Title

BART Impact Studies Transportation and Land Use: Research Design for the Analysis BART Impacts

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Publication Date

1971-04-01

Working Paper 148

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April 1971

University of California at Berkeley
$6.50

Working Paper 148/ BART 2

BART Impact Studies Transportation and Land Use: Research Design for the Analysis of BART Impacts

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Joint Transport Program.

April 1971

University of California at Berkeley
Institute of Urban and Regional Developement

PREFACE

This is the first in a series of working papers dealing with research on the impacts of the Bay Area Rapid Transit (BART) system on the San Francisco-Oakland metropolitan area. These papers present background information on features of the BART system and the Bay Area, surveys of theory applicable to various topics, surveys of data sources with evaluation and documentation, results of preliminary analysis, and design for future research. The emphasis of this particular paper is on research design for measuring impacts on land use and urban development, and it includes a survey and adaptation of existing theory in the area.

Work on the analysis of BART impacts is presently being conducted by a study group consisting of faculty and students in city planning, economics, transportation engineering, and behavioral sciences, supplemented by members of the local community and local agencies, visiting scholars, outside consultants, and others who appear to be pertinent. Support for this group has come from an Urban Transportation Research and Training Grant to the Institute of Urban and Regional Development, from the Urban Mass Transportation Administration of the Department of Transportation.

Douglass B. Lee, Jr.
BART Study Group

ABSTRACT

Benefits cited as justification for investment in public transportation are primarily secondary or "demonstration" effects, such as reduction in congestion, provision of mobility for those unserved by automobiles, and reduction in air pollution. Some of these secondary effects relate to the use of land: revitalize the central business district, reduce the need for parking in downtown areas, increase land values, open up new areas for development, allow for greater residential and employment mobility, utilize land more efficiently, shape urban growth, combat sprawl, etc. BART provides an unusual opportunity to attempt to measure these effects.

Impact analysis means separating the effects of BART on land use from the effects of all other influences on land use, i.e., the state of the system without BART at various points in time versus the state of the system with BART, at the same points in time. Because of the complexity of the system in which BART is imbedded and the lack of a powerful theory that might provide controls for transportation impact analysis, forecasting alternative states of the system is extremely difficult. Development patterns are not subject to known laws. But in a practical sense, a great deal can be learned about transportation impacts using a partial framework.

The theory of land use, transportation, location, and rent are reviewed and modified for application to BART hypotheses. Some problems appear in the measurement of land use and access, and new approaches are suggested. The theory used here is limited to a static partial equilibrium framework. Some general research strategies are then discussed and evaluated, and a series of studies proposed that range from fairly descriptive kinds of monitoring and geographic analysis to relatively microscopic behavioral studies of urban development processes. This latter is a dynamic approach which considers the supply of land use change (investors), the demand for land use change (from households and firms which use BART either directly or indirectly), and the institutional factors (zoning, neighborhood groups, city planning) impeding or stimulating change. Finally, several long-term studies are proposed and discussed briefly.

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INTRODUCTION

Evaluation of secondary impacts of public investment is extremely difficult given the current state of knowledge, and is generally avoided. Since transportation investment is undertaken primarily because of its secondary effects, evaluation of these is necessary, and impact analysis is the first step. Thus, while it is acknowledged that impact analysis excludes evaluation, it should be done with evaluation in mind. Many reasons can be given for regarding property value impacts of transportation as suspect from the point of view of direct or implied evaluation.

A change in the transportation system causes a change in the access surface (the spatial distribution of levels of access). If the change is an improvement, then all locations enjoy an increase in access at least by some small amount. Some locations, however, may be provided with large increases in access, and thus in general an improvement in the transportation system causes a shift in relative access, increasing the share of some at the expense of others. If the aggregate level of activity is unchanged, the result is a spatial redistribution of these activities. Land values in the neighborhood of the new facility are increased while those more distant are lowered. Counting land value increases as benefits of the improvement is spurious unless all properties are included and the measure incorporates losses as well as gains.

Such an effect can rarely be observed for at least two reasons: (1) The secular trend of land values is almost always upward because of increasing demand in a growing metropolitan economy; a spatial redistribution in this case means that some properties do not increase in value as fast as they would have otherwise. (2) If the transportation investment has any benefits whatsoever, most properties will share in these benefits at least in some part. The question then becomes whether the investment produces net benefits, and how the costs are distributed over factors and locations. If the financing is from a property tax, and all properties contribute at the same rate, then those that pay but are unserved suffer a decline in value.

Finally, even if transportation investment leads to net benefits, other investments might produce greater net benefits. Three alternatives can be suggested in the present case:

1. Investment in BART

2. An equivalent investment in automobile transportation services (public plus private investment)

3. No investment by the public sector, i.e., the resources that would have been used remain in private hands, to be allocated by the private market.

Other alternatives are possible, of course, and there is no assurance that these are or even include the best ones.

Impact analysis superficially suggests a before-and-after framework, but this is incorrect. In fact, impact analysis requires forecasting alternative futures for the overall system, and comparing these with the state which actually occurs. An aid to this process would be a control area -- one with similar characteristics to the study area except for the investment under consideration. The control most often proposed for a BART impact study is San Mateo County, which lies just south of San Francisco on the peninsula and withdrew from the District after participating in the preliminary design. What kind of control it serves as is not clear, since (a) it has a functioning commuter railroad running into San Francisco, (b) it has been constructing freeways for some time and may or may not add another parallel north-south major freeway, and (c) it contains the San Francisco airport, already being considered for connection to BART. There may not be much value in collecting data for such an area if comparison with BART areas does not yield any useful conclusions.

Another reason for excluding secondary benefits is that they may be redundant with primary benefits. For example, a portion of travel time savings obviously is reflected in property values.

Hypotheses

Two ways of viewing the transportation-land use relationship are currently found. The first holds that transportation responds to land use development, or transportation follows land use. Transportation planning is thus a process of forecasting land use and then designing the transportation system that best serves the future land use pattern. This implies that land use changes autonomously, in response to consumer preferences, investment decisions, and other non-transportation factors, and the disequilibrium created is balanced by the provision of transportation facilities. Because of the high initial cost, the need for a balanced system without redundancy, and problems of exclusion and land assembly, the facilities are provided by government and charges levied against users through taxes. Evaluation of the transportation provided requires determining how well the given system serves land uses in comparison with other systems that could have been provided, and whether the system creates benefits that exceed its costs including opportunity costs.

An alternate view of the role of transportation is that it strongly affects the patterns of land use and social activity and hence ought to be designed so as to achieve social objectives. The policy value of transportation is seen as the secondary effects it can create. Under this view, transportation facilities are introduced into an equilibrium and land uses adapt themselves into a new equilibrium. Transportation planners have generally assumed the first position, and urban planners have advocated the second.

While both views acknowledge that transportation influences land use, at least to some extent, the specifics of the relationship and the strength of the influence are still largely speculative. Land values increase apparently in response to some transportation improvements, and decline in response to others; sometimes both occur in the same place at different times. It is generally agreed that massive new road construction over the past 20 years, general economic affluence and federal mortgage policies have all helped bring about land use patterns summarized in the phrase "urban sprawl," but the extent to which different transportation policies would have produced different patterns is unknown. Urban physical planners advocating the use of transportation to achieve desired land use patterns have had a notable lack of success, primarily due to their inability to demonstrate that the desired city improvements would in fact result from the proposed transportation investments (as well as that their plans were socially preferable to other alternatives). In fact, transportation investments in the last two decades, mainly highways, have been undertaken largely as a response to the market pressures of travel demand and not as explicit attempts to achieve physical or social goals in the metropolitan community.

More recently, there has been concern about the distribution of transportation benefits. It has been observed that the white suburban upper and middle classes seem to benefit especially from the highway system, and black and inner-city residents either fail to benefit or are directly harmed by highways. It has also been suggested that transportation might be used to reduce structural unemployment by providing access to jobs which were previously inaccessible due to residential segregation, restricted information or other spatial obstacles to obtaining employment. Many central cities have become concerned about the value of continued expressway development in downtown areas and have effectively slowed or stopped further construction. It would appear that there is currently at least some interest in using transportation as an instrument of public policy.

One obstacle to using transportation investment to achieve social goals is the lack of quantitative information about the impacts of transportation on possible goals, either by itself or in combination with other policy instruments. Some of these goals require knowledge of spatial, or land use, impacts. Overall, an improvement in the transportation system should increase the access of each location in the metropolitan area to the collection of all other locations, since at least some points can be reached more easily from every possible location, and none should be made less accessible. This, in effect, distorts the travel time map by contracting it in some directions. Land uses can be expected to respond to this difference, sometimes by shifting the category of use at a particular site. If a site is significally more accessible, then the activity on the site should take advantage of the increase. Since a particular level of access or a particular transportation improvement does not uniquely determine the land use at a site, and since many other forces may be impinging on the site, observing or predicting what land use changes, if any, will occur at any specific site, with or without transportation changes, has not been notably successful in the past.

A number of hypotheses have been culled from received doctrine and the conventional wisdom, and are listed below. They indicate some of the questions that may be of interest to planners, BART researchers, policy makers, and others, in the area of transportation and land use.

1. High capacity transit lines increase land values, especially near access points.

2. BART will increase the compactness of development and help combat urban sprawl.

3. Higher intensity uses will supplant lower ones along transportation corridors.

4. Residential mobility will be increased. In part this will be due to income generated by greater access to employment opportunities.

5. Urban core areas can maintain or improve their position in the urban fabric through greater access and higher volumes of person-trips.

6. New areas can be developed since people will be able to travel farther in the same length of time.

7. Transportation can be used in conjunction with other policy instruments to achieve public ends. For example, urban design techniques and land use control will be effective means for channeling and enhancing development changes stimulated by transit investment.

8. Expectations are an important factor in determining urban development patterns.

9. New land use activities will be generated both from the direct stimulus of BART and the indirect effects of substitution in the mix of consumption goods and in altered behavior patterns.

It should be noted that these hypotheses are not unambiguous in the ways in which they are stated, nor do many of them appear to be compatible with each other. Developing workable research hypotheses from the above statements will require a good deal of further effort.

THEORY

Despite a large store of historical evidence and conventional wisdom, the relationships between transportation and land use are neither documented nor well understood. Experience of the past century has seen dramatic changes in the size and form of urban development and suggests that changes in forms of transportation have been closely connected with this development. Still, the urban growth process is so complex that the independent effects of transportation on land use or vice versa remain mostly conjecture. The introduction of BART provides a unique opportunity to observe the relationships, with the hope that BART impacts can be translated into predictions for similar systems that are contemplated for other cities. It should also be possible to generalize to other forms of transportation.

Land Use and Transportation Theory

The theoretical link between land use and transportation is found in location theory, which is primarily the theory of the firm as it incorporates space as a variable. While the theory of consumer behavior is applicable to many portions of location theory, the household must compete with firms for location and hence is more commonly viewed as a producing unit similar to other producing units rather than as a qualitatively different kind of unit. To the extent that space is a factor in location, it must (a) have a price, or cost, and (b) vary with location. To the extent that space is not a factor in the location of economic activities they could be rearranged in space without consequence. If we assume that space or location does not uniquely determine use, the existing distribution of activities is simply one of an infinity of distributions that would also be consistent with present and past location factors.

Space has a cost in that transactions which occur between spatially separated points must somehow overcome the distance between them. Mail, telephone, shipping, freight, and meetings are examples of efforts to deal with distance. While the effects of distance are felt in numerous ways, attempts to incorporate communication into a theory of intra-urban location have met with two difficulties.[1] First, many forms of communication achieve extremely large economies of scale in their production. The price of making a phone call is highly graduated and probably approximate to some simple function of marginal cost, yet the difference in price between calling someone in the same building and someone five miles away i usually zero. Second, the value to a firm of non-verbal communication (face-to-face vs. telephone, telephone vs. written document) is very difficult to measure.

