Impact of Transportation Facilities on Land Development

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This paper describes a series of experiments that have been conducted using the prototype transportation and land use development model developed by Schneider. The model is used to explore the impact that factors such as centrality, magnitude of growth, network speed, network density, and network geometry have on land development. The relevance and utility of such experimentation to transportation planning are considered, and recommendations with respect to continuing research are discussed.

•A THEORY THAT INTEGRATED the concepts of land development, modal choice, and accessibility was presented by Schneider at a conference on urban development models in the summer of 1967 (1). Subsequently the U.S. Bureau of Public Roads sponsored a research project that undertook to develop a prototype computer model that implemented this theory (2, 3). Since then, continuing research has concentrated on improving this prototype model and further evaluating its usefulness in understanding past and present development and planning for patterns of development in the future. This paper will describe briefly the operation of the prototype model and some experiments that have been performed using the model.

DESCRIPTION OF THE MODEL

Statement of Theory

Basically, the theory states that the amount of development that will take place on a parcel of land is related to the relative attractiveness and the relative accessibility of the site in comparison to all other sites in a region (1). The relationship is shown in the following equation:

$$R_f = R_F \frac{R_a I}{J - R_F I}$$

where

R_f = equilibrium floor area at a site,
R_F = total floor area in the region,
R_a = relative attractiveness of the site (e.g., proportion of developable land),
I = access of the site, and
J = access integral ($\int IdR$) of the region.

The total amount of development, R_F, expected in the region, the amount of land in the region described in terms of its relative attractiveness, the transportation networks

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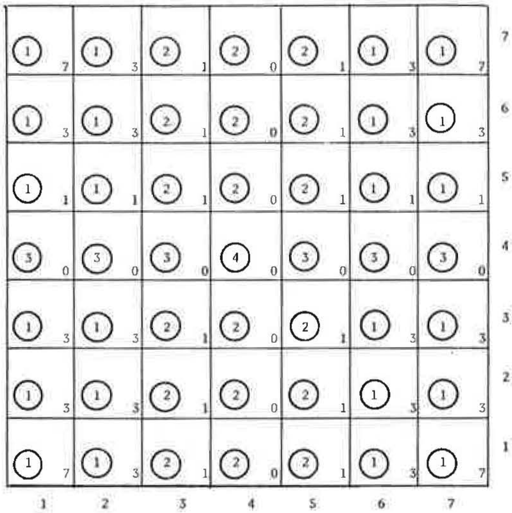

Figure 1. Region with 49 zones.

serving the region, and certain constants related to mode choice are specified as input. The model then allocates urban development to each zone until land development and accessibility in the region are in equilibrium.

Network Characteristics

The model accepts a description of up to 3 hierarchical networks or modes of travel. In this context a viable mode of travel is one that, over some distance, is either cheaper or faster than a competing mode. For purposes of network coding it is convenient, though not necessary, to order the networks in terms of increasing speed and travel cost, so that the cheapest, slowest network is numbered 1 and the fastest, most expensive mode is numbered 3.

The networks are not specified or represented in terms of nodes and links, but are described in terms of travel parameters that would obtain for a given distance on a specific mode. For each network the following parameters must be provided: travel speed (in miles per hour), travel cost (in cents per mile), time penalty (in minutes), and cost penalty (in cents). The travel cost approximates vehicle operating costs, the time penalty can be used to represent terminal time, and the cost penalty can be used to describe fares or parking charges.

A table of travel factors for each mode and combination of modes is calculated by grid intervals from the interactance formula (1, p. 170, Eq. 11), the constants for which must be specified. Up to 10 such tables are provided depending on the number of zone penalty codes used (these are discussed in the next section). The 4 network parameters must be provided for each of the 3 modes for each table. Any or all of these values may be varied from table to table depending on the network the user is attempting to replicate.

Zone Characteristics

A region can be subdivided into as many as 2,500 uniform square zones within a grid of up to 50 subdivisions on a side. An example is shown in Figure 1. Each zone is referred to by its coordinates; thus the southeast corner zone is 71.

A zone may be connected in one of several ways to the 3 hierarchical networks or modes of travel that can serve the region (as described in the discussion of network coding). The 4 connection codes provided are given in Table 1 and are shown circled in Figure 1. A zone coded 1 can use only the number 1 or low-order network, whereas a zone coded 3 can use all 3 networks or travel modes when interacting with another zone coded to the 3 network. A zonal pair coded 3-2 or 2-3 are able to use only the 2 and 1 networks. A code of 4 is a special connector that permits a zone so coded to use either the 2 or 1 network when interacting with zones coded to either the 3 or 2 network. A pair of zones coded 4-4, 1-4, or 4-1 must use the 1 network.

