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Contents

Measurement of Congestion in Transportation Systems[1]

LOWDON WINGO, JR., Resources for the Future, Inc.

FRAMEWORK OF ANALYSIS

> "Under present conditions congestion is the main obstacle to more traffic. While traffic is not an end in itself, cheap transportation is a contributing factor to the economic division of labor. Ready accessibility of centrally located markets is of particular importance, because it determines the size of markets and the extent to which economies of large-scale production and distribution can be reaped. Congestion, by setting a limit and a premium upon the movement of persons in commodities, restricts the effectiveness with which the functions of centrally located markets can be performed."[2]

● THE EXTENSIVE NETWORK of interaction among urban economic activities depends in large part on the organization and technology of transportation integrating the urban structure. Changes is the conditions of transportation will be reflected in the organization of economic activity throughout the urban space, for these changes make themselves felt as changes in the cost conditions of production and distribution. Where the adjustment of economic activity to the organization of the transportation system is good, one can talk in terms of an efficient organization of the economy and its technology of movement. Where the adjustment is poor, this interaction takes place only under conditions of high and increasing costs. One of the characteristics of poor adjustment has frequently been identified as congestion: the greater the congestion the more inefficient the interaction. Hence, the identification of the congestion element in transportation systems in a matter of interest not only to those who have a responsibility for building and managing a transportation system, such as highway and traffic engineers, but to all of those who have a concern with the economic efficiency of the urban complex. Among these are the students of urban structure and land use, for the external diseconomies associated with transportation systems may well have demonstrable consequences for the structure of land values, for factor payments to labor, as well as for the transfer costs entering into the costs of production. It is in this sense that the phenomenon of congestion in transportation systems commands the attention of the urban economist.

What is congestion? A distinguished mathematical economist, Martin Beckmann, who has analyzed highway traffic with tools of queuing theory and probability models, offers a simple definition: "By congestion we mean here traffic conditions which occur at flows that substantially reduce average speed on the road."[3]

Congestion is a relative phenomenon. It can exist for two vehicles as well as for 20,000; it may last for seconds or for hours. The driver waiting first in line at a toll gate is experiencing the same kind of system phenomenon as if he were the twentieth in line. In short, congestion can exist whenever two or more vehicles seek to occupy the same space simultaneously. In this paper, congestion is defined to be any situa-

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[1] The theoretical formulation of the ingression function in this paper is a by-product of an investigation of characteristics of the urban space-economy carried on by the author as an endeavor of the Program of Regional Studies at Resources for the Future, Inc. The contributions of other staff members are gratefully acknowledged.

[2] From Beckmann, Martin, McGuire, C.B., and Winsten, C.B., "Studies in the Economics of Transportation." Yale University Press, New Haven, p. 95 (1956).

[3] ibid., p. 49

tion between two or more vehicles such that one or more experience a time loss due to the behavior of the others.

The nature of this time loss has some inherent complexities. All time spent in transportation involves time loss; hence, the time loss associated with congestion is a surplus over and above that which would be lost under "normal" circumstances; that is, traveling the same route in the absence of other vehicles. Thus, the congestion time loss has a highly subjective element, since it is related to the propensities of the individual road user. In this sense congestion losses become extremely amorphous when viewed from the standpoint of the road user.

As against a framework which looks narrowly at the transportation system as a unit with certain time-loss characteristics to be evaluated, a different framework which views the transportation system as an abstract physical system with economic characteristics may offer an objective basis for analysis. Although this paper will discuss transportation systems within this special kind of framework, the conclusions will have relevance in a more general sense, and the technique of analysis a general applicability to many of the operating characteristics of transportation systems.

This paper uses the device of constructing an abstract physical model embodying those characteristics which seem relevant to the problem as a whole. The behavior of such a model should identify certain features of the abstract system which are general for all real cases having the same basic characteristics as the abstract system. The objective is to identify congestion characteristics which are innate in the system and which do not emerge because of the peculiarities of the specific case.

That movement element which in terms of order and relative volume is the most significant in any urban movement system—the journey-to-work—will be abstracted. The volume and distribution of this element is a function of the locally employed labor force, the spatial arrangement of employment centers, and the time-distribution of its working periods. Where the employed labor force is a greater proportion of the population in one case than another, "caeteris paribus," the volume of this movement component will tend to be proportionately greater; likewise, where a locality operates on a single working shift, or where the places of employment are spatially concentrated, relative volumes will tend to be greater than where employment is organized on multiple shifts, where work periods are substantially staggered, or where employment centers are relatively dispersed. Thus, the variables involved in the demand for movement with respect to the journey-to-work are essentially variables arising from the economic organization of production in the community.

There is one important distinction. The volume of movement in this parlance is a quantitative measure based on the "trip" as the basic unit. Movement, for the present purpose, has no spatial significance; a trip which is a block long has the same value as one which is 10 miles long. The volume of transportation relates the volume of movement to a spatial framework. In its most general form a movement system has the following characteristics:

1. It involves a set of spatially distributed origins (analogous to the domiciles of the employed population);
2. It involves an aggregative destination, or assembly point (as in the places of employment of the employed population);
3. It involves a set of paths having specific capacity characteristics, connecting the origin and assembly points, and a set of carriers. (Here a distinction might be made between simple and complex paths, the former being a path on which the carriers cannot change order, as in the case of a single track rail line. Simple and complex carriers may be distinguished in that a simple carrier is associated with a single, discrete origin-destination pair of points. Under the assumption that the system as a whole operates at capacity velocity, complex paths have the same characteristics as simple paths and complex carriers are ruled out.) With respect to carriers and paths a system may be homogeneous, wherein all carriers and paths would have uniform movement characteristics, or heterogeneous, in which case there would be two or more subsystems (each homogeneous within itself) each serving the same movement demand, but each of which has different movement characteristics in terms of paths and movements.

4. Finally, the movement system is rigorously time-ordered in the following respects:
   a. There is a highly ordered schedule of assembly periods which gives the movement system the characteristics of a cyclical character; and
   b. Each cycle is time-constrained such that all units are required to arrive not later than the scheduled time or deadline, and all are released simultaneously in the ebb movement.
5. Time is valuable to all units.

FIGURE 1

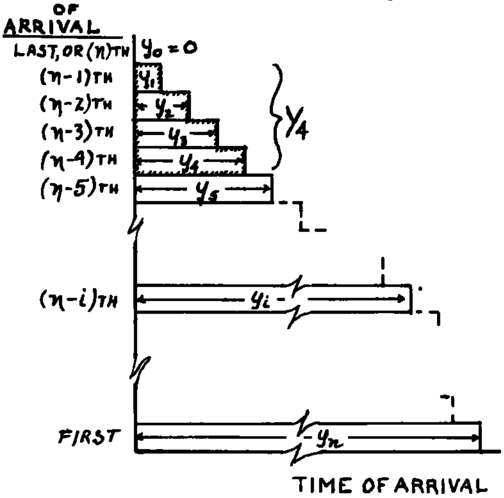

Figure 1.

With these few characteristics some of the relevant features of a highly-ordered, high-volume, simple homogeneous system can be appraised. Are there features of a movement system abstracted from spatial considerations which have implications for the analysis of congestion? There are, in fact, and these implications are associated with a phenomenon which has been called the ingression factor.

NATURE OF INGRESSION LOSSES

Ingression is a condition that exists in movement systems when the instantaneous demand on the system exceeds its instantaneous capacity; that is, when the number of units required to arrive at a given point not later than a given time is greater than the ability of the system to admit said units simultaneously. Ingression losses, then, are time losses imposed on units in the system by the inability of the system to handle all demanding units at the same time.

To illustrate how these losses take place, Figure 1 is based on a simple system (with an instantaneous capacity of 1). In this case, there are n units all of which must arrive at the assembly point not later than the deadline of T o'clock. If the last (or nth) arrival is to meet the deadline, then the next-to-last or (n - 1)th must arrive slightly before it. If the capacity of the system is represented as C units per hour, the (n - 1)th unit must arrive 1/C hours befor the nth unit. Thus in Figure 1 the ingression loss experienced by the (n - 1)th unit is measured by $y_1 = 1/C$; that of the (n - 2)th unit by $y_2 = 2/C$; and that of the first unit by $y_n = n/C$. The total ingression loss of the last five units can then be expressed as the sum of the ingression losses for each unit, or

$$Y_i = \Sigma y_i, \quad (i = 0,\ 1,\ 2,\ 3,\ 4)$$

$$= \frac{0}{C} + \frac{1}{C} + \frac{2}{C} + \frac{3}{C} + \frac{4}{C} = \frac{10}{C}\ .$$

Letting N stand for the number of units making demands on the system the following can be generalized (see mathematical Appendix B-1):

$$Y = \frac{N(N - 1)}{2C}\ ,$$

in which Y = total ingression loss for the inflow[4] phase of the cycle.

[4]By reversing the demonstration, it can be shown that the ingression loss of the outflow phase is equal to that of the inflow phase. Hence, the term "phase ingression loss" refers to the loss associated with a single phase, whether it be of an inflow or outflow character. "Cycle ingression loss" refers to the total loss of an inflow and an outflow movement.

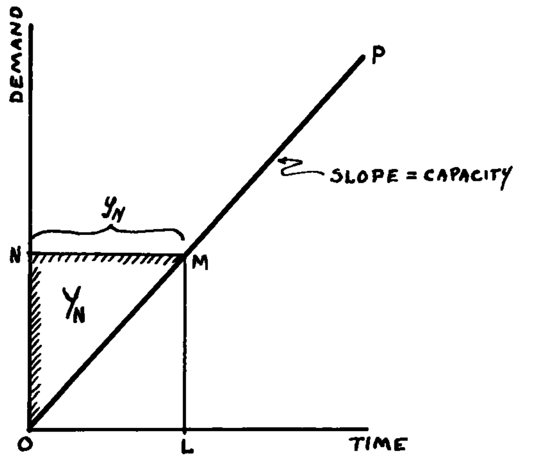

Figure 2.

Where Figure 1 relates the order of arrival to a time scale, in Figure 2 the total deadline demand on the system n is related to a time scale. Here the slope of the line OP represents the capacity of the system. Thus, for N units of demand on the system the first unit must arrive OL time units before the last if the last is to satisfy the time restraint. The total phase ingression loss for the system, then, is measured by the area of the figure OMN. It can be shown accordingly that for any large value of N, the total phase ingression loss Y is approximately equal to $N^2/2C$. In short, as demand increases in the system the total phase ingression loss tends to increase by the square of the demand (see Fig. 3).

Another important feature emerges in the relationship between the marginal ingression loss Y'_N and the average ingression loss $\bar{y}$. If random entry into the system as far as order is concerned can be assumed, over a large number of cycles the average loss to any one unit will tend to approximate the average loss in the system. The marginal phase ingression loss is the change in the total phase ingression loss effected by the entry of the Nth unit into the system. Mathematically, it can be defined for large values of N and C approximately as follows:

$$Y'_N = \frac{dY}{dN} = \frac{N}{C}$$

the average phase ingression loss can be defined as

$$\bar{y} = \frac{Y}{N} = \frac{N}{2C}$$

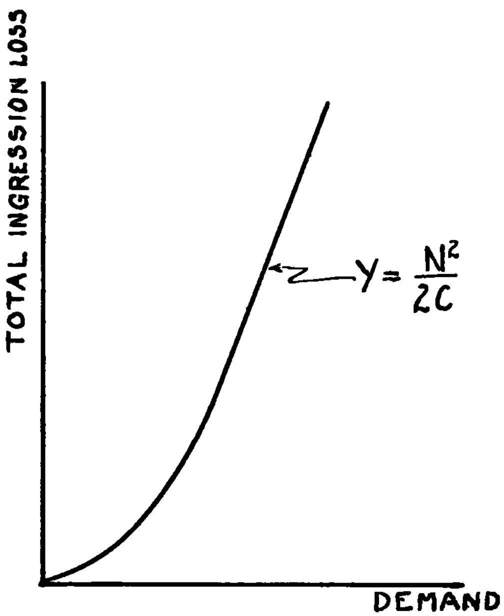

Figure 3.

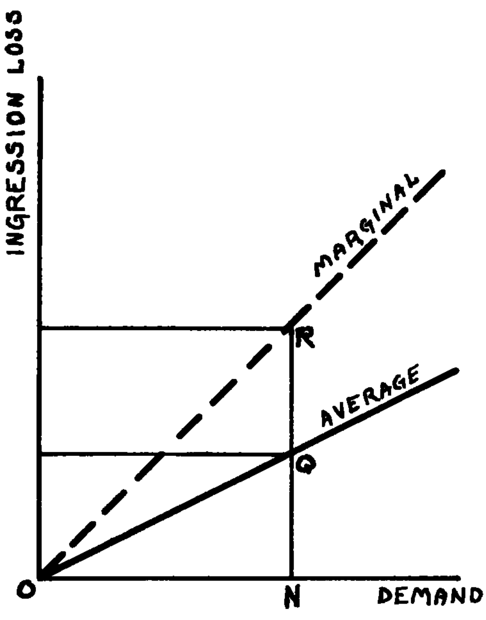

Figure 4.

In Figure 4, the marginal and average phase ingression functions are plotted in terms of total demand N. The entry of the Nth unit into the system, hence, imposes an additional phase ingression loss on the system equivalent to NR, of which the average phase loss QN tends to be borne by the Nth unit over a large number of cycles, while the loss QR is borne by all of the other units in the system. Thus, QR is a pure external diseconomy for all units in the system. Since OR has twice the slope of OQ, then for any value of N, NQ = QR; that is to say that the entry of another unit will tend to impose losses on the remainder of the system equal to the phase ingression loss borne by the marginal unit.

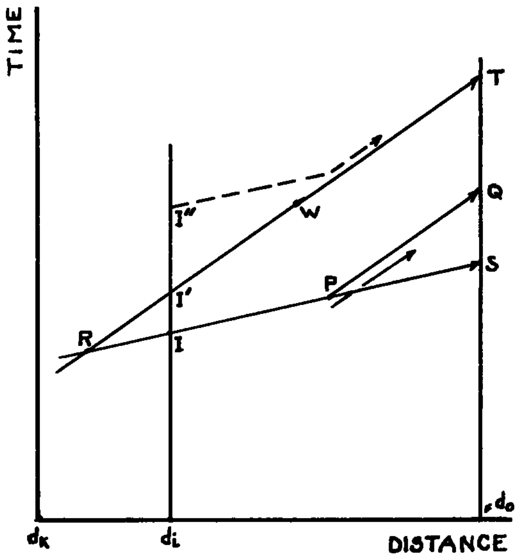

Figure 5.

RELATIONSHIP OF INGRESSION TO CONGESTION

Both ingression and congestion arise from the relationship of the deadline demand upon a system and its capacity. They are thus related phenomena. Ingression is a form of loss which exists in any movement system when instantaneous demand exceeds instantaneous capacity, even when the system is operating at maximum efficiency. In short, given the technology of the system, the ingression function represents the irreducible minimum of time loss resulting from the aggregation of demand.

Congestion losses on the other hand, are time losses which arise from the reduction of the "free-flow," or desired, velocity imposed on a unit because of the behavior of other units in the system. In a "saturated" transportation system where passing opportunities are rare or nonexistent, the movement of all units will approach a uniform flow condition whose velocity is dictated by the slower speeds of the early entrants. This system-dominant velocity may very well be less than the capacity velocity of the system (see Appendix A).

Figure 5 is a time-distance chart based on a simple uniform transportation system of length d_k. T is the deadline at destination d_o. RT is the movement course for any unit moving at system-dominant velocity to arrive at T. A unit domiciled at d_i with a free-flow velocity represented by the slope of RI will determine a point S on the time axis which will represent his deadline if he were to be the first arrival. Hence, IS represents the ideal movement course if conditions permitted him to move at his desired velocity to arrive at d_o first. The course I'T, whose slope represents the system-dominant velocity, is the "latest" course that the unit would tend to follow, for if he began later, say at I", planning to catch up to this terminal travel course by moving initially at his desired velocity, he risks finding the course occupied by a unit entering, say, at W, forcing him to violate his deadline. Under the best of the "safe" conditions, course IS could be realized, in which case the period ST can be defined as the realized ingression loss for this unit for this phase, and there would, hence, be no congestion loss. At the latest I'T would be followed, in which case ST would represent the congestion loss and there would be no actual ingression loss realized. In general, a course such as IPQ would probably be characteristic, where the unit moved at desired velocity until it encountered a slower unit at P, where it was forced to reduce velocity to that of the encountered unit, which might be the end unit of a uniform flow queue. In this case, SQ would represent direct congestion loss, while QT would represent realized ingression loss.[5] In this example, it can be seen that congestion losses and realized ingression losses tend to be complementary. In conclusion, the maximum potential phase (ST - II') ingression loss can be continued as a measure of the congestion potential in this simple example.[6]

How much congestion will be realized in any one circumstance will be a product of the departure-velocity decisions of all units in a given demand situation. To the extent that these decisions appear to have a random nature within the opportunity limits, the actual emergence of congestion in a transportation system will have certain random characteristics which make it difficult to anticipate in time and space, given the present state of understanding.[7]

It will be noted that the ability of a unit located at d_i to select a course is restricted by the pattern of decisions made by units beyond d_i on the system. Once selected, his ability to realize that decision will be limited by the decisions of units between d_i and d_o (as illustrated by the situation at P in Figure 5, where the path is deflected from PS to PQ because of the behavior of a succeeding unit).

A final point involves the relation of ingression to that form of congestion which results from variations in capacity at points along a system. As in a hydraulic system it is the size of the least pipe that determines the rate of flow at the delivery point, so in a transportation system the flow capacity is a function of the least capacity in the system, and its location with respect to the distribution of demand. Up to this point movement systems have been discussed as though capacity were uniform over the length of the system. This posits a uniform, constant-velocity flow. Since this rate of flow may be less than the desired rate of movement for the individual units, this may be defined as a congested situation, and in this sense one can talk about subjective congestion. Now where capacity at all points along the system is not uniform, in other words, where there are capacity "chokes" in the system, objective congestion loss can be defined as that loss which occurs in a movement system at a point where capacity is less than that in the preceding segment of the system. Here the rate of flow is diminished and units tend to queue up, expending time waiting entry through the constricted part of the system.

The intimate relationship between the concept of ingression and objective congestion loss is vividly illustrated in the following excerpt from the Washington Post of November 18, 1958:

> ". . . AEC has its own daily traffic tie-up which an employee describes as one of the most exasperating periods in each day. Up to 700 cars jockey for position on AEC's lone access road leading to Route 240. The employee said it had taken him twenty minutes the night before to get from the parking lot to Route 240, the usual time was from 12 to 15 minutes . . . ."

This is both an ingression and a congestion phenomenon. The over-all capacity of a system is governed by the least capacity at any point. These capacity chokes give rise to a pure form of congestion loss which occurs at any point where capacity is less than that in the preceding segment of the system. Here the rate of flow is diminished and units queue up waiting entry through the choke.

If the rate of approach of units to the choke could be managed, the congestion loss at the choke could be eliminated. At the other extreme, units may approach the choke

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[5] Less, of course, the period II', which would not be absorbed in the movement.

[6] The relationship between ingression and congestion is basically a matter of whether or not the loss resulting from the capacity-demand relationship takes place within or outside of this system.