Thus transportation -- the movement of people and goods -- has usually been taken as the observable manifestation of the cost of distance in the abstract structure of location theory. Firms consume distance or transportation inputs in acquiring goods for production and in distributing them to markets.[2] Transportation not involving people or goods (e.g., communication) follows from the same theory, but lacks empirical support.

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[1]A notable attempt is Richard L. Meier, A Communications Theory of Urban Growth (Cambridge: MIT Press, 1962).

[2]The substitution framework is developed by Walter Isard in Location and Space-Economy (Cambridge: MIT, 1956).

A firm that requires transportation inputs can obtain them either by purchasing transportation services (e.g., shipping costs) or by purchasing location, or some combination. The two are substitutable, in that purchasing a better location leads to lower outlays for the same amount of transportation service (it is a better location for that reason). For any given location, there will be a single profit-maximizing level of transportation outlay. Where profits are positive, the firm can afford to pay up to that amount for the location itself. The actual location chosen by each firm and the price it pays depends upon the actions of all other firms in the appropriate markets.

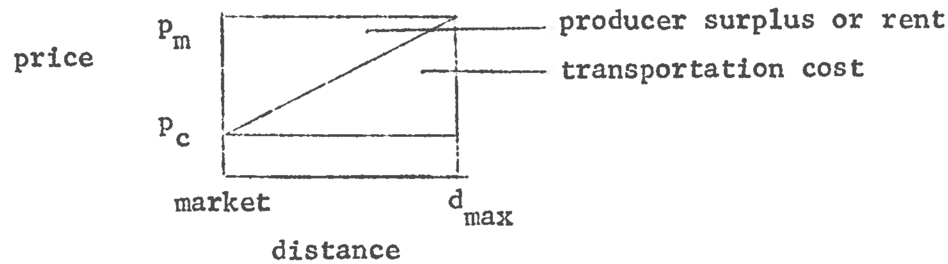
Rent Theory

Competition for location in the classical formulation is handled through the theory of rent. The simplest case is attributed to Von Thunen, who dealt with agricultural land use.[3] Consumption takes place in a single market located at a point on an infinite homogeneous plain, and production can occur anywhere on the plain. Assuming production costs per unit of output everywhere equal, transportation cost per unit of output a linear homogeneous function of distance, and price per unit determined exogenously in the market, production will take place in a circular area around the market. If the market price more than covers costs of production, the maximum distance from the market that production will occur is that distance at which transportation costs just eat up profits, i.e.:

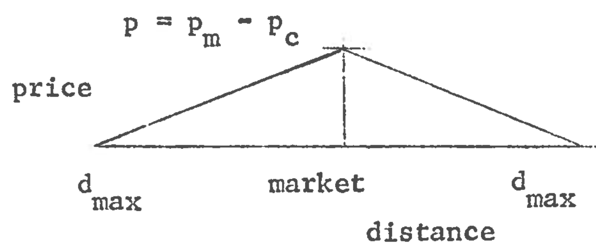
$$d_{max} = \frac{p_m - p_c}{r}$$

[3] Peter Hall (ed.), Von Thunen's Isolated State (Oxford: Pergamon, 1966).

where p_m is the market price, p_c is the production cost, and r is the transport rate.[4] Diagrammatically:



Since sites closer to the market are more profitable, owners of these sites will charge more for their use, up to the amount of the producers surplus at each location. The resulting rent cone is an expression of the value of each location resulting from its nearness to the market, and is thus pure location rent:

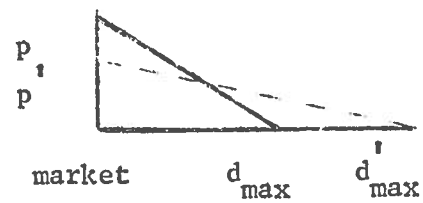


Site rent contains other components which will be elaborated later.

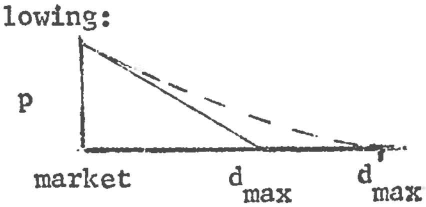
From even this simple rent model, we can make several observations. One is that an increase in the efficiency of transportation (which lowers the cost per unit distance) will cause the rent cone (or production) to flatten out. Initially, at least, d_{max} would increase, but this would increase the total supply and would likely lead to a price decrease. Unless the good is inferior, however, the area under production will be

[4]For simplicity, it is assumed that market price and production cost are measured in terms of the same distance units as the transportation rate, e.g., $50 is the market value of the output of a square mile of land, and this output costs $2 per mile to transport.

greater than before, but some rents in close to the market would be lower. In diagram, the general case would be:



Another observation is that if there were economies of scale in transportation with respect to distance, the rent cone would have a concave surface. Assuming the market price remains unchanged and r is the maximum transport rate for the shortest hauls, then the new cone would look like the following:



This simple rent model can be expanded in several ways. Von Thunen showed how different production activities would form into rings around the market, depending upon which type of production could afford to pay the highest rent in a particular location. This variation, in turn, stemmed from differences in market price, production costs, transportation rates, and yield or productivity of land. While this model delineates a pattern of land uses, it is not as useful for urban land uses as for agricultural uses, and we will develop a slightly different model.

Another extension of the simple model is to allow output per unit of land to vary, presumably as a result of inputs of other factors of production. This can be regarded as a single abstract commodity whose single characteristic is the ratio of non-land to total inputs used in its production. Such a characteristic can be called intensity of land use, and the commodity might be a wide range of activities in actuality. With this modification, the simple rent model yields an intensity function that declines with distance from the market, a concave upwards rent function, and the necessary condition (for a non-zero spatial extent) of decreasing marginal productivity of land as non-land inputs become large.[5] The reason for this last result is not hard to perceive: as long as it costs the same or less to add a unit of output to an already producing location, rather than start production on a more distant site, then production will continue to concentrate at the market.

The idea of a rent surface that decreases at a slower rate at greater distances from the center is not new, but the theoretical rationale for it is still weak. Colin Clark fit a gradient to density of population at different distances from the city center, for a number of large cities, and found that a logarithmic decay function was descriptively more accurate than a linear function.[6] His density gradient is an accepted empirical regularity, but the reasons for the logarithmic form or the use of residential density as the criterion variable have not been satisfactorily presented.

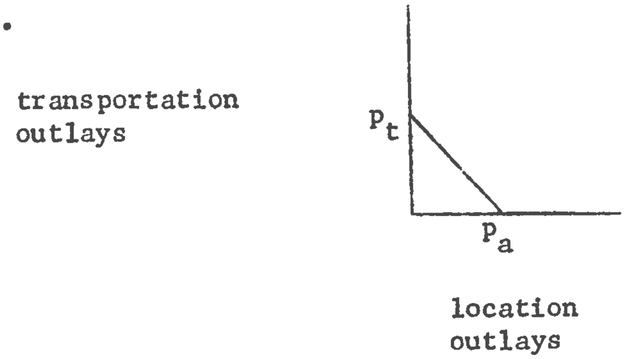
Transportation Input Substitution

In the multi-commodity Von Thunen model, each firm producing the same crop made the same profits. The sum of transportation costs and rent was a constant, so the firm was indifferent as to where it located, as long as it was within the right zone for the crop it produced. The same was true for the single-crop rent model: the firm was indifferent to location

[5] These results are developed in Appendix A.

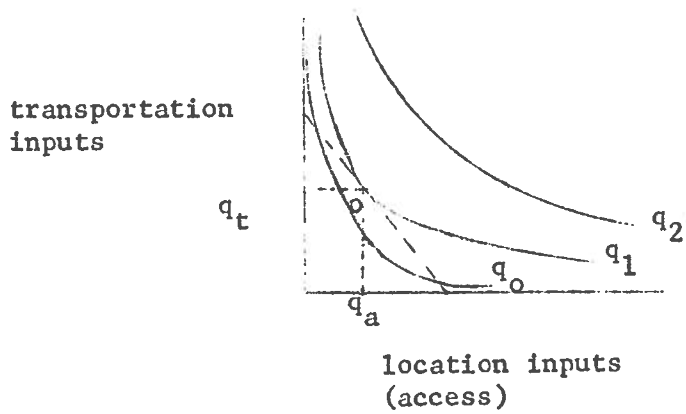
[6] Colin Clark, "Urban Population Densities," Journal of the Royal Statistical Association, Series A, 114 (1951), pp. 490-495.

as long as it was not outside the maximum range. The substitution between transportation outlays and location outlays (rent) is represented by a straight line.



A unit of transportation was substitutable for the same unit of rent no matter where the firm was located.

Taking a more general case, rent is not linear and firms are not homogeneous with respect to production functions. Location, transportation costs, and all other inputs would depend upon each other and the demand facing the firm. If we assume that output and non-transportation inputs have been determined, and that both transportation and location inputs make declining marginal contributions to output, then the firm must consider a set of isoquants such as these:



Each isoquant can be regarded as a level of output or as a level of transportation plus access inputs required to sustain a given output. If we assume that the output decision of the firm requires, say, q_1 of the remaining two inputs, then the relative prices of these determines the input mix, q_a of access and q_t of transportation. The optimal location for the firm is one which offers exactly q_a of access; sites with more access will cost more than they are worth to the firm, and sites with lower access will require too much expenditure for transportation.

Location and access are synonomous in a static framework, but may differ over time. Access is the effective nearness to all other activities or those of interest, and location is a geographic point. As long as nothing else changes, a change in access for the firm means a change in location. If, however, the locations of other firms or the features of the transportation system change, the access of the firm is changed without moving its location. Thus BART alters the access surface for the Bay Area, and the effective locations of many activities are changed without any movement actually occurring. This will be reflected in the prices of locations served by BART.

<u>Site Rent</u>

Purchase of a site involves acquisition of a large number of attributes, of which access is only one.

Site Characteristics:

natural: soil, vegetation, slope, weather, topography

improvements: utilities, internal transportation, grading, surfacing, buildings

Institutional Characteristics:

government: local property taxes, police protection, fire protection, quality of local government, zoning and building codes and enforcement

neighborhood: amenities, social class, reputation or image, civic or informal organizations, quality of schools and facilities historical: land ownership and fragmentation, inertia (not all sites are purchasable at any moment), technology (e.g., efficiency with which it is possible to utilize land)

other: information, availability of capital (interest rates, lending policies, banks) irrationality

Access:

transportation system: facilities, prices or other rationing devices, congestion, alternatives, speed, capacity, actual cost of use

other activity locations: workplaces, shopping, recreation, public facilities, health, education, etc.

To varying degrees, these characteristics all affect the price of a specific parcel of land, or a site.

We have mentioned the urban density gradient; land values can be observed to follow a similar pattern.[7] Adding in building values would accentuate the rate of decay. We have also seen that where land is more costly it will tend to be used more intensively, and that access tends to increase towards the center of an urban agglomeration (this follows from both the density of the transportation system and the density of activities). To what extent are the non-access characteristics listed above spatial, and to what extent do those that are spatial tend to reinforce the gradient pattern? If they are largely independent of the gradient, then we can conclude that access is dominant in shaping urban form.

Natural site characteristics may decline from the center outwards, on the assumption that the best sites are developed first, but changes in

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[7]John R. Hamburg and Robert H. Sharkey, Land Use Forecasts (Chicago: Chicago Area Transportation Study, August, 1961).

the scale of the agglomeration, what characteristics are "best," and technological ability to alter landscape tend to nullify the concentric effect of natural qualities. Some site improvements are cheaper in the core (water distribution), but the majority tend to be obstacles to use (blighted or obsolete buildings). Taxes are generally higher in central cities, amenities and social class lower, land ownership more fragmented and technology older, all of which would tend to depress the center. Transportation is better but more congested and older. Historically, access seems to have been a major influence on activity patterns; the current marginal impact of access is much harder to measure.