A recent improvement that has been made to the prototype model allows the classification of zones by 1 of 4 codes, leading to a total of 10 unique zone-to-zone combinations of codes. For each combination of codes, the user may

TABLE 1
NETWORK CONNECTIONS PERMITTED BETWEEN ZONES

Connection Code at Zone of Destination	Connection Code at Zone of Origin			
	1	2	3	4
1	1	1	1	1
2	1	1, 2	1, 2	1, 2
3	1	1, 2	1, 2, 3	1, 2
4	1	1, 2	1, 2	1

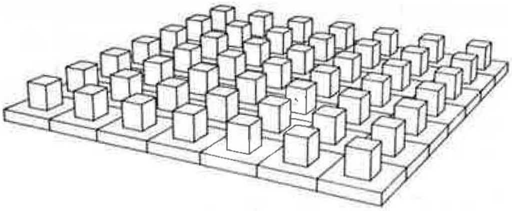

Figure 2. Development pattern for population of 20,000 served by uniform network with a speed of 0.1 mph.

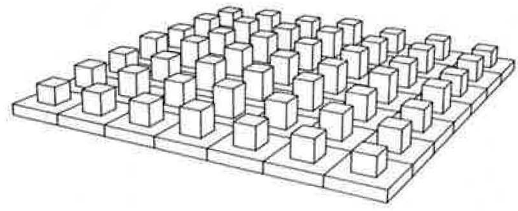

Figure 3. Development pattern for population of 20,000 served by uniform network with a speed of 10 mph.

specify a different set of network parameters, such as costs or speeds, and thereby obtain considerable flexibility in the description of the network that connects different classes of zones. The use of this zone coding scheme, which has come to be called the zone penalty code, is illustrated in the following example.

In Figure 1, zone 45 connects to zone 51 on either the 2 or 1 network. The sum of their penalty codes (0 + 1 = 1) is used to refer to one (in this case the second) of 10 sets of network parameters. For example, all zones with a 0 penalty code could be given a 5-minute terminal time for mode 2 while zones with a 1 penalty code might have a 10-minute terminal time. Thus a sum of penalty codes of 0 (0 + 0) would indicate a total terminal delay on network 2 of 10 minutes; a sum of 1 (0 + 1 or 1 + 0), 15 minutes; and a sum of 2 (1 + 1), 20 minutes.

The relative attractiveness of each zone, R_a, must also be specified. This can be used to denote the proportion of usable land in a zone (for example, by the use of a code of 0.25 for a zone that is 75 percent in swamp water) or may also be used subjectively to represent factors of amenity.

Finally, a zone's development may be constrained to be no more than, equal to, or no less than some specified amount. This is accomplished by use of a 1, 2, or 3 code respectively and specifying a constraint. An additional option is available in which the use of a 4 code specifies that the development of a zone must be greater than the development achieved in a previous run of the model.

EXPERIMENTS WITH PROTOTYPE MODEL

Even the most casual observer of land development in this country would recognize the tendency for development to occur in clusters. Moreover, within any given cluster, there are recognizable forms, most prominent of which is for higher density of development to occur at the center. A series of runs was designed to explore the model's behavior with respect to the various factors that are associated with this tendency.

The Impact of Speed

The first of these experiments involved a series of runs in a very simple region (49 one-mile-square zones) in which all zones were equally attractive and connected to a single network. The speed of the network was then varied from 0.1 to 100 mph. Development equivalent to 20,000 people was allocated to the region for each run. The development pattern associated with a speed of 0.1 mph is shown in Figure 2. The pattern is completely flat and shows no trace of central tendency. Because access is so very poor, there is no position within the region that has any significant advantage over any other position. Figure 3 shows the development that results when the speed is increased to 10 mph. There is some tendency for higher development in the center and lower development at the edges and corners of the region. Figure 4, an extreme example, shows the effect of a speed of 100 mph on development. Here each zone is so easily reached that there are no significant accessibility differentials in the region, and development is essentially flat.

