RICE UNIVERSITY

URBAN TRANSPORTATION: THE RELATIONSHIP BETWEEN TRANSPORTATION NETWORKS AND THE DISTRIBUTION OF URBAN ACTIVITIES

By

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ABSTRACT

URBAN TRANSPORTATION: THE RELATIONSHIP BETWEEN TRANSPORTATION NETWORKS AND THE DISTRIBUTION OF URBAN ACTIVITIES.

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The thesis is based on the hypothesis that there is a mutual interdependency between land use and transportation: different transportation systems stimulate different land use and density patterns and vice versa.

Two basic systems can be identified: the activity system and the transportation system. Depending on the choice of options open to us within those two systems equilibrium flow patterns will evolve through the market mechanism of supply and demand. This flow pattern through the resulting changes in the level of service will establish a modified accessibility pattern which in turn strongly influences the land value pattern within an urban area. Depending on the locational requirements and the rent bidding capability of the various urban activities different locational patterns as well as density patterns within an urban area evolve and ultimately result in different types of physical urban form.

Consequently the first part of the thesis describes the process of how the equilibrium flow is established, whereas the second part demonstrates the impacts caused by different flow patterns on land values, locational patterns, densities and urban form. These impacts become apparent at all scales: the city scale, neighborhood scale, corridor scale
and even at the scale of the individual lot.

Finally an attempt was made to gather methods and procedures that allow to measure and quantify the impacts of transportation as much as possible. However, it has to be pointed out that it is almost impossible to isolate the amount of impact that transportation has on land development from all other variables that are equally important.
INTRODUCTION

At all times, transportation has exerted a decisive influence on cities. The location of most cities is determined by transportation considerations. Similarly, the internal organization of cities is very much dependent on the transportation system. This thesis will examine the hypothesis that different transportation systems stimulate the development of different land use and density patterns, which in turn will modify the transportation system.

The thesis is composed of two distinct parts. Part one will discuss more or less the technical realm of transportation. Chapters 1-4 basically describe the process by which a movement pattern is generated. Two basic systems will be identified: the activity system generating transportation demand and the transportation system representing transportation supply. The characteristics of these two systems will be discussed in detail in chapters 2 and 3. Chapter 4 then demonstrates how a movement pattern evolves as the equilibrium solution to the market mechanism of demand and supply.

Whereas part one discussed the process by which a movement pattern is generated, part two will address itself to the consequences and impacts caused by the flow pattern. Chapters 5 and 6 introduce the notion of accessibility and discuss its role as a locational force. In chapter 7 the direct reflection of the accessibility pattern in the urban land value pattern will be shown, which then acts as the market force of determining the location and intensity of urban
activities. Chapters 8 and 9 discuss these relations in detail. Finally, chapter 10 discusses the impacts of transportation on physical form which evolves as the result of the joint effects of location and density.
PART ONE
CHAPTER 1:
INTRODUCTION INTO TRANSPORTATION SYSTEMS ANALYSIS.
Chapter I outlines the basic framework within which we shall discuss the chapters to follow. We identify two basic systems: The Transportation System and the Activity System. These two systems are composed of many elements that can be varied. Depending on the combination of elements that make up these two systems different equilibrium flow patterns will evolve. These equilibrium flow patterns will have different impacts and consequences which will modify and change the original transportation system and activity system which in turn will result in a new pattern of flows. Thus we see that actions within one of the systems invariably influences the other, and continuous change within these two systems never allows the establishment of an equilibrium.
A. BASIC FRAMEWORK:

Any planner essentially has to deal with two systems: the spatial system (space) and the social system (society).

The spatial system can be described by an apparent physical structure of buildings, streets, and open spaces. Behind this spatial system stands the social system: this is the social, economic and political patterns into which people are organized and through which they carry on their affairs: patterns of relationship among individuals and among groups such as families, business firms, social or civic groups or government.

All those groups do not live isolated; but they interact in various ways through the exchange of persons, goods, news and energies. This interaction produces movement. Since the organizational relationships between the individuals and groups that make up the city are continually changing, the functional requirements which placed the physical demands of movement also are continually changing. On the other hand, the kind of transportation system which is provided will usually affect the way in which the socio-economic system grows and changes.

Therefore, our system of interest can be defined by three variables:

\[ T = \text{the transportation system} \]

\[ A = \text{the activity system - composed of the pattern of social and economic activities} \]
Three kinds of relationships can be identified among these variables:

(1) The flow pattern in the transportation system is determined by both the transportation system and the activity system.

(2) The current flow pattern will cause over time changes to occur in the activity system through the pattern of transportation services provided and through the resources consumed in providing that service.

(3) The current flow pattern will also cause over time changes to occur in the transportation system: in response to actual or anticipated flows, entrepreneurs and governments will develop new transportation services or change existing services.

Before we go into further detail we have to become aware
of the kind of relationship between the activity system and the transportation system:

The activity system of a metropolitan area, a region or a country consists of many subsystems, which overlap and are interrelated: social structures, political institutions, housing markets, etc.

Transportation is only one of those subsystems. Therefore, we have to remember that transportation plays a role in influencing the evolution of the activity system, but, except in very special situations, is not the sole determinant of that evolution. e.g.: The development of automobiles and of extensive systems of freeways do not alone cause suburbanization and dispersal of metropolitan areas, but operate in conjunction with the dynamics of rising income, changing housing, and labor markets and other subsystems.

B. OPTIONS

When we analyze our two basic systems we discover that
there is a wide spectrum of aspects of a transportation system, which can be varied. Not all of these aspects are open to a single decision-maker, nor are all open at the same time. This spectrum of "options" may be summarized as follows:

1. Transportation System Options:

1.1. Technology: This includes the development of new combinations of transportation components which enable transportation services to be offered in ways which were not previously available.

1.2. Networks: Options about networks include the general pattern of the network as well as the approximate geographic location of the links of the network, e.g., the grid system versus a series of radials and concentric circles.

1.3. Line Characteristics: Networks consist of links and nodes. Links correspond to routes, such as highways, airways, rail lines or urban streets. Nodes are those points where various links connect. Options include the detailed physical locations of links and nodes and such characteristics as the number of lanes, the grades and curves of the roadway as well as the type of signalling or traffic control.
1.4. Vehicles: Most transportation modes have vehicles. Major options include the number of vehicles in the system and their characteristics like acceleration and deceleration, fuel consumption and passenger holding capacity.

1.5. System operating policies: These options include: routes and schedules of the vehicles; types of service to be offered, prices to be charged, financing, taxing and subsidy schemes as well as regulatory decisions.

This set of transportation options fully defines the space of possible transportation plans and policies and any transportation system can be identified in terms of these options.

2. Activity System Options

The activity system is defined as all the social, economic, political and other transactions which take place over space and time within a particular region. These transactions, both actual and potential, determine the demand for transportation and, in turn, the levels and spatial patterns of these interactions are affected in part by the transportation services provided. Therefore, in modelling transportation systems, we must clearly identify those options in the activity system which will be expressed in the demands on the system.
2.1. Travel Options:
These are the options open to every potential user of the transportation system: - whether to make a trip at all - where to make it - when to make it and - how, i.e., by what mode and route to make it.

The aggregate result of all the individual decisions about travel is expressed as the demand for transportation.

2.2. Other Activity System Options:
We have seen that the activity system is formed by the sum of all individual actors, carrying out social, economic or political transactions. We have also seen that each individual has a wide range of options about how, when and where he will conduct his activities. Over the long term, these options profoundly influence the demand for transportation. For example: As major changes in a transportation system are made over time, the spatial pattern (i.e., the distribution of population and economic activity) will change, as actors exercise their options for changing the location or scale of their activities. Parallel to that economic forces outside the transportation system such as housing subsidies, mortgaging policies or zoning policies will also have an impact on the spatial pattern of activity and thus affect the demand for transportation. All those forces are completely exogenous and unpredictable for the transportation planner.
C. THE EQUILIBRIUM FLOW

At the beginning of this chapter we stated that our system of interest can be described by the transportation systems options T and the activity system options A, and that as a consequence of those options we experience flows F.

The basic hypothesis underlying this statement is that there is a market for transportation which can be separated out from other markets and which can be described by the market mechanisms of demand and supply. This will be demonstrated on the pages to follow.

1. The Establishment of Supply Functions

For each possible combination of transportation options T we can establish a particular supply function S. These supply functions indicate how the level of service varies as a function of the transportation options and the volume of flows. For a particular transportation system T, the level of service, L, which a traveler will experience is a function of the volume V, of travelers using the system:

\[ L = S(T, V) \]

For example: as the volume of flow in the system increases, the level of service decreases.

So far we have not yet defined what we understand by level-of-service and we have to keep in mind that there is not only one, but a whole list of variables that constitute the level of service.

Those variables are:
Time

- total trip time
- reliability - subjective estimate of variance in trip time
- time spent at transfer points
- frequency of service
- schedule times

Cost (to user)

- direct transportation charges
- other direct operating costs
- indirect costs (interest, insurance, etc.)

Safety

- probability of fatality
- probability distribution of accident types

Comfort and Convenience (for user)

- number of changes of vehicle
- physical comfort
- psychological comfort (status, privacy, etc.)
- other amenities (baggage handling, ticketing, etc.)
- enjoyment of trip
- aesthetic experiences

2. The Establishment of Demand Functions

On the other hand, a certain set of activity system options, A, establishes demand functions, D. These demand functions give the volume of flows as a function of the activity system A, the volume of travelers, V, which will use the system as a function of the level of service, L, which
those travelers experience:
\[ V = D(A, L) \]
For example: as the level of service increases, the volume of people desiring to use the system increases.

3. The Establishment of the Equilibrium Flow

After we have established demand and supply functions for our two basic systems, we are able to predict the equilibrium flow characterized by the volume, \( V \), using the system, and the level of service, \( L \), experienced by those travelers:

\[ F_0 = (V_0, L_0) \]

Therefore, for a particular transportation system, \( T \), and a particular activity system, \( A \), the flow pattern which will actually occur, \( F_0 = F(T, A) \), is the volume \( V_0 \) and level of service \( L_0 \) determined as the equilibrium solution to the supply and demand relations outlined above.

\[
\begin{bmatrix}
    L &=& S(T, V) \\
    V &=& D(A, L)
\end{bmatrix} \rightarrow (V_0, L_0)
\]

Thus, we see that each specification of the transportation system, \( T \), and the activity system, \( A \), implies particular values of the equilibrium flow volume \( V_0 \) and level of service \( L_0 \):

\((T, A) \rightarrow (S, D) \rightarrow F(T, A) = (V_0, L_0)\).

So far we have pretended as if there were only one demand function and only one supply function, but we actually have a network and within this network there are multiple demand functions and multiple supply functions.
3.1. Multiple demand functions:
The area to be studied is divided into zones; there is a
different demand function for each pair of zones (origin
and destination), for different groups of prospective trip-
makers, and for different trip purposes (passengers) or
commodity types (freight). Further, the demand for trans-
portation between each zone pair is a function of the level
of service vector, not a single "price."

3.2. Multiple supply functions:
Each link of the network is represented by a different
supply function. Note that because $L$ is generally a vector
with time, cost, safety, etc., as components, both the
supply and demand functions are potentially very complex.

3.3. Finding the equilibrium pattern of flows:
Instead of a simple graphical exercise, the calculation of
the equilibrium flows is a difficult problem. Some of the conceptual and computational difficulties are:

a. the level of service perceived by a trip between two zones depends upon which path is taken through the network;

b. the level of service over any path is a function of the levels of service over each of the links in that path (e.g., trip time equals the sum of the times over each link in the path);

c. the level of service over a link is a function of the total volume over that link (as given by that link's supply function);

d. the total volume over a link is composed, in general, of flows between many different zone pairs.

D. THE ROLE OF TIME

So far we have only considered the equilibrium flow as the result of demand and supply functions at one point in time; in other words, we were looking at the shortrun behaviour, where we can assume the activity system as well as the transportation system to be fixed. This, however, is not true any more for the long run, where we experience changes in the activity system and the transportation system over time. These long run changes can be described as follows:

1. Changes in the Activity System

As time goes on, because of changes in population, in income, in income distribution, in tastes as well as in relative prices of goods and based on the present accessibility
pattern of the region, an activity system $A_2$ will evolve which differs in location and scale from the original one. These changes will also result in a demand shift which in turn will produce a new flow pattern $F_2$ and through the newly established accessibility pattern $AP_2$ will influence the development of the future activity system $A_3$ as well as stimulate changes in the transportation system.

Legend:

$A_1$ = Activity System at time 1 (1 being earlier than 2)

$D_1$ = Demand Function at time 1

$S_1$ = Supply Function at time 1

$T_1$ = Transportation System at Time 1

$F_1$ = Equilibrium flow at time 1

$AP_1$ = Accessibility Pattern of region at time 1.

2. Changes in the Transportation System

The transportation system also will be subject to changes.
Changes in producers' goals, improvements in technology, changes in the prices of production factors, etc., will influence the resources consumed and the profits gained and will lead to the development of new transportation services or change the existing ones. These changes in the transportation system consequently result in a supply shift, which in turn will generate a new flow pattern and also establish a new accessibility pattern AP₂ within the region which in turn will heavily influence the location and scale of socio-economic activity at time \( t_3 \).

So far in our discussion always either the transportation system or the activity system has been fixed. In reality, however, both of these systems undergo changes simultaneously and a change in one of them influences the evolvement of the other.
Finally, we have to stress that we find a two-way relationship between the activity system and the transportation system: changes in the activity system dictate changes in the transportation system, but changes in the transportation system will act as an agent in the development of the activity system and will be a strong determinant of the location and scale of socio-economic activity.

E. IMPACTS

After we have identified the "options" of the activity system and the transportation system, as well as the mechanism by which a certain flow, F, is generated, let us expand this model by one more step.

Depending on the choice of our "options" within the activity system and transportation system a certain pattern of flows, F, will occur. This resulting pattern of flows, F, in turn produces impacts.

Those impacts can be grouped as follows:

1. Impacts on Users

Users are differentiated by location within the region, by trip purpose and by socio-economic group. Examples: suburban resident commuting to central city job, low-income non-car-owning resident of center city traveling to health facilities.

2. Impacts on Operators

Here we have to differentiate

- by mode
- by link
- by route
For instance, the provision of a rail rapid transit link between downtown and the airport influences the demand for the bus operator, the taxi operator and the park and fly operator along that line.

3. Physical Impacts

Here we consider the impacts caused by the "physical presence" of transport facilities or services, differentiated by type of impact, by link. Examples: families, jobs, taxable real estate displaced by new construction, pollution of immediate environment through noise, fumes, air pollution, and ground water changes.

4. Functional Aspects

Here we consider the impacts on the activity system as users change their travel patterns in terms of choice of routes, etc., in response to changes in the transportation system. Examples: changes in the transportation system will change the accessibility pattern which in turn affects the land value pattern which in turn results in a redistribution of various land-use types and in changes in the density distribution within a city. Or more specifically, the abandoning of a railway link, that a firm uses for the transport of its raw materials may force this firm to use truck transportation which will result in a raise of production costs and force the firm to relocate at a place where it can produce at the same price level.
CHAPTER 2:

DEMAND IN TRANSPORTATION: CHARACTERISTICS OF THE ACTIVITY SYSTEM.
In chapter one we saw that the pattern of flows is the equilibrium solution to the supply and demand relations that we identified. This chapter will discuss the demand side at greater detail. In a first part we shall analyze factors like income, household size, car ownership, etc., that influence and determine the travel decisions of each individual. If we sum up all the individual trips, we arrive at the movement structure within an urban area. Consequently, the second half of this chapter will discuss the aggregate movement pattern according to its spatial, temporal and modal characteristics.
A. FACTORS INFLUENCING INDIVIDUAL TRAVEL DECISIONS

In the previous chapter, we stated that the demand for transportation is the aggregate result of the decisions of every individual about travel: whether to make a trip at all, where to make it, when to make it, and how, i.e., by what mode and route to make it.

Therefore, in order to get a better understanding of the aggregate movement structure, it is important that we gain some insight into its main component, which constitutes it: the individual household, defined as a collection of individuals who choose to reside together. Travel demands of a household stem from both communal and individual decisions. On the one hand certain trips are demanded by the household acting as a unit. Other trips may be demanded by each individual resident, more or less independently of his ties to the home and thus the trips that are ultimately taken by a household's residents cannot be neatly separated into those reflecting communal or individual travel demands.

In the further discussion the number of residents will be used as a measure of household size and we are well aware, that this measure is clearly an oversimplification, which neglects differences in the age and sex composition of each household.

In the section to come we shall discuss various factors that play an important role in the travel decisions of an individual unit. Out of all impacts, family income probably is the heaviest impact as the following graph shows:
Family income does not only directly influence car-ownership, but also has an influence on the total daily trip generation, the amount of traveling allocated to various trip purposes, as well as on the decision of what mode of transportation to choose.