[7] Here the systemic congestion of the above discussion should be distinguished from externally-caused congestion. A traffic accident or a vehicle breakdown can obstruct the flow of units and create a seriously congested situation. Such interruptions are external to this consideration and hence do not enter into the concept of congestion potential.

at the approach capacity. If a system has a capacity choke, the total ingression in the system is computed in terms of the capacity limits set by the choke:

$$Y_c = \frac{N^2}{2C_c}$$

in which

Y_c = total ingression at choke capacity,

C_c = choke capacity.

In the absence of the choke, total ingression would be set by the approach capacity:

$$Y_a = \frac{N^2}{2C_a}$$

in which

Y_a = total ingression at approach capacity,

C_a = approach capacity.

Then the total ingression loss attributable to the choke itself must be the difference between these two ingression levels:

$$X = \frac{N^2}{2C_c} - \frac{N^2}{2C_a}$$

$$= \frac{N^2}{2}\left(\frac{1}{C_c} - \frac{1}{C_a}\right) = \frac{N^2}{2}\left(1 - \frac{C_c}{C_a}\right)$$

in which X = the ingression loss attributable to the choke.

As previously observed, ingression loss at a capacity choke takes place in the form of vehicles queuing up awaiting entry through choke, and hence X is actually a direct measure of a congestion time loss resulting from the capacity impairment. The com-onent $(1 - \frac{C_c}{C_a})$ is of interest because it defines the proportion of the total ingression loss of the system which will take place at the choke. Henceforth it will be referred to as the choke coefficient k, and it can be thus shown that the total length of the maximum queue Q at the choke, and the total congestion time loss X at the choke are functions of the choke coefficient q and the deadline demand N:

$$X = \frac{kN^2}{2}$$

and $Q = kN$,

for all large values of N.

To illustrate this point, a path with a uniform capacity of 2,000 vph on which there is a simple deadline demand of 1,000 vehicles may be examined. Assume that the full demand is asserted at the beginning of the path and is destined for the terminus of the path. Now assume, (1) that there is a capacity choke in the path (e.g. a signalized intersection) which will pass vehicles on the path only 75 percent of the time, and (2) that at the terminus vehicles can be evacuated from the path at a maximum rate of 1,200 vph. (As though it were a second capacity choke.) At the most general level this is a simple system with a total capacity of 1,200 vph, developing a total phase ingression computed as follows:

$$Y = \frac{N^2}{2C_c} \quad (1)$$

$$Y_c = 1{,}200 = \frac{1{,}000^2}{2{,}400} = 416.67 \text{ hr} \quad (2)$$

where the capacity for the total system is set by the least capacity of any point. If there were no chokes and the path capacity dominated, the ingression level would be computed thus:

$$Y_a = 2{,}000 = \frac{1{,}000^2}{2 \times 2{,}000} = 250 \text{ hr.} \tag{3}$$

The net result of the two chokes is to increase the total phase ingression by 166.67 hr.

Now congestion time loss X_1 at the first choke can be determined by taking the indicated ingression at the choke capacity and multiplying it by the choke coefficient k_1, where

$$k_1 = (1 - \frac{C_1}{C_a}), \quad C_1 < C_a \tag{4}$$

in which

C_1 = choke capacity of the first choke,
C_a = approach capacity to the first choke.

Then

$$X_1 = k_1 Y_1, \tag{5}$$

or,

$$X_1 = \frac{N^2}{2C_1}(1 - \frac{C_1}{C_a}) = \frac{N^2}{2}(\frac{1}{C_1} - \frac{1}{C_a}),$$

in which

N = deadline demand,
Y_1 = indicated ingression at first choke capacity.

The approach capacity to the second choke is set by the choke capacity of the first. Hence the choke coefficient for this second choke k_2 would be defined thus:

$$k_2 = (1 - \frac{C_2}{C_1}), \quad C_2 < C_1 \tag{6}$$

in which

C_2 = choke capacity of second choke,
C_1 = choke capacity of first choke,

and congestion time loss X_2 defined

$$X_2 = k_2 Y_{C_2}, \tag{7}$$

$$X_2 = \frac{N^2}{2C_2}(1 - \frac{C_2}{C_1}) = \frac{N^2}{2}(\frac{1}{C_2} - \frac{1}{C_1}).$$

Then the total congestion time loss at both chokes X is defined as

$$X = X_1 + X_2$$

$$X = \frac{N^2}{2}[(\frac{1}{C_1} - \frac{1}{C_a}) + (\frac{1}{C_2} - \frac{1}{C_1})] = \frac{N^2}{2}(\frac{1}{C_2} - \frac{1}{C_a}). \tag{8}$$

Coming back to the example

N = 1,000
C_a = 2,000
C_1 = 1,500
C_2 = 1,200

It can now be computed that the total congestion time loss X imposed by the two chokes is X = 166.67 hr or an average of 10 min per vehicle. It can further be computed that this congestion loss is divided between the two choke effects;

$$X_1 = X_2 = 83.33 \text{ hr}$$

or 5 min per vehicle average.

This total congestion loss figure of 166.67 hr is identical with the additional ingression loss computed earlier. Thus the total loss in a system is equal to the computed ingression at path capacity plus the objective congestion loss set by successive restrictions in capacity in the direction of movement. This formulation applies to the perfectly managed (maximum efficiency) system. It is the minimum level of loss. Inefficiencies resulting from behavior of units are external to this system, and would hence increase the actual level of loss experienced.

Under this simple formulation, the kind of congestion quantified is that which results from successive restrictions on capacity in the direction of movement.

When capacity is uniform throughout (that is, where $C_a = C_1 = C_2$, etc.), no system congestion loss is defined (the ingression loss is still very real, however).

(Note an interesting conclusion from Eq. 8, a project to eliminate the capacity restraint imposed by the first choke would not change the total quantity of congestion loss in the system; it would merely shift it to the second choke.) In short, the actual objective congestion loss at a capacity choke will lie somewhere between zero and X as defined above, and will vary with the rate at which units approach the choke. Congestion loss at this point will be greatest when the approach flow approximates approach capacity; it will be zero when the approach flow is equal to or less than the choke capacity. Here again, the entry decisions of the individual units will determine the scale of congestion within the limits indicated. Here ingression analysis provides directly a measure of congestion potential.

Thus, two features stand out: (1) in the most ideal of transportation systems the occurrence of congestion resulting from unit behavior may be a sporadic, almost random event, but (2) ingression has a direct relationship to the objective congestion potential in the system. Even though some forms of congestion are sporadic and unpredictable, ingression is a determinable, functional characteristic of a movement system emerging solely from the technology of the system as it influences capacity and from the time-distribution of demands on the system. In short, even though the quantitative prediction of congestion resulting from the chance behavior of units in the system appears unfeasible at this stage of knowledge, the prediction of objective congestion potential as measured by ingression is a comparatively simple matter.

Throughout the remainder of this paper ingression will be considered a feature of an ideal movement system, and in this sense, ingression represents the residual congestion potential in any transportation system having the same characteristics as the movement system.

Ingression as a concept, then, has relevance to the traffic and highway planner as a technique for quantifying the congestion element in traffic systems. For students of urban spatial structure and land use, the analysis of ingression has a more intrinsic relevance as a measure of a fundamental external diseconomy associated with urban growth and change; ingression losses deriving from the innate characteristics of transportation systems will be realized whether or not congestion losses occur.

APPLICATION OF INGRESSION ANALYSIS TO SOME SPECIAL CASES

There are a number of special arrangements in transportation systems which have unique implications in terms of ingression losses. These operate either by modifying the capacity of the systems, as in the case of traffic signals or supplementary arteries, or by affecting the nature and distribution of demand in systems, as in the staggering of employment hours. In what follows, several of these basic arrangements will be analyzed in terms of ingression effects, not so much to provide a rigorous analysis as to demonstrate application of the logic of ingression analysis and the manner in which it can be applied to varying characteristics of transportation systems.

Cyclical Interruption of Flow

A common type of time loss in traffic systems is that resulting from the periodic interruption of flow on one system to permit cross flow. The typical device for such interruption is the fixed interval traffic signal. To analyze the phase ingression effects of such interruption a system such as that schematically illustrated in Figure 6 can be set up. Here is a path OD along which there are located N units of maximum deadline

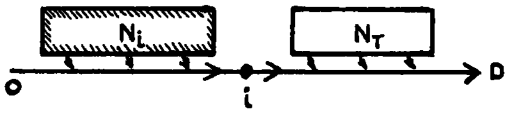

Figure 6. Scheme for interrupted flow system.

demand. At some point I along OD there is a fixed interval interruptor such that a part of the demand N_i must pass through the interruptor in order to arrive at D, while the remainder of the demand N_T is not directly affected by the interruptor. The effects of the interruptor on the flow are shown in Figure 7. It passes pulses of N_i each having a length of p and separated by intervals of length $\bar{p}$. The uninterrupted demand enters the flow by filling in the empty intervals. It is assumed that the first pulse to arrive will be a N_i pulse. There will be some alteration in the ingression values if an N_T pulse is taken as the first arrival, but where N and C are quite large and p and $\bar{p}$ are relatively small the difference is insignificant.

It will be noted that there are two cases. In the first case, the uninterrumpted demand N_T is exhausted before the interrupted demand N_i. The flow pattern thus demonstrates two components—a "saturated" component and an "unsaturated" component which is characterized by unoccupied intervals between pulses of N_i. In the second case the interrupted demand N_i is exhausted first and there is no similar unsaturated segment, since the uninterrupted demand can flow continuously until exhausted after the passage of the last pulse of N_i. It is only in the first case that there are any additional ingression effects over and above what the system would experience in the absence of the interruptor, and these flow from the unoccupied intervals of the unsaturated component.

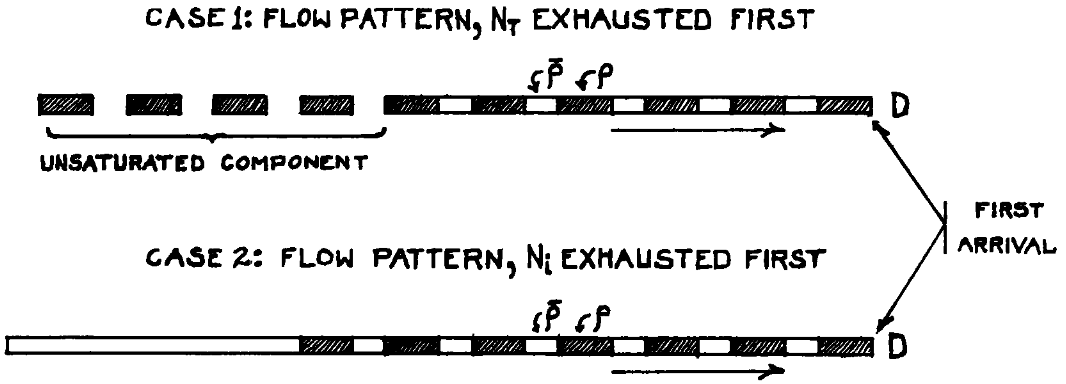

Figure 7.

The number of pulses of N_i can be expressed by $\frac{N_i}{p}$, and the number of pulses of N_T by $\frac{N_T}{\bar{p}}$. Since interruption ingression will only exist where the number of pulses of N_T is less than the number of pulses of N_i, this can be summarized:

$$\text{where } \frac{N_i}{p} > \frac{N_T}{\bar{p}}, \quad \text{then } {}_IY > 0$$

$$\text{where } \frac{N_i}{p} \leqslant \frac{N_T}{\bar{p}}, \quad \text{then } {}_IY = 0$$

or similarly:

$$\text{where } \frac{N_i}{N_T} > \frac{p}{\bar{p}}, \quad \text{then } {}_IY > 0$$

$$\text{and where } \frac{N_i}{N_T} \leqslant \frac{p}{\bar{p}}, \quad \text{then } {}_IY = 0$$

In this first case it can be shown that the additional phase ingression loss from the operation of the interruptor ${}_IY$ is mathematically defined as follows (see Appendix B-2):

$${}_IY = \frac{(N_i - RN_T)^2}{2RC}, \text{ where } R = \frac{p}{\bar{p}}$$

The ingression loss from interruption can accordingly be managed by the selection of values for p and $\bar{p}$, and there is a set of such values that will yield ${}_IY = 0$.

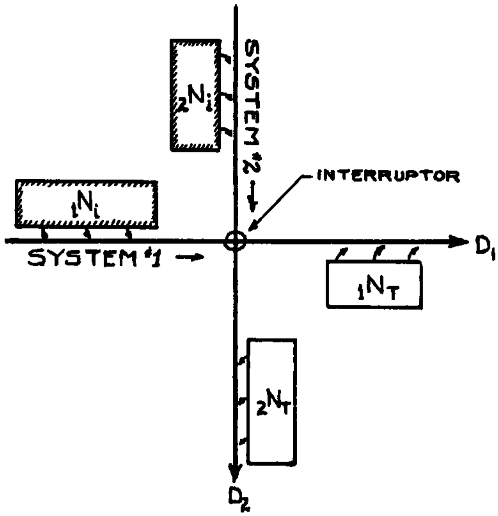

Figure 8.

Cyclical Interruption, the Intersection of Two Systems

The case of two systems with a common deadline so organized in space that part of the flow of each must cross part of the flow of the other at some point I is shown schematically in Figure 8. Instead of 2 demand segments, there now are 4, two in each system: in the first system they are designated as ${}_1N_i$ and ${}_1N_T$, in the second system as ${}_2N_i$ and ${}_2N_T$. To complicate the problem it may be assumed that in each cycle

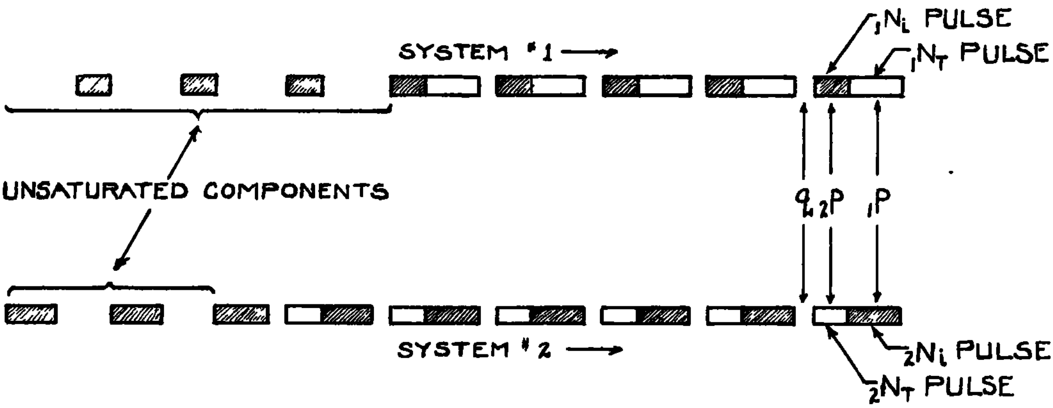

Figure 9. Flow pattern—intersecting systems.

there is a "queuing" time loss indicated by q, which is common to both systems. The pulse pattern is now modified to include 3 elements: the q-loss, the interval during which the interrupted segment of the first system flows through the interruptor ${}_1p$, and the interval during which the interrupted demand segment of the second system flows through the interruptor ${}_2p$. This pattern is indicated in Figure 9.

Some of the characteristics of this simulation are:

1. The introduction of the element q means that there will always be interruption ingression losses in both systems resulting from the effects of q in reducing the capacity of both systems.

2. There will be additional interruption ingression losses in the first system if

$$\frac{{}_1N_i}{{}_1N_T} > \frac{{}_1p}{{}_2p}$$

and in the second system if

$$\frac{{}_2N_i}{{}_2N_T} > \frac{{}_2p}{{}_1p} .$$

3. There is one case in which there will be no interruption ingression losses in either system other than those imposed by q. This case is described in terms of a set of relationships between the four demand segments and the relative lengths of ${}_1p$ and ${}_2p$:

$$\frac{{}_1N_T}{{}_1N_i} = \frac{{}_1p}{{}_2p} = \frac{{}_2N_i}{{}_2N_T} .$$

In all other cases there will be interruption ingression losses over and above the normal system ingression and the q-type losses previously discussed, and such loss may occur in either or both systems.

4. ${}_2p$ can be increased relative to ${}_1p$ with the following consequences: the ingression in the first system will be increased while that in the second system will be decreased. Hence, it is suggested that there is a value of $\frac{{}_1p}{{}_2p}$ which will minimize the total ingression loss in both systems.

Under the assumption that both systems have different basic capacities ${}_1C$ and ${}_2C$, and utilizing the following definitions:

$${}_1N = {}_1N_i + {}_1N_T$$

$${}_2N = {}_2N_i + {}_2N_T$$

$$\text{and} \quad {}_1R = \frac{{}_1p}{{}_2p}$$

the total amount of interruption ingression in both systems (${}_IY_{1+2}$) is defined as follows:

$${}_IY_{1+2} = \frac{[\,{}_1N - {}_1N_T\,({}_1R + 1)]^2}{2_1C_1R} + \frac{[{}_2N\,({}_1R + q_1R + q) - {}_2N_T\,({}_1R + 1)]^2}{2_2C[1 - q\,({}_1R + 1)]\,[{}_1R + q({}_1R + 1)]}$$

This expression is developed in Appendix B-3. Taking the capacities , demand segments, and q as given, it can be generalized that ${}_IY_{1+2}$ is a function of ${}_1R$ thus:

$${}_IY_{1+2} = f({}_1R)$$

A decision problem might call for the selection of one value of ${}_1R$ (or $\frac{{}_1p}{{}_2p}$) which would minimize ingression losses in the two systems. Quite simply, this is the value of ${}_1R$ which will satisfy

$$\frac{d({}_IY_{1+2})}{d({}_1R)} = 0,$$

where the second derivative is positive.

Staggering Demand

A technique for modifying the demand upon the system involves breaking demand down into smaller segments and giving each segment a different deadline, as in the staggering of working hours. This situation lends itself to ingression analysis. A total demand N is broken into 4 segments, N_1, N_2, N_3, and N_4. A deliberately unrealistic deadline requirement says that all units of the earliest segment N_1 must arrive at the destination sometime between T_0 and T_1; for the second segment N_2 between T_1 and T_2, etc. Thus all units must arrive at some time prior to T_4, as illustrated in Figure 10.

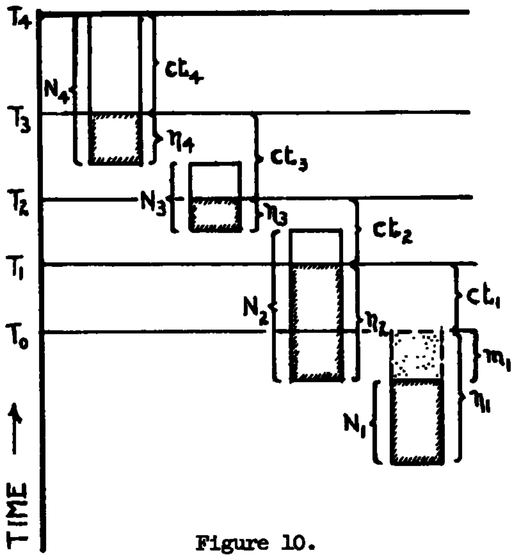

Figure 10.