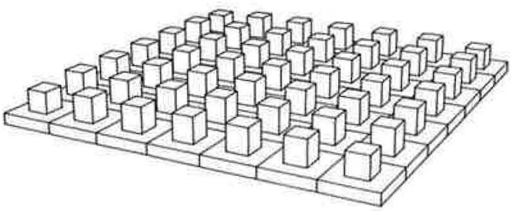

Figure 4. Development pattern for population of 20,000 served by uniform network with a speed of 100 mph.

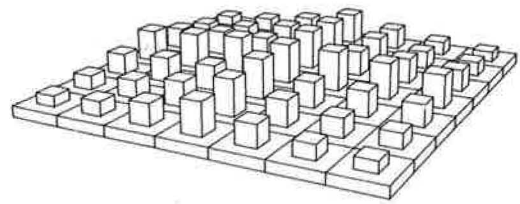

Figure 5. Development pattern for population of 20,000 served by transit network with a speed of 20 mph.

The Impact of Differential Accessibility

In this run, the same 49-square-mile region was used as a base, but 2 networks were used. A public transportation system operating at 20 mph and with a fare of 10 cents was assumed to run along 2 lines, one north and south and the other east and west, through the center of the region. All zones could use this network, but a different terminal time was used for each zone depending on its distance from the transit line. In addition, a walking mode at 3 mph was available to all zones. The development resulting from these assumptions and a population equivalent to 20,000 is shown in Figure 5. The differential accessibility provided by these radial lines results in heavy ridges of development.

The Impact of Magnitude of Growth

Another factor that bears on the relative degree of centrality of development is the amount of development taking place in a given time for a given region and transport system. For our simple, hypothetical region we increased the amount of development from a population equivalent to 20,000 to populations equivalent to 200,000 and 1.0 million. The resulting settlement patterns are shown in Figures 6 and 7. The vertical scale has been adjusted by factors of 0.1 and 0.02 to make the height comparable to the development resulting from 20,000 people (Fig. 3). Higher relative central densities are apparent when growth is increased from 20,000 to 200,000, but the effect is fairly small (only 3 percent). The impact of the increase to 1.0 million (Fig. 7), however, is very substantial. The development in the central square mile (0404) rises from 12 to 2,208, an increase that is 3.4 times the overall regionwide increase of 50 times.

Similar runs were made using the network with 2 transit lines in the center of the region, one running north and south and the other running east and west. The tendency for relatively more development to take place in the center than at the edges is again apparent. Figure 8 shows the development that results from a total population of 200,000, and Figure 9 shows the development resulting from a population of 2.0 million. In both illustrations the vertical scale has been adjusted to keep the height of development comparable to a total population of 20,000.

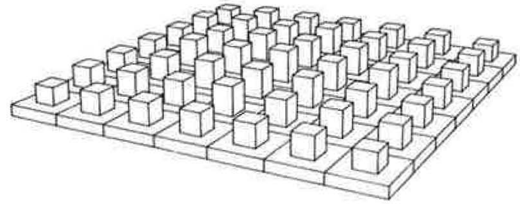

Figure 6. Development pattern for population of 200,000 served by uniform network with a speed of 10 mph.

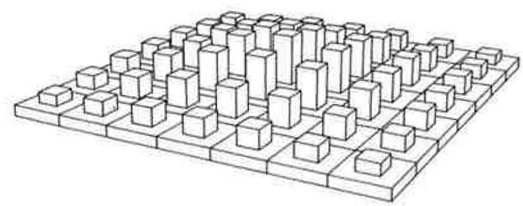

Figure 7. Development pattern for population of 1,000,000 served by uniform network with a speed of 10 mph.

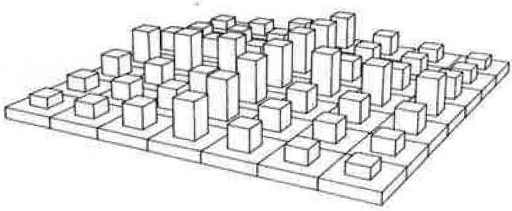

Figure 8. Development pattern for population of 200,000 served by transit network.

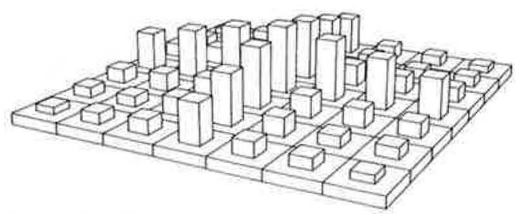

Figure 9. Development pattern for population of 2,000,000 served by transit network.