<u>Land Use</u>

The relationship between access and land use is neither as clear nor as strong as is the relationship between transportation and access, but the former is needed to complete the link between transportation and land use. Two possibilities appear for constructing an access-land use model.

1. Access is the major determinant of land value, or rent, and the amount of rent that each firm could pay at each site could, in theory, be determined. Firms offering the highest prices would obtain the sites of their choice, and these prices would determine the actual rent. If access were a relatively unimportant cost component in the inputs of most firms, and if this component were relatively invariant with location, then the pattern resulting from the bidding process would be relatively dispersed. On the other hand, if access were a major component and varied significantly with location, then competition would be keen for accessible sites and these would be intensively used.

Different kinds of firms would have different levels of rent paying ability. A household, for example, would never be able to compete with a commercial bank in bidding for land, unless, of course, the household were one of a large number which were combined in bidding for a small land area. This suggests that firms be classified according to the amount of rent they can pay, and that these classifications be called land uses. "Residential" would not be a useful land use category, but "Luxury apartments of 20 stories or more" and "Middle income single family residences" might be.

One difficulty with this approach to the access-land use relationship is the number of other factors besides access that affect site value. These factors would be a necessary intermediate step, since land use would depend upon aggregate rent, not just access or location rent.

2. An alternative formulation is to regard the access-using characteristic of firms as the measure of land use. A direct measurement of this variable is trip generation, except that not all person-trips or vehicle-trips have the same value to the producer of the trip. Reducing the cost of daily shipments of ten tons of lettuce is presumably more valuable than reducing the cost of the housewife's morning trip to leave her husband at the BART station. The approximation could be improved by classifying and weighting trips, and including average length, time, and purpose, along with frequency.

Using conventional aggregated land use categories, trip generation is still much more a function of access than of land use.[8] High intensity

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[8]Data from the Chicago Area Transportation Study showed that commercial land uses in the CBD generated 2,132 trips per acre and residential uses generated 2,228; commercial uses in the third mile ring generated 122 trips per acre while residential uses generated 127. Roger L. Creighton, Urban Transportation Planning (Chicago: University of Illinois, 1970), p. 81.

commercial obviously must be distinguished from discount-type commercial and from neighborhood commercial. Such a breakdown would be likely to follow fairly closely the rent-paying categories, but would have more normative content. Deviations of the actual land use and trip generation from that which would be optimal from the standpoint of location would indicate local or selective distortions, some of which might suggest the application of correctives by a public agency.

General Equilibrium

We have mentioned the price of access a number of times, but not the mechanism by which it is determined. Begin with a homogeneous plain, only this time there is a small transportation system. The first firm arrives and is free to locate anywhere at no cost. While there are no other firms to gain access to, there are places firm one will wish to go (for raw material, to dump garbage) and so the firm will locate at the point providing best access to the transportation system. A second firm arrives, and has the choice of purchasing firm one's location or locating elsewhere for free. Since access will have some positive value to firm two, it will offer a price to firm one for its site, which will be accepted or refused. Subsequent firms arrive, make their offers around, and locate. Previously located firms may find that they can now offer more for choice sites, since their profits increase with scale of operation, and they may be successful in relocating.

Firms that have acquired the most accessible sites will find that the marginal productivity of other inputs besides access, including capital, is very high, so they will seek to maximize profits by investing in site improvements. Other firms will find themselves being squeezed out, unable to purchase sites anywhere. Consumers may then find that they are willing to pay a higher price for these goods or services, and the firms reenter the market with higher offers for sites. An equilibrium would occur if each firm were paying, for each input, a price equal to its marginal value product. Since many inputs are required, and many of these have substitutes, many markets are involved in the equilibrium, and they are highly interrelated.

Suppose there is an improvement in the transportation system. The aggregate access of each point will be increased, which will lead some firms to increase their capital investment along with their scale of production. Some sites will shift to a more intensive (relative to location, i.e., access) use. Other firms will decide that they do not benefit from the increased access and consequently relocate to sites which have access levels equal to the old levels at the old sites. These new sites will, in general, be farther from the core. Thus a transportation system improvement has the dual effect of increasing concentration and increasing dispersion. Both may occur, or either one.

If the marginal productivity of access is high (technology is such that more access can be used to expand to a higher level of production with greater profits), there are idle resources in the economy or they can be developed, demand is relatively elastic, etc., then aggregate welfare in the urban region (in terms of gross product, for example) is increased by the transportation improvement. Concentration will occur, but the increased welfare will inevitably be tied to growth, which will enlarge the periphery. On the other hand, if firms generally are faced with severe diseconomies (with respect to access), demand is inelastic, resources are being used to capacity, etc., then activities will redistribute themselves in space without aggregate effect. Concentration may occur at points where access is changed by large amounts, but the more general pattern will be increased dispersion.

MEASUREMENT

Measurement of Access

A common misconception is that intra-urban location theory and rent theory necessarily view the city as having a single center, concentrated at a point. No such constraint is implied by the theory. It is the purpose of theory to state a relationship in its simplest, most uncluttered form; application of the theory is the challenge left to the problem-solver. His problem is to define empirically what is meant by a point market, a transportation rate, a producer, or whatever. In this case, multiple centers require specifying what kinds of activities are analogous to a point market and how, if at all, they are to be aggregated. Measuring access confronts many of these questions.

Access has two main components as previously described: the transportation system and the set of activities. At a given point, access is the aggregate nearness of all other points, and can be expressed as

$$v_i = \sum_{i \neq j} \frac{A_j}{T_{ij}}$$

where v_i is the value of access at the point i, A_j is the attraction of another point j, and T_{ij} is the effective distance between i and j. The summation is over all points other than the origin.

Access is a pure number whose scale is arbitrary, and its meaning can only be obtained by comparison with other variables. Attraction,

A_j, could be the residential population, the daytime population, employment, retail shopping stores, etc., weighted by factors such as income, age, wages, sales, etc., and disaggregated by age, race, income, occupation, etc. The trip index T_{ij} represents the separation between points, measured in airline distance, road distance, travel time by fastest route and mode, trip cost by cheapest route and mode, or some function of these or others such as a weighted combination or distance squared.

The above formulation is highly aggregated, since it implies that there is only one value for access at a point. In fact, access is a highly differentiated good. Access to a household means work, shopping, and recreation trips; access to a manufacturing firm means sources of inputs and destinations for outputs. Attraction in the former case would be measured with employment locations, commercial floor areas, and perhaps others. Attraction in the latter means locating producers of intermediate goods, warehouses, routes for exports from and imports into the region.

What population is chosen to define access depends upon the concept of access being used. Employment of all types represents the nearness to the aggregate location of jobs, and presumably has some value for residences for minimizing the journey to work. Other factors may be more important, however, than the journey to work, and even a work trip cost minimizer only needs access to one location unless he changes jobs indiscriminately and frequently. Cities do in fact exhibit a density gradient, i.e., the more accessible locations are more densely settled and cost more per square foot, but the reason for this may have nothing to do with the journey to work.

Disaggregating employment may offer considerably more information, but the data are difficult to obtain. Some occupations are more concerned with the journey to work than others (white collar workers, for example) but high income professionals generally trade off access for some other good (space and amenities) while those who might be most sensitive to journey to work costs are often obstructed from residential mobility. Thus poor people and blacks cannot select the cost minimizing residential location due to price and segregation constraints.

Access is often symmetric, e.g., between retail commercial land use and residential land use. The preferred location for retail stores is at the point that is accessible to the most people, and the preferred location for residences is the point that is the most accessible to shopping and other activities. The symmetry breaks down when the locations of people at work and at other activities including shopping is considered in addition to their residential locations, and when other activities besides shopping are included in residential location.

When the income of a family is increased, it may wish to alter its residential location. This will almost always mean an increase in the quality of housing, but whether more or less access is consumed is not immediately clear. Transportation and access are complements, and are directly substitutable, so that a poor family that gets a job that allows it to move to a nicer neighborhood closer to the job is consuming more access and less transportation, while a professional who gets a raise may choose to move farther away from his job to get more open space. In the former case transportation becomes the inferior good, while in the latter case it is access. The tradeoff may not be one-for-one, for example, if in moving out (less access) the family consumes more transportation but makes fewer trips (the decrease in access is not fully offset by an increase in transportation outlays).

Trip indexes can also be measured in a number of ways, each with different implications. Using airline distance between zonal centroids produces a measure of "potential" access, which may or may not be achieved in fact through the existing transportation system. Over-the-road distance is more indicative of actual trip impedence, but travel time or travel cost implies a different emphasis on what is being minimized, and these may be out-of-pocket expenses, perceived time or cost, actual long-run average costs, social costs (true marginal costs) or some other metric suggesting a behavioral response on the part of the trip maker.

If a comprehensive set of land uses or some other classification can be designed such that access has some meaning in terms of the classification, then a multiple comparison of surfaces should indicate which locations are most appropriate for which activities. This notion of land use competition has been proposed in a variety of forms, but the competition has been in the form of priorities (e.g., commercial preempts residential) and the classifications have not related well to the access measure. Disaggregation has also not been sufficient for serious analytic investigations. Eventually such a scheme should be solved simulataneously, which could lead to a new generation of land use models, but initial efforts can be calibrated descriptively in a partial framework.

Data requirements are large. Depending upon the level to which this methodology is developed, spatially disaggregated data for a large portion of the Bay Area will be needed in a number of categories.

1. A digitized census tract map of the Bay Area. Areas, centroids, and airline distances can be calculated from these data. The map should be compatible with the ACG-DIME system, whoever acquires and processes it.

2. Appropriate A_j data. Much of this can come from census tapes, but some of the more important attributes will need augmentation from other sources.

3. A transportation network. Major roads, highways, bus routes, and BART lines should also be digitized so that distances can be calculated over the network rather than as the crow flies. BATS may have such a system, and also the programs for trip assignment and modal split. Eventually we would want to handle modal split somewhat differently, but for initial purposes the standard algorithms used in transportation planning will be satisfactory.

4. Travel times and fare and cost structures. Various measures for inter-zonal travel time-cost factors will need to be constructed. In detail, these may get down to the number of transfers required on public transportation and the total cost of the trip, from different points in the urban area.

Selecting an Areal Unit

Two distinct approaches can be taken to the collection of spatially disaggregated data:

1. Rectangular grid (quadrats). The map is divided into squares of equal size (or combinations if the level of aggregation is different for different places on the same map) and data are collected for each square. Political, natural, and social boundaries and features are disregarded in the design of the shape and location of the areal unit.

Gridding has a number of advantages. Spatial referencing, computations of area, density, distance, etc., are much easier; data can be taken from maps and aerial photographs much more easily; comparisons of some types are facilitated because the units are all of equal size in land area, which is an important consideration in statistical analysis. Time series in particular are very difficult without grid units.

2. Administrative units. An enormous multiplicity of spatial partitions can be found in almost any metropolitan area, based on census enumeration, voting registration, school population, poverty, or any of a number of other considerations. While at higher levels of aggregation these units are not compatible in most cases, for census tracts and below the differences can be accommodated fairly readily. Thus if census tracts, blocks, enumeration districts, block faces, or parcels are used as the basic units, most other kinds of spatial units can be made up from aggregations of these basic units.

Since almost all data are collected by administrative units, use of the same or compatible units is necessary for the use of secondary data; using grids would require an independent original data collection effort with its own updating capabilities, and the tabulations would not relate to any of the administrative units and could not be used by them. Since the U.S. Census has developed a basic set of spatial units and has gone a long ways towards providing geographic coding for them and procedures for manipulating the units, this alternative is generally preferred.