The system has a common capacity C for all segments of deadline demand, and thus the expression ct_4 represents the total number of units that can arrive during the scheduled interval T_3 to T_4 (or t_4). In Figure 10, then, there is a surplus of units n_4 which cannot satisfy the deadline requirement and which hence develop ingression losses in period t_3. n_4 also has the effect of pushing back the third segment of demand so that it can utilize for arrival only part of its target period, leaving a surplus of demand n_3 to develop ingression losses in the preceding period. Were it not for n_4, all units of N_3 could satisfy the deadline requirement and arrive during t_3 without developing any ingression loss at all. This effect of cumulative excess demand similarly affects N_2 and N_1, and the total ingression loss is the sum of the ingression losses resulting in each situation.

A qualification is indicated by m_1 in Figure 10. Here the accumulation of n_4, n_3, and n_2 has been so great as to push back N_1, whose deadline period is t_1, to a point where the first unit of N_1 must arrive sometime before T_0. Thus, m_1 represents an element of delay for the entire N_1 segment, during which no N_1 units can arrive because the time is preempted by the demand of later segments.

The ingression loss of the last segment of demand N_4 can be expressed as follows:

$$Y_4 = \frac{n_4}{2C}$$

and similarly Y_3 and Y_2 can be expressed. With Y_1 the case is somewhat different due to the delay element of m_1. The time period represented by m_1 is occupied by no N_1 units and hence must be subtracted out of the ingression expression for N_1. The total ingression losses that would be experienced by m_1 units is expressed as follows:

$$Y_{m_1} = \frac{(m_1)^2}{2C}.$$

Thus, the ingression expression for the deadline demand segment N_1 becomes

$$Y_1 = \frac{n_1^2 - m_1^2}{2C}.$$

In a more general sense, the amount of ingression experienced in any deadline demand segment N_a can be expressed

$$Y_a = \frac{n_a^2 - m_a^2}{2C}$$

or, for the entire system

$$Y = \frac{\Sigma n^2 - \Sigma m^2}{2C}, \quad \text{where } n > 0, \text{ and } m \geq 0.$$

In Appendix B-4, this expression is developed in terms of the size of the deadline demand segments, the capacity of the system, and the distribution of the time restraints.

The decision problem suggested here is the arrangement of the demand segments in a system to minimize ingression losses. Brief examination of Figure 10 suggests that if the time periods are chosen so that $ct_a = N_a$ there will be no ingression loss in the system as described. There will likewise be no capacity wasted.

Ingression Consequences of Alternate Routes

As a final case, a situation in which there are two routes of different capacities connecting the demanding units with the assembly point may be considered. The problem suggested is how to distribute demand between the two routes so that phase ingression losses are minimized. The minimum situation will be realized when the marginal ingression losses along both routes are equal, for at this point to shift one unit from one route to another would result in the addition of a greater amount of ingression on the receiving route than would be subtracted from the total on the other. In a simple system the marginal phase ingression loss has been defined as N/C. Thus, to minimize the total phase ingression loss in such a dual system, the total demand would have to be so distributed that

$$\frac{N_1}{C_1} = \frac{N_2}{C_2}$$

or

$$\frac{N_1}{N_2} = \frac{C_1}{C_2}.$$

In short, the ingression losses in such a system will be minimized when the demand is distributed among alternate routes in proportion to their capacities.

These four situations have been discussed here only to demonstrate the manner in which the concept of ingression can be applied to different flow situations as an analytical device to quantify an important social cost emerging from the organization of the basic elements of capacity and demand in movement systems. Each of these cases suggests a decision problem in the management of a system and at the same time suggests a partial "efficiency criterion" for decision-making in such cases. Ingression behaves like a kind of systemic friction; given the coefficient of friction between two surfaces, the amount of friction is a function of the mass of the body moved. This is not unlike ingression, where given the capacity of the system, the amount of ingression loss is a function of the deadline structure of demand. Friction is associated with the dissipation of energy, ingression with the dissipation of socially valuable time. These time losses can be construed as costs (non-money costs at this stage) associated with the organization of movement systems. Considered as costs, they have policy implications within the framework of cost-benefit appraisal of public policy.

SOME POLICY APPLICATIONS OF INGRESSION ANALYSIS

The usefulness of ingression analysis for decision-making stems from the economic characteristics of ingression losses. Ingression involves the expenditure of a socially valuable commodity—time—in the realization of given social and economic purposes. Decisions about urban transportation systems are essentially public investment decisions, and the decision-making criteria must attempt to relate the social benefits from such investment to the social costs of specific investment programs. Ingression is a measure of such a social cost implicit in movement systems, and in a purely engineering sense, average ingression cost is a measure of systemic efficiency. Considering the "trip" to be the basic unit produced by a movement system, average ingression can be construed a unit input, and hence as a technical coefficient that varies with the scale of the "output." Thus, the principle of economizing suggests that, given a level of output and the "prices" of the inputs, one should select that investment program which will minimize the average costs of the system.

This suggests that to be useful for policy purposes it would be necessary to establish a "price," or value, for the time spent in transit by the system user. This intricate question cannot be investigated here except to say that the economic concept of the marginal value of leisure provides a good theoretical basis for estimating that price, given the structure of wage payments to the user.

The remaining portion of this paper is concerned with some specific illustrations of ingression analysis as a decision-making tool in transportation systems. It will observe some simplifying assumptions:

1. That ingression costs are the only general social costs of immediate concern;
2. That the transportation systems in the examples are simple, homogeneous uniform capacity systems;[8] and
3. That the value of indirect social benefits does not vary substantially among the investment alternatives.

The Role of Ingression in Operation Decisions: Selection of a System-Dominant Velocity

A simple, non-investment type of decision in a transportation system involves the regulation of velocity. This regulation may be conditioned by any of a number of criteria: reduction of the risk factor, increasing rate of flow, vitiating congestion, etc. A situation may be taken where velocity is to be regulated in order to minimize the total time cost of the system, given demand N and the technology of the system, and the distribution of demand along the system. For any unit the time cost of a single trip is equal to the travel time at system-dominant velocity plus the average realized ingression loss, and can be expressed as follows:

$$t = \frac{s}{v} + \frac{N}{2c} = t(v)$$

in which

t = total time-cost of one trip,
s = traveled distance between the origin of the given unit on the system and the system destination,
v = system-dominant velocity (see page 5),
N = total demand on the system, and
c = velocity-specific capacity.

It will be noted that c is some function of v, which will be expressed as c(v), (see Eq. 13 in Appendix A). The total time cost T for one phase of the cycle will be equal to the total travel time plus the total ingression cost of the system:

$$T = \sum_{i=1}^{N} t_i = \frac{N^2}{2\,c(v)} + \frac{1}{v}\sum_{i=1}^{N} s_i$$

In this expression s_i represents the spatial distribution of the demand along the system.

Assuming that c(v) is a more or less conventional function of the form discussed in Appendix A, t(v) will have a minimum value, given s; it will, however, have a different minimum for every value of s. If

$$\sum_{i=1}^{N} s_i = S$$

then

$$T = \frac{N^2}{2\,c(v)} + \frac{S}{v}$$

The decision-problem, then is to select a value for the system-dominant velocity v which will minimize the total time-cost T. This will be the value of v such that

$$\frac{dT}{dv} = 0$$

and the second derivative is positive.

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[8] Although by extension of the argument the variable capacity system could be comprehended with its objective congestion potential, as discussed earlier.

Assuming no other restraints, such a policy formulation might suggest the setting of a minimum speed limit v to maintain rates of flow which will tend to minimize the total time cost to all units. It is important to note that this value of v is unique to the system defined by N and D. For different values of N and D there will be different values of v which will minimize the time-costs of the specific system; in other words, there is no general value of v which is relevant to all values of N and D. If time-cost minimization is the criterion, velocity regulation must be tailored to the specific, demand-capacity characteristics of the system.

Ingression Factors in Urban Transportation Investment Decisions: Case 1, The Simple System

A characteristic type of system investment problem involves an extant system with a high level of congestion and a set of investment alternatives to reduce the time losses in the system. Take such a system with a high degree of ingression Y_0. Assuming that there are a number of alternative projects which can reduce the value of Y_0, each project can be translated by costs into an investment program requiring a set amount of capital I. Hence, I_1 as the capital required by Alternate 1 which will produce a new capacity in the system of value C_1, and hence a new ingression value Y_1. Let p stand for the value of a unit of ingression loss to the road user. Since Alternate 1 will reduce the amount of ingression per cycle, the value of the ingression reduction can be construed as a kind of "social income," J_1 which can be expressed as follows:

$$J_1 = p(Y_0 - Y_1).$$

Assuming no change in demand N,

$$J_1 = \frac{pN^2}{2}\left(\frac{1}{C_0} - \frac{1}{C_1}\right).$$

Define the annual costs K_1 of Alternate 1 to consist of interest and depreciation on capital I_1 plus the increment to operating costs (if any) resulting from the program thus

$$K_1 = (i + d)I_1 + O_1.$$

Then any program a is "justified" so long as the social income produced by it is greater than the annual social costs of the program:

$$J_a \geqslant K_a.$$

In short, to maximize the social income,[9] select that investment program K_a which will maximize the benefit-cost ratio

$$(\max)\frac{J_a}{K_a} = (\max)\frac{\frac{pN^2}{2}\left(\frac{1}{C_0} - \frac{1}{C_1}\right)}{(i + d)I_a + O_a}$$

This is a case in which the substitutability of capital costs for ingression costs is the basis of the decision problem. Given the cost of capital i (assuming that depreciation is a technological constant) and the "price" of ingression losses p, an optimum investment program which will maximize the social surplus from the operation of the transportation system can be identified.

Ingression Factors in Urban Transportation Investment Decisions: Case 2, The Hypersystem

At an even higher level are the decisions involving the long-range programing for the development of an urban transportation system. To discuss decisions at this level it is necessary to digress for a moment to define the concept of a "hypersystem." The term "hypersystem" is used here to describe the organization of two or more move-

[9] The fact that K_a represents any one of a finite set of discrete alternatives suggests that a linear programing formulation of the problem might be more versatile.

ment systems into a higher level, integrated system, the basic characteristic of which is an instantaneous capacity greater than 1.

It can be assumed that the movement hypersystem in this framework is homogeneous, that is, consisting of a given number A of movement systems whose technological characteristics are identical in that their non-instantaneous capacities are equal. The total ingression Y_A in such a system varies with the amount and distribution of demand among the components:

$$Y_A = \sum_{i=1}^{A} \frac{N_j^2}{2C_j}$$

in which

Y_A = total ingression loss per cycle in the hypersystem,

C_j = capacity of component "j," and

N_j = demand on component "j."

At an earlier point it was suggested that the total ingression among several systems with a common assembly point would be minimized under the condition that each component bear that proportion of the total demand that its capacity bears to the total capacity of the several systems. A hypersystem meeting these conditions will be referred to as an optimal hypersystem: no other allocation of capacity to demand will produce a lower level of ingression cost.

Thus, in a non-optimal hypersystem a basic kind of investment decision is what might be called an "optimizing" decision; that is, a decision addressed to reducing or eliminating the disparities in average ingression costs among the component systems. This kind of decision is similar to that discussed with respect to simple systems: the selection of an investment program with the highest social benefit-cost ratio, but with the additional restraint that it must tend to reduce the disparities, for only in an optimum hypersystem are the social costs spread equitably among all components of the system (to a certain extent, in a dynamic situation the operation of the urban land market may have an optimizing effect by suppressing development in high ingression sectors and encouraging it in the low ingression sectors).

There is another kind of investment decision associated with the hypersystem. At what level of average ingression should the total system be planned? The standard which has been followed in transportation planning has been to match hourly demand with equal hourly capacities. This implicitly accepts an average ingression of ½ hr per unit per cycle where the time distribution of demand within the hour is highly concentrated. In other words, the matching of hourly capacities to hourly volumes will produce a low volume of ingression loss only where the peak demand upon a system is evenly distributed throughout the hour. There is little to justify such a standard in terms of investment efficiency. If the marginal value of the road user's time-in-transit is high and the cost of capital low, such a standard could be grossly inefficient, for the social costs of ingression would be excessive. At the other extreme, where the value of such time is low and the cost of capital is high, such a standard might well result in the uneconomic allocation of public investment. In short, the efficient level of ingression loss in an optimum hypersystem will be a function of the costs of capital and the costs of ingression.

In the course of this section, this paper has attempted to illustrate the manner in which ingression analysis can be applied to decision-making with respect to urban transportation systems, under the assumption that the proper criteria for investment decisions relates total direct social benefits to the total direct social costs involved in the transportation system. Hopefully, it served to demonstrate that the social cost factor of ingression has relevance to the appraisal of an investment program for the elimination of a grade intersection as well as to the appraisal of a total mass transportation program for a metropolitan area. The major contribution that ingression analysis can make in social decision-making is to assure a broadening of the conventional benefit-cost concepts to embrace a much larger proportion of the economic effects of changes in urban transportation systems. The traffic engineer and the highway planner play a strategic role in such decision-making; any technique which will permit them to integrate demand-capacity effects into their total framework of analysis and appraisal may make their recommendations more sensitive to the broad array of social objectives and more persuasive to the policy-makers.

CONCLUSION

This paper is an effort to develop a theoretical framework within which the time losses associated with transportation systems can be analyzed. It takes as basic variables, (1) the load imposed upon the system in the form of deadline demand and its distribution in time, and (2) the technology of the system as it affects the capacity of the system. It quantifies the time costs emerging from the ingression features of the system and suggests the limits of objective congestion costs.

Such a theoretical expression has several virtues. It has the merit of generality; it can be applied to any system in which time has value to the participating units, technological capacity can be identified, and in which demand can be quantified with respect to a schedule of deadlines. It has versatility; it is as relevant to the mass transit situation as to the auto-exclusive system, or even to mixed systems. It has a special relevance to conditions of system saturation such as peak-period conditions in urban traffic systems. This versatility has been demonstrated in applying the analysis to several special arrangements of transportation systems. It is simple in that the basic capacity-demand relationship is simple. Complexity in application will vary directly with the degree of precision sought.

Not the least of its virtues are its economic characteristics. The substitution of capital costs for time costs is the basic feature of many investment decisions in transportation systems. Ingression and congestion losses behave as pure external diseconomies such that as the scale of the system increases average time costs likewise increase. It is the economic characteristics of the framework which permits its integration into a broader theoretical framework of the urban space economy.

However, there is much to be done before this framework is empirically useful. It needs direct empirical testing, and this is a problem for transportation research. Simple techniques are needed for identifying the volume of demand and its time distribution in such complex situations as the Central Business District; its stability in the short run under varying conditions must be known. This framework must be given a manageable spatial dimension so that one can talk in terms of the spatial distribution of demand and assembly points as variables in the level of these time costs. Finally, it will take rigorous thought to determine the useful limits of such an analytical technique; to this end, this paper addresses the broad competences of both engineers and economists.

Appendix A

DEFINITION OF CAPACITY

In this hypothetical movement system all units move under "capacity" conditions until demand is exhausted. This assumption is necessary to identify those losses which are innate in the system. Capacity in this sense is not a simple concept.[10]

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[10]The complexity of the concept of capacity has given rise to a multiple definition in highway traffic planning:

"Basic capacity: the maximum number of passenger cars that can pass a given point on a lane or roadway during one hour under the most ideal roadway and traffic conditions that can possibly be attained . . . .

"Possible capacity: the maximum number of vehicles that can pass a given point on a lane or roadway in one hour under prevailing roadway and traffic conditions . . .

"Practical capacity: the maximum number of vehicles that can pass a given point

Fundamentally, capacity in a uniform flow movement system derives from the relationship of velocity and the distance interval between successive units.[11]

Here two senses of the term "capacity" must be distinguished.

1. That capacity which exists at a given average velocity in a specified system (either under free-flow or uniform flow conditions), or the velocity specific capacity c, and

2. That capacity in a specified system which is maximum for all values of velocity, or system capacity C.

Unless otherwise specified, the term "capacity" in this paper will refer to system capacity. The velocity at which system capacity is realized will be referred to as capacity velocity.

If the interval remains constant (is independent of velocity) the volume in a system can be increased by increasing the system's velocity, and hence capacity would depend on the technological limits of velocity. In fact, however, the instantaneous capacity[12] of the movement system will always be 1 until velocity is infinite, also, where the system consists of a single path (where the system consists of more than one path, the instantaneous capacity will be equal to the number of paths). Ruling out the case of infinite velocity, as long as instantaneous capacity is less than system demand (which, by virtue of the time-restraints, is instantaneous) there will be ingression potential in the system, even at a system velocity approaching the speed of light.

In a practical sense, however, the interval between units is not independent of velocity. As a rule, it tends to increase with velocity, and the manner in which it tends to increase is related to three basic technological characteristics. Each unit must accomodate its behavior to that of the unit immediately preceding it. The "behavior" of a unit consists of changing its velocity; thus, if the unit preceding changes its velocity negatively, the subject unit must adjust its velocity to avoid collision. Interval is, hence, conditioned by the behavioral characteristics[13] of the units, or more specifically by the risk, feedback, and mechanical characteristics of the system.

The risk factor is a function of the orderliness of the system; it is inversely associated with the ability to anticipate the behavior of preceding units. A completely orderly system would be one in which the behavior of preceding units could be anticipated by at least the time interval inherent in the feedback and mechanical characteristics of the system, wherein interval would be limited only by the physical dimensions of the units themselves. At the other extreme is the completely disorderly system in which behavior of the lead unit is completely unpredictable. In this case, the behavior of the second unit as it accomodates itself to the behavior of the first is completely unpredictable to the third, and so on through the system. Here minimum interval is

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[10](Continued)

on a roadway or designated lane during one hour without traffic density being so great as to cause unreasonable delay, hazard, or restrictions to maneuver under prevailing roadway and traffic conditions . . ."

Bureau of Public Roads and Highway Research Board, "Highway Capacity Manual." USGPO, Washington, p. 6-8 (1950). See also Institute of Traffic Engineers, "Traffic Engineering Handbook, 2nd Ed, p. 334, New York (1950).

[11]The Traffic Engineering Handbook (p. 331) expresses this as:

$$c = \frac{5280V}{S}$$

in which

c = velocity-specific capacity in vehicles per hour,
V = velocity in mph, and
S = the spacing (interval) between successive vehicles in ft.

[12]That is, the number of units that can occupy any single time-space position on the path.

[13]But not by the actual behavior of the units.

governed by the mechanical and feedback characteristics of the system, and the distance between the units will be governed by the speed with which any one unit can react effectively to unanticipated maximum changes in behavior of the preceding unit. Thus, the extent to which interval is a function of velocity depends on the amount of disorder in the system. Where the system is completely orderly, there will be no association of interval with velocity:[14] where disorder prevails in the system, it is the time of effective response and the velocity that establish interval. It is further obvious that where a system is operating at capacity, disorder may be induced in the system by the unpredictable behavior of a single unit and that this induced disorder will prevail in the system until dissipated by excess capacity.[15]

The time of effective response depends, as has been suggested, on the "feedback" and mechanical characteristics of the system. Feedback involves the sensing of a change in the behavior of the preceding unit and the assertion of controls to accomodate the behavior of the subject unit to it.

A critical relationship exists between the frequency and scope of the changes to be controlled and the time lapse between the detection of change and the assertion of compensating control. Where the sensed changes are comparatively infrequent, the rate of change moderate, and the feedback time very small, a movement system may exhibit a high degree of articulation between units. Where, on the other hand, the system is characterized by comparatively rapid changes with a high rate of change, and where the feedback time is comparatively gross, the degree of articulation may be very low. The crucial "feedback" factor in headway is the time lapse involved from the detection of change in the behavior of one unit to the assertion of compensating control in the succeeding unit.[16] If this is instantaneous, then the only elements to govern interval (assuming a given risk level) are the mechanical characteristics of the system; if comparatively slow, then interval must encompass the feedback time lapse. Assuming a constant level of order in the system, then, slow feedback and high velocity would be associated with a very large interval.