1. The Impact of Income on Car Ownership

As the graph below clearly identifies, a rise in income leads to an increase in car-ownership/family.
2. The Impact of Income on Trip Generation

Again we see that a rise in income leads to an increasing number of daily person trips (Fig. 2A). Almost the same relationship is true for trip generation as a function of car ownership, which of course is no surprise after we have seen the impact of income on car ownership.
2.1 The Impact of Car Ownership and Household Size on Trip Generation:

Both car ownership and household size have significant effects on trip generation rates. Therefore, to examine the partial effect of each, we have to hold the other one fixed. The joint effects of car ownership and household size on the number of "from-home" trips is illustrated in Figure 9. Each curve refers to a particular car ownership group. Thus, the slope of the curve indicates the increment due to household size holding car ownership fixed.

![Graph showing the joint effects of car ownership and household size on trip generation rates.](source4)
3. The Impact of Income on the Choice of Mode

As family income rises, the number of trips using mass transportation will decrease and the number of trips using the automobile will increase.

The decreasing importance of mass transportation relative to the total amount of trip generation can be shown by disaggregating into various levels of car ownership. Using Chicago as an example (Fig. 11) we find that families without cars use mass transportation for most of their journeys, while families with one or two cars use mass transportation at low and nearly constant rates regardless of the location within the metropolitan area. This fixed or constant frequency of transit usage seems clearly related to the fact that there are family members who have to use transit for particular reasons:

- family members who because of age are not able to drive;
- family members, who must travel, but find the family car unavailable;
- family members, who are better off using transit because of their destination (e.g., CBD).
RELATION BETWEEN TRIP GENERATION AND CAR OWNERSHIP

4. The Impact of Income on the Amount of Trips Spent for Various Trip Purposes.

Here again we see that as income changes different percentages of the total amount of travel are spent for different
trip purposes (Figure 12). Since Graph 12 is only hypothesized, we shall show this relation as a function of the total amount of trips generated per family, knowing that there is a close connection between family income and trip generation/family.

Taking the example of Chicago, we find (Fig. 13) that a typical family making four trips/day has 50% of its travel made to and from work (25% to work and 25% from work). The family which makes ten trips/day makes only about 25% of its trips to and from work. The additional travel is usually for a greater number of social, recreation, shopping, school and other trips. This suggests that for significant shifts to be made, there must be changes in the proportions of income, which are spent for travel and for other purposes.
B. CHARACTERISTICS OF THE AGGREGATE MOVEMENT PATTERN

This section will be concerned with the result of all the individual travel decisions: the structure of traffic, which describes how many people travel at various geographical locations at a particular time.

The resulting movement pattern will be complex and difficult to understand. Therefore as a methodological tool, it may be helpful to subdivide the total amount of movement into movement systems and structure it according to relevant criteria. In the section to follow we therefore will consider movement systems as they are set up

- in time
- in space
- by purpose and
- by mode

1. Temporal Characteristics

1.1 Time Characteristics of Total Volume of Flow:

The amount of traffic, no matter whether we consider the total traffic volume generated in a city or the amount flowing through a certain traffic artery changes constantly. We experience variations in the amount of traffic during

- the year for different months
- during the month for different days
- during the day for different hours and
- even within hours we can find variations in traffic.

Taking Chicago as an example we discover the following variations:
Throughout the year the amount of travel taking place within the Chicago area is pretty even. (Figure 14). We discover a slight high in July/August and a low between December and February.

Within the monthly pattern there is a repetitive weekly pattern (Fig. 14). We can see the five day work week and a clear drop of the total amount of traffic at the week-ends.
The greatest variation in travel, however, occurs within the day. We find a regular cycle of travel and identify two peak periods (Fig. 15): one in the morning and one in the evening, and it is this peaking within the day which causes the most severe traffic problems and forces us to meet the capacity requirements of those two hours.
1.2 Time Characteristics of Trip Purpose:

Within the daily 24-hour period, not only the total traffic volume changes, but also the composition of this volume in terms of trip purposes changes. As far as work trips are concerned: at 4:00 A.M. the urban area is nearly at rest. From 7:00 A.M. to 10:00 P.M. there is a big surge of travel to work. This is matched by a slightly greater movement back home in the period between 4:00-6:00 P.M. Other trip purposes have their own patterns.
Personal business trips are fairly evenly spaced throughout the day as are shopping trips. Social-recreation trips peak between 6:00 P. M. and 10:00 P. M.

The reasons for the daily cycle of traffic are founded in the whole way of life of urban society. The times when people rest, work and sleep tend to be stable. Basically we are geared to the sun's setting and rising. Changes in the forms of our social organization like the staggering of work hours or the 24-hour utilization of the day could assist to alleviate rush hour problems, but changes in people's behaviour occur at a slow rate and it is unlikely that there will be any real shifts from this cycle. (See Figure 16).

1.3 Time Characteristics Within Modal Choice:

Not only can we find variations during the day for various trip purposes, but also there are considerable differences in the usage of the available modes during the day. Automobiles provide the most even service through the day. Buses have much sharper peaks during the morning and evening rush hours while rapid transit has the highest peaking at all. This tendency toward peaking is one of the most difficult problems in connection with the provision of mass transportation service. In serving a more specialized group of riders there is substantial loss due to idle man-power and equipment in off-peak hours and it is in these off-peak hours that the greatest loss of riders has occurred. (See Figure 17).
2. Spatial Characteristics

2.1 Temporal Variations in the Spatial Distribution of Origins and Destinations:

The movement patterns which evolve during the day are not constant, but will change as we experience changes in the distribution of origins and destinations, which reflect changes in the distribution of the population during the day.

As the example of the Flint Metropolitan Area demonstrates, the low point in the daily activities of this population occurs at 4:00 A.M. when most people are in their homes. During the daytime hours the population redistributes itself...
VARIATIONS IN POPULATION DISTRIBUTION
FLINT/MICHIGAN 1950

Legend (Persons/Million Square Feet)

- 0-99
- 100-199
- 200-299
- 300-399
- 400-499
- 500-599
- 600-699
- 700-799
- 800-899
- 900-999
- 1000-1249

SOURCE 13
FIG.18
until in Flint the largest concentrations occur at 3:00 P.M. at the time of shift changes at the five large industrial plants.

At each of those day times a different pattern of flow utilizing different channels of movement at varying intensity will occur. (See Fig. 18).

2.2 Variations in the Spatial Distribution of Movement for Different Modes:

We see that the pattern of internal automobile trips conforms closely to the shape of the urbanized area. The bus is concentrated chiefly in the City of Chicago, whereas rapid transit creates a finger-like pattern. Of course these evolving patterns are closely related to the networks supplied for each of those modes. (See Figure 19).
Also at different geographic locations within the metropolitan area, people make different choices among the available modes of transportation, which results in a different mix of traffic with different intensity.

Figure 20 describes this relationship as a function of distance from the CBD. We discover that the proportional use of both rapid transit and bus transportation declines fast with increasing distance from the CBD, while automobile usage rises steadily. The percentage of people using rapid transit at the CBD is very high, but then declines rapidly to about 5 percent of all trips and maintains itself at this level. Bus trips have their biggest share of person trips within 10 miles of the loop.
CHAPTER 3:
SUPPLY IN TRANSPORTATION: CHARACTERISTICS OF DIFFERENT TRANSPORTATION TECHNOLOGIES.
Chapter 3 discusses the supply side of the market mechanism of demand and supply, which was outlined in chapter one. Supply essentially describes the quantities or volumes of movement that each individual transportation system can provide. Therefore this chapter informs the reader about the capacities provided by automotive transportation systems, bus systems, and rail systems.
Whereas in chapter two we were concerned with the demand for transportation and its determinants, we will now turn to the supply side of transportation and focus on the kind of service provided by the most important existing movement systems:

- Automotive transportation
- Bus systems
- Rail systems

The supply of movement has little meaning except as a general description of the physical plant available for movement, unless it refers specifically to the opportunities for movement between designated points in space at specified times. Fundamentally, this is what is meant by "capacity" and on the following pages we will examine these different movement systems under the aspect of capacity.

A. AUTOMOTIVE TRANSPORTATION

The automotive transportation system basically is comprised out of two major elements:

- vehicles, individually controlled by their drivers, and
- a physical network of streets.

The street network in turn can be subdivided into three major components:

- Links (Streets)
- Nodes (Intersections) and
- Terminals (Parking Facilities)

Therefore, the capacity that a network has essentially depends on two factors:

- The capacity of its network components, and
the way in which these network components are
connected with each other.

On the following pages we shall look at the capacities
provided by the individual network components.

1. Capacity of Links

If we would consider the automotive transportation system as
a uniform flow system, then link capacity would be determined by:

- the velocity at which the vehicles move, and
- the distance between individual vehicles.

Therefore, if the vehicles could move in a system so that
the distance between them were independent of their velocity,
the volume handled by the system could be increased by an
increase in the system's velocity and capacity would be
limited only by the technological limits of the speed of the
vehicles.

However, since each vehicle is controlled independently,
vehicles have to be separated from each other by the distance
necessary for a vehicle to adjust its behaviour to that of
the vehicle ahead and the amount of space in the moving stream
of traffic required by one vehicle will vary with the
velocity of the flow.

Three behavioral characteristics determine the safe following
distance: - the level of risk, at which the system operates
- the responsiveness of control or reaction time
- the mechanical characteristics of the system.
1.1 The Level of Risk:
The risk factor is related to the "orderliness" of the system, basically to the degree to which control in the system is centralized, e.g., the ultimate in an orderly system would be a moving conveyor belt. The kind of system described above would be completely orderly, if the units could anticipate each other's behavior with sufficient "lead time" to avoid collision and the interval would then be limited only by the size of the vehicles. In a disorderly system the behavior of the lead carrier is completely unpredictable to the second and so on through the system. Hence, capacity is related to the level of disorder and if there is any degree of disorder in the system, reaction time and the mechanics of the system will set the "safe following distance".

1.2 Reaction Time:
Reaction time can be defined as the time interval between the perception of a change in the speed of the vehicle ahead and the assertion of controls to adjust to it. Reaction time essentially is composed out of three parts:

- time needed to recognize ($t_r$)
- time needed to decide what to do ($t_d$)
- time needed to actually act ($t_a$)

The table below gives a few examples:
### Table: Reaction Time to Various Actions

<table>
<thead>
<tr>
<th>Action</th>
<th>Time Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition ($t_r$)</td>
<td>Action</td>
</tr>
<tr>
<td>- to see or anticipate</td>
<td>0 + 1 Sec.</td>
</tr>
<tr>
<td>- eye movement</td>
<td>0.1 + 0.3 Sec.</td>
</tr>
<tr>
<td>- focussing</td>
<td>0.1 + 0.8 Sec.</td>
</tr>
<tr>
<td>Decision ($t_d$)</td>
<td>For reflexes or prepared standard events like:</td>
</tr>
<tr>
<td>- red light</td>
<td>0 + 0.5 Sec.</td>
</tr>
<tr>
<td>- choice of lane</td>
<td>2 + 4 Sec.</td>
</tr>
<tr>
<td>- pass or cross over</td>
<td></td>
</tr>
<tr>
<td>Action ($t_a$)</td>
<td>- press horn</td>
</tr>
<tr>
<td>- release accelerator</td>
<td>0.3 Sec.</td>
</tr>
<tr>
<td>- press brake</td>
<td>0.5 Sec.</td>
</tr>
<tr>
<td>Total rda Time</td>
<td></td>
</tr>
</tbody>
</table>

Source: (16)

Traffic authorities assume the reaction time to be between one and three seconds.

1.3 The Mechanical Characteristics of the System:

Finally we have to consider the mechanical ability of the vehicle to change speed, which is related to the following technological variables:

- Mass of the vehicle
- Braking power, deceleration
- Road conditions
- Profile of tire tread
- Elasticity of Rubber Tire
- Types and mixture of road surface materials
These factors then determine the actual safe following distance between individual vehicles and as a consequence also the capacity of the road. The interaction between safe following distance, speed and capacity can be seen at the example of the capacity of one freeway lane (Figure 21).

**SINGLE FREEWAY LANE CAPACITY**

The maximum flow of a freeway lane is about 1,500 vehicles/hour and it occurs at a speed between 20 - 25 MPH. At greater speeds the increasing separation for safety between following vehicles causes the flow to decrease. Therefore attempts at increasing maximum flow by raising the speed limit are fruitless unless accompanied by some way to offset the consequent increase in safe spacing with manually controlled vehicles. Automatic control may be an answer to significantly increasing capacities.
Figure 22: Factors Influencing Road Capacity.
Yet driver-behaviour is only one determinant of capacity and in order to arrive at possible capacities we must consider other factors like traffic influences, environmental influences, road influences and planning influences. This is summarized by Figure 22.

Thus we arrive at the following "ideal" and possible capacities for various types of roads.

<table>
<thead>
<tr>
<th>Type of Road</th>
<th>Type of Traffic</th>
<th>Ideal Capacity Per Lane VEH/Hour</th>
<th>Ideal Capacity Per Road VEH/Hour</th>
<th>Possible Capacity Per Lane VEH/Hour</th>
<th>Possible Capacity Per Road VEH/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Lane</td>
<td>Non-Divided Highway</td>
<td>--</td>
<td>2,000</td>
<td>--</td>
<td>1,000</td>
</tr>
<tr>
<td>3-Lane</td>
<td>Non-Divided Highway</td>
<td>--</td>
<td>3,000</td>
<td>--</td>
<td>1,500</td>
</tr>
<tr>
<td>4-Lane</td>
<td>Non-Divided Highway</td>
<td>1,500</td>
<td>6,000</td>
<td>750</td>
<td>3,000</td>
</tr>
<tr>
<td>2x2 Lane</td>
<td>Divided Highway</td>
<td>2,000</td>
<td>--</td>
<td>1,000</td>
<td>--</td>
</tr>
<tr>
<td>2x3 Lane</td>
<td>Divided Highway</td>
<td>2,000</td>
<td>--</td>
<td>1,000</td>
<td>--</td>
</tr>
</tbody>
</table>

2. The Capacity of Intersections

While the previous section examined capacities in a free flow situation, this section will consider capacities for the case
that two traffic streams intersect.

Vehicle maneuvers at an intersection can be divided into four basic categories:

- Diverging
- Merging
- Crossing
- Weaving

With the exception of diverging movements, they all require a driver decision in the acceptance of a suitable time gap in the traffic stream, and consequently the supply of these minimal time gaps necessary for merging or crossing directly results in a theoretical capacity. This minimum time gap can be defined as the point at which the amount of time gaps accepted by drivers is equal to those rejected. (Figure 23)

![Graph showing the relationship between total amount of time gaps and accepted time gaps.](FIG.23)

The size of a suitable gap is dependent on many factors, of
which the more important are:

- Vehicle characteristics
- Driver characteristics
- Stream volumes
- Angle of Approach and Departure
- Speed of approaching and departing streams
- Relative speed
- Sight distance requirements

Thus we see that in contrast to the free flow the capacity of an intersection cannot be determined in a general way, but only as a function of the various traffic streams.

There are three general types of intersections:

- Intersections at grade; intersecting roads meet at a common level
- Grade separated intersections with or without interchange facilities
- Combinations, using elements of intersections at grade as well as of grade separated intersections

2.1 Intersections at Grade:

Capacity of uncontrolled intersections is very low. As crossing movements become heavier and the turning flows more complex, areas of pavement increase and ability of drivers to react to the situation correctly is reduced. To a certain extent markings by arrow and line can assist, but physical separation of areas involved is preferable, using raised islands and reservation areas. These measures are known as channelization and their main purposes are:

- Separation of traffic streams by direction, turning movements and speed, and
- Control of approach angles and speeds by funneling to assist the driver and give easy vehicle operation.

As the main stream volume grows even larger compared to the crossing traffic volume, the artificial creation of suitable time gaps may become necessary, which will be achieved by the installment of traffic lights. If this measure is exhausted, then grade separation may be required.

The following graph provides a rough estimate as to the design of an intersection at grade required for various proportions of main traffic stream to secondary traffic stream. (See Figure 24).

2.2 Grade Separated intersections:

Capacity of grade separated interchanges is affected by the individual components of the design layout and depends primarily on the standards adopted for points of mergence with the main through flows and the capacity of the connecting roadways (ramps) linking these terminal areas. Once again it has to be remembered that the total capacity of the intersection is determined by the capacity of the weakest component.
UNFAVORABLE CONDITIONS: TIME GAPS $\Delta t = 8$ SEC.

SECONDARY TRAFFIC STREAM

FAVORABLE CONDITIONS: TIME GAPS $\Delta t = 6$ SEC.

A (---) NO EXTRA MEASURES
B (-----) CHANNELISATION OF SEC. ROAD
C (-----) CHANNELISATION OF BOTH ROADS
D (-----) LIGHTS OR GRADE SEPARATION
E (-----) S > M

SOURCE 19

FIG. 24
The capacity for each of these components therefore has to be determined individually. On the following pages general values will be given for

- the capacity of ramps

- capacity of points of mergence (ramp and outer lane of main throughway)

- capacity of total intersection.