The Definition of Land Use

In referring to land use, a wide range of characteristics are being summarized:

Stock Characteristics	Site Improvements	non-developable land (swamp, topography, lake)
		undeveloped land without utilities
		vacant land with utilities
		land with temporary structures
		land with permanent structures
	Structures	type of building, number of floors, floor area
Activity Characteristics	Human Activity	vacant structures, residences, parking, recreation
	Economic Function	corresponding to SIC Code
Relationship of Activity to Stock	Intensity of Use	density of population, families, employment; overcrowding; floor-area ratio
Other	Institutional	age, condition, value, tenure, zoning, type of ownership

Activities change more rapidly than structures, resulting in an activity different from the one for which the structure was intended. Use may change during the course of a day, as when school buildings are used for adult trade education, civic groups, cultural events, sporting events, etc. The same parcel or structure may contain a variety of activities within it. These problems are serious because the land use impacts of BART may not take the form of a land use change or may be so subtle that only a very fine classification will detect them. Changes may occur in land holding practices, extensions or reductions in the period of leases, changes in tenure, acceleration in the turnover of property or changes in the attitudes of property owners towards risk and speculation. BART may actually prevent a change, or reduce one, if other influences are counter to those induced by BART.

Current classification of areas of land according to use seems to depend upon several characteristics of the activity. A typical partition is Residential, Commercial, Industrial, Public, Vacant, and Unusable. The last two categories are inherent in any partition of this type: cells which are presently empty and cells which cannot be occupied. The major question is how to label the other cells.

Public use divides the set according to ownership, with the remainder being private. The remaining three categories are thus a partition of the private land presently occupied. Residential land is occupied by dwelling units, a form of consumption by the population. Industrial land activities are concerned with production, and commercial activities with distribution. In general, industrial activities should be located where they can best produce, with access to materials, labor, and transportation of materials, labor, and output. Commercial activities should be located to best serve the population, and residential areas should be located to secure desired amenities and access to desired commercial and industrial areas. The locations of the three categories are thus interdependent.

While it is difficult to quarrel with the rationale for these classifications, they do not provide any information with respect to two important attributes: ability to pay rent and the volume of trips generated.

Ability to Pay Rent

If all sites were ranked according to their value and all activities according to their ability to pay, then sites and activities could be matched starting from the top down. Unfortunately, ability to pay is difficult to determine even on a firm-by-firm basis, and this attribute also varies for the same firm in different locations. The parameters of ability to pay are

a. gross revenues (income)

b. taxes

c. maintenance

d. costs of inputs (consumption of other goods)

e. the interest rate

Within a metropolitan area the costs of maintenance and non-transportation inputs would not vary much with location (except labor), and taxes would be stable over large areas. The interest rate affects mainly the dynamic component, i.e., how fast change occurs. Gross revenues (rental in the case of residential land use) would vary considerably with location for some kinds of activities (residences, commercial) and not very much for others (industrial). The determination of ability to pay would thus depend on demand for the output of the activity for some activities, and on costs of doing business for other activities.

A classification scheme which reflected the different parameters of the ability to pay attribute would be especially useful in the analysis of development. For example, the current use of a particular site might be two-family residential and there might be several other activities that could pay a higher rent on the site. One might be an apartment building and another a specialty foods store. Assume in this case that the apartment building could afford the higher price. The change from one residential use to another, then, would represent a greater change in intensity than the change from residential to commercial. It is thus misleading to imply that industrial preempts commercial which preempts residential; these categories cannot be ordered. Designing a set of categories which could be ordered would therefore be a distinct improvement.

Trip Generation

A similar argument holds for land use categories and trip generation. Present categories do not conform with trip generation characteristics, despite the fact that average residential sites produce a different number of trips and at different times from the average commercial site. A large apartment building generates more trips than a neighborhood grocer, which in turn might generate more trips than a highly automated processing facility. Trip generation also has a number of characteristics:

a. trip type or purpose

b. trip length

c. frequency and time distribution

d. cost (including speed, private and social, comfort, safety, and option demand)

Again, if land use categories accurately reflected trip generation potentials, spatial analysis of urban activities would be greatly facilitated. It is likely that a set of categories developed along trip generation would conform well to a set developed according to ability to pay rent.

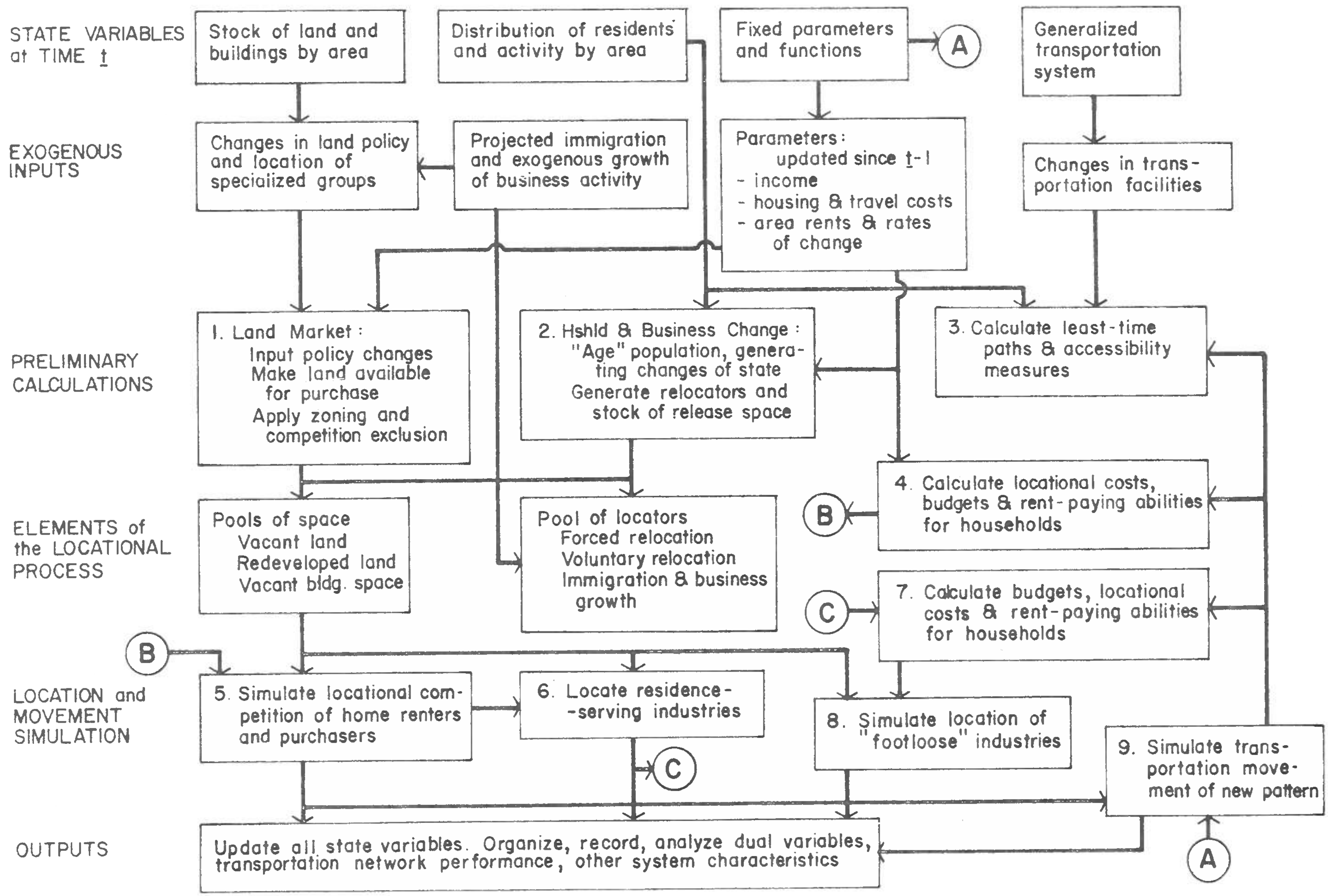
In predicting land use change, the problem of interdependence still remains. As soon as one site changes, then the potential for all other sites is changed. While this suggests the need for a general equilibrium framework, the extreme difficulty of actually developing such a framework is compounded by the fact that the urban land market is always in a state of disequilibrium. Land investment has a durability that prevents changes from occurring other than very slowly, and the use which supplants another may depend upon the costs of conversion from the existing use versus demolition and construction. Land use change thus depends upon locations of other activities, transportation, and current use of the site. A framework for studying these changes must necessarily be both partial and dynamic (non-equilibrium).

RESEARCH STRATEGY

A significant degree of choice is open to the investigator of land use impacts of transportation, and none of the alternatives can be considered safe. An overly general framework is likely to sink purely from its own weight, while a case approach may simply document the obvious without contributing anything to an understanding of the process. Whatever path is taken, a great deal of insight and judgment are required.

The Comprehensive View

An attempt to break the relationship between transportation and land use into components that are less complex internally than the overall process and connected together in fairly simple ways is useful primarily for its instructional value. Individual components must be well-defined problems, and the interconnected structure of components should be a relatively closed system, i.e., its connections to the rest-of-the-world should be fairly simple. Many examples of applications of this systems approach to transportation and land use can be found, but they seldom get beyond the schematic diagram stage. One used in the Penn-Jersey Transportation Study is shown in Figure A, but it is only one of several that would serve as well. As comprehensive overviews go, it is relatively descriptive, simple, pragmatic, and aggregated. No two of these analytic frameworks appear to have much in common, which suggests that there are many ways of breaking the transportation and land use system into components.



Source: Almendinger [338], p. 16

Figure A FLOW CHART: ONE ITERATION of the REGIONAL GROWTH and TRANSPORTATION MODEL

Describing the process is equally arbitrary in the picture presented. At time t_o the state of the system is a set of land uses at all metropolitan sub-areas, or territorial units of observations, and a set of transportation and land use factors: (1) stocks, (2) activities, and (3) relative levels of intensity, or adaptation, of the activities to the stock. The stock of transportation is the existing infrastructure of networks and rolling stock; the activities are the flows and volumes of vehicles, persons and goods by the different modes.

In the period under observation, the variables which change are:

i Economic variables such as level of area product and employment, distribution of income, public economic policy (taxes, credit, etc.).

ii Production activities, the number and characteristics thereof, technology (e.g., production functions), sizes of units, concentration and merging, expectations, e.g., of entrepreneurs.

iii Demographic and social variables: changes of population through natural increase and migration, household and family formation, social stratification and its characteristics, consumer preferences with respect to travel, housing, auto ownership, occupation, and residence relocation.

These changes bring about changes in demand for spaces and location which must be matched against the available land and structures which are fixed at any given moment. Processes of adjustment and equilibrium that take place are: migration of activities to different locations, use conversions, "filtering-down" of residences and commercial structures, higher or lower intensities of use, and space expansions. The allocator is the market mechanism through prices and rents as affected by local, regional or national government policy (zoning, building regulations, mortgage markets, etc.).

Changes also take place over time in the existing stock of land and structures in response to disequilibria between demand and supply:

i Conversions of agricultural land to vacant land for speculation

ii New subdivisions

iii Demolitions and clearances

iv Additions of land by reclamation (flood control, Bay fill, etc.)

v Installation of services and utilities on undeveloped land

vi Depreciation and attrition of existing stock of structures

vii Additions and alterations for rehabilitation

viii Additions and alterations for conversions of use

ix Building of new housing or commercial units

A similar process takes place in the transportation sphere. New demands of travel and movements by time, origin-destination and mode appear and are mediated with the available capacity through the transportation market allocator (where travelled time, vehicle time, expected accident cost are the "currency") and government controls. Changes in the supply to meet disequilibria are:

i New roads and highways

ii Widening and other alterations of existing highways and roads

iii Deterioration of existing roads and highways

iv New transit lines

v Extensions of BART

vi Changes in frequencies, speed, etc. of other transportation lines

vii Closure of public transportation lines

These two sets of forces clearly form a feedback system with multiple interrelationships. Changes in the spatial allocation of activities cause changes in the demand for travel and communications. In turn, the condition and capacity of the transportation network influences the location of activities through the relative accessibility given to various sites. The particular time path of adjustments and the disequilibria due to different time lags will affect the outcome of the process, which will never reach equilibrium because new changes occur faster than responses can be made to previous conditions.