The mechanical characteristics of the system are purely technological. What is the lapsed time (or distance) from the moment that maximum controls are asserted to the time that the unit is decelerated to zero (this being the maximum behavioral response demanded of the unit)? This time (or distance) is a function of the mass of the system and its velocity and an inverse function of the braking power that can be applied by the unit at any one moment. Thus, that component of interval associated with inertial characteristics of the system can be diminished through a reduction of the unit's mass and/or velocity, or through an increase in braking power.[17]

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[14] Because the behavior of all preceding units would be completely predictable, and there would be no time loss in adjusting to it.

[15] Discussion of the queueing phenomenon in the "Highway Capacity Manual." p. 34.

[16] In a vehicular traffic system, the traffic engineer characterizes this feedback element as "driver perception and reaction time."

[17] This relationship has been generalized for automobiles in the "Traffic Engineering Handbook," p. 72, as follows:

$$B = \frac{0.0105\ V^{\exp 7/3}}{f}$$

in which

B = vehicle braking distance in ft,
V = velocity in mph, and
f = coefficient of friction (at a velocity of 20 mph).

Which can be restated

$$B = \frac{0.0105\ NV^{\exp 7/3}}{F}$$

in which

F = the minimum force necessary for deceleration, and
N = the mass of the carrier.

In summary, the velocity-specific capacity c of the system is a direct function of the velocity V of the system and an inverse function of the interval I among units:

$$c = \frac{V}{I} \tag{9}$$

Interval contains three components: the length of the unit L, the interval component resulting from feedback time lapse i_f, and the interval component associated with the mechanical characteristics of the system i_m, the latter two being modified by a disorder function, henceforth expressed as a "risk coefficient" r as follows:

$$I = L + r\,(i_f + i_m). \tag{10}$$

Here the risk coefficient r will vary from zero (where the system is completely orderly) to 1 (where the system is completely disorderly).[18]

The relation of the risk coefficient to some measure of orderliness will depend on the scope of potential loss, the "negative payoff," associated with malarticulation of the system. It would be a misleading conclusion to assume that the risk coefficient should always be 1 as long as there is any negative payoff. However, the size of the risk coefficient has a direct effect on the capacity of the system; hence the real problem of valuation of the relationship of disorder to the risk coefficient resides in the relating of the marginal change in payoff to the marginal gain in capacity of the system. The gain in capacity can be measured in terms of the reduction of ingression in the system, while the valuation of the increase in negative payoff is perhaps somewhat more complex.

Mathematical expression can now be given to the relationship between capacity and the factors associated with it.

$$i_f = Vt_c \tag{11}$$

in which

t_c = time lapse associated with the feedback organization.

$$i_m = \frac{aMV^b}{F} \tag{12}$$

in which a and b are technological constants,

M = mass of carrier,

F = minimum braking power to decelerate a carrier of mass M moving at velocity V to V = 0 in distance i_m. (See footnote 17.)

Then

$$c = \frac{V}{rV\left[t_c + \frac{aMV^{(b-1)}}{F}\right] + L} \tag{13}$$

(Substituting Eq. 11 and Eq. 12 in Eq. 10 and Eq. 10 in Eq. 9)

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[17](Continued)

This can be associated with the more general statement in Eq. 12.

[18]Thus, with respect to vehicular traffic, safe (velocity-specific) capacity might be defined as that relationship between velocity and interval that exists when the spacing of units is governed by "driver stopping distance." Since auto traffic has the characteristics of a highly disordered system, it would have a risk coefficient approaching one. Thus, the traffic engineer's definition of driver stopping distance is analogous to the concept of interval with a risk coeeficient of 1. Driver stopping distance is defined in the "Traffic Engineering Handbook" as having three components (p. 71): (1) Driver perception-reaction time (which is analogous to the feedback component), (2) Brake-lag distance, and (3) Vehicle braking distance (the latter two being subsumed in the mechanical component of the author's formulation).

and

$$C = c(\max) \quad (14)$$
$$= c, \text{ where } dc/dv = 0$$
$$\text{and the second derivative} < 0$$

in which C = system capacity

The capacity of the movement system, then, will vary with system velocity, but in a fashion determined by the level of system disorder, by the nature of the control system, and by the technological relationship of mass and braking power of the units of the system.[19]

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[19]"The Highway Capacity Manual" (Table I, p. 3) presents some 23 expressions for "safe following distance" in terms of velocity. All of these expressions have the general form

$$I = xV^y + zV + L$$

if

$$x = \frac{aMr}{F},$$

$y = b$, and
$z = r\,t_c$.

This general form is converted to the author's expression, which is the denominator in Eq. 13. Thus, "safe following distance" corresponds in mathematical expression with the concept of interval, especially if r = 1, as seems indicated.

If the five expressions which accept x = 0 (which appear to assume no braking distance) and the three expressions which take z = 0 (thus assuming no driver reaction time) are disregarded, 15 expressions are left which are "full." These 15 equations describe a set of curves which are convex upward and which are heavily skewed in the direction of the vertical (or capacity) axis. (See Figure 1, p. 2 of the "Highway Capacity Manual.") Their maximums fall between 8.3 mph and 28.3 mph, and they range in volume between 1,050 and 2,520 vehicles per hour for a single traffic lane. The values for t_c ranged from 0.50 to 1.00 second (with 9 accepting the high value); 13 of the 15 accepted y = 2, while 2 assumed y = 2.3 (this is the decimal equivalent of 7/3 (see footnote 17); the values for x when divided by the conversion factor $\frac{(22)^2}{15}$ to compensate for expression in terms of ft/sec ranged from 0.0116 to 0.157 with 12 using values less than 0.05. The important point is that as long as x, y, and z, have positive values greater than 1, there will always be a "maximum" capacity associated with a system, and that capacity will be defined by the velocity. It is this "maximum" capacity that is implied in the use of the term "system capacity."

It should be acknowledged that where feedback is instantaneous, and where the mechanical characteristics of all carriers are uniform, theoretically the most persuasive expression is that which takes the coefficient x = 0, such that

$$I = zV + L$$

A little reflection will justify this: if the feedback time is instantaneous two vehicles could be moving in the system "bumper to bumper" (I = L) and any change in the behavior of the first would be simultaneously compensated for by the second; here both x and z = 0. Where the braking distance is uniform for all units, it cancels out as a spacing element, leaving only the independent variables of velocity and feedback time.

A capacity expression based on such a spacing expression yields a C that increases with V to some asymptotic value. This value is, in fact $z^{\exp -1}$ at a capacity velocity of infinity.

For purposes of simplicity, this paper has assumed that x has a positive value greater than 0 because this appears to conform more closely to empirical observations.

See also discussion in Beckmann, et al., op. cit., p. 19.

Appendix B

MATHEMATICS OF INGRESSION

B-1: System Ingression—(Refer to Figures 1, 2, 3, and 4)

The quantity of ingression loss experienced by the (n - i)th unit is

$$y_{n-i} = \frac{i}{C}. \tag{15}$$

For convenience of notation this expression can be modified:

$$y_i = \frac{n-i}{C} \tag{16}$$

in which

y_i = ingression loss experienced by the ith arrival,
n = total number of arrivals, and
C = capacity of the movement system.

Expressing the total number of arrivals n as system demand N, the mathematical expression for total ingression loss Y in such a system can be derived as follows:

$$Y = \sum_{i=1}^{N} y_i = \frac{1}{C} \sum_{i=1}^{N} (N - i) = \frac{N^2 - N}{2C}, = \frac{N(N-1)}{2C}. \tag{17}$$

The average ingression loss $\bar{y}$, or ingression loss per unit demand is then,

$$\bar{y} = \frac{N-1}{2C}. \tag{18}$$

The marginal ingression loss in terms of demand y'_N is $\frac{dY}{dN}$, or

$$y'_N = \frac{2N-1}{2C} \tag{19}$$

and the marginal ingression loss in terms of capacity y'_C is $\frac{dY}{dC}$ or

$$y'_C = \frac{N - N^2}{2C}. \tag{20}$$

Where both N and C are quite large, the following can be approximated:

$$Y = \frac{N^2}{2C} \tag{21}$$

$$\bar{y} = \frac{N}{2C}$$

$$y'_N = \frac{N}{C}$$

$$y'_C = -(\frac{N}{C})^2.$$

Ingression loss being a time loss, it is expressed in units of time established by the capacity statement, which may be in terms of units per second, minute, hour, etc. Where risk factors and demand on the system are fixed, the level of ingression loss in the system can be decreased only through an increase in the capacity of the system, and this can be effected in only two ways: (1) by increasing the number of paths (and thus increasing the instantaneous capacity of the system) and (2) by modifying the technological features of the system (braking power, feedback time, mass). (See Appendix A.)

B-2: Ingression Loss in a Simple, Interrupted System—(Refer to Figures 6 and 7)

The problem is to define interruption ingression loss Y' in terms of the length of the system T, the position of an interruptor i, the distribution of units along the system N_i and N_T, the basic capacity of the system C, and the pulse characteristics of the interruptor p and $\bar{p}$.

(a) N = total demand in the system;

(b) N_i = first element (or interrupted) demand;

(c) N_T = second element (or uninterrupted) demand;

(d) R = pulse-interval ratio = $\frac{p}{\bar{p}}$, when p = the time length of the period in which flow takes place through the interruptor, and $\bar{p}$ = the period of no flow.

k = the proportion of N_i moving in the saturated component; or the number of pulses of interrupted demand matched by pulses of uninterrupted demand divided by the total number of pulses of interrupted demand, thus

(e) $R = \frac{kN_i}{N_T}$, and $k = \frac{RN_T}{N_i}$

(f) r = ratio of interruption, or relative pulse = $\frac{p}{p + \bar{p}}$ length (also referred to as the interruption restraint).

$$Y'_2 = \frac{(N_T + kN_i)^2}{2C}, \tag{22}$$

from the general ingression equation $Y = \frac{N^2}{2C}$. This is the simple ingression loss generated in the saturated sector.

$$Y'' = \frac{(N_T + kN_i)}{C}(1 - k)\,N_i, \tag{23}$$

Y'' is the ingression imposed on the nonsaturated component by the time necessary to exhaust $(N_T + kN_i)$ which is the demand in the saturated component.

$$Y'_1 = \frac{[(1 - k)N_i]^2}{2rC}, \tag{24}$$

Y'_1 is the simple ingression loss deriving from the nonsaturated segment, from the general ingression equation (see Eq. 22). Here $(1 - k)N_i$ is the demand in the unsaturated component and r is the interruption restraint on the capacity of the unsaturated component. (See description of problem, pp. 9, 10.)

$$\bar{Y} = Y'_1 + Y'_2 + Y'' \tag{25}$$

by definition, $\bar{Y}$ being the total ingression loss in the system.

$$\bar{Y} = \frac{(N_T + kN_i)^2}{2C} + \frac{(N_T + kN_I)(1 - k)N_i}{C} + \frac{[(1 - k)N_i]^2}{2rC} \tag{26}$$

$$N_T = N - N_i, \tag{27}$$

by definition.

$$\bar{Y} = \frac{(N - N_i + kN_i)^2}{2C} + \frac{(N - N_i + kN_i)(1 - k)N_i}{C} + \frac{[(1 - k)N_i]^2}{2rC} \tag{28}$$

but $$(N - N_i + kN_i) = [N - (1 - k)N_i] \tag{29}$$

Let $$(1 - k)N_i = a \tag{30}$$

by definition.

Then $$\bar{Y} = \frac{(N - a)^2}{2C} + \frac{(N - a)a}{C} + \frac{a^2}{2rC} \cdot \tag{31}$$

$$\bar{Y} = \frac{rN^2 - 2raN + ra^2 + 2raN - 2ra^2 + a^2}{2rC} = \frac{a^2(1 - r) + rN^2}{2rC} \tag{32}$$

$${}_iY = \bar{Y} - Y, \text{ and } Y = \frac{N^2}{2C}, \tag{33}$$

by definition, interruption ingression loss ${}_iY$ being the difference between the aggregate ingression loss of the interrupted system $\bar{Y}$ and its simple ingression loss Y.

$${}_iY = \frac{a^2(1 - r)}{2rC} \tag{34}$$

but $$R = \frac{r}{1 - r} \tag{35}$$

from (d) and (f).

$${}_iY = \frac{a^2}{2RC} \tag{36}$$

but $$a = (1 - k)N_i, \quad k = \frac{RN_T}{N_i}, \tag{37}$$

from Eq. 30 and (f).

$$a = N_i - RN_T \tag{38}$$

$${}_iY = \frac{(N_i - RN_T)^2}{2RC}, \tag{39}$$

substituting Eq. 38 in Eq. 36.

Where $R = \frac{p}{\bar{p}}$, and $a > 0$ under the considerations previously posited, $0<k<1$. Thus interruption ingression loss varies with the location of the interruptor (N_i / N_T) and the pulse-interval ratio. Given a density distribution in such a system, the amount of interruption ingression depends essentially on the positioning of the interruptor, increasing as it approaches the assembly point. It depends, in the second place on the value of R.

B-3: Interruption-Ingression, Effect on Compound System—(Refer to Figures 8 and 9)

A realistic restraint on the value of R emerges from the intersection of two simple systems, much as in the manner of the intersection of two arterial streets, where a traffic signal regulates the alternate flows of traffic.

(a) ${}_IY_1$ and ${}_IY_2$ = interruption ingression loss on systems 1 and 2, respectively;

(b) ${}_IY_{1+2}$ = interruption ingression loss in both systems;

(c) ${}_1N$ = total demand on system 1;

(d) ${}_2N$ = total demand on system 2;

(e) ${}_1N_T$ and ${}_2N_T$ = uninterrupted segment of demand on both systems;

(f) ${}_1R$ and ${}_2R$ = pulse-interval ratios on systems 1 and 2, respectively;

(g) ${}_1C$ and ${}_2C$ = respective capacities of the two systems; and

(h) q = queuing loss constant.

To find: The total interruption ingression loss in both systems in terms of the pulse-interval ratios, the capacities of the systems, and the distribution of demand on both systems with respect to the point of intersection.

$$ {}_{I}Y_{1+2} = {}_{I}Y_1 + {}_{I}Y_2 \quad (40)$$

by definition.

Let

$$ {}_1N_i = {}_1N - {}_1N_T \quad (41)$$

and

$$ {}_2N_i = {}_2N - {}_2N_T $$

by definition.

$$ {}_{I}Y_1 = \frac{({}_1N - {}_1N_T - {}_1R_1N_T)^2}{2_1C_1R} \text{ and } {}_{I}Y_2 = \frac{({}_2N - {}_2N_T - {}_2R_2N_T)^2}{2_2C_2R}, \quad (42)$$

see Eq. 39.

$$ {}_1R = \frac{p}{\bar{p}} = \frac{{}_1p}{{}_2p + q} \quad (43)$$

and

$$ {}_2R = \frac{p}{\bar{p}} = \frac{{}_2p}{{}_1p + q}, $$

see definition (d) in Subsection B-2.

$$ {}_1p + {}_2p + q = 1 $$

Then

$$ {}_2R = \frac{1 - q({}_1R + 1)}{{}_1R + q({}_1R + 1)} \quad (44)$$

$$ {}_{i}Y_{1+2} = \frac{[{}_1N - {}_1N_T\,({}_1R + 1)]^2}{2_1C_1R} + \frac{[{}_2N({}_1R + q_1R + q) - {}_2N_T({}_1R + 1)]^2}{2\,{}_2C[1 - q({}_1R + 1)][{}_1R + q({}_1R + 1)]} \quad (45)$$

substituting Eq. 44 into Eq. 42 and Eq. 42 into Eq. 40.

Eq. 45 answers the requirements. Given two intersecting systems, their capacities, their distribution of demand with respect to the point of intersection and given the technological constant q, the total interruption ingression loss in the two systems is a direct function of the pulse-interval ratio R (expressed in terms of the first system ${}_1R$). Examination of this equation indicates that there is a case, given the demand on each system and the value of ${}_1R$, in which there is a value for ${}_1N_T$ and ${}_2N_T$ such that the aggregate interruption ingression loss will be zero. In all other cases, however, there is a positive interruption load loss in the system. Given all other factors except ${}_1R$, there is a value for ${}_1R$ that will minimize this interruption ingression loss. There is a different value for ${}_1R$ that will equate the average ingression loss in the two systems. In the special case where $\frac{{}_2N_T}{{}_2N} = \frac{{}_1N_T}{{}_1N}$ the ${}_1R$ which will equate the average values will also provide the minimum interruption ingression loss in the systems.

B-4: The Ingression Consequences of Complex Time Restraints

Assume that the arrival time restraint requires that all units be present at the destination at some time during the time period $T_1 - T_2$ (the time-space fixed arrival restraint hitherto has required that all units be present at the destination at the fixed time T). So long as the demand on the system does not exceed the capacity of the system during this period, there is no ingression loss, that is to say, an arrival time can be selected for each unit such that it will fall within $T_1 - T_2$, and associated with a departure time, such that the only time loss is that of ideal travel time. Where demand exceeds capacity, however, it is necessary to satisfy the restraint that the excess demand arrive at the destination in advance of the period, and there wait until the period begins. Thus ingression loss exists in this system only when demand exceeds the derived capacity of the period and can be expressed as follows:

$$Y = \frac{(N - Ct)^2}{2C}, \text{ where } N > Ct\text{; for all other values of } N,\ Y = 0. \tag{46}$$

in which

N = total demand in the system,
C = capacity of the system, and
t = elapsed time between the limits of the arrival time restraint.

An extension of this argument will govern the case in which the total demand is broken up into segments, each having a different arrival time restraint, but using the same system. This is analogous to the staggering of working hours in the CBD and can be expressed as follows:

(a) $\veebar$ = an operation symbol, viz. $a \veebar b$: "a or b, whichever is larger;"
(b) n'_a = cumulative excess demand not satisfied by capacity of periods a to x;
(c) N_a = actual demand associated with period a;
(d) C = capacity per unit of time;
(e) n_a = excess of demand for period a over capacity for period a;
(f) t_a = time length of period a;
(g) x = total number of periods;
(h) $a = 1, 2, 3, \ldots, x$;
(i) m_a = impairment of volume in period a resulting from cumulative excess volume in period a + 2 and later; and
(j) Y_a = ingression loss developed by excess of demand over capacity in period a.

$$n'_a = [(N_x \veebar Ct_x) - Ct_x] + [(N_{x-1} \veebar Ct_{x-1}) - Ct_{x-1}] + \ldots + [(N_{x-(a-1)} \veebar Ct_{x-(a-1)}) - Ct_{x-(a-1)}] \tag{47}$$

Let

$$[(N_a \veebar Ct_a) - Ct_a] = n_a \tag{48}$$

Then

$$n'_a = n_x + n_{x-1} + \ldots + n_{x-(a-1)} = \sum_{b=x-(a-1)}^{x} N_b \tag{49}$$

$$m_a = n_x + n_{x-1} + \ldots + n_{x-(a-2)} - ct_{x-(a-1)} = \sum_{b=x-(a-2)}^{x} n_b - ct_{x-(a-1)} \tag{50}$$

$$Y_a = \frac{n'_a(n'_a - 1) - m_a(m_a - 1)}{2C} \tag{51}$$

or, in high volume systems

$$Y_a = \frac{n_a'^2 - m_a^2}{2C}$$

$$Y = \sum_{a=1}^{x} Y_a, \tag{52}$$

in which Y = total ingression loss over x periods.