2.21 Ramp Capacity:

<table>
<thead>
<tr>
<th></th>
<th>One Lane Ramp</th>
<th>Two Lane Ramp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible Capacity</td>
<td>1,000-1,200 VEH/h</td>
<td>Up to 2,000 VEH/h</td>
</tr>
<tr>
<td>Ideal Capacity</td>
<td>1,200-1,500 VEH/h</td>
<td>Up to 3,000 VEH/h</td>
</tr>
</tbody>
</table>

Depending on the slopes of the ramps and the amount of truck traffic these figures have to be reduced in the following way:

<table>
<thead>
<tr>
<th>Slopes</th>
<th>Amount of Trucks in %</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2%</td>
<td></td>
<td>1.00</td>
<td>0.90</td>
<td>0.83</td>
<td>0.77</td>
</tr>
<tr>
<td>3 - 4%</td>
<td></td>
<td>1.00</td>
<td>0.83</td>
<td>0.71</td>
<td>0.62</td>
</tr>
<tr>
<td>5%</td>
<td></td>
<td>1.00</td>
<td>0.77</td>
<td>0.62</td>
<td>0.53</td>
</tr>
</tbody>
</table>

2.22 Capacity at Point of Mergence Between Ramp and Outer Lane:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>With Stop</th>
<th>With Merging Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible Capacity</td>
<td>1,000 VEH/h</td>
<td>1,300 + 1,500 VEH/h</td>
</tr>
<tr>
<td>Ideal Capacity</td>
<td>1,400 + 1,500 VEH/h</td>
<td>2,000 + 2,200 VEH/h</td>
</tr>
</tbody>
</table>

2.23 Capacity of a Complete Grade - Separated Intersection:

For varying volumes of the main through flow the following maximum ramp volumes result:
B. MASS TRANSIT SYSTEMS

Both bus systems as well as rail rapid transit systems are very similar as far as the factors determining their line capacity is concerned, but they differ in the amount of orderliness inherent in the system. The buses basically are mixing with other road traffic and are therefore subject to the same restrictions discussed at the beginning of this chapter. On the other hand, rail rapid transit runs on a fixed track from which it cannot deviate and except for the deficiencies of the driver has a very high order of orderliness.

1. Line Capacity of the Rail Rapid Transit System

The hourly capacity of a single track is determined by the number of trains which can pass a given point during one hour and the number of passengers carried in each train. This relationship can be expressed by the following equation:

\[ Q = \frac{60 \cdot K \cdot N \cdot L}{H} \]  

(Source: 21)

Where \( Q \) = capacity (in passengers per hour passing any given...
point on a single track):

\[ H = \text{Headway in minutes} \]

\[ K = \text{Loading coefficient (in passengers per foot of train length)} \]

\[ N = \text{Number of cars/train} \]

\[ L = \text{Length of each car (in feet)} \]

So we see that the hourly capacity essentially depends on two major factors:

- The loading coefficient \( K \), and
- The headway \( H \), which we shall discuss in the following.

1.1 Headway:

The basic alternatives in selecting a desirable headway are to use short slow trains at frequent intervals or longer, faster trains at less frequent intervals. The optimum solution depends on many factors of which station spacing is probably the most significant. Greater station separations allow higher average speeds and fewer trains. The average speed that can actually be realized by a train depends upon the following factors:

- its maximum speed
- its rates of acceleration and deceleration
- its station stop time, which is mainly dependent on the amount of traffic in the station considered, the physical outlay of the station and the efficiency of the train and platform staff. In addition, the station
stop time is in itself dependent upon headway, since the number of passengers to be loaded per stop decreases with increasing train frequency. (See Fig. 25)

One more remark has to be made about the relationship between station spacing and average speed.

[Diagram: Impact of Speed on Station Spacing]

Average speed is limited by the maximum tolerable acceleration and deceleration rate, the maximum speed and station standing time. Assuming that the acceleration rate and deceleration rate is fixed and cannot exceed a certain limit unless all passengers are seated, for higher maximum speeds longer distances will be required to reach that speed and the distance in between the two stations also increases. If we consider this fact from the point of area served by the transit system we find: existing subways employ station spacings of about half a mile and consequently operate at 20 - 25 MPH. By spacing stations more than two miles apart,
freeway speeds can be approached, but then only one-fourth as many people will be able to walk to the station. The bulk transit system then becomes dependent upon collection and distribution systems supporting the stations. Summarizing we can describe capacity as a result of the following factors. (See Figure 26)

Thus, based on various combinations of train length, station stop times and train performance we can arrive at possible capacities as shown in Figure 27.
Fig. 27. Single-Track Passenger Capacity
(For T = 40 seconds, k = 3.1 passengers per foot)

<table>
<thead>
<tr>
<th>Running Speed (In miles per hour)</th>
<th>Average Acceleration (In MPH per second)</th>
<th>Passengers per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L = 400 feet</td>
<td>L = 500 feet</td>
</tr>
<tr>
<td>20</td>
<td>3.0</td>
<td>60,600</td>
</tr>
<tr>
<td>30</td>
<td>3.0</td>
<td>56,200</td>
</tr>
<tr>
<td>40</td>
<td>2.65</td>
<td>52,100</td>
</tr>
<tr>
<td>50</td>
<td>2.0</td>
<td>44,600</td>
</tr>
</tbody>
</table>

Source: 23

In the usual case, however, such factors as station separation and acceleration ability are fixed. Under these circumstances the capacity problem reduces to one of determining that combination of train speed and length which will

- Maximize capacity with a given amount of equipment or
- Provide a given capacity with a minimal amount of equipment.

Figure 28 illustrates one method of determining this optimum combination and helps also to explain the complex interrelationship between the various factors which are involved.

In (A) minimum headways are plotted versus speed for trains of various lengths, assuming a station stop time of 40 seconds.

In (B) capacities are plotted corresponding to these figures.

In (C) average speeds are plotted by combining the maximum speed for each train length and headway with station stop time, assuming a station separation of 1/2 mile.

In (D) then the equipment required to meet these conditions is
OPTIMUM COMBINATIONS OF HEADWAY AND TRAIN LENGTH

Similar sets of figures can be drawn for different assumed station stop times and for different station separations (if this factor is variable to determine the most probable range of values for train length and speed.

C. COMPARISON BETWEEN THE CONSIDERED MODES

Finally, it is useful to obtain a comparison of the efficiency of the considered modes. We have to be aware though, that the
confrontation of numbers only allows a qualitative comparison if they are referred to a reasonable and uniform basis. Possible measures against which the performance of the systems considered could be evaluated are:

Person-Miles/Hour and Lane (12 Ft. Width)
Persons/Hour (Line Capacity)
Area Required/Person.

(Figure 29)

Figure 29.

<table>
<thead>
<tr>
<th>Traffic Mode</th>
<th>Capacity For Lane Width of 12 Feet (Persons/Hour)</th>
<th>Travel Speed (Miles/Hour)</th>
<th>Total Transport Capacity Per 12 Ft. (Person Miles/Hour)</th>
<th>Proportion (2) x (3)</th>
<th>Area Required/Hour (Sq. Ft.)</th>
<th>Area/Person (Sq. Ft./Person)</th>
<th>Proportion (6) x (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian</td>
<td>20,000</td>
<td>4</td>
<td>80,000</td>
<td>10</td>
<td>210,000</td>
<td>10</td>
<td>0.02</td>
</tr>
<tr>
<td>Bicycle</td>
<td>5,000</td>
<td>6.5</td>
<td>32,500</td>
<td>4</td>
<td>350,000</td>
<td>70</td>
<td>0.16</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>2,500</td>
<td>10</td>
<td>25,000</td>
<td>3</td>
<td>520,000</td>
<td>210</td>
<td>0.5</td>
</tr>
<tr>
<td>Automobile/City Street</td>
<td>1,000</td>
<td>8</td>
<td>8,000</td>
<td>1</td>
<td>420,000</td>
<td>420</td>
<td>1</td>
</tr>
<tr>
<td>Automobile/Freeway</td>
<td>2,500</td>
<td>33</td>
<td>82,500</td>
<td>10</td>
<td>1,750,000</td>
<td>700</td>
<td>1.7</td>
</tr>
<tr>
<td>Bus in City</td>
<td>10,000</td>
<td>6.5</td>
<td>65,000</td>
<td>8</td>
<td>350,000</td>
<td>35</td>
<td>0.08</td>
</tr>
<tr>
<td>Street Car in City</td>
<td>20,000</td>
<td>6.5</td>
<td>130,000</td>
<td>12</td>
<td>350,000</td>
<td>17</td>
<td>0.04</td>
</tr>
<tr>
<td>Subway</td>
<td>40,000 (85% Occupancy)</td>
<td>23</td>
<td>920,000</td>
<td>125</td>
<td>122,500</td>
<td>30</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Source: 25
CHAPTER 4:

THE PATTERN OF FLOWS.
Chapter 4 finally describes how based on the supply and demand characteristics of different transportation systems a flow pattern evolves. In order to achieve this objective we introduce the gravity concept of human interaction and other simulation models. Special emphasis is put on the important role which the geographic distribution of different types of activities as well as different network configurations and capacities have on the resulting flow pattern.
In chapter 2 we looked at the demand for transportation and the factors determining the individual's trip decisions. Chapter 3 discussed the supply of various transportation modes in terms of the capacities offered by the individual network components and the resulting capacity of the entire network.

This chapter will discuss how based on the characteristics of the activity system - the distribution of the different urban activities - and based on the characteristics of the transportation system - different network configurations and their capacities - a pattern of flows evolves, which can be described as the equilibrium solution to the demand and supply relations discussed in the previous chapters.

A. THE GRAVITY CONCEPT OF HUMAN INTERACTION

We have seen that a metropolitan area is composed out of a multitude of individuals interacting with each other. Therefore, in order to describe the resulting movement properly, it would be necessary to predict the basic decisions related to transportation separately for each individual:

- whether to make a trip
- where to make the trip
- at what time to make the trip
- which mode and route to take

Since this behavioral approach, which would allow us to take into account the biases and perceptions of each individual, cannot be implemented yet, we must deal at the macro level. That is, we must deal with the aggregate behaviour of large
numbers of people and this is where the analogy to Newtonian physics of matter comes in, that makes the gravity concept applicable to human interaction. The behaviour of molecules, individually, is not normally predictable but in large numbers their behaviour is predictable on the basis of mathematical probability. Similarly, while it may not be possible to describe the actions and reactions of the individual human in mathematical terms, it is quite conceivable, that interactions of groups of people may be described this way. But it is important to keep in mind that, although the use of analogy in developing a concept may be attractive, it may defeat its purpose, if strict and inflexible adherence is insisted upon. In this case, a fundamental difficulty arises from the different nature of the two basic units of measure involved: the individual human being can make decisions with respect to his actions while the individual molecule (presumably) cannot. This does not imply, that interaction of humans in large numbers cannot be described mathematically, but it does mean that the threshold where the power of individual decision making critically affects the results must be determined before the concepts can be broadly applied in practice.

1. The Basic Concept of Interaction

In general terms, the gravity concept of human interaction postulates that an attracting force of interaction between two areas of human activity is created by the population masses of the two areas and a friction against interaction is
caused by the intervening space over which the interaction must take place. That is, interaction between the two centers of population concentration varies directly with some function of the population size of the two centers and inversely with some function of the distance between them. In mathematical terms, one way in which the relationship may be expressed is as follows:

\[
I_{ij} = \frac{f(P_i, P_j)}{f(D_{ij})}
\]

Where \(I_{ij}\) = interaction between center \(i\) and center \(j\), \(P_i, P_j\) = populations of areas \(i\) and \(j\), respectively; and \(D_{ij}\) = distance between center \(i\) and center \(j\).

Stated in this way, the hypothesis is based upon the reasoning that:

-(a) to produce interaction, individuals must be in communication, directly or indirectly, with one another;
-(b) an individual as a unit of a large group may be considered to generate the same influence of interaction as any other individual;
-(c) The probable frequency of interaction generated by an individual at a given location is inversely proportional to the difficulty of reaching, or communicating with, that location;
-(d) the friction against this transportation or communication is directly proportional to the intervening physical distance between the individual and the given location.
Using the original Newtonian formulation, the "force" of interaction between two concentrations of population, acting along a line joining their centers, is directly proportional to the product of the populations of the two centers and inversely proportional to the square of the distance between them; that is, mathematically:

\[ F_{ij} = \frac{P_i P_j}{D_{ij}^2} \]

where \( I_{ij} \) = the force of interaction between concentrations \( i \) and \( j \).

Following the analogy from physics, the "energy" of interaction between the two centers, \( E_{ij} \), which results from this force, would be:

\[ E_{ij} = K \cdot \frac{P_i P_j}{D_{ij}} \]

Where \( E_{ij} \) = energy of interaction between \( i \) and \( j \), and

\[ K = \text{a constant of proportionality, equivalent to the gravitational constant of physics.} \]

Thus, the energy of interaction between any two centers of population increases as the product of the two populations increases and falls off as the distance between the two centers increases. The total energy of interaction of a given region \( i \) would be the sum of the energy of interaction of \( i \) with each of the \( n \) other regions into which a given universe may be divided. That is:

\[ E_i = K \sum_{j=1}^{n} \frac{P_i P_j}{D_{ij}} + \frac{P_i P_2}{D_{i2}} + \ldots + \frac{P_i P_n}{D_{in}} \]

or more formally:

\[ E_i = K \sum_{j=1}^{n} \frac{P_i P_j}{D_{ij}} \]
2. Adaptation of the Basic Concept to Transportation

The adjustments of the basic concept described in the previous sections open the way for introducing different kinds of key variables in place of population and distance, in the formulation of the gravity model.

In the case of intra-metropolitan transportation two major adjustments seem to be appropriate:

1. Since with respect to intra-metropolitan interaction time of communication is a critical factor, it would be better to replace distance as a friction factor by travel-time. The problem then arises as to how to define travel-time if more than one mode of transportation connects two zones within the metropolitan area.

2. Since we are interested in the demand within the rush hour, where we experience almost an exclusive flow from home to work or vice versa, we should replace population at the destination area by work places as an attracting force.

Thus we arrive at the following formulation:

The amount of trips between a zone i and a zone j is directly proportional to the amount of trips originating in zone i and the amount of trips terminating in zone j and inversely proportional to the travel time between the two zones. That is, mathematically:

\[ F_{ij} = Q_i \cdot \sum_{j=1}^{n} Z_j \cdot t_{ij}^{-a} \]
Where \( F_{ij} \) = amount of trips between area \( i \) and \( j \)
\( Q_i \) = amount of trips originating in area \( i \)
\( Z_j \) = amount of trips terminating in area \( j \)
\( t_{ij} \) = travel-time between area \( i \) and \( j \)
\( a \) = reaction to travel-time (empirical constant).

With the aid of this model we are able to obtain the amount of trips between each single zone within a metropolitan area and the results can be displayed numerically in a trip matrix or graphically by a desire-line chart. (Fig. 30)

Before we actually can go on to the prediction of flows over the proposed network alternatives, an initial division has to
be made between the users of public and private transportation. In a final step we want to gain information about the volume of vehicles or persons using any link of the future network. Any given network will only carry a particular number of vehicles or persons under given operating conditions. The success of a network depends primarily on its location and its ability for carrying vehicles and persons. Thus, any transportation network, which has been formulated must be tested to determine whether the location and capacity are correct. There are two parts to the testing phase: the assignment of the interzonal transfers to the network and a review of the finished assignment.

The rationale behind traffic assignment is that between any two zones there are normally a number of different possible routes, each having its own characteristics of distance, travel-time, speed, level of service, and other design features. A driver will evaluate these features, either consciously or subconsciously, and choose one route to use. It is also likely that if he makes this trip regularly he will nearly always use the same route. In order to simulate his behaviour "travel resistance" is calculated for each route. Ideally, travel resistance is a statement of all the factors considered by a driver in choosing a route, expressed numerically.

Assignment methods fall into four general categories:
- "all or nothing" assignment with no capacity restraints
- diversion curve assignment with no capacity restraints
- "all or nothing" assignment with capacity restraints
- Proportional assignment with capacity restraints.
In all or nothing assignment, all vehicles are assigned to the path with the least travel resistance between origin and destination zones. Diversion curve assignments divide the total number of trips between origin and destination, between two routes, depending on the relative values of travel resistance on the two routes. Proportional assignment divides the total trips between several routes, depending upon the relative values of travel resistance for the several routes. Finally, the review will involve an inspection of the relative loading of different sections of the network and the determination of the travel time on sections of the network. After the first assignment and review, it may be necessary to modify the transportation network where the desired level of service has not been obtained.
Summarizing, we can say that the process by which we arrive at the flow pattern generally consists of the following steps:

1. Projection of population and employment by zone
2. Prediction of trip ends generated in each zone
3. Prediction of interzonal distribution of trip ends (e.g., gravity model)
4. Prediction of modal split
5. Prediction of distribution of flows over the proposed network.

Yet from the point of view of an equilibrium analysis, there are serious internal inconsistencies in this sequence of steps. For instance, the estimation of trip ends assumes implicitly a general level of service in the system, and a level of service is assumed explicitly for input into the interzonal distribution calculations (e.g., using a gravity model). The last step of the process, traffic assignment, predicts an "actual" level of service for flows in the network. However, the initial estimates of level of service used for trip generation and distribution are rarely revised to be consistent with the travel times which are predicted by the traffic assignment.