While a great deal of emphasis cannot be placed on a comprehensive framework for investigating BART impacts on land use, it is useful to try to grasp the scope of the problem before designing specific analyses. The framework may keep us from overlooking important areas of study, it may lead to a better balance between different areas of study, and it may prevent us from undertaking foolishly ambitious or overly open-ended studies.

Broad Strategies

Emphasis could be placed in any of three general approaches, but a better approach would be to use all three selectively. The purpose in discussing them is to prevent study from becoming limited to any single one, because in the overall design all three should be addressed. Specific studies may concentrate on a single approach, but after considering the implications of the alternative approaches.

1. Descriptive. Conceptually, the relationship between transportation and land use can be regarded as a black box, whose contents are unknown. An input to the box is a transportation system change, and the output of the box is a land use change. The mechanism by which the effect is transmitted is not considered -- only the question of whether there is any statistical procedure for estimating the output of the box given only the inputs. If the existence of a relationship can be established, then the box can be opened up and study directed at understanding its workings. In the case of BART, the state of the system would be recorded before the new system, the change introduced, and the state of the system recorded periodically thereafter.

From this it would appear that descriptive studies are the natural precursors of behavioral studies. Several major difficulties, unfortunately, limit the value of descriptive analysis for the purpose at hand. First, the state of the system as a result of BART is different from the recorded state of the system by an amount that is unknown but includes the effects of all other things besides BART on the state of the system. Second, while other important variables can be controlled by statistical means, the number of controls needed in this case is unusually large, precisely because not enough is known about causal relationships to know *a priori* which variables to control for and which ones to simply ignore. The fact that there is no way to duplicate a non-BART situation to compare with BART and that there are no two BART stations sufficiently alike illustrates the complexity. Thirdly, the system is so extensive that recording the full state of the Bay Area transportation system at any point in time is not really possible. Therefore we will have to make some choices among the various possible data to monitor based on suspected relationships in the black box.

2. Behavioral. An alternative approach to descriptive analysis is one which attempts to identify a series of micro-analytic cause-and-effect relationships (or at least smaller black boxes) which will link the major elements, in this case transportation (BART) and land use. If the small linkages are successful, then aggregate patterns may be built up from the microscopic ones. Presumably BART will have an effect on trips people make and the modes they use, and other persons will perceive an opportunity for more effectively utilizing this stream of trips. Thus a land use change requires that investors think that an economic opportunity exists, and that trip makers think that BART offers them something better than whatever they were doing before.

Many difficulties are present in using the behavioral approach, which make it less attractive. The problems of the descriptive approach may also appear in behavioral analysis, only at each step of the process. Errors in each link are amplified by the linkage, since there is no control between non-adjacent links. The result may be something that is no more reliable than a descriptive analysis and considerably more work. Links that operate adequately in isolation may not hook together, or may behave perversely.

It is not necessary to make a hard choice between the two. Most studies combine as much as possible from both, depending upon the state of theory in the field, and shift emphasis from one to the other as appropriate. In research on BART land use impacts, the openness of the system affected and the inadequate state of knowledge on the subject lead us to emphasize a more behavioral approach for the initial phase of the work.

3. Normative. In some cases it may be more appropriate to ask what is the best use for a given site rather than what is the current use or what will be the future use if given changes occur. Defining what is meant by best is usually difficult and most often comes down to what would occur if there were no market imperfections, neighborhood effects, or externalities of any kind. It would be rare to find a situation in which the correct use of a site could be determined from non-market criteria. There may, however, be efficiency or equity goals to be served by shifting the use of certain sites. If transportation is to be used as the instrumental variable, then the question is back to being a positive one -- what will be the effect of a change in transportation on land use? On the other hand, if the change is to be administered directly (e.g., through urban renewal) or through non-transportation policy instruments, then the criteria are outside the scope of this study.

Normative concerns are in the efficiency of the provision of transportation services and in the equity with which the costs and benefits are distributed. Efficiency arises in pricing and investment so as to achieve optimum utilization of BART facilities, pricing in relationship to under- or over-pricing in other modes, allocation of resources to transportation versus other goods, and similar questions. Inequities may arise because user charges do not cover costs, negative and positive externalities exist, and subpopulations who should be served are not. Land use effects appear not only because of the spatial redistribution effects of transportation investment but more directly in the land consumption and immediate impacts of highways, elevated systems, parking, subways, etc. Since activities are not distributed heterogenously in space, a particular transportation system will serve some population components and economic activities better than others, giving rise to possible inequities. There are thus important normative issues in transportation that have significant implications for land use.

A Sequential Strategy

It is particularly important in a subject area as potentially broad as the land use impacts of transportation that the initial research design not unduly restrict later efforts, as would happen if we chose to undertake large projects which yield useful results only when completed, or if subsequent research did not utilize the information gained in preliminary studies. Thus an optimal design will be a kind of branching process in which there are a number of options available at the end of each study, with the choice of emphasis in subsequent work dependent upon the outcome of the previous study. For example, if early case studies turn up consistent patterns, these patterns can form the basis for more aggregate statistical analysis and at higher levels of abstraction. On the other hand, if early studies reveal the uniqueness of the situation studied, then a more microscopic approach should be taken.

If the optimal path towards the objective of understanding the impacts of BART on Bay Area land uses could be plotted before the research began, there would be no need for a branching process and the study sequence could be described in detail at the outset. This is seldom possible in ground breaking research of any kind, and it appears especially difficult in urban research involving a wide range of possible variables. Hence studies undertaken later in time are specified here in less detail. The choise of which subsequent studies to be emphasized and which to be discarded will depend upon the preliminary research.

If this strategy is to operate effectively, there must be rules or guidelines of the following form: "If the outcome of study A_1 is X_1 then begin studies B_1 and B_2; if it is X_2 then begin study B_3." This is an abstract and oversimplified version of a decision rule, but conveys the essential elements. Only if the likely outcomes of a particular study can be specified beforehand, can the decision rule be contingent upon specific results; otherwise, it can only be stated in general terms. Three such rules have been proposed and were used in preliminary work:

1. If a preliminary survey of alleged land use impacts indicated that the BART effects were strong and identifiable, then propose aggregate analyses and questionnaire surveys in the second phase; if the preliminary survey indicated that a complex set of factors was relevant and BART effects deeply imbedded, then propose more unstructured kinds of case studies. The latter occurred most often in preliminary analysis.

2. If preliminary surveys of data availability showed that comprehensive stores of compatible data exist in machine record format and only a limited number of variables are required, then recommend econometric modeling be considered in the second phase and a land use model in the third phase. But if data are erratic and variables are many, then more partial kinds of analyses should be recommended, requiring smaller volumes of data. The latter approach was indicated.

3. If a survey of transportation and land use theory shows that a large body of applicable knowledge is ready for calibration or testing, then design a series of statistical tests and data gathering activities that will maximize the information gained in regard to the theory. But if the theory is lacking or underdeveloped, then more ad hoc kinds of heuristic search procedures should be recommended to identify and formulate

hypotheses. While some theory was found, the latter course of action was clearly the most reasonable.

Staging

The first stage consisted of three studies that have been completed.[9] These are numbered 1-3 in Figure B. In these studies the decision rules described above were applied with the results indicated, along with suggested priorities for stage 2.

Stage two will consist of studies carried out largely independently by single investigators or small teams. While the studies themselves will be carefully designed and controlled, and will be evaluated and selected on the basis of their contribution to the overall effort, little attempt will be made to draw them into a tight framework. Frequent and regular meetings will be held among investigators for information and criticism, with the expectation that third stage studies will emerge from the collective effort. Data resources will be developed selectively based on cost, value of the information to the study, and communality among users.

A brief description of the activities shown in Figure B follows:

Stage 1:

1. Survey of agencies likely to posess land use information. Questions about attributes of information, through field interviews; acquisition of some source documents and data descriptions.

2. Collection of locations and nature of claimed or expected impacts of BART on land use. Attempt to categorize impacts by type and BART

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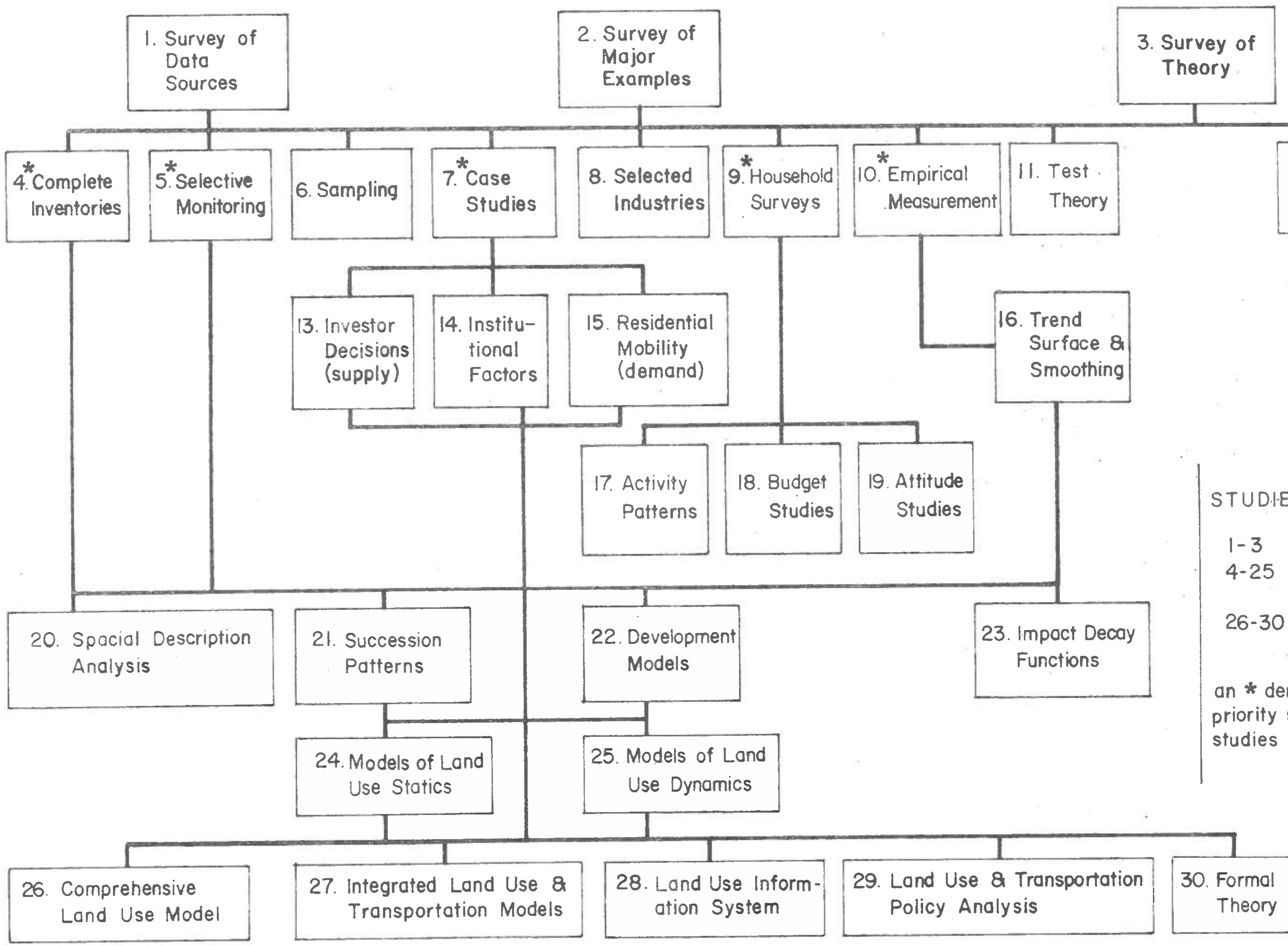
[9] Material from the data survey (study no. 1) has been integrated with a general data source and needs survey, and will appear subsequently. The report in hand includes the results of the theory survey (no. 3) and the impacts survey (no. 2) will appear as a working paper titled Background Information on BART Stations.