Two conclusions are immediately generated from this expression: the maximum ingression loss results when all of the t's are equal to zero, this being the case of the fixed arrival time restraint. When this is the case, the value of this expression becomes $\frac{N^2}{2C}$. A minimum value for this expression exists for any set of t values such that for every pair Ct_i, N_i, $Ct_i \geqslant N_i$.

This is in essence the case of the total ingression of N broken down into k independent systems, each having identical capacity restraints, and the value of the expression becomes:

$$\frac{N_1^2 + N_2^2 + N_3^2 + \ . \ . \ . + N_k^2}{2C} .$$

Where neither of the special conditions above exists,

$$\frac{(N_1 + N_2 + N_3 + \ . \ . \ . + N_k)^2}{2C} \geqslant Y \geqslant \frac{N_1^2 + N_1^2 + N_3^2 + \ . \ . \ . + N_k^2}{2C} .$$

Thus the expression to the right can be modified to meet the conditions specified where the time-of-arrival restraints are defined as a time period, as mentioned earlier.

The Central Business District and Its Implications for Highway Planning

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IN EVERY American city there is one major focus or area of concentration known as the Central Business District or the CBD (Fig. 1). This area is variously treated in highway planning. In some cities major routes still pass through the district, causing serious traffic congestion at busy periods. In other cities major through routes by-pass the CBD or at least avoid its peak intersection. In still others, although major arteries do not enter the district they are routed around its circumference with shuttle buses or other arrangements to take pedestrians into the CBD. However it is treated the district remains a major target area for those planning the transportation routes of the metropolis.

This paper proposes to discuss the CBD. First, some of the area's distinguishing characteristics will be considered.

The characteristic that most people probably think of immediately is the presence of high buildings. Though isolated buildings may stick up above the skyline elsewhere in the city the CBD has the greatest concentration of such buildings, the greatest average building height.

A concentration of certain functional establishments is even more of an index to the CBD. Here, typically, are the major office buildings and banks, the major hotels, the principal concentration of business services, and various associated establishments. Department stores and specialized clothing stores are likely to be present also in spite of the growing competition from outlying shopping centers. Typically, the whole CBD assemblage serves the entire city rather than a section of it, and people of all levels rather than those of any one class or group.

A feature of the CBD that will play an important role in this paper is the peak land value intersection. The district is likely to have one intersection around which land values average higher than anywhere else in the city.

There are still other features and characteristics. In the largest cities the CBD ordinarily shows a pronounced regionalization, with a financial district, a theater district, and the like. And, unfortunately, many CBDs show their age, since the district was one of the first parts of the city to be built and hence is likely to be suffering from obsolescence. This suggests still another element of the picture: a zone of deterioration that characteristically borders much of the district.

But how are these aspects of the CBD related to highway planning? A few relationships seem obvious. In the first place, in every city the primary CBD transportation problems are those of access and parking. These are the basic concerns. Closely related are decisions regarding mass transit, and decisions as to whether to allow direct access to the CBD or, instead, to take such drastic steps as restricting individual cars to circumferential routes, leaving the district a pedestrian's domain.

The value of routes built to the CBD has been questioned on the grounds that freeways for moving people into and out of the district may use up so much land that nothing worth reaching is left at the center. But an opposite point of view recently expressed is that highway programs may do more to rejuvenate the CBD than urban renewal will.

Certainly, care must be taken in planning routes that traverse the district. It is coming to be realized that an office and banking complex is likely to form the vital heart of the CBD. This must be left intact. Nearly every CBD has barriers to expansion in several directions—a steep slope, a stream, railroads, possibly a park. There may be some one direction, on the other hand, in which the district is growing. A freeway would certainly fail of its purpose if it blocked this direction of natural growth.

Considerations such as these point to the need for more knowledge about the district—not just more about a certain CBD but more about CBDs in general.

This is not to imply, of course, that no research thus far has been aimed at the district. Numerous local CBD studies have been carried out in connection with city planning, and a few more basic studies have been made or are in progress. The latter attack has taken several directions. A few of these may be noted.

There have been, for example, attempts to calculate or estimate the population of the CBD for various hours of the day (2, 3). Origin and destination surveys have formed the bases for the chief studies along this line. It need hardly be pointed out that such estimates are of prime importance in traffic planning.

This has been just one line of CBD research. Various others might be mentioned. An urban land economist used directories as a basis for analyzing changes in functional establishments in the CBD of Madison, Wisconsin (7). This was an attempt to discover more about the reputed decline of CBDs. The Alderson and Sessions study of the Philadelphia CBD (1) has attracted wide attention since it was aimed at forecasting future space demands in the CBD of that city and hence future transportation needs. And there have been various other lines of research initiated which will not be discussed here.

For the most part these studies have had two characteristics which limit their value. Almost without exception they have been focused upon only one CBD—that of some particular city. Secondly, little attention has been paid to the delimitation of the district that they have focused on.

This matter of delimitation has not been given the attention it deserves. If the planning board in a city wishes to make studies of that city's CBD for local planning purposes, it is obviously their perogative to delimit the district as they see fit. But it is the author's belief that one of the best ways to learn more about the nature and functioning of the CBD is through comparative studies of such districts in a number of cities. For these comparisons to mean anything, a standardized method of delimiting the CBD must be used in the various cities.

A few years ago the author collaborated with J. E. Vance, Jr., now on the faculty at the University of California, in a comparative study of the CBDs of nine moderate-sized American cities: Grand Rapids, Mobile, Phoenix, Roanoke, Sacramento, Salt Lake City, Tacoma, Tulsa, and Worcester. A primary aim of this study was the development of a standardized delimitation method so that a comparison of the districts of several cities would mean something.

After investigating various possibilities it was decided that the only practicable approach was through land-use mapping. In each of the nine cities mapping covered the land use of what might be called the obvious CBD and extended well beyond, including all of the area that by any stretch of the imagination might be considered as belonging in the district. From this field work three maps were made for each city—one of ground floor use, one of second floor use, and a third map on which the use of the third and higher floors was generalized. Calculations from these maps formed the basis for the delimitation technique and for various comparisons of the CBDs of the nine cities.

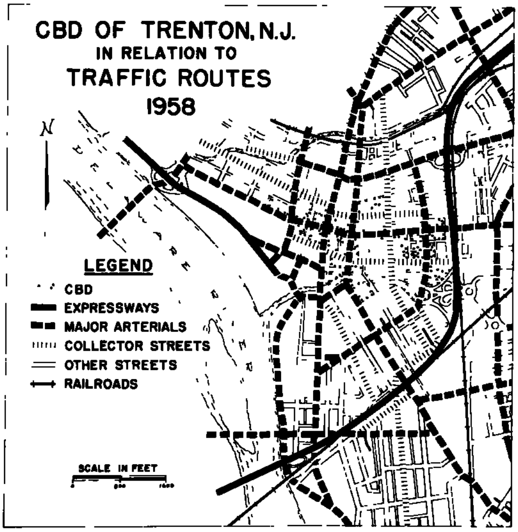

Figure 1. The Central Business District of Trenton, delimited according to the technique described in this paper.

The technique developed (5) can be only briefly summarized here. It was early decided that it should be based upon complete city blocks, since to split blocks would involve too many subjective decisions. Another element of the method was the designation of certain types of land-use occupence as noncentral-business in character. These included residences, industrial establishments, organizational establishments, wholesaling, governmental and public use, vacant building space and vacant lots, and commercial storage. In contrast, all other land uses were considered to be central business uses.

The technique involves the application of two indexes. To be considered as lying within the CBD a block has to have a Central Business Height Index of 1 or more; that is, central business uses (in contrast to noncentral-business uses) have to average one story or more for the block. Secondly, the block has to have a Central Business Intensity Index of 50 percent or more; that is, at least 50 percent of all floor space at all levels combined has to be in central business uses. In addition to qualifying on the bases of both of these indexes, the block has to be one of a contiguous group of such blocks surrounding the peak land value intersection. Finally, a few special rules were set up to meet frequently recurring problems.

It is not claimed that the area delimited by this method is the CBD. The district's edge is gradational so that no line boundary can be more than an approximation. But it is believed the area arrived at represents a fair approximation of the extent of the district. The most important point is that since the same delimitation technique is used in each city the delimited areas should be comparable.

Of course, the purpose of a standardized delimitation procedure is to give a basis for comparing CBDs. In the previous work (4) only nine were compared, and these were in cities which did not depart far from 200,000 in population. But a comparison even within these limits made possible the beginnings of some generalizations regarding the CBD.

For example, for the cities studied the average land use was determined. Total CBD floor space was found to be greatest in Salt Lake City and least in Mobile. Particularly notable was the great relative importance of service, financial, and office uses in Tulsa's CBD, especially the high proportion of space devoted to headquarters offices and general offfices. Worcester's CBD was found to have a higher proportion of residential and industrial use than any of the others. The importance of these noncentral uses reflects the fact that Worcester is an old northeastern city, established at a time when homes as well as factories were built as closely as possible to the center of the city. These are only samples of the many conclusions made possible by a comparison of the one land use proportions of the several CBDs.

Land use was also analyzed in terms of walking zones (6), based on the peak land value intersection: Zone 1, 0-100 yd from the intersection; Zone 2, 100-200 yd, etc. The analysis was carried out for each floor in each zone for each city, and for an average of eight of the cities.

Some interesting facts emerged. For example, the tallest buildings were found not to occur close to the peak intersection, but, instead, in the second 100-yd zone from the intersection. Department stores tended to cluster near the peak intersection; so, too, did clothing stores. Hotels, on the other hand, were more common several hundred yards from the intersection than in its immediate vicinity. Similarly, offices seemed to avoid the first 100-yd walking zone around the peak intersection.

Variation in CBD size from city to city was also a subject of concern. Does the CBD size vary directly with city size? Though the investigations suggested that this was the case, the cities studied were too limited in size range to give much information on this point.

Another subject investigated was barriers. Railroads, steep slopes, parks, water bodies, public buildings and expressways are among the barriers that have impeded expansion of the district and thus have affected CBD shape. It is rare indeed for the district to be open for growth in all directions. Much more often the types of barriers mentioned have limited growth in certain directions thus doing much to account for the present CBD outline.

The studies told something, too, of the actual mechanics of CBD growth. Typically, the district is not static, but, instead, is shifting in one direction or another, and zones of assimilation and of discard are observable. Interestingly, the center of area of the CBD generally lies in that direction from the peak land value intersection in which the district appears to be expanding.

Enough has been said to indicate the nature of the results. They are just a beginning on what could be learned about the CBD through comparative studies based on districts delimited by the same technique in various cities.

The most important step in expanding such comparative studies should be the delimitation of CBDs in a complete size range of cities. In the research described in this paper only cities of approximately 200,000 population were studied, but there is no reason the technique should not work for much larger cities. Just how does the CBD change in size, in land use, and in other respects with increasing city size? Does central business floor space vary directly with city size no matter how large the city? At what size does the CBD begin to exhibit functional subregions—a financial district, a theater district, and the like? Such knowledge should be useful in transportation planning.

A second line of attack that seems promising has to do with the mechanics of growth. Reference was made earlier to the fact that the CBD is not static but, instead, seems to be advancing along some edges and retreating or declining along others. This process needs to be examined more carefully through the comparative study method.

There are other questions for further research. How does the CBD vary with type of city? One might expect it to be better developed in cities that are predominantly commercial than in industrial cities but this remains to be proved. How can differences in CBD quality be measured? The same amount of floor space may be devoted to central business functions in one city as in another, but in one the hotels and other establishments are of much higher quality. An objective method of measuring such quality differences is badly needed.

Another general problem that needs further study has to do with the functions that add most to the CBD in contrast to those that are of little value. What, might be asked, is the ideal assemblage? Agreed that a prosperous CBD is desirable for a city, just what combination of functions best achieves this end?

In summary, what this paper has tried to point out is that the CBD should be better understood if it is to be dealt with properly either in route planning or in other ways. A recommended line of attack is through comparative studies of CBDs, delimited on a standardized basis. But this is a type of research for which it is difficult to find support since it is basic rather than applied and particularly since it is multi-city in character.

All this may seem distant to highway research, but this is not necessarily true. Good planning of transportation routes in urban areas requires an understanding of the city, and there is no section of the city that is more complex and sensitive than the Central Business District.

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New Roads for Old Cities: European Experience

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● CITY TRAFFIC and parking are troublesome the world over; whether they involve quantities of big vehicles on the straight roads of American cities, or a lot of little cars mixed with trucks, bicycles, horse and ox-carts on the winding streets of European towns. Many cities on the Continent had to be rebuilt following their wartime destruction. The opportunity existed to plan anew, to build, and to learn from the accomplishments and mistakes in rebuilding.

Invited by the Federal Republic of Germany to study reconstruction, the author was given an unusual insight into that country's planning efforts; therefore, this paper will be slanted toward German experience, but will also deal with impressions gained in Austria and Holland, where interesting things have been done.

European cities have as yet escaped many of the harmful consequences of automotive travel that are plaguing the urban centers of the United States. There is no outward evidence that business flees to the country leaving the downtown shopping streets to wither away. Railroads, streetcars and other common carriers are doing a good business and the service and equipment are improving, while they are deteriorating in this country. Farms and fields and woodlands are not being recklessly destroyed by an uncontrolled scattering of new developments in the country. For the most part the hearts of the urban areas are teeming with life, the stores are prospering in locations they have occupied for decades and over centuries, and the whole pattern of urban living conveys a sense of stability. These European conditions are comforting to Americans who hear and see a great deal of the threatening doom of cities.

Urban growth and the adjustment to new conditions have continued in Europe throughout the centuries of social and technological progress. Ancient, medieval, Renaissance and modern street patterns exist side by side—or have successively replaced each other without disrupting that delicate relationship between people and their environment that makes the public love and support their cities. The crooked foot paths and narrow shopping alleys of the towns of the middle ages are taking on a new significance under the realization that there should be shopping lanes exclusively for pedestrians. The broad and tree-lined avenues and the monumental squares of renaissance towns built in the grand manner make it possible today for undreamed of volumes of twentieth century motor cars to flow and to find at least once in a while a parking place. Past efforts to make cities beautiful and impressive are finding their reward today. Landtakings, demolition and boldness in planning, that even in this age of redevelopment seems astounding, have become more than justified. Millions of tourists spend their money to see these old accomplishments in urban design that rich America has been unable to achieve.

Modern cities that have risen on the hopeless heaps of rubble left by the bombings of the last war present fascinating laboratories for urban research. The rebuilding of German cities has brought about the opportunity to change the street plans and improve traffic. But this could only be done to the extent that the city architects provided the vision and leadership for the preparation of the plans, and the prevailing laws and financial limitations permitted their execution. The hampering forces to the achievement of ideals were the government's insistence to hold to the rights of individual property owners and the popular demand to rebuild along the old lines. In spite of it all, the reconstruction is now approaching completion, at least in West Germany, and the accomplishments in the repair to dreadful war damage are tremendous. Traffic and transportation, next to housing, have been the most important concerns of all cities in the process of reconstruction. Each town has it General Plan that establishes the transportation system; the use of land for housing, industry, etc.; the open spaces; forests and water; and various stages for the execution of improvements. (See Flaechernutzungs Plan, Stadt Stuttgart.)

The General Plan is developed in the city building office which combines all the departments needed for the planning and execution of an integrated program for improvements in the city. For example, the city of Hamburg has a building office with seven departments under a chief architect who has control over all building activity, the planning of the city and the design of public buildings. He directs and correlates the work of his departments of (1) town planning, (2) housing, (3) school and public building planning, (4) streets and utilities, (5) building inspection and zoning control, (6) parks, playgrounds, and cemeteries, and (7) surveys and deeds. Directly above him is the political government represented by two senators in charge of building who act as intermediaries between politics and planning. They have their contact with the voters through an elected fifteen-man building commission. Besides the seven technical departments, offices for personnel, the assessors, and the legal department are tied into the building office. This type of organization not only makes it possible to prepare comprehensive plans, but also to have them carried out. The director is a civil servant under tenure. In Germany, an awareness of the importance of the chief of building operations to the life and prestige of the city results in the choice of superior personnel for these posts. The positions are usually held by architects with training in city planning and experience in private practice and in some municipal building department. The men holding the job in larger cities are broadly educated, and have an understanding of the problems of the cities, the needs of people and the art of civic design gained through their work and extensive travel in Europe and other continents. Most of the European cities have a proportionately larger territory within their boundaries than do American cities. Annexation of bordering communities is going on all the time. Having the plans under full control in one political entity makes planning there easier than in so many American cities where a great number of local governments are involved, (for example, in metropolitan Boston, with over sixty separate cities and towns, it is virtually impossible to accomplish unified planning).

Germany started a network of superior highways for long-distance travel in the 1930's with the construction of the Autobahnen. These are limited-access roads that connect the outskirts of the principal cities and lead to the borders of the country. They were built primarily for military reasons. Their design standards were visionary at the time of their construction; now they seem antiquated and ready for widening and improvements at intersections. More of them are needed. The country has had to first rebuild practically all bridges on the road because they were blown up at the end of the war; it is now replacing pavements that have become worn under twenty years of hard usage which included five years of war. The increase in road construction for Germany in 1958 was 25 percent over 1957, while for the U. S. it was only 12.5 percent. The total length of the Autobahnen in 1955 was 2,175 kilometers—approximately 1,360 miles—and for a 12-yr construction program, an additional 2,000 kilometers (1,250 miles) are planned. To give the figures meaning, West Germany has an area of 94,252 square miles or approximately the equal of the combined states of New York and Pennsylvania. In function, the Autobahnen serve Germany as the Pennsylvania and New York turnpikes do their states. The other roads of the transportation network consist of state highways, country roads and local roads, much as it does in this country with one major exception; there are no ugly wooden telegraph poles and, in comparison to this country, practically no billboards. Wires are often carried in pre-cast concrete conduits in slabs that form the shoulders or bicycle paths of the roads. Cities are building high-speed feeder roads (Schnellwege) leading to the Autobahnen to improve the present hazardous and inadequate connections.

The street layout of European cities never follows the checkerboard gridiron pattern for which U. S. traffic engineers have developed their technique. Each of the old cities presents a special problem that is usually far more difficult to solve. Only one general principle remains in common with this country; that is, to keep all traffic out of the heart of the city that does not have to be there. Out of this premise grows the method for relieving downtown congestion that is rather generally applied in German cities. A curved highway, or a rectangular belt of tangential roads is developed around the core of the city to draw off the traffic. This is an old way of keeping the heart of the city alive. It was just as good at the end of the middle ages when horses and carriages replaced the beasts of burden as it is today when the motor cars are taking over. In some cities, the central area is still the original medieval town. When the old city walls were leveled, the areas cleared of fortifications were converted into a ring road; as, for example, at the famous Ring Strasse in Vienna, without which the city could not function today. From the businessman's point of view, these Ringstrassen—or Anlagen, as a similar park belt is called in Frankfurt—are the best "locations" in town. The park and the central position give the buildings a quiet yet prominent location with convenient access from all points of the city. Since the United States lost the "city beautiful movement," to which Chicago owes a tremendous debt of gratitude for its Michigan Avenue and Lake Shore Parks, its roadsides are being neglected.