Yet one more distinction should be made: The distinction between direct and indirect demand models. As we have seen in an indirect demand model, the volume of flows between two zones by a specific mode is derived in a sequence of steps, whereas in direct demand models the volume of flow is estimated by an explicit demand function which can have the
following form:

\[ V_{KLM} = \phi_{m0}(P_{KL}) \phi_{m1}(v_{KL}) \phi_{m2}(c_{KL}) \theta_{m21} \theta_{m22} \]

where: \( \phi, \theta \) = parameters of the model

\( V_{KLM} \) = volume between area K and area L by mode M

\( P_{KL} \) = Population in zone K or L

\( v_{KL} \) = Median income in zone K or L

\( t_{KLM} \) = travel-time and fare between K and L by mode M

\( c_{KLM} \) = travel-time and fare between K and L by mode M

\( \theta_{mq} \) = "cross-elasticity" of mode M volume with respect to jth level of service variable of mode q

\( \theta_{mm} \) = "direct elasticity" of mode M to jth level of service variable of that mode.

Source: 29

Once the volumes between the zones for a mode M over a path P are determined directly from the demand-supply equilibrium equation, then the total volume flowing in the region from all origins to all destinations over all modes and paths can be obtained by summing up those partial volumes.

Each of the two approaches has its disadvantages. While the indirect approach has the problem of internal inconsistency, the direct approach has the problem that there is no way of ensuring that the various partial sums are in fact reasonable.

In our discussion of the evolvement of the flow pattern we have seen the importance which the distribution of residents and work places, as well as different network configurations, have on the flow pattern. A few simple examples will demonstrate the change in flow patterns as a result of changes within those variables.
For this purpose we choose a very simple model and assume:
- we only consider the peak hour traffic, which means that we only have to consider movements between residences and work places;
- residents are distributed at an equal density throughout the city;
- the effects of travel distance within the city can be considered as negligibly little;
- existing work places are considered as the attracting force.

In the example of a linear city with all of the work places concentrated at the CBD we can calculate the resulting traffic relations in the following way:

We subdivide the total city into zones, each one containing 1/8 of all residences. If we say that the total amount of trips generated by all residences is $F_s$, then the amount of
trips crossing at the first cut is $F_{S/8}$, at the second cut $2F_{S/8}$, etc., and consequently the maximum trip volume at the center going into one direction will be $F_S$. Assuming further, that the work places are concentrated at one point, the average travel distance along the main transportation artery will be $L/4$ and the total mileage traveled in the system will be $\frac{F_S \cdot L}{2} = \frac{F_S \cdot L}{8}$.

The same method has been used for other distributions of work places and different network configurations and Fig. 33 demonstrates clearly how different distributions of residences and work places and different network configurations lead to completely different flow patterns. (Source: 30)
<table>
<thead>
<tr>
<th>VARIATION</th>
<th>DESCRIPTION</th>
<th>FLOW PATTERN</th>
<th>DIRECTIONAL TRIP GENERATION</th>
<th>MEDIUM TRAVEL DISTANCE</th>
<th>TOTAL MILEAGE TRAVELED</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINEAR CITY WITH A CONCENTRATION OF WORKPLACES IN THE CENTER</td>
<td></td>
<td></td>
<td>( \frac{S}{2} )</td>
<td>( \frac{1}{2} )</td>
<td>( \frac{S}{4} )</td>
</tr>
<tr>
<td>LINEAR CITY WITH 50% OF WORKPLACES AT EACH END</td>
<td></td>
<td></td>
<td>( \frac{S}{4} )</td>
<td>( \frac{1}{2} )</td>
<td>( \frac{S}{4} )</td>
</tr>
<tr>
<td>LINEAR CITY WITH WORKPLACES EQUALLY DISPERSED</td>
<td></td>
<td></td>
<td>( \frac{S}{4} )</td>
<td>( \frac{1}{2} )</td>
<td>( \frac{S}{6} )</td>
</tr>
<tr>
<td>CROSS WITH A CONCENTRATION OF WORKPLACES AT THE CENTER</td>
<td></td>
<td></td>
<td>( \frac{S}{4} )</td>
<td>( \frac{1}{4} )</td>
<td>( \frac{S}{10} )</td>
</tr>
<tr>
<td>CROSS WITH 25% OF WORKPLACES AT EACH END</td>
<td></td>
<td></td>
<td>( \frac{S}{4} )</td>
<td>( \frac{1}{2} )</td>
<td>( \frac{S}{8} )</td>
</tr>
<tr>
<td>CROSS WITH WORKPLACES EQUALLY DISPERSED</td>
<td></td>
<td></td>
<td>( \frac{S}{6} )</td>
<td>( \frac{1}{2} )</td>
<td>( \frac{S}{12} )</td>
</tr>
</tbody>
</table>

FLOWPATTERN AS A FUNCTION OF NETWORK CONFIGURATION AND ACTIVITY DISTRIBUTION
PART TWO
CHAPTER 5:
THE INFLUENCE OF TRANSPORTATION ON CITY DEVELOPMENT:
A MODEL OF THE URBAN LAND MARKET.
While Part 1 of this thesis demonstrated the process by which a flow pattern is generated, Part 2 will be concerned with the consequences caused by the flow pattern. As an introduction this chapter discusses a model of agricultural and urban land development which provides an overview of how transportation through accessibility joins other forces which determine the locational pattern of activities within an urban area.
When we consider the differentials in land values among the sites of an urban area, we can identify two main determinants of land value:

(a) the use capacity of a site (e.g., differences in fertility of agricultural sites, or differences in allowable floor area because of zoning regulations); and

(b) the location of a site and resulting differences in the accessibility of this site based on the transportation services the site enjoys.

Therefore it is of special interest for our purposes to examine the role which transportation plays within the urban land market, and in this context we shall study Von Thunen's model for the agricultural land market, which was carried further by Alonso for the urban land market. (Source: 31)

A. THE AGRICULTURAL LAND MARKET

In Von Thunen's model the farmers are grouped around a single market, where they sell their products. The profits of the farmer then will be equal to the value of the crop minus production costs minus transportation costs. Since the costs of transportation increase as distance to the market increases, we can say that the profits derived by the farmers are tied directly to their location. (Fig. 34)

If the functions of farmer and land owner are viewed as separate, farmers will bid rents for land according to the profitability of the location and the profits of the farmer will therefore be shared with the land owner through rent payments.
The farmer notices that the gap between production costs and revenues at a nearer distance to the market is greater than at his location and he will bid rents for these locations up to the amount of the gap. The competition among farmers for the more favored locations converts this gap into rent and wipes away any surplus profit which the operator at any site might obtain. Thus the farmers' profits are everywhere the same and what has been called profits becomes rent.

Thus the farmer's profit curve also becomes a bid rent function, representing the price or rent per acre that farmers will be willing to pay for land at the different locations. This rent curve then can be described by two parameters:

(a) The level of the rent curve, which will be set by the price of the produce at the market; and

(b) The slope of the rent curve, which is fixed by the transportation costs.

Thus, each bid rent curve is a function of rent versus distance, but there is a family of such curves, the level of any one
is determined by the price of the produce at the market.

Fig. 35

The price of the product is determined by the supply-demand relations at the market. If there is an over-production of a specific product, the price of the product will drop and a lower bid rent curve will come into effect, so that the area within which the product is grown will be reduced. (Fig. 35)

But there is not only one crop grown, but a whole series of them. Each of those crops is able to establish another bid rent curve differing in the level of the rent curve and also the slope of the rent curve.

In Fig. 36 farmers that grow crop 1 can outbid the farmers that grow crop 2 until both curves intersect and the reverse situation takes place to the right of the intersection point. Therefore, crop 1 will occupy the area between the market center and the distance at which the two bid rent curves intersect and crops will occupy the locations at the outskirts
of the region.

B. THE URBAN LAND MARKET

In comparison with agriculture, the urban case presents another difficulty. In agriculture, the location is extensive. Many square miles may be devoted to one crop. In the urban case a site tends to be much smaller and the location may be regarded as a dimensionless point rather than an area. Yet the thousands or millions of dimensionless points which constitute the city, when taken together, cover extensive areas. In contrast to the agricultural area the urban area is composed of a lot of different land uses. For our purposes these land uses basically can be reduced into two groups.

- Businesses, and
- Residences.

1. The Location of Businesses

Whereas the farmer pays for the productive ability of land, the businessman pays for the selling ability of the land and he makes his decisions so as to maximize profits. Profit may be defined as the remainder from the volume of business minus operating costs minus land costs.

\[ G = V - C - R \]

where

- \( G \) = profits in dollars
- \( V \) = volume of business in dollars
- \( C \) = operating costs in dollars
- \( R \) = land costs in dollars.

Since in most cases the volume of business of a firm as well as its operating costs will vary with its location, the rate
of change of the bid rent curve will bear no simple relation to transport costs (as it did in agriculture). Therefore, the slope of the bid rent curve, the values of which are in dollars per unit of land, will be equal to the rate of change in the volume of business minus the rate of change in operating costs, divided by the area occupied by the establishment.

A different level of profits would yield a different bid rent curve. The higher the bid rent curve, the lower the profits, since land is more expensive.

Thus we have, as in the case of the farmer, a family of bid rent curves along the path of any one of which the businessman is indifferent and the level of the curve is determined by the level of the profits.

2. The Location of Residences

The household differs from the farmer and the urban firm in that satisfaction rather than profits is the relevant criterion of optional location. A consumer, given his income and his pattern of tastes, will seek to balance the costs of commuting against the advantages of cheaper land with increasing distance from the center of the city and the satisfaction of more space for living. Along any bid rent curve, the price the individual will bid for land will decrease with distance from the center at a rate just sufficient to produce an income effect, which will offset the costs of commuting.

Just as in the case of the farmer and the businessman, different levels of satisfaction correspond to the various levels of
the family of bid rent curves of the individual households. The higher curves obviously yield less satisfaction because a higher land price is implied, so that at any location the individual will be able to afford less land and other goods.

3. The Equilibrium Location of the Individual Establishment

If we now superimpose the actual structure of land prices in the city on the family of bid rent curves of a businessman or resident, the equilibrium point will be where the curve of actual prices (SS) will be tangent to the lowest of the bid rent curves with which it comes in contact. At this point will be the equilibrium location and the equilibrium land rent for this user of land. (Fig. 37)

We also know that the steeper curves occupy the more central locations. Therefore, if the curves of the various users are ranked by steepness, they will also be ranked in terms of
accessibility from the center of the city. Thus if the curves
of the business firm are steeper than those of residences, and
the residential curves are steeper than the agricultural,
there will be business at the center of the city, surrounded
by residences and these will be surrounded by agriculture.
This reasoning applies as well within land use groupings.
Given two individuals of similar tastes, both of whom prefer
living at low densities, if their incomes differ, the bid rent
curves of the wealthier will be flatter than those of the man
of lower income. Therefore, the poor will tend to central loca-
tions on expensive land and the rich to cheaper land on the
periphery. This stems from the fact that at any given location
the poor can buy less land than the rich and since only a small
quantity of land is involved, changes in its price are not as
important for the poor as the costs and inconvenience of com-
muting. The rich, on the other hand, buy greater quantities
of land and are consequently affected by changes in its price
to a greater degree.
Thus, through the ranking of bid rent curves by steepness, we
are able to establish a relative distribution of activities
through the mechanism of land prices.

4. Market Equilibrium

The market equilibrium then is established by the relations
of demand and supply. We know that each type of land use,
i.e., different socio-economic groups of the population or
different types of firms, is locating according to its own
principles and criteria.
On one hand each of the individual land use categories has a demand for a certain location, characterized by a certain level of accessibility. Besides that there are demands for certain scenic qualities, soil conditions, or a certain social or physical environment, or a certain amount of floor space. The sum of all those factors that determine the demand for a specific type of land use we call the locational characteristics of the land use categories.

On the other hand we have the supply of various areas where each area has to offer a sum of special qualities which we call areal characteristics. Those can be described as natural qualities (noise and air pollution) and zoning restrictions. In addition to that we have various accessibilities related to work, recreation, education and shopping.

The evolving pattern of the metropolitan area then can be defined as the equilibrium solution between supply, described by the areal characteristics and demand, described by the locational characteristics of the individual land use categories. (Fig. 38)

Transportation especially through the type of networks, speeds and modes provided has an influence on the supply side and through the supply side influences the way a metropolitan area grows and changes.
FIG. 38

- Locational Distribution of Activities

- Price

- Demand

- Supply

- Characteristics of Land Use Categories:
  - Location
  - Space Requirements
  - Social and Physical Environment

- Area Characteristics:
  - Natural Qualities
  - Taxing Conditions
  - Environmental Qualities
  - Zoning Laws
  - Accessibility to Work
  - Accessibility to Shopping
  - Accessibility to Recreation

- Income Distribution

- Transportation Networks
  - Speeds
  - Modal Split

FIG. 38
A. THEORETICAL RATIONALE

Every establishment, if it is to operate, needs some contact with others and consequently there will be an attempt on the part of any given establishment to achieve maximum accessibility to others with which it interacts. Since each establishment has a number of ties to others, that may be scattered spatially, it will be pulled in different directions. Fig. 39, for example, tries to identify the factors influencing the location of industrial plants and displays the different

![Diagram of Entrepreneurs' Factors]

LOCATION FACTORS FOR INDUSTRY

SOURCE 32

FIG. 39
The final choice in the location will ultimately be determined by the tie or group of ties most important to the operation of the establishment.

The conclusion that we can draw from Fig. 39 is that the locational choice of an establishment is governed by two factors:

- the location of other establishments,
- the existing means of transportation.

Therefore, the term "accessibility" may be considered to denote the ease of interaction in an urban area; that is, the ease with which activities throughout the region may be reached from a particular subarea or district of this region, and it has to be emphasized that accessibility does not only take into account how easy it is to overcome the friction of distance in a region, but also how attractive a certain zone is in terms of locations of activities once you get there.

Let us consider an example: Imagine a clerk within a public administration office, whose office after ten years of employment was equipped with a new revolving chair and modern office furniture with all kinds of drawers and hanging files, and his office is equipped in such a striking manner that this official can reach everything within his office just by stretching his arm out and turning the chair. There is no doubt: the accessibility of those pieces of furniture has decisively improved.

Now let us imagine that this clerk may have his furniture, but that on the other hand a governmental economy program did not allow any more, that all these drawers be filled with material. The furniture, consequently, stands there empty and its
basically good accessibility is of no use for our clerk. Why? Because the clerk basically did not want to reach the furniture, but its contents.

Now let us transfer this example into the context of a city. Let us change the furniture into districts or neighborhoods and the revolving chair into our transportation system. Then the accessibility from a certain origin within the city will be high, if the *effort* to reach all the other destinations within the city is *small*, but the content that can be reached at those destinations (in terms of living places, working places, shopping places, etc.) is *big*.

Therefore, we can say that accessibility as a concept relates the *effort or cost* to overcome the spatial separation of activities to the *benefits* gained through this effort.

**B. MEASURES OF ACCESSIBILITY**

We consider that a measure of accessibility should be sensitive to the following factors:

(a) The geographic distribution of the activity to which one wishes to be accessible;

(b) The mode of transportation by which one chooses to travel;

(c) The service characteristics of that transportation mode, i.e., its speed, cost, comfort, convenience;

(d) The emphasis which one places on the various aspects of transportation, i.e., time versus cost, versus comfort, versus convenience;

(e) The general willingness to travel of the class of trip-makers being considered.

There are many different ways of constructing accessibility measures, which are sensitive to the five factors listed above. One of the simplest, which has been used a good deal in
planning work, is the number or proportion of activities of a given type which are within some distance—measured by time or cost—of a designated district. The major difficulty with such a measure is that it does not take into account variations of the distribution of the activity within the stated bound. For example, if the measure is the proportion of households within 30 minutes of a district, the value of the measure will be the same whether the households are clustered within five minutes of the districts or in a band 20–30 minutes away from it. It thus assumes an equal value to all the opportunities within 30 minutes and does not allow for the greater value of nearer opportunities within this limit.

As we attempt to construct more sophisticated measures which more nearly represent the manner in which persons value the proximity of opportunities, we quickly discover the strong interrelationship between measures of accessibility and models of trip distribution: that is, models which predict the way trips emanating from one district distribute themselves to the other districts in the region. This is natural, since one may assume that the same thought process that determines how one measures his accessibility to the region also determines how he chooses destinations within the region.

Thus we can describe the accessibility R for a certain area i as follows:

\[ R_i = \sum_{j=1}^{n} A_{ij} e^{bt_{ij}} \]

Source: 33
Where \( R_i \) = accessibility of area \( i \)

\[ A_{tj} = \text{attractivity of area } j \] (expressed by the number
of work places, number of inhabitants, or other
functions)

\( t_{ij} = \text{travel-time between area } i \text{ and area } j \)

\( b = \text{friction factor} \)

\( e = \text{base of the natural logarithm}. \)

This formula may look as a very simple tool and yet there
are still quite a number of difficulties that have not yet
been resolved completely to our satisfaction:

(a) We stated before that each kind of activity has differ¬
ent locational requirements; in other words, not every
establishment weighs accessibility to the same type of
activity in an equal way. For example, an industrial
plant may be primarily interested in the accessibility
to its resource areas, an office building primarily in
accessibility of its employes and residences in a com¬
bination of accessibilities to job, school and recreation.
This raises the question as to what measure to choose
as a measure of attractivity at the destination.