Figure B: STUDIES in LAND USE and TRANSPORTATION



STUDIES

1-3 are completed
4-25 are second stage
26-30 are long term

an * denotes high-priority second stage studies stations by type of impact expected.

3. Survey of land use and transportation theory, with evaluation and modification.

Stage 2:

4. Complete recording of selected variables for selected areas. Resolve problems of classification, definition, areal unit, compatibility of sources, processing costs, potential users, accuracy of original data, etc.

5. Begin continuous or periodic recording of selected variables likely to reflect BART effects (indicators) such as land use changes, property transactions, building permits.

6. Structure a random sampling of selected variables for comprehensive population. Population might be Bay Area persons, families parcels, streets. etc. (*A priori* information for reliable structuring is essentially nonexistent.)

7. Begin micro-analytic investigations in depth (i.e., in time and detail) for specific locations, e.g., stations. Field work and scholarship (e.g., searching public records) by skilled investigators concentrating each on one case.

8. Survey by questionnaire or interview -- firms in selected categories, e.g., hotels, department stores, low-income employers, etc.

9. Sample survey or panel survey random households, or BART-rider households, for residential mobility and housing or location preferences.

10. Acquire and process of data to represent variables indicated by theory as appropriate to land use and transportation research (e.g., "access").

11. Empirically test the hypotheses generated from existing theory. Experimental design, data processing and analysis.

12. Construct additional pure theory on the basis of existing theory and available empirical studies.

13. Undertake studies of how decisions about land use changes are actually made, with emphasis on those persons or organizations that have the resources to implement change (speculators, insurance companies, banks, home owners, builders, retail managers, etc.).

14. Study institutional impediments to or accelerators of land use change, e.g., neighborhood organizations, trade organizations, zoning regulations, financial institutions, political and social factors.

15. Study BART ridership to assess the influence of BART on their demand for residential and employment locations.

16. Construct continuous surfaces of selected variables over the areas contiguous to the BART line.

17. Analyze household activity patterns to determine how persons use land, i.e., land based facilities, and transportation in combination.

18. Classify and analyze household budgets to determine how consumption resources are allocated to transportation and what effects this has on land use, e.g., residential location and recreation.

19. Undertake behavioral studies of persons for predicting response to future changes in transportation, including: visual effects, class consciousness, popular image of system, psychic satisfactions of different modes, etc.

20. Analyze and process spatial data with techniques commonly used in quantitative geography to look for and describe patterns of distribution and change. (Mechanical devices, e.g., plotters, for graphic display).

21. Carry out dynamic counterpart to cross-sectional spatial analysis.

22. Design and fit partial models of urban growth and change dynamics, with transportation system attributes among the independent variables.

23. Formulate and fit distance decay functions for various effects of or responses to BART stations or structures.

24. Build cross-sectional land use models.

25. Build longitudinal land use models.

Stage 3:

26. Devise regional residential and commercial allocation, or growth, models for forecasting land use patterns in consistent fashion.

27. Combine land use models with models developed in other parts of the study which might be used for research, policy evaluation, or choosing among alternative configurations of service.

28. Create regional data bank and information system providing land use and transportation information to agencies and individuals in the Bay Area.

29. Make recommendations for future use of transportation as a land use policy instrument.

30. Further develop the basic theory of land use and transportation, in a general form that is applicable to a wide range of circumstances, e.g., different modes.

Not shown in the diagram of Figure B are feedback relationships or interconnections between the outputs of one series of studies and inputs to other studies. For example, the results of developing new theory and testing deduced hypotheses will presumably affect the design of research in household or investor studies. The connections in the diagram are primarily for showing decision lines. For example, the results of case studies would have implications for whether to concentrate on supply, demand, or institutional factors in further work.

Proposed Studies

The establishment of BART will impose a new pattern of accessibilities along its corridors. This pattern will not be continuous (as it is in the case of new highways) but will be centered at the break-up points of transportation along the radials which are the stations. These are the points of transfer connecting with other transportation sub-systems or directly with land using activities.

The relative private benefits and costs at different locations for the different urban activities in the private market (regulated by government policy) will account for the changes that may take place in the spatial structure of the Bay Area. (Besides offering better transportation services in the area it traverses BART will give more access to the urban fringe and to potential suburban extensions.) Lower land costs, quality of the environment and higher commuting costs at the periphery are weighed against the costs of more intensive development at more central locations (demolitions, land assembly, etc.).

The development around each station will depend upon the competitive position of its area within the total system in terms of (1) accessibility, (2) the role it will play in the transportation system (transfer, terminal, serving reverse commuting, etc.) and (3) the comparative advantages that the existing characteristics offer for future investments. These characteristics have to be considered within the framework of the overall spatial structure of the Area and its historical development.

Seven studies are proposed for the next stage of the project:

Selected Data Inventories

Monitoring Land Use Change

Investment Decisions

Institutional Factors

Residential Mobility

Household Budget Studies

Trend Surface Analysis

Some of these studies overlap with each other by sharing data, by sharing results, or by focusing on the same location. Some are concerned solely with land use while others provide information that will be of use in different kinds of studies.

Selected Data Inventories

It takes a good deal of planning, effort, and time to establish a working file of data that is free of errors, bugs, and missing items, and is stored in a conveniently accessible format. Even with a source as relatively clean as the U.S. Census, the setup cost is far from zero, and for land use information the problems are acute. Different agencies are collecting data according to different definitions and processing it under different formats for different machines. Much of it is not machine readable at all. Thus construction should begin soon on important base files.

1. Land Value. While California has been moving towards standardizing assessment procedures and record maintenance, the compatibility problems in using data from different municipalities in the same file are still enormous. Efforts should be directed at storage and

retrieval of recently acquired land value data around BART stations, and expanding this file to all stations and a more general coverage.

2. Geographic Base File. An extremely important component of the BART data base is a geographic referencing capability, and land use studies will depend especially heavily on it. Implementation of the ACG-DIME system is currently under way in the Bay Area, but considerably more effort is needed on this task.

Monitoring Land Use Change

With the present state of knowledge about transportation and land use it is hazardous to try to pick the key variables from the very large set of potentially valuable ones. The four listed below are the result of combining reasonable guesses with likely data availability.

1. Zoning Changes. It is already evident that pressure is being put on existing zoning ordinances, both to allow for an increased intensity of use based on BART expectations, and also to prevent such change from occurring. While no mechanism exists for systematically collecting and centralizing these data, the volume of such changes should be small enough so that a system could be set up and maintained at a reasonable cost.

2. Building Permits. Municipalities regularly issue building permits for new construction and remodelling, and the data are fairly accessible. In this case, the volume of records would most likely be so great that the BART file would have to be limited by processing only certain permits (according to value or type), or certain locations (near stations), or (least desirable) by sampling.

3. Assessment Changes. Public evaluation of property for tax purposes is based on characteristics of the existing stock and activity on a particular site, and on expectations of the future value of the site. Land value can be conceived of as a surface over the Bay Area, with peaks at central business locations and gradually diminishing towards the periphery. The shape of this surface will undoubtedly be affected by BART, and in fact already has been affected.

4. Market Transactions. A complementary file to the assessment records is actual sales of real property. Limitations imposed on the building permits file would also be applicable to both assessment and property transactions data.

Investment Decisions

If we think of land use changes occurring in a market then those individuals or organizations that actually make the decisions about land use can be regarded as the suppliers of land use change. By our definition, a land use change means a change in the kind or amount of capital and is hence an investment (or disinvestment). The supply side of land use impacts depends upon capital investment decisions, which are affected by the usual considerations such as technology, and input costs (construction, technology) and the private financial market (interest rates, money supply, lending policies, risk). At least six different factors should be considered in analyzing real estate investments.

1. Land Use Type. The conditions of supply and demand vary with the type of land use and thus it is customary to study the different sub-markets for such categories as single-family housing, apartment

buildings, commercial uses, shipping centers, industrial buildings, etc. Certain special uses may require different degrees of management skills and consequently offer a higher capitalization rate, such as hotels, motels or theaters, compared to more general uses such as office buildings or stores on long term leases which require less direct control.

2. Gross Income. This depends on the type of use and the characteristics of demand, not only the general trend in the area but also the demand for the specific features of a particular site and the quality of services offered. A vacancy factor is also included to account for lags in turnover and market frictions.

3. Operating Expenses. They vary with particular investments and they can be classified as: (i) general costs such as wages and salaries, leasing costs, utilities and services, repair and maintenance; (ii) replacement reserves for expenditures required at longer intervals than general repairs and (iii) insurance and property taxes.

4. Risks and Errors. An investment plan includes a prospective view of the future as well as estimation procedures and thus it is influenced by the attitudes of investors towards risks and their ability to reduce errors. The site may prove to be less attractive than calculated, the vacancy factor may rise or the operating expenses may increase due to inflation, underestimation of costs, etc. Particular contractual forms and basis for finance (lease, fee-ownership, purchase-lease back) as well as type of investor are attached to different degrees of risks involved. Long-term investors (business corporations, life-insurance companies, pension funds), will have a different view towards risk than smaller firms or individuals who operate on a short term basis on little equity.

5. <u>Leverage</u>. This is the ratio of non-equity funds to equity funds. A higher leverage can bring a higher rate of return on investment but also an increasing danger of bankruptcy.

6. <u>Taxes</u>. (Income and capital gains taxation). This factor also causes variability of investment plans according to characteristics of the particular investor, his situation with respect to taxable income brackets and his use of various potential tax shelters. Depreciation allowances are particularly important here.

Different measures of the outcome of a real estate investment can be used. For example, with all its limitations, the after-tax internal rate of return on equity, defined in the following formula:

$$E = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} + \frac{P_n}{(1+r)^n}$$

Where:

E = Value of equity invested at time 0.

CF_t = Annual net cash flow at the end of each period (Annual revenues less operating expenses, debt service and income taxes).

P_n = Net value of the reversion period n (Gross value, less capital gains tax, less unpaid amount of mortgage). It takes into account true depreciation or appreciation of the investment.

n = Number of periods.

r = Internal rate of return

The limitation of this measure is that it assumes that all cash in-flows are reinvested at a compound rate of interest, whereas in fact, the rate at which reinvestments can be made changes over time with economic conditions. The method also tacitly assumes the predictability over long-term periods of time.

We propose to study the supply side of transportation impacts by analyzing different actual cases stratified by the variables described above and by location (with respect to accessibility to BART stations). A case study approach will be used at the beginning, then sampling as patterns emerge that can be tested on a broader scale.

The study would cover:

1. "Ex ante" calculations and perception of demand for the site by the investor according to the factors outlined above.

2. "Ex post" characteristics of the investment (actual results at an intermediate period).

3. "Prospective" view of the investor as to future outcomes in light of the experience with the investment to date.

Interviews would be conducted at the time the investment is being made (construction period or early operation of the facilities) and again in the "after BART" situation.