Many opportunities to provide protective planting along inner belt roads were also lost in Europe in the pressure to create as much marketable and income-producing real estate as possible. The recently developed inner belts created as traffic roads are on the street level with only occasional grade separations at intersections; the major intersections are commonly handled with traffic circles. The city of Stuttgart is turning a difficult topography to the advantage of an interchange solution; it intends to dig into the hillside to create tunnels for the turning movements. Ordinarily traffic from the central area is led into the inner belt at intersections with a channelized traffic flow pattern which they have learned from the U.S.

There is a tendency to set aside streets exclusively for pedestrians in the shopping areas and in old cities where the space between buildings is too narrow for cars. The old, narrow roads have become lanes for stores; they have that subtle width that tempts pedestrians into becoming shoppers. In Vienna, a pedestrian underpass has been created in the form of a most attractive shopping area with a central cafe. The approaches are by escalator and the underground shops and restaurant deny all thought that an underpass must be that dirty, smelly and unsafe place for women known from experiences in this country.

Widening and straightening of roads, creating new frontage lines, establishing arcades along the shops are continuing operations to help traffic flow. Here is where the ingenuity, patience and persuasive power of the city planners come into play. Street widenings in this country are associated with ugly scars that never seem to cure themselves. However, if an architect is working with the city planner, some rather remarkable results can be achieved. Take for example Georg Strasse in Hannover. Here on a broad diagonal street a large public building was to be erected. Skillful maneuvering on the part of the city architect resulted in placing the building on the block behind the one cut diagonally, which was then cleared, planted and architecturally treated to enrich the setting for the new building and to form an attractive park for recreation with strips for parking on its fringes.

Downtown parking is the same problem the world over to which the present solutions are mere palliatives. Europe has the advantage of possessing public squares and market areas that offer parking spaces. Cities are building large garage structures, and in some places like Munich, underground areas or basements of commercial building groups are used for parking. Frankfurt closes the street crossings of one of its main streets (Kaiserstrasse) and devotes the side streets solely to parking and deliveries.

Each country solves its traffic and city planning problem in its own way.

Rotterdam in Holland has made the most of any city out of rebuilding a bombed-out central area. Immediately after the catastrophe in the spring of 1940, the city took over the entire damaged area. For five war years, the architects and planners of the city were busy developing the most farsighted plan that could be conceived. The required open space between buildings was increased by twenty percent. Dwellings were created in tall—high rise—slab structures. The famed pedestrian shopping streets called Ljinbahn were built. Now that reconstruction is nearly finished, the world finds that Rotterdam has the most modern downtown area; every problem has been most beautifully solved except for traffic and parking. Little did its planners—working in isolation during the war years—know about the post-war increases in cars and in car sizes.

The number of passenger vehicles has quadrupled in the last ten years in Western European countries. Adding further to the space problem, the small cars are becoming medium sized and motor cyclists shift to cars as they now can afford them. The average number of persons per passenger car varies country by country, and even city by city; Sweden has 9 persons per car; Switzerland, 15; Austria, 20; Italy, 40; and Germany, an average of 19, with 8 to 12 in many cities, compared with 3 for the United States and 5 for Canada.

The increasing number of cars, combined with the concentration of an increasing number of people due to higher buildings in the central areas, cause the dilemma of cities. This fact is proved by experience in Europe as much as here. Germany is trying to do something about it.

A new law is being debated, which attempts to relieve congestion by setting a lower limit to the density of building. By requiring more open space, two things are aimed for: first, better housing and more healthful conditions to life in the city; second, less congestion on the roads. This new Federal Building Law of Germany proposes a sweeping reform to meet technological progress and to provide for improvement in the social and cultural life of the people.

While in this large country, it would be useless to attempt to imitate what Germany or other European countries have done in their smaller territories, it is nevertheless possible to draw important lessons from European experience: this paper has pointed to these:

1. The hearts of European cities are sound.
2. Transportation on common carriers flourishes.
3. Natural landscape and the source of water in the land around cities are being conserved.
4. Urban design with the aim to create a beautiful city has found its reward.
5. The increase of open space and the reduction in the density of development of urban land promises to keep cities alive and the roads functioning.

To sum up, the building of roads in cities is an integral part of the planning of cities. Results grow out of the coordinated attack of all problems related to bettering man's environment in this age of rapid technological progress.

General Planning, Urban Renewal, and Highways

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●THIS MEETING presents a fine opportunity for the author to talk with another group of co-workers, for we all are working together toward the achievement of something greater than the specific objectives of our respective programs. Urban renewal and highways are in themselves limited goals. The larger goal we recognize and work toward is better, more productive living.

In particular, it is desired to discuss planning growth and improvement of cities and of urban regions and metropolitan areas; but because this type of planning is influenced by highway planning, and vice versa, much of what is said is in terms of both. This is so although highways sometimes run for miles without touching a city, no city is untouched by highways.

It might be helpful to begin by mentioning the basic aids to urban renewal that are administered by the Housing and Home Finance Agency. The first is Title I of the Housing Act of 1949, which first authorized Federal financial assistance to communities for slum clearance and urban redevelopment. In 1954 Title I was broadened to include assistance for the prevention of slums and urban blight through the rehabilitation of blighted and deteriorating areas. Urban renewal, as understtod and practiced today, is a combination of clearance and rehabilitation.

A community that qualifies for Federal assistance may obtain various technical and financial aids. Financial aids include advances, loans, grants, and certain types of mortgage insurance for private redevelopers, as well as public housing for displaced families.

How does a community qualify for these aids?

The basic prerequisite to eligibility for Federal aid is what is called a "workable program," certified by the Administrator of the Housing and Home Finance Agency. A community's workable program is the community's own plan of organized, total action, based on the full use of local private and public resources, to eliminate slums, prevent blight, and protect sound neighborhoods. It consists of seven basic elements: sound housing and health codes, enforced; neighborhood analysis; effective administrative machinery; financial capacity to conduct a renewal program; feasibility of rehousing families displaced from slums; community-wide citizen participation and support and; a general plan for the community's development.

This last item, general planning, deserves elaboration. Emphasis here is on the word, "general." The plan must be comprehensive. It must be subject to constant reviews as local conditions change. It must provide for the community's future along broad lines, and may, therefore, never be considered complete. It must allow for growth and change and must provide not only for housing people in decent dwellings and healthful neighborhoods but also for moving people more efficiently to and from their places of work, to and from commercial centers, and to and from the great highways that connect their city with others and for the efficient movement of goods.

It is hardly remarkable that action should be preceded by a plan. Yet until very recently—and the sad evidence exists throughout the land—plans and their attendant actions, whether for land development or redevelopment or highways, were usually independent of and frequently largely unrelated to other plans and actions.

We are now moving in the direction of correcting the errors of our misguided or unguided past. A few figures provide some measure of the motion forward. At the end of last year workable programs had been certified for more than 700 American cities, large and small, and over 350 communities were actually engaged in conducting some 600 urban renewal projects.

Speaking of the workable program, Housing Administrator Albert M. Cole said:

> "There are few concepts that have carried us so far at so little cost. The workable program idea that a community should analyze itself, assess its

faults and virtues, and plan comprehensively for the future, makes sense. It makes sense not only as a prerequisite to receiving Federal aid, but because it is a good thing in any event."

A community with a certified workable program is ready to make formal application for Federal funds to assist it in undertaking an urban renewal project. As a first step, the community applies for an advance of money to enable it to prepare its urban renewal plan. If the Urban Renewal Administration approves the advance—which is chargeable to gross project costs, when and if the community carries out the project—a capital grant reservation is also made. This is simply an earmarking of funds from the total amount authorized by Congress to assist local projects, not an actual transfer of funds.

Then comes actual preparation of the urban renewal plan; that is, the blueprinting of work to be undertaken in the project area. Here the community's general plan assumes a great significance. The urban renewal plan must conform to the general plan of the community as a whole.

Minimum requirements of the Urban Renewal Administration with respect to the general plan are:

1. A land use plan.
2. A thoroughfare plan.
3. A community facilities plan.
4. A public improvements program.
5. A zoning ordinance and zoning map.
6. Subdivision regulations.

Unless and until there is conformity to the general plan, the Federal Government will not enter into a loan-and-grant contract with the community. Through such a contract, the community obtains a temporary Federal loan to provide working capital and an outright grant to cover up to two-thirds of the net cost of carrying out an urban renewal project.

The point I wish to make is that Federal financial aid for urban renewal provides, in addition to certain clearly visible and tangible project benefits, a strong incentive to general planning. In the following generation there is little of higher importance than general planning in solving the tremendous problems of housing people and moving them from place to place decently, efficiently, safely, and comfortably.

The Housing Act of 1954 provides another important form of aid. Section 701 makes it possible for state planning agencies to obtain grants, up to 50 percent of the cost of the work, to help them give planning assistance to communities of less than 25,000 population. Similar grants are available to official state, metropolitan, and regional planning agencies for work in metropolitan areas and urban regions.

Although this program has been in operation just a little more than four years, it has already been of great service. Equally important are the facts that many communities lacking the financial resources to support permanent agencies have been enabled to carry out the work of general planning and that metropolitan planning has been greatly stimulated and accelerated. At the end of the year more than 800 small communities and about 55 metropolitan areas and urban regions in nearly 30 states were engaged in planning activities under the urban planning assistance program.

Not all of those 800-odd small communities—and the additional hundreds that may be expected to receive aid under the program in the years just ahead—are likely to undertake urban renewal projects. Nevertheless, all of them should be able to build a solid foundation for over-all civic improvement as a result of their general planning. All of them, along with the urban regions and metropolitan areas taking advantage of the benefits of the program, will be increasingly aware of the enormous impact that urban renewal and highways have on each other.

At the Federal level the need for close relationship between urban renewal planning and highway planning has for a number of years been recognized by the Urban Renewal Administration and the Bureau of Public Roads, and there is increasing coordination of policies and procedures. For example, applications for Federal aid to carry out urban renewal projects must include maps showing the location of major highways—including, of course, federally assisted highways—that are under construction, being planned, or contemplated. In turn, copies of these maps, with urban renewal areas indicated, are forwarded to the appropriate Bureau of Public Roads division offices.

State and local authorities have been advised of the need for coordination and of procedures to be followed. It is important to mention that there are coordination problems besides that of physical relationship of urban renewal and highways. The matter of timing urban renewal activities and highway activities must be given very careful consideration, in order to assure that the improvements created by one of those activities will not needlessly raise land values—and thus land acquisition costs—for the other.

It is also important—indeed, imperative—that urban renewal and highway activities be coordinated so as to minimize the problems of relocating displaced families. The relocation problem is a large one. During the period covering fiscal years 1958, 1959, and 1960, it is expected that urban renewal will dislocate 83,000 families; highway construction, 75,000 families; other government activities, 89,000 families—a total of nearly a quarter of a million households. Certainly every community involved must plan and program its relocation requirements carefully if it is to avoid undue strain on its housing resources and public resistance to the programs in which all are interested.

The basic responsibility for community planning and coordinating urban renewal and highway planning lies with the communities themselves, and no amount of Federal requirements and directives can substitute for this local responsibility. Among the communities that have met this responsibility and done effective jobs of coordinating their urban renewal and highway programs are Norfolk, Virginia; New Haven, Connecticut; Nashville, Tennessee; Atlanta, Georgia; Detroit, Michigan; and Cincinnati and Dayton, Ohio.

In conclusion these points should be emphasized:

1. The Housing Act of 1954 has been extremely effective in advancing general planning in individual communities.
2. More thorough and widespread metropolitan planning should be advocated. This is necessary not only for urban renewal purposes but perhaps even more so for better highway planning in urban areas.
3. Although policies and procedures can be coordinated at the national level, specific urban renewal and highway projects must be coordinated at the local level.
4. There must be close working relationships between local urban renewal people and highway officials at state and city level, all in concert with sound city and metropolitan planning.

An era of unprecedented urban growth and change has been entered. Superhighways will contribute to both urban sprawl and greater concentrations in central areas, and we shall witness the painful process of natural selection in central area functions.

But what of the vast area in between—the aging obsolescent area?

Here the urban renewal planners and planners of inner circumferentials get all tangled up with each other and some say these vast areas will be dismal economic wastelands. Who says the pattern of circumferentials and radials is right, anyway? One of Europe's greatest planner-doers recently advocated the super-grid as a better alternative because it permits greater flexibility for future growth.

We must be increasingly unwilling to proceed under established concepts. Faster rates of growth and change demand more frequent challenge. In any event, let us hope that working together we can plan and build cities better suited to future needs than did our forefathers. It will not be easy.

Measurement of Central Business District Change And Urban Highway Impact

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The problem of evaluating the impact of urban freeways on the city center has not yet been studied in any systematic way. In fact, no approaches to the subject have been developed and no ideas have been advanced as to just how to go about such an investigation (1, 2). At this elementary stage in the development of knowledge concerning land use structure and its relationship to transportation, the problem must be presented in very broad terms involving some degree of subjective analysis. Nevertheless, it is clearly realized that a proper assessment of highway impact on any land use or activity must necessarily evaluate conditions within the freeway network itself, which may alter impact; secondly, it must fully understand the characteristics of the object supposedly receiving the impact. In addition, closely related variables must also be understood. Of course, in evaluating the role of freeways on the central business district (CBD), it is critical that trends within the CBD be fully realized. Only by considering both inherent and closely related change in the freeway network, and independent change in the CBD, can the impact of freeway development on the city center be fully realized.

Although improvements in both inter and intracity transportation may have a marked effect on an urban economy, there are many other simultaneous changes in the structure of the metropolis which may also have a broad impact. These include inter-regional migration, defense spending, national market conditions, the availability and adequacy of water, industrial waste problems, labor conditions, and the sheer multiplying effects of urban growth itself, as well as many other things. As any urban area increases in population it becomes more self-sufficient in providing the range of goods and services required by its inhabitants. Thus, some new establishments are woven into the economy for this reason alone. With all of the variables operating and having some mutual effect on each other, a substantial research problem arises in segregating the influences of freeways, even in a general manner, and particularly in assessing their influence on the CBD. As a general rule, it is extremely difficult, statistically, to isolate from a complex set of factors, the effects of a single factor (such as the impact of urban freeways on the CBD) unless one has previously determined the effects which some of the other important factors have had on CBD activities.

First, primary variables inherent in the freeway network itself, and then the closely related variables, will be discussed. Secondly, CBD district changes will be presented an analyzed in relation to future freeway development.

INHERENT VARIABLES IN ASSESSING THE IMPACT OF URBAN FREEWAY DEVELOPMENT

Extent of the Freeway Network and Its Degree of Completion

The extent and degree of completion of an urban freeway network looms as a significant variable in the study of economic impact. Present highway impact studies essentially reflect the effect of an isolated facility on adjacent land values or on retail sales (3). In the few instances where land values have been studied in conjuction with freeways which were parts of systems, the percentage increases in the value of land over the time span considered were not nearly as spectacular as in the cases where

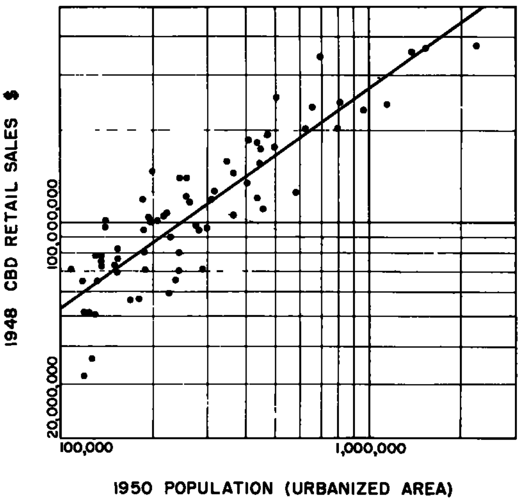

Figure 1. Urbanized area population, 1950 vs CBD retail sales, 1948.

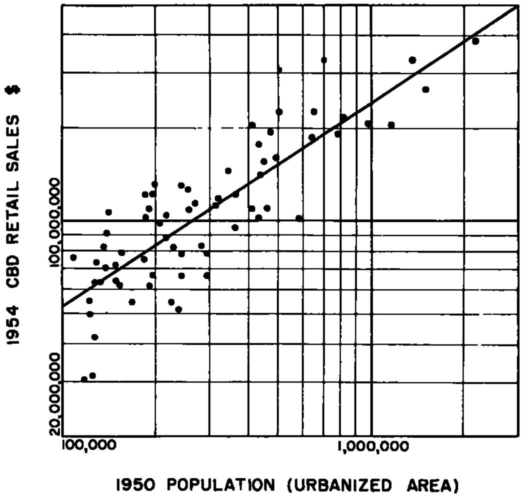

Figure 2. Urbanized area population, 1950 vs CBD retail sales, 1954, (corrected to 1948 dollars).

only isolated freeways were examined (4, 5, 6). As these studies were not designed to examine economic impact of a freeway network, their results are limited.

It is obvious that the completion of one element of a freeway system, say a radial route connecting the city center with the suburbs, will for a time place the land in that segment of the city in a comparatively more favorable position. Excluding the effects of intercity highway improvement, of which the radial route may be a part, this single freeway will only shift demand for land from one sector of the city to another, with no economic benefits from the freeway accruing to the city at large. It follows that as the freeway system develops the impact along any given route is proportionately diminished. Unless the reduction of time-distance from the outlying areas causes more business activities to be located in the city center, it will receive no benefit from the radial route. Actually, the radial route may also encourage decentralization of business activities in the center of the city. In this respect the freeway is a two-way avenue which may promote decentralization or deter it. Finally, on the question of urban freeway network extent, there are variations from one city to another in the possible freeway network as conditioned by topography. In many cities topographic features limit the possibility of providing optimum freeway systems. This may be particularly critical in and around the CBD. On this account, the freeway impact varies from city to city.

Degree of Development and Completion of the Inner-Distributor Loop

Of particular importance in determining the effect of freeway system development on the CBD is the completion of the central traffic distribution system. Because radial freeways carrying several thousand vehicles per hour each cannot effectively intersect at a point, the ability of radials to serve the CBD depends on the adequacy and completion of the central distribution system (7). The inner distributors are the most expensive portions of the entire freeway system because of the high cost of central land, the large amount of land used, and the cost of constructing the many interchanges and ramps. Because of the planning and financing problems, most central city distribution systems will not be constructed until late in the current National Highway Program. This time lag will preclude an early test of freeway impact on a city center, even if the mechanics of such an evaluation can be devised.

The ability of the central distribution system to handle the traffic input from radials is recognized as the most critical problem facing freeway planners and designers to-

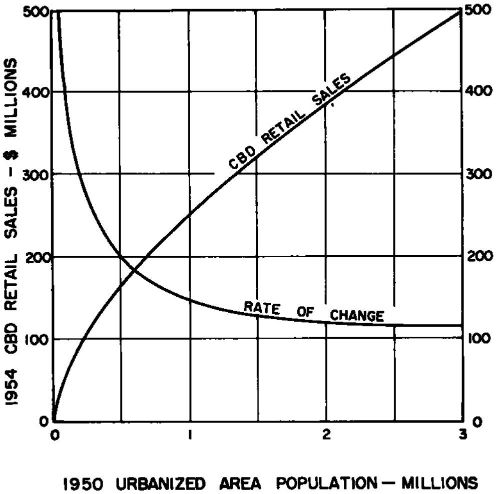

Figure 3. Characteristics of CBD retail sales and city size, 1954.