(b) We also know that travel times between zones for differ¬
ent modes of transportation are not the same. We know
that there exist different travel times for private and
public transportation and those travel times even vary
with the time of the day.
Also switching times and waiting times at stops for pub¬
lic transportation and search time for a parking place
at the destination have to be taken into account. This raises the question as to the measurement of travel time between zones.

(c) Further, we have to consider our friction factor $b$, which expresses the reaction of people to distance or in other words, it expresses the propensity of people to make a trip. We assume that this propensity declines as travel time increases. The accessibility surface that evolves is influenced by our choice of the "dynamic area" of travel time, i.e., the decisive range of travel time within a certain region, which is usually between 5 - 30 minutes, but is based entirely on the assumption that people are willing to make trips with durations up to 30 minutes and that beyond this time their propensity towards making a trip sharply declines.

(d) Finally, we have problems in evaluating "accessibility"; as mentioned before, we know of different kinds of accessibilities and we have to decide which ones we regard as relevant. Apart from this difficulty, our model only produces dimensionless numbers and its output cannot be expressed in a well-known measurement like dollars. But this does not make any difference for our purposes since we are not interested in absolute values, but in the differentials in accessibility of locations within an urban area. Thus we can pick our highest value point within the urban
area and express all other accessibility points as a percentage of the highest value. Finally, we can connect the points of equal value into iso-potential lines and we arrive at an accessibility surface.

(Fig. 40)

This accessibility surface can be read like a contour map. For instance, where the isopotential lines come close together there is a steep drop in the degree of accessibility; where there are closed contours, there is an "island" of poor or
good accessibility, relative to that existing in the surrounding area. The accessibility map expresses patterns which have long been vaguely assumed and is of high value in planning for a redistribution of population within the region.

C. THE INFLUENCE OF TRANSPORTATION ON ACCESSIBILITY

As we have seen before, the accessibility of a location within an urban area is mainly determined by the amount of attractions that can be reached from this location as well as by the effort necessary to overcome this spatial separation. This is where transportation enters the picture. Improvements of different modes of transportation change the time-distance factor and by this increase accessibility between locations. Different technologies and different network configurations lead to different accessibility patterns. This becomes clear when we compare the areas served within 30 minutes travel-time for various modes of transportation.

Fig. 41 shows the 30 minutes iso-time lines of a regional rapid transit system operating at a speed of 40 MPH. These and the following iso-time lines correspond to a total time of 30 minutes including walking time as well as riding time. Typical is the nodal pattern of the areas at the outskirts. Fig. 41 also displays how the iso-time lines vary for a central and a peripheral point of origin and thus demonstrate the role of location within an urban area.

Fig. 42 shows the same relation for a local mass transit system operating on fixed tracks at a speed of 12 MPH, and the differences in the iso-time line pattern between the
regional rapid transit system and the local mass transit system becomes obvious.
Let us confront the public transportation systems with the iso-time line pattern set up by the private automobile. We find an almost circular, extensive iso-time line pattern. (Fig. 43)
A full size road system allows for all points to be reached fast at any time, as long as capacity is not exceeded. Whereas all public transportation, with the exception of taxis, serves line or node shaped areas, the private automobile does not know such limitations and there is no point that could not be reached by the automobile. Especially if the trip does not occur between areas that are not served well, the time advantage gained by the private automobile grows to such a degree that there are extreme obstacles necessary to prevent this trip to be performed by the private automobile.
Finally, let us examine as to how changes in accessibility are brought about through changes in the transportation network. This can be demonstrated at the example of the construction of a new road.

Before the construction of the new facility we have a pattern of iso-time lines measured from a common point of origin like the one displayed in Fig. 45A.
After we introduce the new facility depending on its speed and capacities a new pattern of iso-time lines is established and we will have areas where both iso-time line patterns overlap. If we go one more step further and superimpose those two patterns, we arrive at zones of time advantages.
There will be points from which it will take equal time, no matter whether the old or new facility is chosen, but the introduction of the new facility also creates points that offer time savings by the use of the old or new facility. Thus all points to the right of the line of no time gain will choose the new facility and by this will link the area served by it in a new way to all other areas within the region and thus influence the accessibility of this area to the rest of the region.

D. THE ROLE OF PHYSICAL ACCESS

So far we have considered accessibility on a macro-scale and have shown the importance of transportation in linking areas and influencing the time-distance factor. Yet in order to be fully accessible, a site depends on one more quality; that is, the way the site has physical access to the transportation facility.

Direct access and, similarly, near proximity to highway access points are of demonstrated value. Most importantly, any frontage on a public-built road is valuable, if only because it substitutes for privately-built and dedicated roads and streets. But more than this, the higher the road type and the more the traffic, the more valuable the abutting lands are likely to be.

Although highway access is important to practically all types of land uses, direct access to highways is prized by businesses, especially retail establishments. This is shown in Fig. 47.
Highway access and exposure, i.e., access to the commercial property from the highway and visibility of the business establishment from the highway appear to be the critical factors to a much greater degree in the case of retail enterprises than in the selection of new locations for warehouses and distribution facilities.

1. The Highway-Land Interface

Land parcels are the basic units from which all flows of goods and persons originate and to which all goods and persons are destined. These units are not self-contained, but are highly interdependent. This interdependence requires that they have access to a transportation system.
The way how access is regulated along a certain transportation link entirely dictates the locational pattern of activities along this link.

If we provide continuous access to each individual abutting lot along a route carrying a high volume of traffic, a strip or ribbon development may be generated. If we restrict access to certain points along that route a nodal pattern at the intersections will occur. This has the same effect as stops have for a mass transit system operating along a fixed track: the stops being nothing else but controlled access points (Fig. 48).

Thus we have seen how transportation criteria determine the type and location of activities, but also the reverse is true and the activities located along that route influence the transportation characteristics of this route:

Land use units alter both the practical capacity of the roadway and the volume of traffic constituting the flow. Of primary importance, the private thoroughfare or approach of
each land-use unit forms an intersection with some segment of the public highway system. Fig. 49 shows the irregularities in flow caused by continuous access along this route.

The impact of this intersection is to lower practical capacity. The amount by which capacity is lowered depends, among other things, on the design characteristics of the intersection, the volume and direction of traffic flowing through the intersection and the composition of the traffic. These factors, in turn, are a function of the physical, social and economic attributes of the land use. Furthermore, each land use influences the size of the traffic stream flowing through the public highway network. Volume additions to various links in the network are a function of the amount of traffic generated
and attracted by individual uses and the location of the land with respect to other such interacting uses.

Each volume addition by a land use not only pushes the traffic load of the system closer to capacity, but also indirectly affects capacity itself. It does this by changing the kind and number of vehicles moving through established intersections in the highway network. Thus it is that the number of land uses attached to a segment of highway, the characteristics of these uses, and their location with respect to one another are associated with the ability of the roadway to accommodate traffic.

On the other hand, the continuous volume additions by new establishments locating along the route may make access conditions to other activities along the same route so difficult that they begin to lose their customers and are forced to relocate.
CHAPTER 7:

THE IMPACT OF TRANSPORTATION ON LAND VALUES.
The theoretical rationale underlying chapter 7 is that the impact of transportation through its influence on the accessibility pattern is directly reflected in the land value pattern of an urban area. Again the impact of transportation can be observed at various scales: at the entire urban scale as the result of all transportation systems, at the corridor scale along well defined lines of transportation, as well as at the intersection scale reflecting one point within the total network.
Although many factors affect the value of a given price of land (e.g., scenic value, productivity, provision of utilities, adjacent land uses, etc.), the land value surface is essentially a direct reflection of accessibility within the urban area.

Stanislaw Czamanski in his statistical analysis of factors influencing land values in Baltimore came to the conclusion that the most important factor determining the values of urban land is accessibility to the central urban functions. Other factors like age of existing structures and zoning regulations are secondary factors. Fig. 50 and Fig. 51 demonstrate the close correlation between accessibility and land values.

Historically, accessibility was highest at the city center, because it has developed over time as the major focus of routes and consequently is the most easily reached part of the entire urban area. In a similar way accessibility is greater at sites located along the radial and circumferential routes and at the intersections of these than it is away from them. Moreover, since some parts of the urban area are served better with transport than others, the land values will decline more rapidly with distance from the central peak along some routes than others. The result is a marked sectoral variation in the general level of the value surface.

Thus, we can identify at least three elements present in the pattern of all cities:

(a) Land values are highest in the city center and decrease
with increasing distance from the city center.

(b) Land values are higher along the major traffic arteries than in the areas away from them.

(c) At the intersections of major arteries land values tend to reach local peaks of higher value than the general level of land values for the surrounding area.
If we now combine these three characteristics in one diagram, the following general surface of land values evolves (Fig. 52):

If we consider the impact of transportation on land values, we can use two approaches:

(a) we can use the comprehensive approach, which describes the land value surface as the result of all transportation systems existing in an urban area.

(b) we can take the partial approach and try to identify the impact that one single mode of transportation has on land value distribution.

Both methods will be used later on. We shall use the example
of Chicago for the comprehensive approach and the examples
of the Gulf Freeway and the Chicago C. B. & Q. Railroad for
the partial approach.

A. THE IMPACT OF TRANSPORTATION ON LAND VALUES: CHICAGO
1830-1930

The best way to describe the impact of transportation is to
historically trace the development of both land values and
transportation systems within the Chicago area.

Fig. 53 displays the value surface of residential land as
well as the corresponding transportation system for various
stages in the development of Chicago. The areas with the
highest land values are traced out on the maps describing
the transportation system and we see how the peak land values
coincide with the changes in the internal transportation system
of Chicago.

More detailed we can identify seven stages in the development
of the Chicago transportation system:

(a) Era from 1836 - 1848:

During this time the coverage of Chicago streets by plank
roads was started, which in turn immediately were used by
omnibus lines.

(b) Era from 1848 - 1858:

During this time the construction of the major railroads
was accomplished, which lead to the emergence of Chicago
as a railroad center. The construction of these railroads
because of increased accessibility also caused a major
influx of population into Chicago, increased the demand
for residential land and lead to increases in land value.

(c) Era from 1859 - 1882:
In this era the omnibus lines were replaced by the horse car lines. "The horse street car lines followed mostly the principal routes of the omnibus lines and while the older system continued to compete with the car lines for a time, it was handicapped by the bad condition of the pavements and the new car lines soon gained most of the traffic."
It also can be seen how close the peak land values follow the major transportation arteries.

(d) Era from 1887 - 1894:
A succession of devices for faster means of local transportation followed each other rapidly in this period, enabling people to skip the intermediate areas partially filled with obsolete houses filled by lower socio-economic population segments and seek home sites where the houses were new.
These devices were: cable lines
               elevated steam railroads
               electric surface lines.
Homer Hoyt comments on the development of land values during this period: "The superiority of the transportation facilities on the South Side and their steady improvement in this period are among the chief causes in the uninterrupted rise in its land values throughout the era from 1882 - 1890." (Source: 43)
He also comments on the impact of projected elevated and surface lines:

"Not merely the lines that were actually constructed, but visionary lines that were projected by promoters but never built had a great influence on the speculative real estate market of 1889 and 1890. In the welter of projects that were discussed or that were started but could not overcome all the obstacles to obtaining the consent of property owners, securing an ordinance from the city council, and raising the necessary capital, it was difficult for the average lot-buyer to decide which transportation lines would succeed and which would fail. Even in the case of lines already partly constructed, it was often not known where the termini would finally be located. Nearly every subdivision was sold under the assurance that an elevated line or electric street-car line would run directly past the buyer's lot, or as close as it would be desirable to have it run."

(e) Era from 1894 - 1898:

The period from 1894 to 1898 was marked by the building of many new transportation lines, both elevated railroads and electric surface lines in the north and west sides.

Homer Hoyt comments:

"In 1895 and 1896 many new electric surface lines were built on the North and Northwest sides, particularly on Belmont, Irving Park, and Lawrence avenues, and territory that had the worst transportation before now secured the best. A rapid conversion of horse-car lines into electric-trolley systems was also taking place in these years until in 1897 the South Side surface lines had only 7.5 miles of horse-car lines compared with 141.5 miles of electric and 30 miles of cable lines, and the West Side lines had only 6.5 miles of horse-car lines compared with 165.5 miles of electric and 30 miles of cable lines. The promises of improved transportation made in the boom of 1890 had been fulfilled, but the actual construction of the new lines did not produce the effect on land values in the depressed market from 1894 to 1898 that the mere promises of such facilities had exerted on the excited land market of 1890."
(f) Era from 1898 - 1918:

"One of the factors that was of the greatest aid in the renewal of real estate activity was the improvement in transportation. From 1890 to 1900 there had been a revolutionary change in the internal transportation system of Chicago. Elevated lines had been constructed on the South Side, the West Side, and finally on the North Side, and these were at last linked together in a union loop in the central business district in 1900, which thereafter became known as the "Loop." Of even greater importance was the substitution of electric power for steam and horse power in the elevated and surface lines. From 1895 to 1897 many new street-car lines were laid in the northwest section of the city, and these new lines were being operated by electric power. In addition, horse-car lines, the slowest parts of the transportation system, were being rapidly electrified at this time, and, finally, electric power was installed in the cable trunk lines.

Effect on different sections of the city.—Prior to 1893 the South Side had by far the best transportation facilities, with four railroads providing good suburban service. The North and West sides not only had fewer railroads and cable lines, but they were further greatly handicapped by the barrier of the Chicago River, with its frequent opening and closing of bridges. The rapid decline of traffic on the Chicago River, together with the new elevated lines, whose high bridges remained permanently open, removed the disadvantageous factor affecting the North and West sides.

In the early twentieth century the side of the city that grew most rapidly was the North Side and the northwest sections. The South Side suffered from the aftermath of the World's Fair boom, the obsolescence of its buildings, and the spread of vice elements. Nevertheless, the growth of its great industrial plants held a large population and finally enabled new high residential sections to be developed on the edges of its old areas.

There was a certain pattern of growth, however, that affected all sections of the city. The elevated lines in the three sections were being pushed into undeveloped tracts, and along these newly constructed elevated structures on the South and West sides, and on the North Side after 1900, rows and rows of apartment buildings were being erected. The migration of factories from the river was beginning, and industrial plants were filling in the area near the Loop on the three sides of the city, and were also moving outward to belt-line locations or to newly created industrial districts. The direction of growth of the high-grade residential area was proceeding
outward in straight lines and along the Lake Shore. The newly arriving immigrants were pushing the old members of foreign colonies farther out. Meanwhile, the central business district was drawing support from all three sections of the city and developing as an exclusive retail center."

**Era from 1918 - 1936:**

"The increase in land values during this period was greatest in two semicircular belts, North and South, that traced arcs around the old blighted area where population declined between 1920 and 1930 and where the population that remained consisted of races or nationalities that were lowest in the economic and social scale. It was in this area that was largely settled between 1899 and 1926, that the largest increases in land values occurred. The extension of transportation facilities into these areas had likewise facilitated the process of settlement and the rise in land values."

This development is well reflected by the land value map of 1926 and it is remarkable how well once again the peak land values follow the elevated lines. Concluding, it has to be remarked though, that although transportation definitely influences the shape of the land value surface, there are other factors like the lake front, the Chicago River, or economic and population growth, that also contribute to land value. So far we do not have objective methods that allow us to isolate solely the impact of transportation and we only can build a good hypothesis for its case.

After we have explored the joint effect of various modes of transportation on the land value surface, we try to isolate the particular impacts on land value that individual modes are exercising. In the next two sections of this chapter we shall analyze the impacts of the automobile as well as the rail system on land values.
B. IMPACT OF THE AUTOMOBILE ON LAND VALUES: THE GULF FREEWAY.

In order to identify the impact which the construction of a freeway exerts on land values, the following approach was taken: (Fig. 54) a band of 1-1/2 to 2 miles width accompanying the freeway was chosen as the analysis area. This band was subdivided into two groups; band A representing the primary area, immediately adjacent to the freeway, and band B representing the secondary area without any frontage on the freeway. Furthermore, the 6.5 miles of freeway analyzed were subdivided into six sections of approximate length. In addition land value data were gathered for four points in time:

- in 1940 before the facility was started;
- in 1945 after the route became known and work was started on Section 1;
- in 1950 after 6.5 miles of the freeway were opened;
- in 1955 after the total facility had opened to Galveston and several years had passed.

Thus it was possible to display the impacts on land value in two ways:

(a) land values as a function of distance from the CBD (longitudinal section);

(b) land values as a function of lateral distance from the freeway for each section. (Cross section).

It has to be pointed out that the land values displayed here do not take into account the difference in land value for different land uses such as commercial, residential, industrial,
etc., but rather represent an average of those.