Institutional Factors

In the operation of the land use change market, there are a number of institutional variables. Some examples of the most important ones are:

a. Zoning. Land use controls may facilitate or hinder development. In some cases they are designed to prevent changes from occurring in desirable neighborhoods, and these may prevent land use impacts from being manifested. In North Berkeley, for example, the zoning ordinance was tightened specifically to prevent land use changes in response to BART.

b. Community Organizations. Local organizations, e.g., neighborhood associations, businessmen groups, and ethnic minority organizations may respond to the BART stimulus by either encouraging or resisting change. Resolution of economic conflict or disequilibria may then take place in the political or organizational arena.

c. Land Ownership. Where ownership of land is highly fragmented into small parcels, it is difficult for a developer to assemble enough property to be able to implement substantial or discontinuous land use changes. (Of course, many changes do not require land assembly or even land transactions.)

d. Building codes, trade union practices, and the policies of municipal governments, commercial banks, large corporations. All of these will obviously have important influence.

e. City Planning. City planning bodies may to some extent direct or divert various BART-created forces acting on land use; (it will be useful to examine whether BART-stimulated changes are largely determined outside, or even in opposition to, the planning function).

The studies or institutional factors will necessarily be of the case type, anthropological in methodology. This means spending considerable field research with a number of individuals and groups and reliance upon the background, training and judgment of the investigator to perceive the important variables and their interrelationships.

Residential Mobility

This type of study is geared towards the evaluation of BART impacts from the point of view of the demand side. These impacts will be felt through the actual patronage of BART (if BART has no ridership, then it can have no land use impacts other than those felt in the construction of the system or those decisions erroneously made in anticipation of ridership). It is appropriate, then, to study those who ride in order to determine what the demand for land use change will be.

Effects should be separated according to the different types of market demand changes:

1. Impact on housing services and residential location demand caused by the new accessibility patterns.

2. Impact on the demand for consumer goods and services and consequently on sales and location of commercial uses.

3. Impact on location of employment on the basis of new patterns of accessibility for labor inputs, e.g., office buildings.

Besides this classification, the impact should be analyzed from the point of view of different socio-economic groups and kinds of households which would provide insights on the redistribution aspects according to income groups, minorities, handicapped persons, etc.

Some hypothetical ridership patterns and their resulting effects on land use might be:

1. Upper middle-class whites who flee the central cities can continue to work downtown and commute in reasonable comfort while avoiding tedious traffic tie-ups. These people demand single family homes, or high quality apartments, in suburban areas such as Fremont and Walnut Creek.

2. Low income workers find improved employment and thus higher income through riding BART and consequently seek new residences which may be outside the central city, perhaps closer to their new jobs.

3. Shoppers in Daly City, Oakland, Berkeley, etc. take more trips to San Francisco (or vice versa), with regional retailing concentrating around BART stations in central cities, seeking direct access to the station itself.

4. Teenagers or other population groups finding BART attractive, popularize certain locations which then cater to their tastes.

5. Areas for industrial location and office buildings find relatively increasing demand near BART stations with good feeder-bus services.

6. Recreation centers such as the Oakland Coliseum area are commercially strengthened on week-days and holidays by greater accessability.

Recent research has reaffirmed the need to emphasize the study of the market arising from household mobility rather than focusing on total stock demand. At any point in time, a proportion of the metropolitan population (part of the existing population plus in-coming migrants) is in the market in search for new accomodations. Two stages may be distinguished in the process:

1. Entrance into the market (which and why families move)

2. Final outcome (where families move into and what kind of housing they get.

This framework may provide a more useful understanding of the process because the explanatory variables may differ according to the stage.

Throughout the whole process the most consistent variables appear to be income and race:

> Lower income households and nonwhites tend, more than others, to move shorter distances, locate in the central city, rent apartments, have fewer rooms, pay lower rent, or own cheaper houses.[10]

The poorest statistical predictors of the first stage are housing and neighborhood types and current accessibilities, while age of household head (related to the family cycle and size) and attitudinal

[10]Edgar Butler, Stuart Chapin, et al., Moving Behavior and Residential Choice, NCHRP Report No. 81 (Washington: Highway Research Board, 1969), p. 4.

variables provide excellent statistical explanations. For stage two, these two variables are in turn very poor predictors but the opposite holds for type of move (short or long) and for current location: families who make shorter moves and to central city are more likely to rent apartments, live in smaller dwelling units and pay less rent on lower value units.

Explanatory Variables[11]

The variables that may be considered in the analysis are:

1. Background factors.

Income. At the time of the move (a "permanent income" approach could be adopted instead)

Race. (higher than average mobility for non-whites)

Household Size. (at the time of the move) For the second stage.

Age of Head of Household. (at the time of the move) Related to the family cycle, younger heads are comparatively more likely to be residentially mobile.

Mobility Background. Previous movers are more likely to move once more.

2. Attitudinal Factors. (for the first stage)

Familism. An index of values of basic vs. extended family orientation.

Consumerism Style. An index of consumption patterns which considers consumption for the family as against expenditures directed to outside of the family.

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[11] See Edgar Butler, Stuart Chapin, et al. Ibid.

Social Mobility Orientation. Index considering the efforts to "get ahead."

Urban and Suburban Orientation. Contrast between urban center and suburban desirability.

Mental Well-being.

Neighborhood Evaluation. Strong vs. weak ties with current neighborhood.

Housing Evaluation. Overall housing satisfaction and attitude with respect to number of rooms.

Accessibility Evaluation. Attitude towards public transportation, job-home separations, etc.

3. Immediately Previous Residential Factors.

Tenure. Households that own are less likely to move than are renters.

Dwelling Unit Type.

Rent Level. (if rental tenure) or value of dwelling unit (if owned).

Number of Rooms.

Environmental Condition. Households who live in poorly rated neighborhood and housing conditions by outside evaluators would tend to be more mobile. Ratings consider exterior appear and state of repair of dwelling units, extent of mixed uses and noise in streets.

Accessibility Condition.

4. Move-Related Factors.

Reasons for Moving: job change; forced move or household formation; location oriented (convenience or neighborhood quality); tenure-dwelling unit preferences (e.g., own single-family house); dwelling unit characteristics (space, quality).

Type of Move, Within neighborhood; to another part of metropolitan area; from outside the metropolitan area.

Location in Metropolitan Area: entral city, outside central city. Both of these last two variables may be related to the reason to move insofar as "push" or "pull" factors are important.

5. Final Outcome Variables.

Accessibility. Relative location to employment place downtown, shopping facilities, school, etc. It is this variable which is most directly affected by changes in transportation services and the introduction of a new facility such as BART.

Dwelling Unit Type. (Single family unit, apartment, etc.)

Tenure.

Housing Costs. Rental level or value.

Number of Rooms.

Neighborhood Type: Availability of services and environmental condition.

Data requirements for both the residential mobility and the investor decision studies are quite urgent, since actions are already being taken under the stimulus of BART. There exists in the Bay Area at the present time a set of expectations concerning BART that may or may not be fulfilled, but which nonetheless affect current decisions. After BART commences operations, these data will no longer be obtainable.

Household Budget Studies

When a new good is offered to the consumer, or the price of a currently consumed good changes, there will be a shift in the mix of goods that is consumed. In economic theory, this shift is broken into two components: a substitution effect and an income effect. With respect to BART, a substitution would occur if a trip maker decided to use BART instead of his previous mode; an income effect occurs if he can make the same number of trips as before but at less cost, in which case he has more income to spend on other goods.

It is possible that BART might have a substantial impact on some individuals as travel consumers. For example, the worker who switches from auto to BART may find that the costs in terms of expense, time, and stress in driving effort, minor accidents, theft, servicing time and inconvenience, insurance, financing, etc., were much greater than he had previously perceived, and that he now has surplus time and money to devote to other activities. One of the few places where this kind of information can be picked up is in a budget study, using a panel or cross-sectional sample of Bay Area households.

Land use effects may be several stages away from the initial decision to use BART, but they may nonetheless be significant. The major value of budget studies, though, will be in other areas of BART analysis; land use studies are only one of many areas that can draw upon household expenditure data.

Trend Surface Analysis

The most important variable emerging from the survey of theory described above is access. It is simple in the abstract, but becomes progressively more complex in measurement and use. Operationalizing the definition of access in its numerous conceptual forms, and empirically measuring and fitting access surfaces to the Bay Area, will provide a major input to many of the proposed BART studies. Access is primarily a spatial variable, but its measurement is crucial in many relatively non-spatial areas of analysis, such as latent demand and unemployment effects.

Given a map with a set of points and values defined at those points, a surface can be fitted to the points. The method of fitting the surface can be handled several ways, and the purposes are varied.

1. Single surface static analysis. The surface can be made sufficiently complex so that all points are fitted exactly, or almost exactly. The surface then gives a value of access (to unskilled jobs, for example) for all locations on the map. This surface can then be decomposed into several simpler surfaces that relate to specific hypotheses. One might be the density gradient, which would be analogous to a secular trend; the extent to which this surface explained the primary surface would be of interest, and its effects removed from the primary surface. Decomposition could also be into subcenters or other regular patterns.

2. Double surface static analysis. A more meaningful analysis can be obtained by comparing a surface with another which can be regarded as a norm. For example, the potential access surface (airline distance) can be compared to a transit access surface to find out which areas are not as well served as could be expected from their location. The conclusion might be that the area is served in other ways, that there is no demand, or that a program should be begun to improve service to the area. Access to unskilled employment can be compared to the locations of low income residences. In each case it is the differences between two surfaces, or the residuals, that are of interest.

3. Double surface dynamic analysis. If the two surfaces compared are the same measure at different points in time, then shifts can be located in space. An area may have decreased in absolute level of access (through congestion or eliminated service) or in relative access (other areas gained more). Those cases which appear to be a movement away from an equilibrium should be investigated in more detail and reasons or corrections formulated.

Long Term Studies

Five long term studies are shown in Figure B. According to the research strategy described above, long term studies should be indicated by the studies carried out in the second stage, rather than be selected at this point. However, a list of possible candidates described by subject area can be presented here, along with the kinds of payoffs each might produce and the approximate costs that they would involve. Decision rules, i.e., how one subject will be chosen over another, methodologies and information requirements for each type of study will also be included.

Comprehensive Land Use Model

Land use models developed in the early 1960's were comprehensive computer-based residential or residential-commercial land use models for metropolitan areas. Millions of dollars have been spent on the models, and not much more than experience gained from them.[12] Several

[12] These conclusions are based on a fairly thorough survey and evaluation of land use models as of 1968, found in Douglass B. Lee, Jr., Models and Techniques for Urban Planning, Internal Research Report No. VY-2474-G-1, Buffalo: Cornell Aeronautical Laboratory, Inc., September 1968, or Douglass B. Lee, Jr., Urban Models and Household Disaggregation: An Empirical Problem in Urban Research, Cornell Dissertations in Planning, Ithaca: Department of City and Regional Planning, Cornell University, September, 1968.

macroanalytic regularities have been employed in constructing these models, and considerable descriptive material used to flesh them out, but they lack adequate detail for policy use and contribute little to theory development. In this report, when we refer to land use models we mean something that is much more partial and limited in scope.

Further research may reveal the knowledge necessary to construct an effective comprehensive model, but present expectations are that the benefits of such an effort will not be worth the price for some time in the future. The same applies on a smaller scale to the use of current models.

A term frequently heard in modelling circles is simulation. Usage of this word varies a great deal, and its meaning is somewhat compromised. We will use it to mean a computer program that has the purpose of investigating the aggregate performance of a system by specifying the microscopic behavior of all components, their interrelationships, and operating the system as an experiment in synthetic time. Purists also require a random, or Monte Carlo feature, but this is not necessary to our usage nor to our models.

If the aggregate behavior of the system could be specified, then there would be no point in assembling pieces in a complicated (inevitably) computer program. Even if only the form of the behavior can be postulated, testing does not involve simulation. Thus simulation is a last resort, and should be discontinued as soon as the desired information can be obtained and formalized. Urban simulations are likely to be expensive and non-productive.