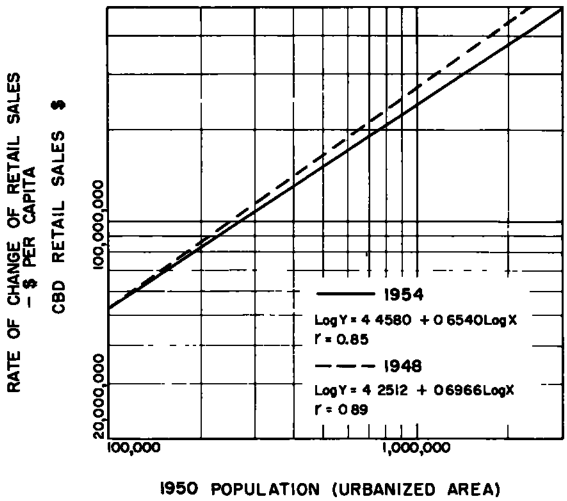

Figure 4. Urbanized area population, 1950 vs CBD retail sales; 1948 - 1954 comparison, (corrected to 1948 dollars).

day. There is mounting evidence that the accumulated ramp capacity of the inner distributor may limit the use of the freeway system during the high volume traffic periods. This serves to illustrate further that aside from its completion in terms of timing, the inner-distributor loop will have a significant bearing on the operational efficiency of the entire freeway system. This introduces another important variable in assessing highway economic impact. The adequacy of design, timing of development, and operational efficiency of the inner-distributor system may all have considerable effects on CBD development.

Extent of Central Space Used for Highways

The critical design feature of central urban freeways is access capacity. This calls for the maximum possible number of access ramps serving the city center consistent with design standards, and thereby requires an extensive amount of land. Under the circumstances, the land demand for the central portions of the freeway network is substantially greater per unit length of highway than for suburban or intercity segments. The central distributors of most freeway networks require about 40 acres of land per mile, exclusive of interchanges with other freeways (8). Suburban locations, on the other hand, require between 20 and 30 acres per mile. Some idea of the magnitude of land requirements for interchanges may be given by two examples from California. The interchanges between the Harbor and both the Santa Monica and San Diego Freeways in Los Angeles will require almost 90 acres each (8).

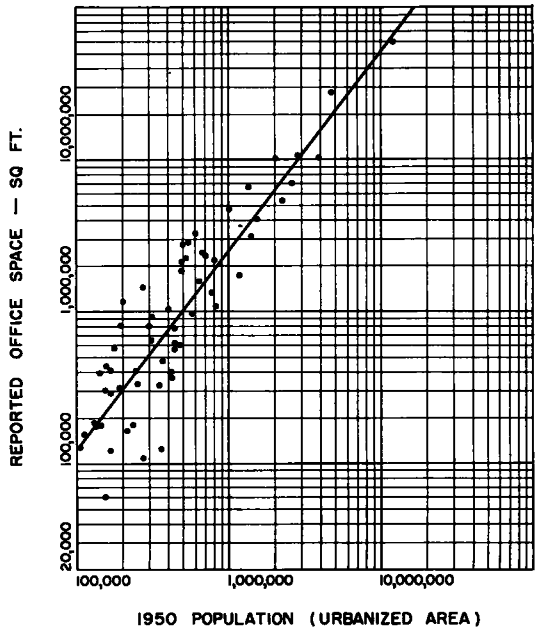

Figure 5. Urbanized area population, 1950 vs reported office space, 1946.

Another implication of the extensive

space use for central freeways relating to the evaluation of highway economic impact, concerns the land market mechanism itself. The elimination of a large percentage of central land from the market is bound to influence rents in the entire downtown area. Central land is a very limited resource by virtue of its location at the focus of intercity and intracity transportation. It follows the normal economic trends of price increase when the supply is curtailed.

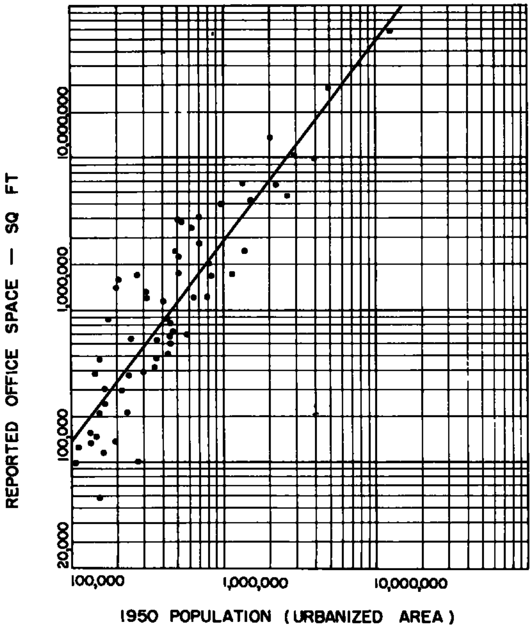

Figure 6. Urbanized area population, 1950 vs reported office space, 1956.

Extent of Freeway Interference with Business Linkages

Another important factor of the large space consumption of the freeway in the central region of the city is its capacity to create a detachment in what might formerly have been a relatively homogeneous functional node. In spite of careful attention to land use in the planning of inner freeway segments, this type of detachment will certainly occur in some areas. It assuredly influences land values insofar as this detachment weakens business linkages which formerly contributed to the economic cohesion of an integral portion of the central city region.

In the highway impact studies dealing with land values, relatively symmetrical land use patterns occurred on either side of the new freeway, with a few exceptions (3). This has led to the concept of decreasing land values as distance from the freeway increases. In the case of the inner-distributor loop, however, there are

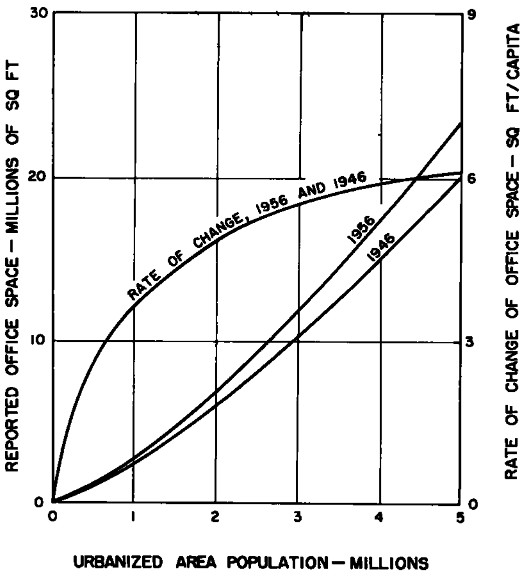

Figure 7. Urbanized area population, 1950 vs CBD office space; 1946 - 1956 comparison.

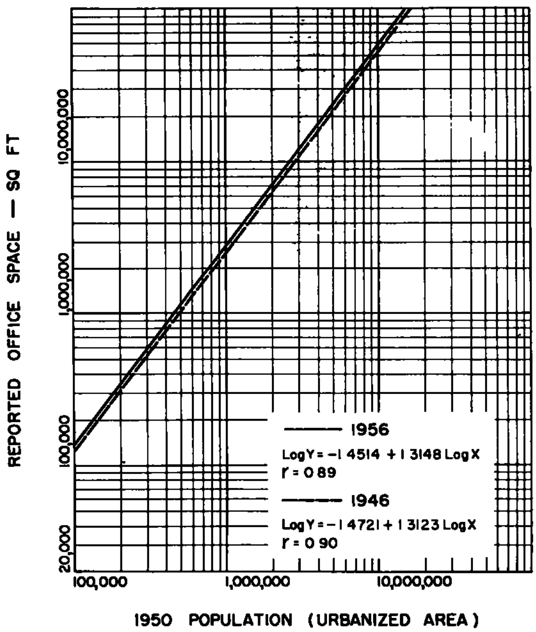

Figure 8. Urbanized area population, 1950 vs reported office space; 1946 - 1956 comparison.

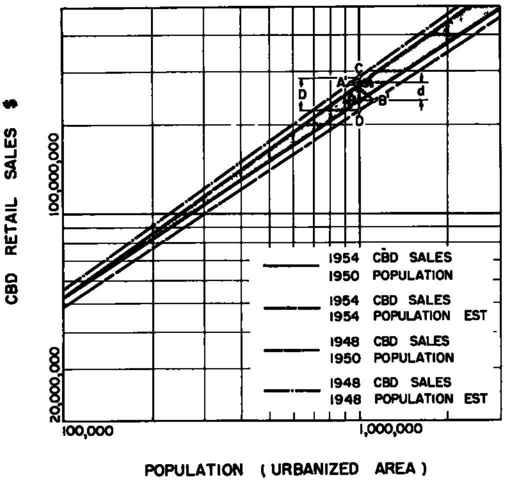

Figure 9. Urbanized area population vs CBD retail sales; 1948 - 1954 comparison, (with and without population correction).

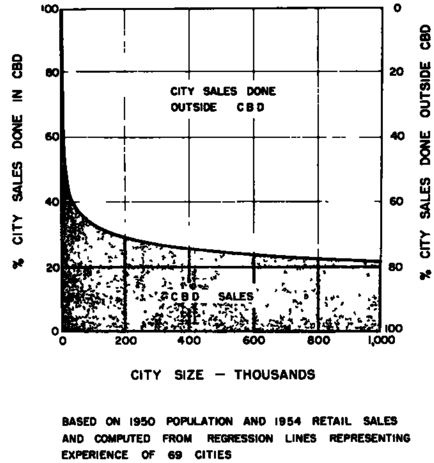

Figure 10. Proportion of city retail sales in CBD.

drastically different sets of land values and uses on either side. The CBD core, located inside of the loop, has land values typically twenty times those outside the loop (9). Furthermore, with the construction of an inner-distributor loop, the transition between the two categories of land use becomes quite abrupt, creating a sharp discontinuity in any gradient of land values which formerly existed.

Extended Time Required to Construct System

In general, the extended period of development for an adequate system or urban freeways, even under the best circumstances of planning and programing, is the greatest single obstacle to the study of impact itself. The fifteen-year study of land values and land use along the Gulf Freeway in Houston shows with each successive five-year increment of time the percentage of increase in land values becomes smaller leaving little doubt that impact is variable with time (6).

Unlike the small city highway bypass, a before-and-after study of any urban freeway network requires considerable time. The developing system will preclude a stagnant condition even for a moderate period of time, in which to evaluate highway impact of the CBD.

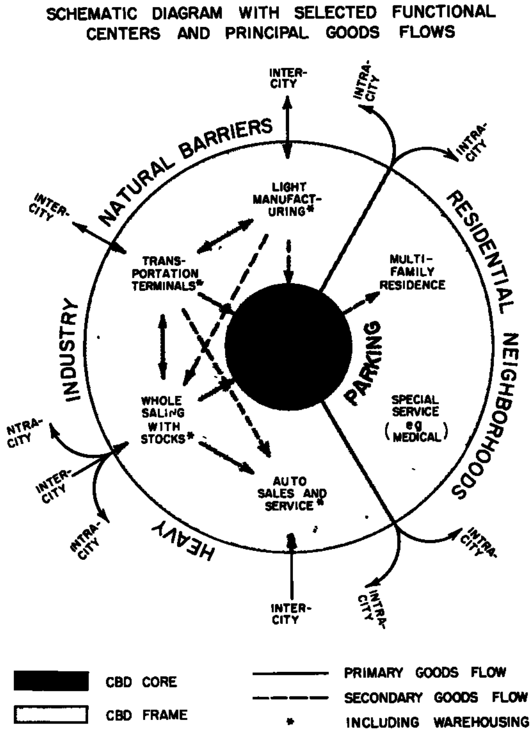

Figure 11. The CBD core-frame concept.

Extent of Changes in Trade Area Structure

Aside from the specific impact of urban freeways on the city, the intercity routes of which most of them are a part also have substantial implications for change in the urban structure. Their impact on the city relates primarily to changes in economic activity caused by a reduction in time-distance between cities and between the city and points within its trade area. It is highly probable also that changes in the spatial configuration of the trade area also occur with improvements in the intercity transportation system, as the history of railroad development in the United States indicates. Because of the extension of a rail network into the West from the established trade centers near the Mississippi River, the Plains States were not able to develop regional capitals on the scale of St. Louis, Chicago, Minneapolis, etc., and these older cities remain the primary centers of wholesale trade for the Plains States today.

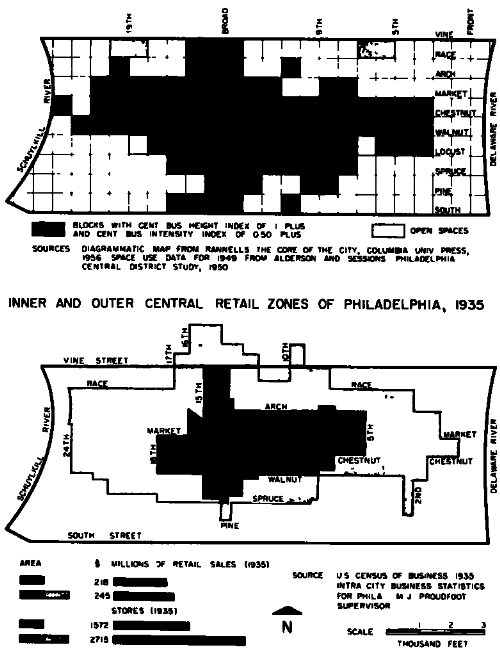

Figure 12. Philadelphia central business district, delimited by the Murphy-Vance-Epstein technique (above). Inner and outer retail zones of Philadelphia, 1935 (below).

Extent of Centralization of Activities

Some of the general economic effects occasioned by intercity highway improvement undoubtedly show up in an increased demand for some categories of urban land. One aspect is reflected in the centralizing of business activities. A good indication of this is the increasing per capita use of central office space with increasing urbanized area population (7). Another example is the way the service industries of one city can extend the range of their trade area because of better transportation, thus providing competition to their counterparts in outlying areas of the metropolitan complex or in nearby cities. The intensity of this impact will vary from city to city, of course, depending upon its size and position in the regional complex. For instance, the development of a freeway between Seattle and Tacoma, 30 miles apart, may be of greater advantage to Seattle than to Tacoma, a city with only one-fourth as large a population as Seattle's.

NON-INHERENT VARIABLES IN ASSESSING THE IMPACT OF URBAN FREEWAY DEVELOPMENT ON THE CBD

Planning and Urban Redevelopment

Land use determinants arising out of public policy will naturally affect the market mechanism controlling the price of urban land. This introduces another variable in

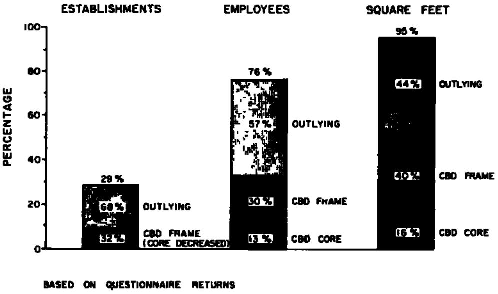

Figure 13. Percentage increase in insurance activities 1946-1958; headquarters and regional offices.

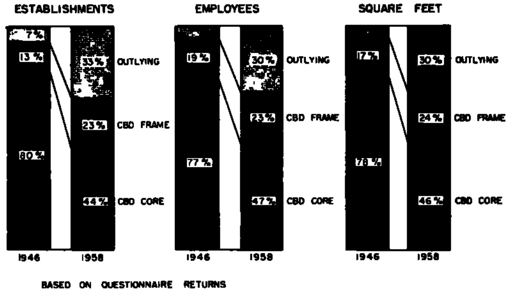

Figure 14. Relative location of insurance companies; headquarters and regional offices.

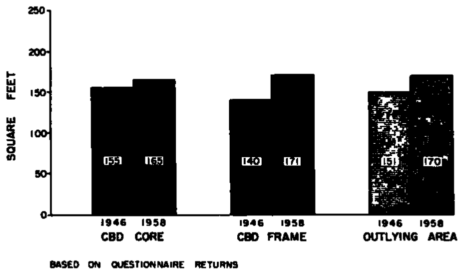

Figure 15. Average floor space per employee; headquarters and regional offices.

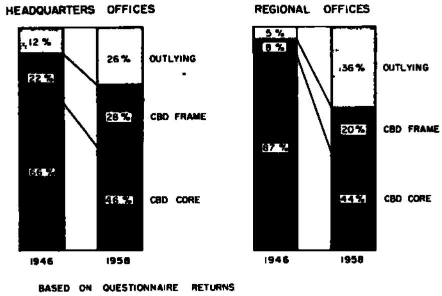

Figure 16. Relative location of insurance establishments.

the evaluation of urban freeway impact. In most of the freeway impact studies to date care has been taken to segregate land in different zoning classifications so that comparisons are always made between land parcels in the same classification. Besides land use zoning, urban redevelopment is a planning measure which may have even greater effect on the assessment of highway impact on central land.

Although urban redevelopment may occur in many areas of the city, it is the central and older sections which are becoming the first concerted objects of this activity. The large areas coming under redevelopment in the central regions of many cities remove land from the market, as in the case of freeways. Most central redevelopment projects have been for housing. The decision to construct housing in central areas is not necessarily based on economic reasoning, but may, and usually does, involve a different set of determinants than in the original development of the land. These may include a wide range of social goals, as well as the preservation of central land values. These urban redevelopment projects have a substantial economic impact of their own, and may be of such magnitude as to interfere with the possible measurement of freeway impact. An example is the redevelopment of the lower Eastside of New York City into "highrise" apartments adjacent to the lower end of Roosevelt Drive.[1]

In addition to the development and exercise of public policy in municipal planning, collaborative planning effort by private central interests is a variable to contend with in evaluating highway impact on the CBD. In over a dozen large cities central associations of private businessmen are active in promoting "downtown" as well as specific collaborative projects (10). Notable examples of effort from such groups are the Gruen Plan for downtown Fort Worth and the Charlestown Project in Central Baltimore. In the latter city a highly competent technical staff has been retained to aid the Central Baltimore Association in formulating and planning major redevelopment projects. The

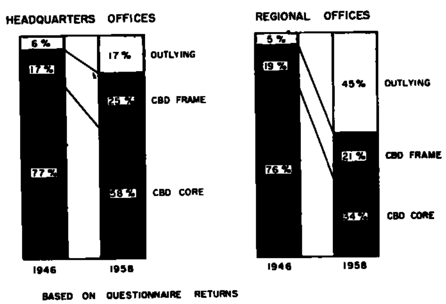

Figure 17. Relative location of insurance employees.

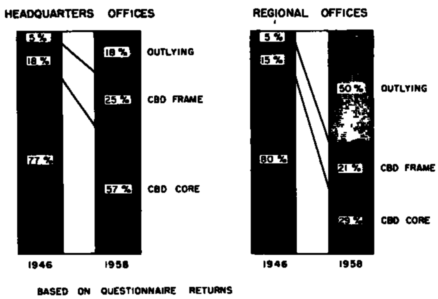

Figure 18. Relative location of insurance floor space.

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[1]For example, the recent housing projects completed adjacent to Roosevelt Drive in the lower Eastside of Manhattan account for a population of approximately 30,000 people. See New York City Housing Authority, "Project Statistics," N. Y. (June 30, 1955).