From the analysis we can draw the following results:

(a) Land values decrease as distance from the center increases. This is the case for property fronting at the freeway as well as for property not fronting on it. (Fig. 55)

(b) Land values generally increased although at different rates during the 15-year study period. (Fig. 55).

(c) Property fronting on the freeway shows higher values than property in the secondary area and displays the reaction of land values to the better accessibility and visual exposure of these lots from the freeway. (Fig. 55).

(d) The increase in land values was strongest for the downtown section of the freeway. This is the area where the freeway is separated and feeds into four one-way streets and thus constitutes the interchange for traffic moving between the Gulf Freeway and North-South streets leading into the central business district and to other parts of the city. (Fig. 55).

(e) It also became apparent that large undeveloped tracts experienced the strongest increases in land values which is demonstrated at the example of Section 3. This section consisted of mostly vacant land held by estates and owned for years. As soon as the route was definitely established, much of it was bought by promoters and resold to industries. It was developed very rapidly since the freeway was built and the values of both bands showed
LANDVALUES ALONG THE GULF FREEWAY

SOURCE 43

FIG. 55
(f) Finally the results from the cross sectional approach show an interesting fact. While in the first three sections land values of property adjacent to the freeway exceed those in the secondary area in the course of the 15-year study period, the reverse process can be observed for Sections 4-6. One explanation for this phenomenon could be the fact that these areas experienced a major population growth during 1940-50 and much of the land has been developed for residential use and multi-apartment use, which lead to an increase in residential land value, whereas the lots adjacent to the freeway and usually being developed as commercial and industrial property, were not developed yet. (Fig. 56).

C. THE IMPACT OF THE RAIL SYSTEM ON LAND VALUES: THE CHICAGO C. B. AND Q. RAILROAD EXAMPLE.

In this section we shall use the example of the so-called west suburban urbanized area served to a large extent by the Chicago, Burlington and Quincy Railroad from Cicero to Downers Grove, a distance of about 15 miles, and examine how residential land values relate to lines of public transport. Figure 57 embraces the suburban communities served by the CB and Q Railroad. Its service area overlaps to the north with the area served by Congress Street and the Douglas Park and Garfield elevated. Each cube on the isometric diagram of Figure 57 represents a quarter section of land and the height of this cube is proportional to the value per front foot of
the residential land contained in the quarter section.

We can identify the following characteristics:
(a) It is obvious that the railroad rides a ridge of residential land values, that is, the value of the residential land slopes away from the rail line parallel to the right of way.
The Douglas Park and Garfield elevated also rides a value ridge. Based on this evidence we probably can take one step more and assume that each line of public transport rides a residential land value crest of its own making. (Fig. 58).

(b) Residential land values not only slope away from the rail line but also dip between each station. The values form a modified cone or pyramid around each station. (Fig. 59).

(c) Thirdly, values are a function of the distance from the city center; each successive cone tends to be a little higher as one approaches the city. (Fig. 60).

The longitudinal section's graph (Fig. 61) reveals this concept with the stations at the high points on the graph and
the areas between the stations at the low points.

(d) The cross section's graph (Fig. 62) also reveals the pyramid effect of residential land, but it also reveals
another value configuration when we go to the more detailed scale of a block by block diagram. The railroad actually runs in a valley extending about 1/4 mile from the railroad on each side of the tracks. Residential land values rise sharply to peaks on both sides of the rail line about 1/2 mile from the railroad and then drop sharply to 1-1/2 miles from the tracks. It seems that people want to avoid the immediate proximity to a railroad line, but also do want to be close to it and therefore tend to pay for their ability to locate in this distance range.

(e) Finally regression analysis was applied to the land values and a straight line was plotted. (Fig. 61). Vertical lines on the graph each represent three minutes running time on the average. It is then discovered that residential land values in this example decrease on the average one dollar/front foot for every minute of suburban express train running time between these stations and the impact of decreasing accessibility to major activity centers on land values becomes evident.

Finally it has to be said that the "valley effect" probably is only true for residential land values and that commercial and industrial land values tend to peak with increasing proximity to the stations. If we superimpose those two different value surfaces, we arrive at the following pattern:
D. THE IMPACT OF INTERCHANGES ON LAND VALUES

At the beginning of this chapter we also noted the local peaking of land values at the intersections of major radials and circumferentials and we shall discuss this in the following section at the examples of

(a) the freeway interchange complex;

(b) the fixed rail rapid transit station.

1. The Freeway Interchange Complex

Interchanges vary in function and can be classified as follows:

1.1 Express Interchanges:

They transmit road users from one road system to another for purposes of continuing their trip. Because of the complexity of movement involved in these interchanges, they do not have significant influences on land value although they seem to represent the highest level of access.

1.2 Arterial Interchanges:

They have the dual function of exchanging traffic between two road systems as well as providing access to major streets which immediately service abutting land uses.

1.3 Service Interchanges:

They have the principal function of providing convenient service for road users and secondarily serving important abutting land uses and traffic exchange purposes.
In our discussion we will concentrate on the arterial interchange complex. (Fig. 66)

This complex is defined to be that area of the highway that includes an intersection of the highway with some other road, involving a transfer between the two and encompassed by the ingress-egress ramps and the intersection of the frontage roads with the intersecting road.

The area within the interchange complex consists of four zones, two on each side of the facility. The first and third quadrants and the second and fourth quadrants show similar characteristics in reference to the direction of the flow of traffic traveling on the highway. Since those two quadrants are the "lead-in" quadrants, it has been found that they were preferred by commercial development.

A close examination by The Texas Transportation Institute of
a 1/2-miles area of 72 interchanges revealed that proximity to the interchange held definite advantages.

The mean land values fell from $17,000 per acre for that directly on the interchange to a low of $5,500 per acre for that approximately 1/2 mile from the interchange. (Fig. 67).
Figure 68 gives a visual interpretation of the percentage increase in property values within the influence of the interchange complex. An interesting relationship was found between distance from the interchange and the effect of being located at an egress ramp. The price per acre had a pronounced peak at the ramp locations.

But proximity of the property to the highway interchange is only one factor for the increase in land value. The other factor that has to be considered is the kind of land use prior to the construction of the road facility.

Increases in land values are generally highest when a conversion in land use took place like a conversion from agricultural or vacant land to residential, commercial or industrial uses. Generally lands adjacent to improved highways develop faster than others. A comparison of land value increases of land abutting on frontage roads versus non-abutting land revealed the following value increases:

- Unimproved land + 152%
- Agricultural land + 12%
- Commercial land + 97%
- Residential land + 90%

As far as residential land is concerned, this does not mean that the absolute residential land values decreased, but that the increase for abutting residential land was 90% less than that for the non-abutting. This suggests the fact that direct access to a frontage road for residential land use would probably be not as important to overall residential
development as would general accessibility to the facility.

2. The Rail Rapid Transit Interchange Complex

As far as rail rapid transit is concerned, because access to the system is confined to a limited number of stops, it is there where the biggest gains in land value occur.

The development of land around a transit station can be characterized by three areas. (Fig. 69). About 200,000 sq. ft. is directly applicable to the transit station (A). About 2,000,000 sq. ft. includes facilities directly related to functions located at the transit stop (B) and an area of about 1/2 mile radius will be directly influenced by the rapid transit station (C).

In Toronto along the Yonge Street subway land values along the right-of-way tripled in two to five years, and at stations went up as much as 10 to 12 times.

E. THE INFLUENCE OF TIMING ON LAND VALUES

Generally we can identify six phases in the development of a transportation facility. These phases are:
(a) Route selection:
At this point in time, no one is sure as to exactly where the facility will be located; although a general corridor is under consideration the high degree of uncertainty as to what the future land uses attracted by this facility will be affects land values of nearby property. In inner city areas this often can result in quite large decreases in land value, if this period of route selection lasts too long.

(b) Detailed planning:
This occurs after the route has been chosen. Still no visible action takes place and land speculation continues.

(c) Clearance and displacement:
This phase will be omitted if the facility is placed in vacant land.

(d) Construction:
Transportation during this period may be worse in the area served by the new facility because of the disruptions caused by the movement of equipment and the tearing up of existing facilities. This can generate severe losses to those types of businesses depending on local traffic. On the other hand construction confirms that the new facility will eventually exist and hence land value impacts begin to be felt.

(e) Early operation:
Major adjustments in land use happen and large changes in land values occur during this period.
(f) Mature operation:

After a few years, surrounding land uses have made the most dramatic adjustments to the traffic facility. The biggest surge in traffic volume - from zero to the initial operating level - has taken place. Nevertheless, certain other land value effects can occur during this mature operating period: they result from gradually rising traffic levels on the artery, but also from continual extension of urban development outward along the artery and intensification of land uses in already built up areas adjacent to it.

Summarizing, we can say that the biggest changes in land value occur during the construction and early operation periods. We also can say that a new traffic artery has no positive impact on the value of adjacent land unless other economic factors favoring urban growth are already present in the area. For example, expressways passing through relatively undeveloped rural areas have almost no impact on adjacent land values, unless there is a strong demand and competition of population, employment sources and commercial activity for the newly accessible amount of land.

Also, the net impact of a major transportation line upon nearby land uses is greatest when the movement from actual intensity of pre-artery land use to the highest potential intensity is at a maximum. However, two constraints have to be considered: the cost of conversion of the land from one use to the other and the time period required for conversion. Vacant land for
example is easier and less expensive to shift directly to its final use rather than clearing and replacing an already existing land use. Land which is already ripe for development in terms of being zoned and equipped with utilities has time advantages. (Source: 50)
CHAPTER 8:

THE IMPACTS OF TRANSPORTATION ON LAND USE DISTRIBUTION.
In the last chapters we discussed how based on differences in transportation systems a different accessibility pattern evolves which in turn is directly reflected in the land value pattern. Since each individual activity has its own accessibility requirements as well as a maximum rent price which it can afford to pay, we arrive at different land use patterns for different transportation systems. Based on differences in the type, location or access controls of the transportation facility a different mix of activities is attracted. Chapter 8 discusses these relationships in selected examples. Finally, transportation does not only influence the distribution of urban activities, but also represents a land use itself.
Once again in describing the impact of transportation on land use distribution the same two approaches used in the previous chapter can be taken. We can view it as the result of the combination of all modes as well as the impact of each single mode along defined lines of transport.

As far as the overall effect of transportation on land use distribution is concerned we have various theories:

(a) The concentric zone model (Fig. 70) states that at any given moment in time land uses within the city are organized into zones differing in age and character and located in a definite order from the city center.

However, according to Hartman, the development of pure concentric land use patterns will only result if there is a strong radial component in the transport system and then only if the number of radial routes is quite large and they are closely spaced. Fewer radial routes spaced more widely apart give rise to marked differences in intra-urban accessibility to result in a 'star' shaped form, in which concentric arrangements of land use are distorted and even destroyed.

This leads us to another theory: the sector models (Fig. 70).

(b) Models of this type are developed on the assumption that the internal structure of the city is conditioned by the disposition of routes radiating outwards from the city center. Differences in accessibility between radials cause marked sectoral variation in the land value surface
and correspondingly an arrangement of land uses in sectors.

(c) However, the specialized locational requirements of certain activities, the tendency of activities to agglomerate and the repulsion of some activities by others which is linked to the differences in rent paying ability force activities to cluster in separate districts within the city and develop several discrete centers within the urban area. This is the basis of the multiple nuclei-theory of Harris and Ullman. (Fig. 70).

The three models are not mutually exclusive and elements of all three might be expected in cities. Marble has suggested a fused model in which growth proceeds radially from the city center and from various other nuclei, but is intercepted by axial growth pushing outwards along the lines.
of least resistance from the main center to result in a star shaped city in which distinct social, economic, and technical zones are developed.

Major lines of transport - rail as well as automobile - seem to be responsible for this linear and axial development and also seem to attract certain kinds of land uses.

A. EFFECTS OF THE AUTOMOBILE ON LAND USE DISTRIBUTION

1. Ribbon Development: The Spokane Example

One of the major effects on land use distribution caused by the automobile is the tendency of certain types of businesses to locate in ribbons or strips along major traffic arteries. In his survey of 285 business centers in Spokane, Washington, Garrison identified certain businesses to locate either in clusters at intersections or along major arterials. (Fig. 71).

<table>
<thead>
<tr>
<th>Groups and Types of Business</th>
<th>Gas</th>
<th>Restaurant</th>
<th>Auto repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping Groups</td>
<td>Building supplies</td>
<td>Bar</td>
<td>Radio-TV, sales, service</td>
</tr>
<tr>
<td>Clothing</td>
<td>Shoe repair</td>
<td>Furniture</td>
<td>Auto accessories</td>
</tr>
<tr>
<td>Variety</td>
<td>Appliance</td>
<td>Auto accessories</td>
<td>Other retail, fuel, etc.</td>
</tr>
<tr>
<td>Dairy</td>
<td>Misc. repair, plumbing, etc.</td>
<td>Lumber yard</td>
<td>Gift and novelty</td>
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<tr>
<td>Jewelry</td>
<td>Motel</td>
<td>Mission</td>
<td>Others</td>
</tr>
<tr>
<td>Lawyer</td>
<td>Others</td>
<td>Meat</td>
<td>Fruit, vegetable, produce</td>
</tr>
<tr>
<td>Post office</td>
<td>Printing</td>
<td>Office equipment</td>
<td>Funeral home</td>
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<tr>
<td>Department</td>
<td>Arterial Conformation</td>
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<td>Sporting goods, bicycle</td>
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<td>Other professionals</td>
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<td>Shoe</td>
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<td>Bank</td>
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<tr>
<td>Auto Row</td>
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<tr>
<td>Bakery</td>
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<tr>
<td>Auto dealer</td>
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<tr>
<td>Florist, nursery</td>
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<td>Music, hobby</td>
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<td></td>
</tr>
<tr>
<td>Hotel</td>
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</tbody>
</table>

SOURCE 52
FIG.71
The locational pattern of nucleated and arterial centers is shown in Fig. 72 and Fig. 73 and show the different location habits of the two conformations of business. Nucleated shopping centers (Fig. 72) are widely dispersed throughout the city, whereas arterial centers are highly concentrated, oriented to and outlining a few major streets. (Fig. 73). When these spatial distributions of the two conformations are compared with patterns of traffic flow in the City of Spokane, obvious relationships between traffic flow and the two types of centers appear. Arterial centers are oriented to major traffic flows and seek out major axes of movement. This is suggested by the example of the traffic oriented locational pattern of service stations and garages. (Fig. 74) (Fig. 76). Nucleated shopping centers on the other hand are more diffuse. Larger shopping centers tend to seek out major traffic intersections, whereas smaller nucleated shopping centers are widely scattered, relatively evenly distributed throughout populated parts of the city and the distribution of smaller centers tends to approximate the distribution of population. (Fig. 75).

2. The Impact of The Automobile on Commercial Land Use: The NE Expressway in Atlanta.

This study used the same approach as taken in the Gulf Freeway study and looked at the impact on land use distribution at three different periods:
1941-46: Time period before the freeway was built

1946-51: The time period of overall study and early construction of the first part of the freeway

1952-56: Period of the completion of the U-E leg of the freeway.

Fig. 77 shows the growth and location of commercial and industrial land uses during this period. This freeway was designed as a limited access facility and had no frontage roads. Therefore major growth occurred in the immediate vicinity of the freeway along existing streets.

Another important aspect has to be mentioned in connection with the construction of limited access freeways. Limited access freeways split the areas through which they run into two definite parts, which are connected only by few cross streets developed for that purpose.
This leads to a complete change in the structure of the movement pattern. Because there is need for lateral movement as well as movement along the expressway routes, the few streets which do cross the freeway become important thoroughfares. (Fig. 78)

Commercial activity along the major thoroughfares crossing the expressway has increased greatly and these thoroughfares developed strip character. Primary cause of this growth is the increased importance of these streets as a result of crosstown traffic being channeled over them.

3. The Impact of the Automobile on Industrial Location:

The Route 128 Example in Boston.

Route 128 is a limited access divided 4 and 6 lane circumferential highway extending for about 60 miles around metropolitan Boston. It is located in a semi-circle about 10 miles from the Boston CBD. Its most important link was completed in 1951. In 1958 it carried a volume of 40,000-50,000 vehicles/day.

As a circumferential highway the route cut across large sectors of undeveloped land between older radial highways. This highway essentially supported the suburban trend of people and industry in the post-war period by giving access to low priced land in areas on the edge of the metropolitan labor market, not too far from the core of the city and yet close to attractive suburbs. At the same point many in-town businesses ran short of land for expansion. Developers took advantage of this situation and promoted the development of Route 128 industrial sites.
Geographically industrial development clustered in seven areas. (Fig. 79). By September, 1958 the capital investment amounted to 105 Million $ and 23,300 persons. Out of these 50% of both investment and employment were concentrated at the New England Industrial Center, Newton, Needham and Waltham. It is significant that these areas of high concentration of industry are centrally located on Route 128 close to radial highway routes 9 and 20, and the Massachusetts Turnpike. These three highways carry the major traffic flow from Boston to the West and South.

