in the model.

For the model to account for events or impacts over time and by area, data were collected for the period 1963 to 1973 and stratified by traffic analysis zone. The boundaries of these zones were originally established in a transportation study of the Boston metropolitan area in early 1960 (1). The data were stratified into one of three time periods: 1963 through 1966, 1967 through 1970, or 1971 through 1973. These periods corresponded to the preconstruction, construction, and operating phases of the extension of the South Shore Line. The stratification of data in this fashion was dictated by the fact that the transportation service characteristics will remain the same over time. Thus, the only measurable differences that occur are during the periods before and after the opening of the line to the public. A similar situation exists for the zoning index. The 1943 zoning ordinance remained relatively unchanged until 1971 when it was replaced with a new set of regulations. Thus, the selection of model variables and the model structure were influenced by the availability and form of data.

Data on location and type (single and two family) of residential dwelling unit construction from 1963 through 1973 were gathered for the city of Quincy. Each new dwelling unit was placed in one of 13 traffic analysis zones. Since the analysis zones are unequal in size, a land density measure was used. The number of new residential dwelling units that were constructed in zone i per square hectometer per time period (acre per time period) (D_i) was used to measure the change in development over time.

A zoning index (Z_i) was introduced to reflect the character of current and future land development that is and will be permitted in zone i. The zoning index is the ratio of land area zoned for low-density residential development to land area zoned for medium and high-density residential development. The zoning index is a continuous variable that can have values between zero and infinity. A value of zero indicates an area is zoned for medium and high-density uses only. In contrast, the value of infinity indicates that a zone can be used for low-density residential uses only. The zoning indexes for Quincy ranged from a low of 0.06 (or 5.5 percent of the land area zoned for low-density development) at Quincy Center to a high of 4.6 (or 82 percent of the land area zoned for low-density development) at a traffic zone that is east of Wollaston Station and borders on Quincy Bay. Typically, for neighborhoods that were primarily of single and two-family dwelling units, the zoning regulations were more restrictive. The traffic zone for Hough's Neck and Germantown, the peninsula that extends into Quincy Bay near the Braintree border, had the greatest zoning change. Before rezoning, 56 percent of the land was zoned for low-density development, and, after rezoning, 82 percent of the land was zoned for low-density development.

The impact of transportation on each analysis zone was measured by the transportation service variables. Travel time by automobile, bus, and rail rapid transit was considered as well as measures of public transport inconvenience. Accessibility to stations was measured in terms of travel time needed to commute between the zone centroid and nearest transit station and the number of vehicles used to commute between the zone centroid and the Boston CBD. These variables measured the inconvenience of public transport. For example, before 1971, a commuter from Quincy Center had to transfer among three public transit vehicles. Currently, the commuter has direct transit rail passage to the Boston CBD.

In 1967, the commuters and land users did not experience a change in public mass transportation that could be measured in terms of travel time savings, but they did know that an improved service would eventually be offered. A Y-variable was introduced into the model to reflect the influence that the state of construction had on the transit line. This variable reflects the lack of direct transit service to the Boston CBD for the period 1963 through 1966 ($Y = 0$), and it reflects the anticipated and actual service for the period 1967 through 1973 ($Y = 1$).

RESULTS

Multiple linear regression analyses were performed on various linear and log-linear transformations for the variables discussed above. The results indicate that the log-linear model gives the best results. The Z_i zoning index and the Y-variable are statistically significant at the 10 percent level. The transportation service variables were not found to be statistically significant. The mathematical form for the log-linear model is

$$D_i = 0.292(0.393)^{Z_i}(1.71)^{Y} \quad (1)$$

This model has a 36 d.f. and a coefficient of determination equal to 0.63. The model shows that, after construction began on the transit line extension, there was an increase in dwelling unit construction. As a result of the improvement in the public transportation service that was offered to the entire study region, one would expect this increase in dwelling unit construction. Before construction of the transit line, Y equals zero; therefore, Equation 1 is reduced to

$$D_i = 0.292(0.393)^{Z_i} \quad (2)$$

After the construction of the transit line is initiated, Y equals one; therefore, the model simplifies to

$$D_i = 0.499(0.393)^{Z_i} \quad (3)$$

The curves of Equations 2 and 3 are shown in Figure 2, and they illustrate the effects that the construction of the extension line and implementation of a zoning ordinance had on the residential development in Quincy.

The introduction of the transit line extension caused an overall expansion in residential dwelling unit construction, as shown by Equations 2 and 3. However, the greatest portion of this overall growth occurred in zones that permitted this kind of development in the past. Zones containing the new transit stations or a high level of commercial activity had the least restrictive policy for high-density land use and showed the greatest increase in residential construction activity. In contrast, zones that border on Quincy Bay experienced a lesser increase in construction activity. This was due to the restrictive land use policy. These results are shown in Figure 2. The indexes for zones with a high degree of construction activity and a low degree of construction activity range from 0.1 to 0.2 and 2.0 to 4.6 respectively.

Thus far, the discussion has focused on the initiation of construction of the new line. A discussion of the effect of controlling the magnitude of residential dwelling unit construction by changing the zoning regulation policy is investigated below. The concept of demand elasticity (3) was used to evaluate the sensitivity to zoning policy change. Zoning elasticity is defined as the ratio of the percentage of change in construction of new residential dwelling units to the percentage of change in zoning regulations. The zoning elasticity based on the above mathematical model is

$$e_Z = -0.934Z_i \quad (4)$$

Since the zoning elasticity is a function of the zoning regulations before the zoning change, then the analysis zones that were previously restricted to low-density uses become more sensitive to the zoning changes than those zones that were permitted medium and high-density development. A hypothetical example illustrates this effect and will also illustrate the use of the mathematical model.

Two traffic analysis zones (zones 1 and 2) were assumed to have equal land areas of 40.47 hm^2 (100 acres) each. Zone 1, the business and commercial zone, has 4.05 hm^2 (10 acres) of land zoned for low-density development. In contrast, zone 2 has 32.38 hm^2 (80 acres) zoned for low-density development or for single and two-family dwelling units. It was assumed that a new, less restrictive zoning policy for low-density development was imposed on each zone. Thus, the area of low-density development land from each traffic analysis zone that was reclassified as medium and high-density development land was 4.05 hm^2 (10 acres). By use of the definition of zoning index, the zoning index for zone 1 before and after rezoning equals 0.11 and 0.0 respectively. The percentage of change in residential dwelling unit construction per square hectometer (acre) per time period (D_i) is forecast by using the zoning elasticity equation (Equation 4). Thus, from Equation 1, the zoning elasticity is estimated to be equal to -0.103. Since there is a 100 percent change in the zoning index, the percentage of increase in residential dwelling unit construction is forecast to be equal to 10.3. A similar calculation for zone 2 results in an increase of 156 percent. A comparison of the percentages of change in residential dwelling unit construction shows that a neighborhood 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.