Accessibility Effects on Shaping Settlement Patterns

A variety of patterns of human settlement can be observed ranging from the densely packed metropolises of the East to the extensive cities of the West and Midwest. The following simulation experiments explored the impact of accessibility on these forms.

The Linear City—Linear cities are typically found in valleys and owe their shape in large measure to the topographic features of their regions. However, a linear city typically has a transportation facility that runs its length and strongly influences its development patterns. A simulation was made for a region 13 miles long by 7 miles wide. A transportation facility 7 miles in length and operating at 25 mph was provided to serve the region. All zones were given access to the facility, but zones through which the facility passed and zones adjacent to the facility had a terminal time to get to the facility based on a speed of 3 mph. The remaining zones using the facility had a terminal time based on a speed of 1 mph until they reached the 3-mph area adjacent to the facility. Development equivalent to a population of 50,000 was then allocated to the region. The resulting distribution is shown in Figure 10. Settlement takes place along the facility in a relatively dense ridge. Development within a half mile of the facility is twice as dense as development 2 miles distant. Development in this dense 2-mile band represents 75 percent of the total development in the region.

Accessibility Changes During the Evolution of a City—Many cities have experienced the bulk of their growth during periods when there was little or no change in transportation technology. The automobile has represented a major change in technology and has prompted much speculation over its impact on settlement patterns. A series of simulations was designed to explore this effect.

In the first test, a region 11 miles long by 11 miles wide was given 2 transit lines, one running north and south and one running east and west. People could use these facilities for a fare of 10 cents and travel at a speed of 25 mph, but they were obliged to walk to the nearest of the 13 transit stations. Development equivalent to a population of about 750,000 was then allocated to this region. The resulting settlement pattern is shown in Figure 11. A distinct pattern of development in the vicinity of the transit lines results.

Without changing the transportation network, we made another run but this time allocated twice as much urban development. The distinctive peaking in zones of high relative accessibility, as described earlier, is shown in Figure 12. The peaking is quite

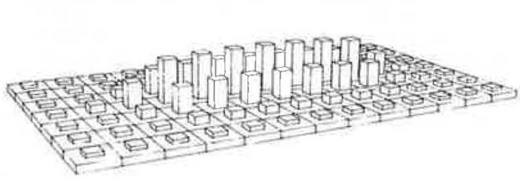

Figure 10. Development pattern for population of 50,000 in linear city.

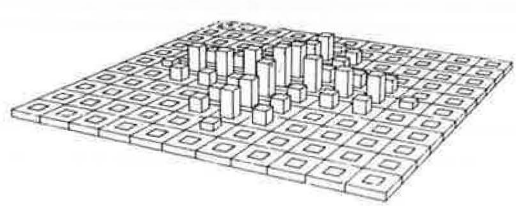

Figure 11. Development pattern for population of 750,000 served by transit network.

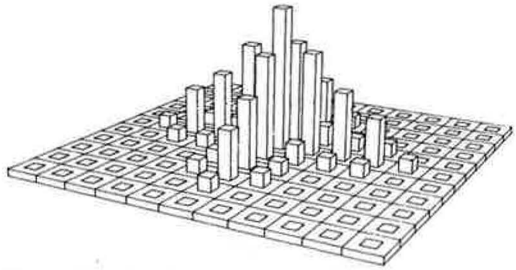

Figure 12. Development pattern for population of 1,500,000 served by transit network.

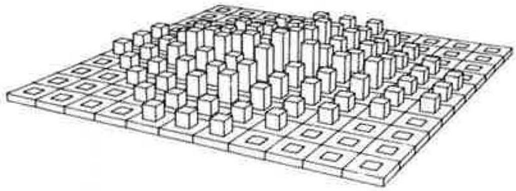

Figure 13. Development pattern for population of 1,500,000 served first by transit then by automobile network.

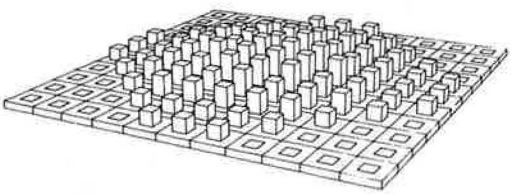

Figure 14. Development pattern for population of 1,500,000 served by automobile network.

extreme and is illustrative of the dense central cities that grew up during the era of the cable cars, elevated lines, subways, and commuter railroads.