Former locations of companies that moved to new locations on Route 128 are shown in Fig. 80. Most of these companies' former plants were located near the Boston CBD. In terms of total investment in relocated companies 68% were located within a 2-1/2 mile radius and 96% within a 4-1/2 mile radius from the CBD.

It is interesting to see how the relative importance of site selection factors varies according to the particular needs of the industry types. The survey separated the industries into four types: Distribution, Production, Research and Development and Service. Fig. 81 displays the results.

Distribution Plants Stressed: Commercial accessibility
Land for Expansion

Production Companies Stressed: Land for Expansion
Attractive Site
Commercial Accessibility
Labor Market
Employee Accessibility
INDUSTRIAL DEVELOPMENT ALONG ROUTE 128

FIG. 79
FORMER LOCATIONS OF COMPANIES

Research and Development Stressed: Employee Accessibility
Labor Market
Land for Expansion
Attractive Site
Advertising

Service Industry Stressed: Employee Accessibility
Labor Market
Land for Expansion
Attractive Site

Each dot represents the location of a company prior to its relocation on Route 128.

SOURCE 55
FIG. 80
The desire for better access shows up prominently for all companies: commercial access for distribution and production plants, and employee access for research and development and service companies.

The impacts of industrial growth can be illustrated by the example of the New England Industrial Center, a 100-acre site, which was 93% developed by September, 1957. Assessed valuation of property increased from $113,000 in 1953 to $5,729,000 in 1957 and resulted in an increase of tax revenue to Needham of $290,000. Thus 10% of the total real estate revenue was produced by only 1.2% of the town's acreage. A decrease in tax rate was the result of these valuation changes.
B. THE IMPACT OF THE RAIL SYSTEM ON LAND USE DISTRIBUTION:

THE YONGE STREET SUBWAY EXAMPLE IN TORONTO

After we have seen the impact of the automobile on land use distribution, in this section we shall use the example of the Yonge Street subway in Toronto and examine how different land uses relate to lines of public transport.

Toronto's subway system is laid out in the classical way—the cross. It divides the city into four almost equal segments and serves directly the most heavily populated areas.

The Yonge Street Line was the first one to be opened in 1954 and connected the downtown area with high-income suburbs.

(Fig. 82).
Considering the period between 1952-62 we can identify the following impacts:

(1) Based on the considerable changes in accessibility and reflected in a rapid increase in land values, a wave of new building construction accompanied the construction of the subway line. (Fig. 83)

When we compare the floor area added to the land area involved in new construction (Fig. 84), we see that we experienced a tremendous growth in floor area on a rather moderate amount of ground area. In other words, the construction of
the subway line created a well-defined corridor of intensified development.

When we look at individual land use types, the following picture is presented to us. As expected, a heavy growth of offices occurred in a narrowly defined belt along Yonge Street. Within a five-year period over 5,000,000 square feet of new office space was added. (Fig. 85).

APARTMENT FLOOR AREA ADDED 1952-62

SOURCE 57

Fig. 86

Apartments construction reveals a similar degree of concentration. Except for two areas along the lake shore, apartment construction follows the Yonge Street corridor to the north
again. Over 8,000,000 square feet of new high rise apartments sprang up in areas that had been occupied by old single family dwellings. In the first ten years of its operation, this short stretch of subway attracted over 2 Billion Dollars of new construction for every mile of the system. (Fig. 86).

When we look at industrial and warehousing construction we discover major development along the central waterfront and along the railway zones to the Northeast, but we do not see any response to the Yonge Street subway. One major reason for this is that industrial land uses ask for large lots, show rather low employment densities and cannot be stacked on
top of each other and intensified like the previous two land uses. (Fig. 82).

As a measure of the importance of this expansion, employment increased from 8,600 in 1956 to 15,100 in 1960 and was beyond 19,000 in the areas influenced by the subway. (Fig. 88)

As the table below indicates, the five largest centers of non-industrial development account for over 41% of all floor area added, over 83% of all office space and 67% of all apartments. The northern sector of the city including the Uptown, St. Clair and Eglington areas, accounted for nearly 40% of the office space added, over 40% of all apartments
and 23% of general commercial construction.

C. TRANSPORTATION AS A LAND USE

Transportation does not only affect other land uses, but also constitutes a major land use in itself. This becomes evident, how much of our urban land is dedicated to transportation facilities.

Most land use studies undertaken today indicate that street rights of way occupy between 25% - 33% of all developed land regardless of city size or density. (Fig. 89).
This percentage would even be greater if we included the
land consumed by parking in the urban areas.

Previous figures also represent an average for whole metropolitan areas and figures are changing, when we look at different areas within our cities.

Let us consider, for example, the amount of land used for streets and parking in our central business districts. While in 1930 the proportion of ground area devoted to roadways was 21% in the Los Angeles CBD, this figure jumped to 59% in 1960.

As shown in the table below almost 50% of all downtown land is occupied today by streets, alleys, sidewalks and parking.

<table>
<thead>
<tr>
<th>CENTRAL BUSINESS DISTRICT</th>
<th>YEAR</th>
<th>TOTAL ACRES</th>
<th>PER CENT OF CBD LAND DEVOTED TO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Streets</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>1960</td>
<td>400.7</td>
<td>35.0</td>
</tr>
<tr>
<td>Chicago</td>
<td>1956</td>
<td>677.6</td>
<td>31.0</td>
</tr>
<tr>
<td>Detroit</td>
<td>1953</td>
<td>690.0</td>
<td>38.5</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>1958</td>
<td>321.3</td>
<td>38.2</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>1958</td>
<td>580.2</td>
<td>34.6</td>
</tr>
<tr>
<td>St. Paul</td>
<td>1958</td>
<td>482.0</td>
<td>33.2</td>
</tr>
<tr>
<td>Cincinnati</td>
<td>1955</td>
<td>330.0</td>
<td></td>
</tr>
<tr>
<td>Dallas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Area</td>
<td></td>
<td>344.3</td>
<td>34.5</td>
</tr>
<tr>
<td>Sacramento</td>
<td>1960</td>
<td>350.0</td>
<td>34.9</td>
</tr>
<tr>
<td>Columbus</td>
<td>1955</td>
<td>502.6</td>
<td>40.0</td>
</tr>
<tr>
<td>Nashville</td>
<td>1959</td>
<td>370.5</td>
<td>30.8</td>
</tr>
<tr>
<td>Tucson</td>
<td>1960</td>
<td>128.9</td>
<td>35.2</td>
</tr>
<tr>
<td>CENTRAL BUSINESS DISTRICT</td>
<td>YEAR</td>
<td>TOTAL ACRES</td>
<td>Streets</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>Charlotte</td>
<td>1958</td>
<td>473.0</td>
<td>28.7</td>
</tr>
<tr>
<td>Chattanooga</td>
<td>1960</td>
<td>246.0</td>
<td>21.8</td>
</tr>
<tr>
<td>Winston-Salem</td>
<td>1961</td>
<td>334.0</td>
<td>25.1</td>
</tr>
</tbody>
</table>

Source: 59

In 1964 approximately 50% of the total land area of the Houston CBD was devoted to the automobile in the form of street right of way, parking lots and the ground area of parking garages. (Fig. 90).
Public and private parking spaces in lots and garages increased from 15,629 spaces in 1953 to 28,487 spaces in 1963 and reached the amount of 30,528 spaces in 1969. Another example that demonstrates the enormous land consumption of the private automobile is the Kansas CBD. Fig. 91 displays the amount of land used by streets, the amount of unusable land within interchange areas, etc., and the amount of land dedicated to major parking facilities.

But it also has to be mentioned that in many cities railroads and especially railroad terminals constitute a major land use in the urban area. For example, approximately 20% of Chicago's downtown area is devoted to railroads. 15% of the total land area of Basel/Switzerland are dedicated to railroads.

1. Comparative Area Requirements

The comparison of the space requirements for various modes of transportation reveals more aspects of transportation as a land use.

Transit in contrast to the automobile has very low space requirements. Study results of the road research laboratory show how the area required per person transported varies with the type of vehicle, width and nature of road, average occupancy and duration of peak period. (Fig. 92).

Rapid transit requires about 3% of the area needed for automobile travel on arteries and about 10% of that for freeways at today's occupancy levels.
Fig. 92 - AREA OF GROUND REQUIRED FOR A ONE-MILE JOURNEY (Dynamic Conditions)

<table>
<thead>
<tr>
<th>TYPE FACILITY</th>
<th>SQUARE FEET PER PERSON</th>
<th>2-Hour Peak</th>
<th>1-Hour Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Streets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car with Driver Only</td>
<td>40-100</td>
<td>80-200</td>
<td></td>
</tr>
<tr>
<td>Car with 1.5 Persons</td>
<td>27-67</td>
<td>53-133</td>
<td></td>
</tr>
<tr>
<td>Car with 4 Persons</td>
<td>10-25</td>
<td>20-50</td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td>4-10</td>
<td>8-20</td>
<td></td>
</tr>
<tr>
<td>Urban Freeway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car with Driver Only</td>
<td>20</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Car with 1.5 Persons</td>
<td>13</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Car with 4 Persons</td>
<td>5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Pedestrianway</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Rapid Transit</td>
<td>1-2</td>
<td>2-4</td>
<td></td>
</tr>
</tbody>
</table>

Source: 62

Fig. 93 in a similar way describes for various modes how much road space is needed for the transport of 200 persons and we see the tremendous advantages of mass transportation systems.
## Ground Area Requirements for the Movement of 200 Persons

<table>
<thead>
<tr>
<th>Mode of Transport</th>
<th>Area Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Streetcar</td>
<td>1800 SQFT</td>
</tr>
<tr>
<td>2 Buses</td>
<td>2300 SQFT</td>
</tr>
<tr>
<td>100 Motorcycles</td>
<td>18500 SQFT</td>
</tr>
<tr>
<td>50 Cars</td>
<td>38000 SQFT</td>
</tr>
</tbody>
</table>

Two factors contribute to the increased space requirements of the private automobile:

(a) Increased right-of-way requirements

(b) Area requirements of intersections
Fig. 94 points out the constant increase in road width,

whereas Fig. 95 shows comparative freeway and transit rights-of-way. Rail and bus rapid transit rights of way are generally under 90 feet in contrast to those for freeways which range upward from 135 feet.

The second major factor for the increased land consumption of the automobile is the area requirements at intersections. As shown in the table below urban freeway intersections may require 40 or more acres of land depending on the angle of intersection and the number and volume of movements accommodated.
Table: Area requirements of typical freeway junctions in Chicago, Ill.

Eden and Northwest Expressways 46 Acres
Dan Ryan & SW Expressways at Halsted Street 38 Acres
Ohio-Ontario Streets & NW Expressway 50 Acres
Dan Ryan & SW Expressways and Franklin Str. 62 Acres
Dan Ryan Expressway and East and West Legs 79 Acres

Only a rather small part of this acreage is actually dedicated to streets itself. The rest is just unusable land enclosed by ramps, without any access and of rather odd shapes.
The higher we choose the speeds that can be driven on the freeways, the larger the radii of the on and off ramps have to be and the higher the increase in unusable land. We can reduce the speed standards and by so doing, the radii at intersections can be much smaller and the total amount of land required at the interchange is drastically reduced, but we also have to be aware that by this action we also considerably reduce the capacity of the total interchange. (Fig. 96)

But not only the freeway interchanges contribute to the increased land consumption, the same is true for regular at grade intersections. The space required for extra storage lanes for left turn movements, median dividers and road widenings for right turn movements more than double the space requirements for an ordinary intersection. (Fig. 97)
ADDITIONAL LAND CONSUMPTION BY INTERSECTIONS

FIG. 97
CHAPTER 9:
THE IMPACTS OF TRANSPORTATION ON THE DENSITY DISTRIBUTION OR URBAN ACTIVITIES.
Transportation through its influence on accessibility and land value pattern does not only have an effect on the location of activities, but also on the intensity at which these activities locate. This chapter therefore discusses the impact of different transportation technologies on density distribution within an urban area. Impacts are examined on a macro level as well as a micro level. On the other hand it also becomes apparent that density through the factors of trip generation and trip length has a strong influence on transportation and dictates the type, amount and location of transportation facilities required.
Whereas in the previous chapter we tried to identify how transportation influences the location of activities, this chapter will examine the influence of transportation as to the intensity at which these activities locate within the urban area.

A. A COMPARISON OF AVERAGE CITY DENSITIES

Considering densities on a global basis, we discover wide differences. Especially differences between North American and European cities are quite striking.

The six leading U.S. and Canadian cities have an average density of approximately 14,000 people per square mile compared with a density of about 23,000 persons/square mile in eleven worldwide cities. (See table below).

<table>
<thead>
<tr>
<th>World Area</th>
<th>Central City</th>
<th>Year</th>
<th>Population (sq.mi.)</th>
<th>Density (persons/sq.mi.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. and Canada</td>
<td>New York City</td>
<td>1960</td>
<td>7,781,984</td>
<td>24,697</td>
</tr>
<tr>
<td></td>
<td>Chicago</td>
<td>1960</td>
<td>3,550,404</td>
<td>15,836</td>
</tr>
<tr>
<td></td>
<td>Los Angeles</td>
<td>1960</td>
<td>2,479,015</td>
<td>5,451</td>
</tr>
<tr>
<td></td>
<td>Philadelphia</td>
<td>1960</td>
<td>2,002,512</td>
<td>15,743</td>
</tr>
<tr>
<td></td>
<td>Detroit</td>
<td>1960</td>
<td>1,670,144</td>
<td>11,964</td>
</tr>
<tr>
<td></td>
<td>Montreal</td>
<td>1956</td>
<td>1,109,439</td>
<td>23,525</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td>3,098,916</td>
<td>14,215</td>
</tr>
<tr>
<td>Other</td>
<td>Tokyo</td>
<td>1960</td>
<td>9,124,217</td>
<td>44,078</td>
</tr>
<tr>
<td></td>
<td>Greater London</td>
<td>1960</td>
<td>8,210,000</td>
<td>11,377</td>
</tr>
<tr>
<td></td>
<td>Shanghai</td>
<td>1953</td>
<td>6,204,000</td>
<td>17,982</td>
</tr>
<tr>
<td></td>
<td>Osaka</td>
<td>1960</td>
<td>5,158,010</td>
<td>41,935</td>
</tr>
<tr>
<td></td>
<td>Berlin</td>
<td>1960</td>
<td>4,244,600</td>
<td>12,339</td>
</tr>
<tr>
<td></td>
<td>Buenos Aires</td>
<td>1955</td>
<td>3,575,000</td>
<td>48,310</td>
</tr>
<tr>
<td></td>
<td>London</td>
<td>1948</td>
<td>3,339,000</td>
<td>28,538</td>
</tr>
<tr>
<td></td>
<td>Bombay</td>
<td>1960</td>
<td>3,000,000</td>
<td>100,000</td>
</tr>
<tr>
<td></td>
<td>Rio de Janeiro</td>
<td>1955</td>
<td>2,900,000</td>
<td>48,333</td>
</tr>
<tr>
<td></td>
<td>Calcutta</td>
<td>1961</td>
<td>2,926,498</td>
<td>74,200</td>
</tr>
<tr>
<td></td>
<td>Paris</td>
<td>1955</td>
<td>2,850,000</td>
<td>19,388</td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td>4,684,666</td>
<td>23,338</td>
</tr>
</tbody>
</table>

Source: 67
The greatest densities as would be anticipated are found in Asiatic and Latin American cities. It should, of course, be realized that there is no consistent definition of central city limits and that this variability can influence density values and comparisons.

B. DENSITY DISTRIBUTIONS WITHIN URBAN AREAS

So far we have only discussed densities expressed as averages over total urban areas. However, activities within an urban area are not distributed equally, but rather show considerable variations. In fact, the way in which densities are distributed throughout the urban area seriously influences travel patterns throughout the entire area and it is important to obtain some background information on the internal distribution patterns within the urban area.

In order to do this, we shall use the method of gradient analysis, first employed in this context by Colin Clark. In order to measure the density distribution within an urban area, a series of concentric rings about the center of the city are drawn, generally at each mile radius. (Fig. 98). Total population within each ring was calculated and hence average density was computed. Where these circles cut the boundaries of the census tracts or other administrative divisions by which the original data were classified, arbitrary apportionments of population had to be made. This was done in proportion to the area of the tract lying in each ring, after known open spaces had been excluded. After the detailed analysis of more than 100 cities, Clark came up with the following findings: "In every large city, excluding the
central business district, which has few residents, we have
districts of dense population in the interior, with density
falling off progressively as we proceed to the outskirts of
the metropolitan area. Furthermore this falling off of
density follows a simple mathematical equation of exponen¬
tial decline and can be expressed as follows:

\[ y = A \cdot e^{-bx} \]

Source: 69

where \( x \) = distance in miles from the center of the city
\( y \) = density of resident population in persons/acre
\( A \) = density at the center of the city
\( b \) = rate of decline of density
\( e \) = basis of natural logarithm.

The coefficient \( b \), which differs widely, can best be con¬
sidered as a measure of spread within a city. A high value
b means that density declines sharply with increasing distance from the center, i.e., we find a compact city. A low value means that density declines more slowly and the city is more spread out.