In a true simulation, each individual in the system (person, automobile, train, investor, etc.) is recorded at each moment in time.

For simulating social systems, some degree of aggregation is almost always desirable, and this usually removes the need for pseudo-random events to occur in the program. Monte Carlo simulation is not likely to be appropriate for BART research on land use impacts.

Integrating Land Use and Transportation Models

Behavioral models or descriptive models developed in stage two studies may form the nucleii for expanded models which include one or more of the original models as submodels. Often models have to be re-built in the light of experience and information gained in the first pass, and building in compatibility between models is an obvious consideration for the next pass.

Integration may occur in several ways:

1. Parallel integration. If BART is the source of inputs, and land use is the output of interest, parallel models would relate BART to land use but in various selected ways, e.g., to different land uses. A model of land rent might be combined with an investor model to give a partial development model by equilibrating supply and demand.

2. Series integration. Connecting different links to form a single link between BART and land use would be one form of series integration. Models relating system characteristics to patronage at stations, and patronage characteristics to retail activity could be combined in this way.

3. External integration. Land use models may be connected to models of other aspects of the system, e.g., an investor behavior model and a fiscal or commercial financial model. Travel demand models could be connected to residential land use models.

Second stage models are likely to be hand-operated, or may use fairly simple accounting programs for implementation. After these have been tested, they should be automated for further construction and testing. Thus reliance on computers will increase gradually from a fairly low level as initial models are integrated into more complete ones. Difficulties with models go up geometrically with size, and so only very reliable and thoroughly tested models should be combined or enlarged in subsequent work. Costs, of course, go up at a similar rate, but can be more efficiently allocated from knowledge acquired in earlier phases.

Land Use Information System

Many Bay Area agencies already use land use information in their work. ABAG prepares regional land use studies and is particularly concerned with open space and pollution; BCDC is concerned with bayshore land uses and their effects on the ecology of the Bay; BATS constructed a land use model for forecasting travel demand in the Bay Area; CREUE developed the BASS land use model and has applied it to several communities in the Bay Area; Santa Clara County has constructed a relatively advanced information system (relative to Bay Area public agencies) which includes land use data; OPINS is an information system project in Oakland that has included land use as a major task area; dozens of municipal and county planning agencies prepare land use plans and analyses; some state and special agencies, such as Highways, the Golden Gate Bridge Authority and the Division of Bay Toll Crossings, have an interest in land uses in portions of the Bay Area. BART itself will need land use data. An extensive list of agencies, both public and private, could be generated for those who would use land use information if the collection effort were provided.

None of the efforts to date to collect land use data has been on a scale adequate to the needs of a BART impact study. BATS for example is unable to utilize its own land use data because the unit record (the parcel) is so small that data processing costs exceed their available budget. Thus their land use model depends upon land use data collected on a highly aggregated scale by other agencies. So far, each collection and tabulation of Bay Area land use data has been independent of all others and each has been a "one-shot" attempt.

Evolving needs for Bay Area land use data appear to now justify a higher level of expenditure and greater integration of data between the various agencies. Initial data efforts in this study would be geared to agencies known to need it. Of course full advantage would be made of assessment records, existing information systems, and other sources that are already at least partially automated. Only information that has sufficient import to be continuously or periodically updated would be included. Capabilities for tabulation, statistical analysis and display would be essential, especially techniques for spatial analysis and geographic display, e.g., automated mapping.

Such an information system could be established as a research project and eventually maintained as a service of the University of California (in one of the urban research centers or related to U.C.'s Survey Research Center or Computer Center), or given over to a regional agency such as ABAG or BARTD. The system should be designed to support this study's research, at a minimum, but if it is to be anything more than a research tool it must be useful to other agencies. One goal would be to maximize exchange of information between various producers of data.

Since the construction of a land use information system is incremental, so are the costs. Additions to the data system would not be made unless the major portion of the existing system is self-supporting. Support for the system should be initiated at a fairly low level (e.g., on the order of $50,000 per year) until widespread support is manifest, and additions should not be undertaken until the value of the first increment has been documented.

Land Use and Transportation Policy Analysis

As information is gained about the impacts of BART, applications to public policy problems will develop. For example, recommendations concerning land use controls, other supplemental or feeder forms of transportation, and right-of-way acquisition should be forthcoming. The project will benefit from facing these kinds of questions, and the results will be more useful to persons in policy positions.

Formal Theory

It is difficult to combine theory, empirical research and application in a single project. But the gap is not impossibly wide for land use-transportation research, and the pressure on each side should be beneficial: empirical analysis should have an applicable purpose and also contribute to the development of theory; theory should not be expanded or enriched in directions that provide insight only into abstractions; and short run problem solving should not submerge the accumulation of knowledge that will expand our capacity to deal with new problems.

If leads develop suggesting important aspects that have been missing from previous theory and the talent is available, then the most important and long run payoffs can be achieved in this area. The value of constructing theory over more immediate kinds of analyses is that theory has general applicability and can be helpful in understanding transportation and land use in a wide variety of contexts, not just the Bay Area or rail rapid transit. The difficulty is that useful theory comes hard, and its value is not easily determined. Sometimes only the historians can tell us.

CONCLUSION

No distinctly normative studies have been proposed for land use analysis, but the normative component of various studies is expected to grow as study progresses. Descriptive studies will be valuable, but immense amounts of effort can be sunk into large scale data acquisition and processing without obtaining sufficient control to draw useful conclusions from the analysis. Hence a good deal of emphasis must be placed on narrow scope case-study kinds of observation and documentation, realizing that the framework is partial and generalizations will be risky. Hopefully the scope of later studies can be larger. At the moment, we are looking at a dynamic disequilibrium concerning which there is not much theory.

APPENDIX A: LAND RENT AND LAND USE INTENSITY

Rent at a particular distance from a point market is equal to gross receipts minus production costs minus transportation costs. Allowing production per unit of land to vary according to

$$Q = K^a \quad , \quad K \geqq 0$$

where Q is the units of output, K is the units of non-land inputs, and a is a constant, rent is

$$R = pQ - rdQ - kK$$

where p = market price per unit of output, r = transport rate, d = distance from market, and k = cost of non-land inputs, per unit. Values for p, r, and k are specified exogenously; d is a functional variable, K is to be optimized, and a will be constrained by the model. Substituting,

$$R = (p - rd)\ K^a - kK$$

To maximize rent at a given distance, set the partial derivative with respect to K equal to zero, which gives

$$aK^{a-1}\ (p - rd) = k$$

The first expression in the left hand side is the marginal productivity of non-land inputs, and the other expression is the gross profit per unit of product as a function of distance (we will assume that this is greater than zero wherever there is rent). Thus the optimal use of land is achieved when the marginal value product of non-land inputs just equals their price.

Solving for K,

$$K = \left[\frac{k}{a\,(p - rd)} \right]^{\frac{1}{a - 1}} , \quad a \neq 1$$

The second order conditions for a maximum require that

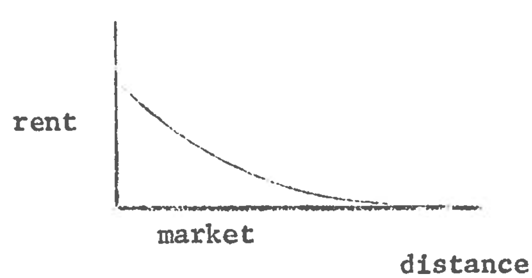
$$\frac{\partial^2}{\partial K^2} (R) = a\,(a - 1)\,(p - rd)\,K^{a-2} < 0$$

This implies that $0 < a < 1$. Substituting back into the rent equation,

$$R = (p - rd) \left[\frac{k}{a\,(p - rd)} \right]^{\frac{a}{a - 1}} - k \left[\frac{k}{a\,(p - rd)} \right]^{\frac{1}{a - 1}}$$

$$= (p - rd)^{\frac{1}{1-a}}\, k^{\frac{a}{a-1}} \left[a^{\frac{a}{1-a}} - a^{\frac{a}{1-a}} \right] > 0$$

The first derivative of this function is negative when $d > 0$ and $(p-dr) > 0$, implying that it slopes downward in moving to the right of the origin. Rent is thus a decreasing function of distance. The second derivative is positive through the same region, indicating a concave shape something like the following:



Constraining a to be between zero and one implies DRTS, i.e., additional inputs of non-land resources makes a positive but declining contribution to output.

Taking the partial derivative of the function for K, non-access inputs, we find it to be negative throughout the relevant region, and hence intensity of land use declines with distance from the market, i.e., with decreasing access.

Consider a change in the transportation system such that transport rates per unit of distance fall, which means r declines. From the function for rent, it is clear that rents will increase at any given distance for an improvement in the transportation system. If all other things remain unchanged, rent will increase by the amount of the transportation cost savings. In fact, it will increase by more, since the exponent on per-unit delivered profit is greater than one (the number of units is a multiplicative factor obtained from the other terms in the expression). This is due, of course, to increased intensity of use because of increased access. This is confirmed by looking at the expression for K, which increases as r decreases, for a given distance (note that the exponent is always negative).

In a dynamic view one has to take into consideration the different benefits and costs in time. Demand for specific locations may be changing and as well as marginal cost curves of non-land inputs (technology, firm organization). Changes in the transportation network (e.g., BART) shift the incidence of accessibility inputs which may lead to a different use of a particular site.

Under perfect competition and given diminishing returns to non-land inputs, the objective function is maximization of present value of the marginal product of land. But a particular land use may introduce an irreversibility which can be overcome only by high costs of demolition or conversion. The optimal time of development may not be the current time. It may pay to postpone development of the land to a later time.

Given the time-path of the current development value of the land at time t (V(t)), if it is developed at its "highest and best use" at time t by assuming perfect certainty of future events, the optimal time of development is found by maximizing the present value (at time 0) of this value.[12]

$$V(0) = V(t)\, e^{-rt}$$

V(0): present value of the land developed at time t

V(t): current development value at time t

r: rate of discount.

$$\frac{d\, V(0)}{dt} = V(t)\, e^{-rt} - r\, V(t)\, e^{-rt} = 0$$

$$\frac{V'(t)}{V(t)} = r$$

Thus, the land should be developed at the time when the rate of increase of the development value of the site equals the discount rate.

The calculation should consider the net income which could be gained by an interim use of the land. Then, the present value at time (0) is:

$$V(0) = \int_{0}^{t} Y(t,i)\, e^{-ri}\, di + V(t)\, e^{-rt}$$

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[12] Following Donald Shoup. "The Optimal Timing of Development." Papers and Proceedings of the Regional Science Association, Vol. XXIII (1969).

Where:

Y(t,i): net income gained by interim use of the land in time i up to time t (revenues minus expenses and taxes).

$$\frac{d\,V(0)}{dt} = \int_0^t \frac{\partial Y(t,i)}{\partial t} e^{-ri} di + Y(t,t)\, e^{-rt} + v'(t)\, e^{-rt} - r\, V(t)\, e^{-rt} = 0^{13}$$

$$\frac{V'(t)}{V(t)} = r - \frac{Y(t,t) + e^{rt}\int_0^t \frac{\partial Y(t,i)}{\partial t}\, e^{-ri} di}{V(t)}$$

Development to a higher use should take place when the rate of change of development value of the land is equal to the discount rate minus the rate of return in prior use which is gained by deferring development one more period.

The result explains why it may be profitable to have idle land ripening for development from the point of view of the individual entrepreneur. In reality, market imperfections take place and the conditions of certainty must be replaced by uncertainty and risk. The discount rate is not constant. The model illustrates the fact that present value of the land may be higher than what may be expected from the existing use, in that future earnings are considered.

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[13] Application of Leibnitz' formula assuming that Y(t,i) and $\partial Y/\partial t$ are continuous functions of both t and i.

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