To examine the pattern of development that the theory suggests will occur with the introduction of the automobile, we superimposed a one-mile grid of streets on the region. A speed of 20 mph and a travel cost of 2 cents per mile were used. Development that had taken place prior to the introduction of the automobile was retained, the automobile network being introduced only after regional development equivalent to a population of 750,000 had already occurred. The pattern resulting from this allocation is shown in Figure 13. Although the earlier pattern of central ridges is still apparent, all the new development can be seen to have taken place in the areas now accessible by automobile. The flattening or blunting of the tendency toward high densities by the introduction of the automobile network is quite dramatic.

In the final run in this series, we assumed that an automobile network rather than a transit network was available at the very beginning of growth in the region. An allocation of urban development equivalent to 1.5 million people was made in the region. The resulting pattern of development is shown in Figure 14. There is some tendency for higher densities to occur in the center of the region, but the dominant impression is one of a sprawling, ubiquitous development.

Although these tests are only hypothetical, they provide persuasive illustrations of the differences in urban development patterns that might result under different transport technologies. In all of these tests, the land in each zone was assumed to be equally attractive. That is, no judgment was made as to suitability, topography, provision of utilities, or amenity. The differences in pattern resulted solely from differences in access.

Three-Mode City

To further examine the impact of accessibility on settlement as suggested by the theory, we set up a multiple rail network with 5 lines converging at the edge of a region that was hypothetically situated next to a large body of water, and that had a peak of development, therefore, offset from the geographic center of the region. The network and region utilized for this run are shown in Figure 15.

The heavy lines are rapid transit lines having a speed of 25 mph and a 10-cent fare in this test. The shaded area is served by a bus network (or streetcar network) with a speed of 15 mph, a fare of 10 cents, and a terminal time of 15 minutes (5 minutes of walking at each end plus a 5-minute waiting time). The remainder of the area has no means of transportation but walking. Urban development equivalent to a population of 1.0 million was allocated to the region; the resulting pattern of development is shown in Figure 16. The 5 radial rapid transit routes are prominent. The surface transit

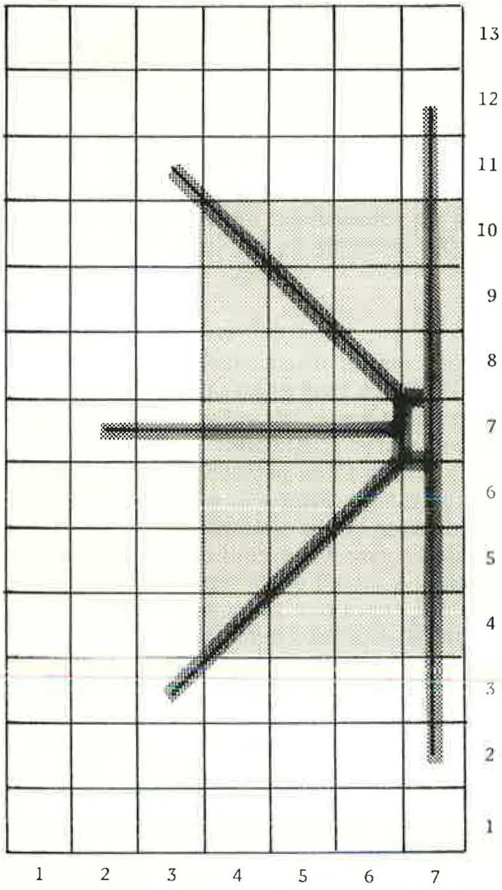

Figure 15. Network in 3-mode city.

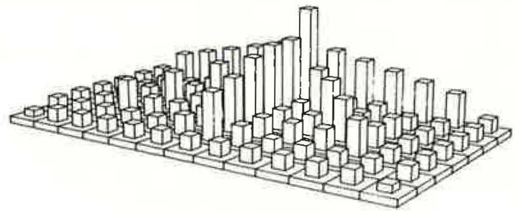

Figure 16. Development pattern for population of 1,000,000 in 3-mode city.

system also appears as a flat platform lower than the rapid transit system but considerably higher than the development in zones without transit service.

CONCLUSIONS

The tests described in this paper represent a continuing effort to understand the process of land development and, from a theory advanced by Schneider, to attempt to replicate patterns of urban development. The prototype development model that implements this theory of land development has been made more realistic in terms of the network descriptions that it will accept. The results of these tests are at the very least suggestive of the manner by which urban settlement has been shaped by different transport access. A program of research is continuing in which still more realistic replications will be attempted and in which factors such as the gross cost of land development may be incorporated into the model.

ACKNOWLEDGMENT

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