If a metropolitan area is to have a high total population, it must either put up with a considerable degree of overcrowding in the inner areas, or it must spread itself out; this is the verbal expression of the mathematical formula given before. Spreading out, however, is only possible where transport costs are low in relation to the citizens' income. Thus we can at once see the two basic possibilities for city development, if the population is increasing: either transport costs are reduced, enabling the city to spread out; or they cannot be reduced in which case density has to increase at all points. In the former we get a diagram of two intersecting lines; in the latter case two lines more or less parallel. (Fig. 99).

This becomes especially clear when we draw on one diagram the density distributions for one city at different points in time. Fig. 100 displays the development of the London and Chicago density curves throughout time. Both cities show the same pattern. The 19th century curves are all steep and central densities are high. The cities are very compact. In the 20th century we notice that the slopes of the curves become less steep, central densities drop and the density peak moves away from the city center. The cities spread out.
TRANSPORT COSTS CANNOT BE REDUCED

TRANSPORT COSTS CAN BE REDUCED

IMPACT OF TRANSPORTATION ON DENSITY DISTRIBUTION

SOURCE 70
FIG. 99
The following table describes this relation in terms of Colin Clark's parameters:

### CENTRAL DENSITIES AND DENSITY GRADIENTS IN CHICAGO,*1860-1950

<table>
<thead>
<tr>
<th>Decennial Census</th>
<th>Central Density A</th>
<th>Density Gradient b</th>
<th>Decennial Census</th>
<th>Central Density A</th>
<th>Density Gradient b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1860</td>
<td>30.0</td>
<td>0.91</td>
<td>1910</td>
<td>100.0</td>
<td>0.36</td>
</tr>
<tr>
<td>1870</td>
<td>70.8</td>
<td>0.87</td>
<td>1920</td>
<td>73.0</td>
<td>0.25</td>
</tr>
<tr>
<td>1880</td>
<td>96.6</td>
<td>0.79</td>
<td>1930</td>
<td>72.8</td>
<td>0.21</td>
</tr>
<tr>
<td>1890</td>
<td>86.3</td>
<td>0.50</td>
<td>1940</td>
<td>71.1</td>
<td>0.20</td>
</tr>
<tr>
<td>1900</td>
<td>100.0</td>
<td>0.40</td>
<td>1950</td>
<td>63.7</td>
<td>0.18</td>
</tr>
</tbody>
</table>

* Urbanized area.

Source: 71

One explanation of this phenomenon can be found if we replace the distance relationship by a travel time relationship. Fig. 101 shows the change in coverage of area as a result of changes in transportation technology. In other words, through the changes in transportation technology and as a consequence of the increase in travel speed the distance that could be covered within the same amount of time (e.g., 30 minutes) is constantly expanded.

Thus it becomes possible to locate at a more and more increasing distance from the city center (as the center of gravity of work places). Omnibuses and horse cars which traveled at a rate of 6 miles an hour instead of a walking pace of 3 miles an hour doubled the radius of settlement. Cable cars in the 1880's with a speed of 12 miles an hour, doubled the radius again along trunk lines. Suburban
RESIDENTIAL POPULATION DENSITIES IN LONDON AND CHICAGO

SOURCE 72

FIG. 100
steam railroads and elevated electric lines, traveling at 25 - 30 miles an hour again doubled the radius of settlement along their routes. The universal adoption of the automobile with a possible speed on freeways of 60 miles has enabled the worker to go 20 times farther in an hour than he could in 1840.

The effect of doubling the radius of the settled area, if the settlement is carried out to a full circle, is not merely to double, but to quadruple the original area. Therefore, as the increased speed of transportation has tapped a widening area on the outer edge of the city, the amount of land available has increased at a rate greater than the increase
in the length of track. The amount of new land, however, has not increased by the square of the distance added by the new lines, because the supply of land so added has been confined to belts along the lines themselves. Only the use of the automobile with its unlimited coverage of area was able to overcome this in the last 30 years.

"Urban maturity" also appears to influence city composition. When the year that central cities first reached 350,000 people is plotted against 1950-60 central city densities, there is a general consistency (Fig. 102). Cities that reached 350,000 inhabitants between 1830 and 1890 (before the advent of the street railway) generally had the highest densities, whereas cities that reached 350,000 between 1930 and 1960 (the automobile era) generally had the lowest densities. Thus city age reflects nothing but the effect of the mode of transportation prevailing at that time.

However, the mode of development and building at different points in time also has to be taken into account. Older cities built with small lots and subdivisions will have higher densities than cities built at other times with other modes of subdivision. Furthermore, the controlling influence of timing of development on subsequent form has to be noted. According to K. E. Boulding's first principle of structural growth, "At any moment the form of any object, organism or organization is the result of its laws of growth up to that moment. Growth creates form, but form limits growth."

Different influences on the pattern of development at
different times and the resultant structure of the city sets limits on its subsequent growth. In this way the timing of growth affects the density patterns. Fig. 103 displays the density distributions for various cities throughout Europe and North America. A comparison among those cities demonstrates the truth of the above paragraph. We see how cities built according to a certain law of growth 100 years ago still are influenced by it today.
COMPARATIVE POPULATION DENSITY DISTRIBUTIONS

SOURCE 75
FIG.103
Finally, some remarks have to be made about the contrasting changes in Western and non-Western cities. Whereas in the Western central cities central densities rise and then fall, in non-Western cities they register a continual increase. In the West density gradients fall as cities grow; in non-Western cities they remain constant. (Fig. 104).

Colin Clark identified transportation as the determinant of this drop in the density gradient. Transportation may have been the factor to allow it to happen, but the real reason has to be sought on the demand side. The western world has experienced a revolution in levels of living such that the richer, more mobile groups have increased not only numerically but also proportionally. Hence accelerated sprawl facilitated by improved transportation systems has been stimulated by greater demands for peripheral lower density land with consequent reductions of the density gradient. The western world has experienced significant changes in the nature of demand for residential land. Changed transport systems have merely ensured an
adequate supply to meet the demands.
If in Western cities the poor live at the center and the more mobile rich at the periphery, in non-western cities the reverse is true. The least mobile groups occupy the periphery. Any income improvements lead to greater demands for central locations and increased overcrowding sprawl reflects projection of the overall surface outward as densities increase throughout.
In spite of reductions of transport costs in non-Western cities, the groups located where the possibilities of savings are greatest are the groups least able to take advantage of the possibilities. Changes on the supply side occasioned by transport improvements are of little utility. Differences in movements of central densities and density gradients throughout time rather are a function of the inverted locational patterns of socio-economic groups within Western and non-Western cities and consequent contrasts in demands for residential land.

C. IMPACTS OF LINES OF TRANSPORTATION ON DENSITY
Transportation not only influences the distribution of activities on a macro scale, but also on a smaller, more limited scale along major corridors and lines of transportation. Once again we shall use the example of the Gulf Freeway in Houston and describe the density pattern that we find within a mile wide band centered on the freeway, by a longitudinal as well as a cross sectional graph. The longitudinal section shows the same general trend which
Colin Clark's density curves reveal: a decline of residential density with increasing distance from the central business district. But looking at the time series between 1940 and 1960 we also discover continually rising densities along the freeway after the beginning of construction in 1945. (Fig. 105). Although we saw that a transportation facility cannot produce growth, this example demonstrates that a major transportation facility like a freeway has great influences in redistributing growth within an urban area through its influence on the pattern of relative accessibility.

The cross-sectional graph (Fig. 106) on the other hand shows that residential density is not distributed uniformly within the mile band. Rather we discover that residential density tends to reach a peak at some distance from the freeway facility. This displays the tendency of residences to locate at places that guarantee good access to the facility, yet avoid its negative impacts in terms of noise and pollution. It is needless to say that work places probably would show the opposite pattern: a peak directly at the freeway and decreasing as distance from the facility increases. Unfortunately this cannot be demonstrated quantitatively since census data by place of work are not collected by the U. S. Census.
DENSITY DISTRIBUTION ALONG THE GULF FREEWAY

SOURCE 77
FIG. 105
CROSS-SECTIONAL DENSITY DISTRIBUTION ALONG THE GULF FREeway IN 1960

SOURCE: 77

FIG. 106
D. THE IMPACT OF DENSITY ON TRANSPORTATION

So far we have concentrated on the discussion as to the intensity of land use that various transportation systems stimulate. Yet there are also important effects that land use intensity has on transportation.

There is an especially close similarity between density and per capita trip generation. In almost every case overall trip generation decreases as cities become more dense. This is because in densely populated central cities many trips are made as pedestrians.

Other reasons for lower trip generation in high-density areas are low car ownership and low incomes. Both factors correlate with low rates of trip generation.

The effects of central city density on automobile availability are shown in Fig. 107. The availability on one car remains relatively constant at all density levels; however, multiple car ownership decreases as density rises, with a corresponding increase in the proportion of households with no automobiles available.

Furthermore, the implications of density on trip length are apparent: an increase in density could reduce average trip lengths and vice versa.

Perhaps the most significant effect of density on urban travel is the close correlation between high density and high usage of public transportation. Transit depends on spatial and temporal concentration of movements. Densities
of 14,000 persons/square mile and more seem to be necessary for the operation of rapid transit. The greater spread of the population reduces the number of people within easy walking distance and hence potential to transit. Finally, population density obviously affects the density of trip origins, and hence the spacing of transportation corridors and demands. For example, where densities are greatest, freeway systems are spaced the closest. Based on the criterion of one freeway mile per 10,000 persons, it is difficult to provide desired capacities, where substantial areas of central cities exceed 20,000 persons/square mile. Area requirements also increase as densities get greater.
Based on the above criterion 5 - 6% of all urban land would be devoted to freeways at an overall density of 10,000 persons/square mile. Over 10% of all land would be used by freeways when densities exceed 18,000 persons/square mile.
CHAPTER 10:

THE IMPACT OF TRANSPORTATION ON URBAN FORM.
Considering the joint effects of location and density a physical urban form evolves. Using the tool of a mathematical model, Chapter 10 discusses the impact of alternative transportation systems on urban form. It becomes evident that transportation, although it is a very strong force, is not the only force influencing urban land development.
Whereas the previous two chapters were concerned with how transportation influences the choice of location and density at which urban functions settle, this section tries to identify the impacts of transportation on city shape. During the discussion of Alonso's Model of the Urban Land Market, we have seen that a site goes to that activity which can best use it, in the sense of realizing from its use the highest material return. Other activities that are outbid have to locate further away at sites characterized by higher transportation costs but lower land costs. Thus, the transportation system to repeat is a means of substituting one place for another.

As transportation systems differ in their design and these designs differ in their substitution effect, the spatial pattern of activities differs. Where there is one big center and transportation efficiency is equal in all directions, the rate of substitution is also equal and the prevailing form of the city will, theoretically, be circular. (Fig. 108)

If we provide superior transportation services along a few of the routes, a simple radial reform results. (Fig. 109).
We can identify high ridges of development along these routes and there is less demand for the area between them which results in interstices of vacant land. This pattern basically would be generated by a street car system, where stations are close together, resulting in continuous access conditions along these radial lines.

As mentioned before, those ridges of high intensity of development will be continuous if access to these routes is continuous; otherwise it will concentrate at points of superior access. In this case, the prevailing spatial pattern of the activities will be not merely radial, but also nodal. (Fig. 110). This is the kind of form which a subway system or to a lesser degree a radial freeway system is likely to induce.

But variations in network configurations are not the only influence which transportation has on city form. Another
one that has to be mentioned is network speed. A prototype model developed by Morton Schneider demonstrates those relationships.

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

\[ R_f = R_P \cdot \frac{R_a \cdot I}{J-R_P \cdot I} \]

where

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

For his experiments Schneider used a very simple region consisting out of 49 one mile square zones, in which all zones were equally attractive and connected to a single network. The speed of the network was then varied from 0.1 to 100 miles per hour.

[FIG 111] Development pattern for population of 20,000 served by uniform network with a speed of 0.1 mph.

At a speed of 0.1 miles per hour the development pattern is
completely flat and shows no trace of central tendency. Because access is so very poor, there is no position within the region that has any significant advantage over any other position. (Fig. 111).

Figure 112 shows the development that results when the speed is increased to 10 miles per hour. There is some tendency for higher development in the center and lower development at the edges of the region.

At a speed of 100 miles per hour each zone is so easily reached that again there are no significant accessibility differentials in the region and development is essentially flat. (Fig. 113)

After we have experienced the impact of different network speeds on city form, we also have to direct our attention to the fact that a transportation system does not only consist
out of one network, but that there are several modes with overlapping networks which all complete with each other and have their effects on urban form by the way they redistribute people within the urban area. The following graphs will illustrate this relation.

**FIG 114** Development pattern for population of 20,000 served by transit network with a speed of 20 mph.

**IMPACT OF COMBINATIONS OF MODES ON LAND DEVELOPMENT**

First two networks were used: a public transportation system operating at 20 MPH and a fare of 10 cents with a cross-shaped network configuration and a walking mode at 3 MPH available to all zones. The differential accessibility provided by these radial lines results in heavy ridges of development. (Fig. 114).
The next example illustrates the development pattern generated by three modes: a rapid transit line running at a speed of 25 MPH and a 10-cent fare with 5 lines converging on one central point, a bus or street car network with a speed of 15 MPH and a 10-cent fare, and a pedestrian system. (Fig. 115).

Urban development equivalent to a population of 1 million inhabitants was allocated to the region. The resulting pattern of development is shown in Fig. 116. The 5 radial rapid transit lines are prominent.

The surface transit system also appears as a flat platform.
lower than the development in zones without transit service. Finally, we have to remember that most of our cities were not built in one era of transportation technology, but rather are the product of a series of transportation technologies each of which had a distinct impact on city form at the point in time, when it was first introduced.

The following examples demonstrate this relation.

**FIG. 117** Development pattern for population of 750,000 served by transit network.

**FIG. 118** Development pattern for population of 1,500,000 served by transit network.

**FIG. 119** Development pattern for population of 1,500,000 served first by transit then by automobile network.

**FIG. 120** Development pattern for population of 1,500,000 served by automobile network.

**SOURCE** 80

**IMPACT OF DIFFERENT TECHNOLOGIES ON LAND DEVELOPMENT**
In the example of Fig. 117 two transit lines, one running north and south and one running east and west. People could use these facilities for a 10-cent fare and at a speed of 25 MPH, but had to walk to the nearest transit station. Development equivalent to a population of 750,000 was allocated and a distinct pattern of development in the vicinity of the transit lines is visible. Without changing the transportation network twice as much urban development was allocated. (Fig. 118). Again the peaking in zones of high accessibility is quite extreme and illustrates the dense central cities that grew up during the era of the cable cars, elevated lines, subways and commuter railroads.

Then a one mile grid of streets at a speed of 20 MPH and a travel cost of 2 cents per mile was superimposed over the region to symbolize the introduction of the automobile. This network was not introduced before the region had reached the size of 750,000 inhabitants. (Fig. 119)

Although the earlier pattern of central ridges is still apparent, all the new development can be seen to have taken place in the areas now accessible by automobile. The flattening or blunting of the tendency toward high densities by the introduction of the automobile network is quite dramatic. This occurs because new time-distances change potential in every part of the region. A new level of transportation efficiency means a flatter slope, a territorially larger region, a more spread out center and a lower regional
density, assuming of course that the total population increases less than proportionately to the increase in area and that there are no unusual restrictions on space supply.

Fig. 121 illustrates some of the basic relationships between regional center, size of the region, transport efficiency and intensity of development.

RP' represents that range of the region where accessibility will cause future density to exceed present density by a definite amount. For the range represented by the segment OR the reverse is true. Future density will be lower than present density. So you could say that OR is overdeveloped and has to be redeveloped and RP' is underdeveloped, while the greatest change occurs at the points O and P.

Finally, in Fig. 120 it was assumed that an automobile network rather than a transit network was available at the very
beginning of growth in the region and describes the develop-
ment of cities like Los Angeles, Houston and Dallas. There
is some tendency for higher densities to occur in the center
of the region, but the dominant impression is one of a
sprawling, ubiquitous development.
Thus we have illustrated in a striking manner the differ-
ences in urban development patterns that might result under
different transport technologies. However it has to be
stressed that in all these examples the land in each zone
was assumed to be equally attractive. No judgment was made
to suitability, topography, provision of utilities or amenity.
Moreover the transportation systems used in our examples
imply great differences in cost, in quality of social and
cultural life, and, if the metropolitan area is composed of
independent communities, differences in the balance of
economic and political power among these communities.
These considerations, although of high importance, are
beyond the scope of the present investigation. Our main
concern here was to demonstrate the differences in pattern
resulting solely from differences in access.
CONCLUSION

The discussion shows that transportation has a strong influence on the internal organization of a city. However, the approach we have to take is largely empirical and often based on historical evidence. Although transportation seems to be a strong factor in the locational choice of urban activities, it is not the only determinant. So far only very few conclusive methods exist that would allow us to quantify and isolate the impact of transportation from all other locational determinants. Our ability to influence land use patterns through transportation planning consequently still will be rather limited until we have laid a more solid foundation of understanding.
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