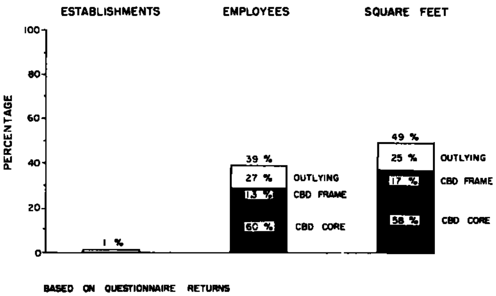


Figure 19. Percentage increase utility activities 1946-1958; headquarters office.

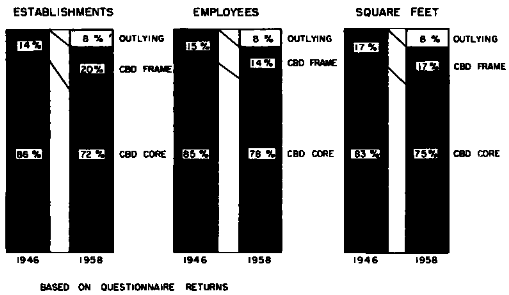


Figure 20. Relative location of utility companies; headquarters offices.

point here is that this type of positivistic effort may have a profound effect on the CBD regardless of highway development itself.

Provision of Off-Street Parking near the Core

The development of central parking garages is another significant variable in the evaluation of freeway impact on the city center. Without central off-street parking improvements the freeways will not be able to increase the daytime population of the CBD core. The responsibility for these terminal facilities may be that of either private or public enterprise whereas freeway development is a public function, exclusively. This division of responsibility, plus the inevitable problem of formulating public policy on the local level, may well preclude the provision of sufficient parking in time to meet rising demands induced by freeway development. Without central parking, the full potential of the freeway system may not be realized, and a consequent reduction of its impact on land values and land use in the CBD may occur.

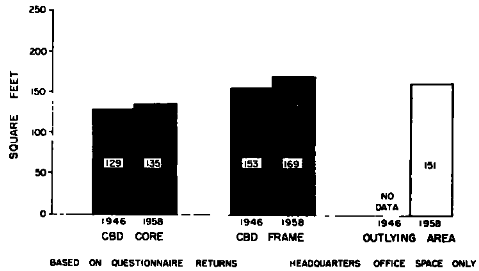


Figure 21. Average floor space per employee; utility companies.

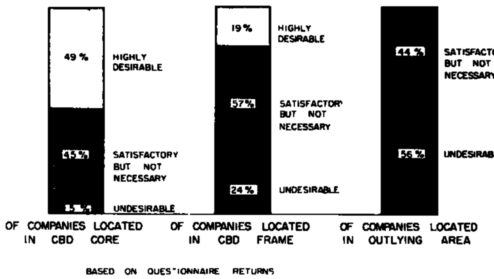
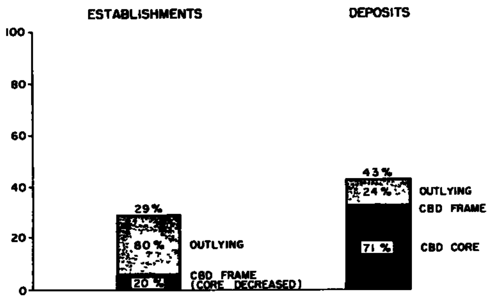


Figure 22. Opinion on location of headquarters office in CBD core.

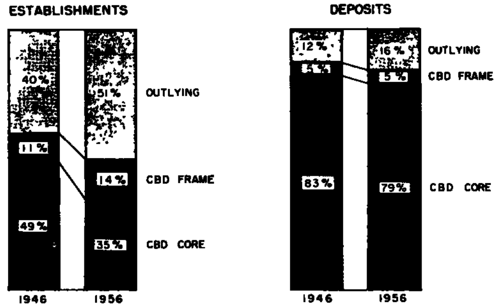
Development of Mass Transit

Although few major cities in the United States have made substantial inroads in integrating the development of mass transit with freeways, sufficient advances have been made to imply widely differing schemes and possible degrees of success (11). Also, like urban freeways, the benefits from a modernized mass transit will only be realized with the development of a full system of routes and terminals, all of which will require many years to be realized. Transit service, therefore, looms as an important variable to contend with in analyzing the central impact of urban freeways, not only from the magnitude of the system developed, but the extended time required for its completion. Actually, mass transit and the freeways are competitive in serving a portion of the person-trips to the CBD. In this respect the economic impact of these two systems is almost inseparable.



BASED ON STATES WITH NO BRANCH BANKING LAWS

Figure 23. Percentage increase in banking activities, 1946-1956.



BASED ON STATES WITH NO BRANCH BANKING LAWS

Figure 24. Relative location of banking activities, 1946-1956.

A SPATIAL FRAMEWORK FOR THE ANALYSIS OF CBD CHANGE

Any study analyzing central land use changes is concerned with an appropriate spatial framework. That used here is the Core-Frame Concept as developed elsewhere by the authors (7). The "core" and the "frame" are viewed as two separate functional areas of the CBD.

For purposes of this analysis three terms relating to the spatial organization of the city are utilized: the central business district core, the central business district frame and the outlying areas; referred to in the figures as CBD core, CBD frame, and outlying.

The CBD core refers to the concentrated grouping of large buildings in the city center and is characterized by a dense daytime population and intensive land development. Floor space is essentially devoted to retail trade, consumer services, and office use. The core has limited lateral dimensions, is geared to the pedestrian scale, and is easily recognized from an aerial view by the clustering of tall buildings. This area is devoted primarily to people, paper, and parcels.

The CBD frame is the predominantly commercial area surrounding the core and contiguous industrial land use. Here the land development is extensive, as compared with the CBD core, including a measurable quantity of unbuilt-on land for parking, storage, and the maneuvering of vehicles. Few buildings in the CBD frame have elevators, and the linkages between establishments are vehicular rather than pedestrian. Predominant uses in the CBD frame are wholesaling with stocks and warehousing, automobile services, transportation terminals, service industries, and sometimes medical and governmental services. The CBD frame has been characterized in the literature as a zone of transition; an interstitial area between the intensely developed land in the central

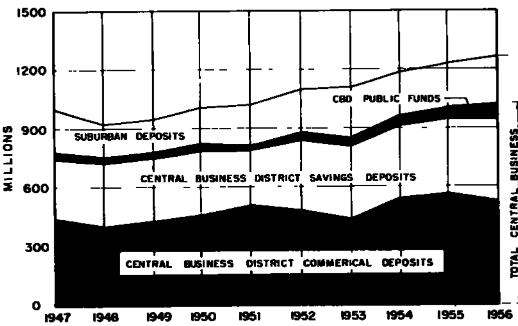
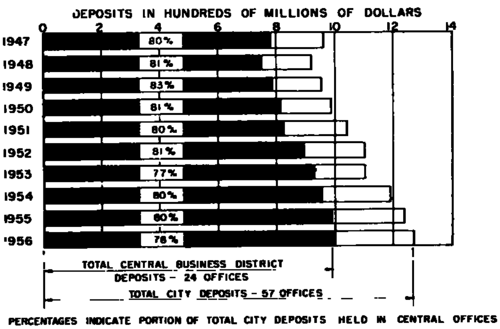


Figure 25. Comparison of central business district and citywide deposits, 1947-1956.



PERCENTAGES INDICATE PORTION OF TOTAL CITY DEPOSITS HELD IN CENTRAL OFFICES

Figure 26. Comparison of downtown and total city bank deposits, Seattle.

core and the inlying residential areas. Here outmoded housing has given way to the uses previously mentioned. The CBD frame typically has between three and six times the area of the CBD core, depending to some extent on topographic conditions. It is of particular interest to the study of decentralization because the frame area is seen to be the focus of a substantial number of establishment moves from the CBD core. This change is not to be considered as merely an expansion of the core into the adjacent area, but represents a reorientation of location based on changed requirements for transportation linkages. For example, the headquarters offices of insurance companies are relocating in the CBD frame and outlying areas because of the changing characteristics of the activity, rather than for reasons of expansion (7).

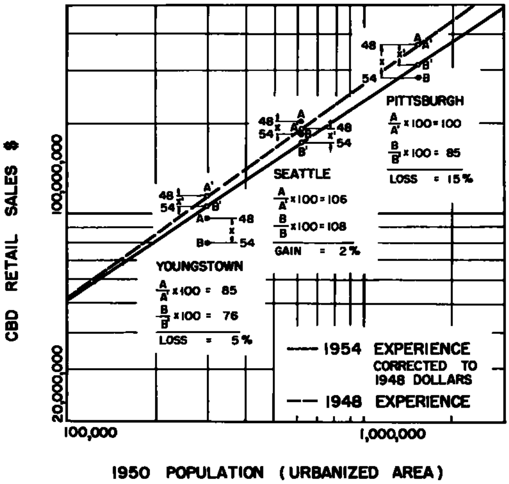


Figure 27. Deviation and relative change in CBD sales, 1948-1954.

The outlying area includes all other portions of the urban complex not included in the CBD core and CBD frame. This category may include the suburban areas of the central city, incorporated areas of perimeter cities, or unincorporated areas which are urban in character.

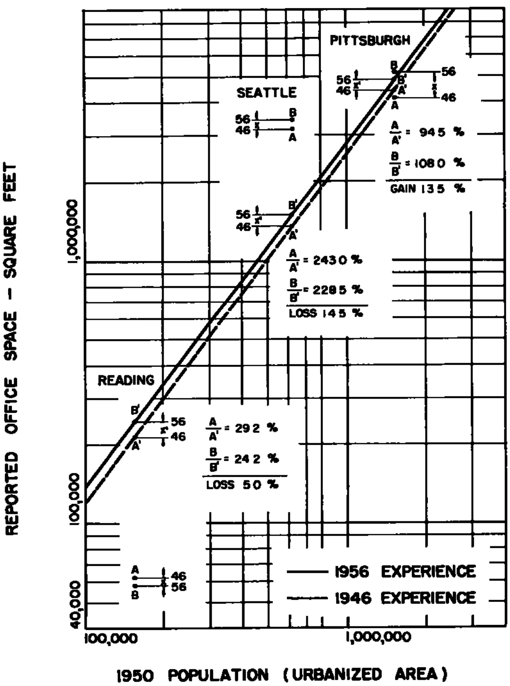


Figure 28. Deviation and relative change in office space, 1946-1956.

CENTRAL BUSINESS DISTRICT CHANGE

Nature of Central Change

In addition to the previously discussed variables, changes are occurring in the city which may be entirely independent of transportation improvement. A knowledge of these is especially important in assessing transportation impact on the CBD, which is an area that is constantly acquiring, discarding, and rearranging activities. In contrast, other parts of the city, while changing the intensity of settlement, do not exhibit the same degree of assimilation and discard of functions. For example, office buildings have a continually fluctuating range of establishments.

Evaluation of CBD change on a national scale is a considerable task, even without considering transportation improvements. For example, technological change influences merchandizing, office operations, and location advantage, as in the increasing use of business machines, which may alter the composition of the labor force and its patterns of travel.

Regardless of the complexity of evaluating and understanding CBD change, some insight into gross trends can be gained. Studies of central office space and retail sales have been undertaken to determine trends in the functions accounting for well over one-half of the CBD core uses. (Figures 1 through 8 show results graphically.) In addition, specific studies were undertaken (7) on the decentralization of a range of activities which by tradition have been centrally located. These studies record trends generally concerning the post World War II decade, a period actually preceeding the development of urban freeways in all but a few cities. Even in the few cities with freeway construction, complete systems were not developed. Thus, recorded CBD trends cannot be considered attributable to highway transportation improvement.

CBD trends will be discussed within the context of centralization and decentralization. Centralized activities are considered to be those which are located within the CBD, although they may not necessarily be clustered. The terms clustering and dispersal are not synonomous with centralization and decentralization, respectively; certain centralized activities may be dispersed throughout the CBD and certain decentralized activities may be clustered in one outlying area.

Findings on Change

CBD change will be first evaluated on two bases: (1) trends adjusted for population growth (termed "per capita" basis) shows CBD change relative to the estimated urbanized population growth within the time interval, and (2) trends based on no change in urbanized area population (termed "absolute" basis) shows CBD change independent of population change. Trends determined on a per capita basis are of greater magnitude than those found on an absolute basis.

On a per capita basis (urbanized area population) there has been a slight diminuition of CBD core activities. This is substantiated by the following, based on the generalized experience of the cities studied (7).

1. Absolute CBD retail sales (adjusted for changes in dollar value) have decreased between 1948 and 1954 for 69 cities, ranging linearly from 14 percent in a city of 100 thousand to 28 percent in a city of 3 million. This directly accounts for an approximate loss of 265 retail workers in the smaller city to about 4,500 in the larger.[2] (Fig. 9)
2. CBD reported office space has decreased between 1946 and 1956 for 60 cities, ranging linearly from 20 percent in a city of 100 thousand to 9 percent in a city of 1 million (7). This accounts directly for an approximate loss of 133 office workers in the smaller city to 6 thousand in the larger city.[3]
3. Between office and retail workers, there has been an approximate reduction of between 400 in the city of 100 thousand people to 10,500 in the city of 3 million over the time span. This amounts to roughly a 5 or 6 percent reduction in the core labor force in both cases.[4]

On an absolute basis there has not been any perceptible diminuition of CBD core activities. This is substantiated by the following as based on general experience curves. (Figs. 4 and 8)

1. Absolute CBD retail sales (adjusted for changes in dollar value) have decreased between 1948 and 1954 for 69 cities, ranging linearly from an imperceptible amount in a city of 100 thousand to 20 percent in a city of 3 million. This accounts directly for approximately no loss in CBD workers in the smaller cities and about 3,200 in the larger (7).
2. CBD reported office space has increased between 1946 and 1956 for 60 cities, ranging linearly from 20 percent in a city of 100 thousand to 9 percent in a city of 1 million. This accounts directly for an approximate increase of about 133 office workers in the smaller city CBD to 6,000 in the larger city (numbers coincidentally the same as in No. 3 above) (7).
3. Between office and retail workers, there has been approximately an increase of between 133 in the city of 100 thousand to 2,800 in the city of 3 million over the

[2]Based on a 69 city average of $26, 500 in retail sales per person.
[3]This calculation is based on 150 sq ft per office worker.
[4]This is a conservative estimate.

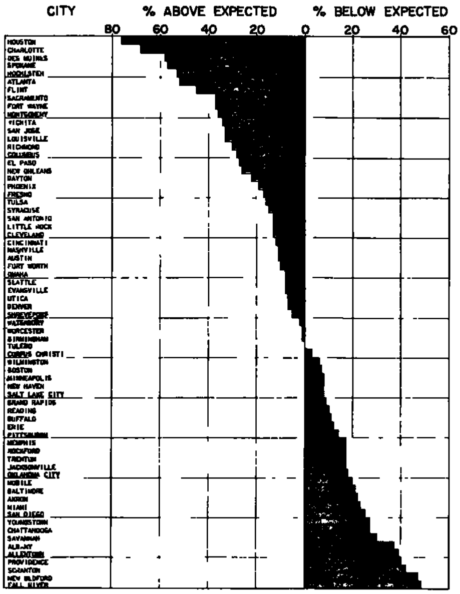


Figure 29. Deviation status of cities, 1954; CBD retail sales.

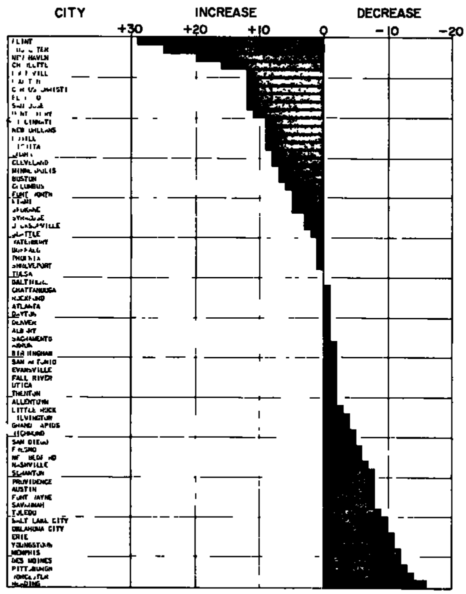


Figure 30. Relative change in CBD retail sales, 1948-1954.

time span. This amounts to roughly one percent increase in the core labor force in both cases.

The foregoing demonstrates that CBD sales diminished slightly on a per capita and an absolute basis, whereas office space declined on a per capita basis, but increased an equal percentage on an absolute basis. In effect, the loss in retail sales is compensated for by additional office space.

Studies of selected business activities, which have been traditionally centralized, reveal a range of decentralization trends.

1. Administrative office space in the insurance business has decentralized 41 percent from the CBD core and 26 percent from the entire CBD between 1946 and 1958. The CBD frame has increased about 40 percent in importance as a locational zone.[5] (Figs. 13 through 18)

2. Administrative office space in the electrical utility field has decentralized 10 percent from the CBD core and 8 percent from the entire CBD between 1946 and 1958.[6] (Figs. 19 through 22)

3. Bank deposits have decentralized 5 percent from both the CBD core and the entire CBD between 1946 and 1956, although banking offices have decentralized 28 percent from the CBD core and 18 percent from the entire CBD in the same time period.[7] (Figs. 23 through 26)

It is cautioned that most of the above findings are determined from regression analysis of many cities. While this gives the general experience of the group of cities in terms of the variables tested, it must be used with caution in its application to any particular city. For example, many cities have good reason to be high or low in respect to the regression line. As has been mentioned, the cities with high central place importance are consistently higher, while others in the areas dominated by regional

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[5]Based on questionnaire returns from 69 of the 150 largest mutual, life and fire and casualty companies in the U.S. (7).

[6]Based on questionnaire returns from 106 of the 142 largest private and municipal utility organizations (7).

[7]Based on a sample including all deposits and establishments in 20 standard metropolitan areas in 11 states (7).

capitals are consistently lower. Regardless of the conclusions drawn above, the basic data are shown so that the reader may draw his own conclusions for the status of the CBD.

Significance of CBD Change

The preceding findings immediately suggest interpretation. One may be initially inclined to extrapolate all trends into the future, but, in most instances, the procedure would be contrary to current happenings and to the underlying causal factors of the trends.

In respect to the retailing function, recent changes reflect the continuation of long term trends in the use of outlying shopping facilities. Prior to the high degree of family mobility attained by the use of the automobile, shopping in outlying locations was primarily of a convenience goods nature, and outlying businesses occurred only in small aggregations. As cities grew and distance to the CBD increased, these small shopping clusters began to assume a larger share of total city sales. Nevertheless, the CBD was still the only business area of the city where major shopping goods could be purchased. In the last decade or so, however, the increase in automobile ownership and its use has permitted large aggregations of outlying businesses to develop. These large aggregations have in turn been able to support shopping goods establishments which are much more competitive with the CBD than the convenience goods establishments associated with the small outlying business clusters in former years.

In view of the rapidly increasing family mobility in outlying areas and the decreasing number of residents near the CBD, it is not surprising that there has been a significant absolute decline in CBD retail sales. Nevertheless, family mobility in relation to the automobile cannot be expected to increase substantially more, as virtually no family in suburbia is without an automobile. The ability of each family to own two or even three automobiles will not increase family mobility for the purchase of goods to any significant extent. Thus, it would be illogical to project the retail trends demonstrated in this research, and elsewhere, very far into the future. As a matter of fact it is highly probable, in view of central city redevelopment projects and increasing

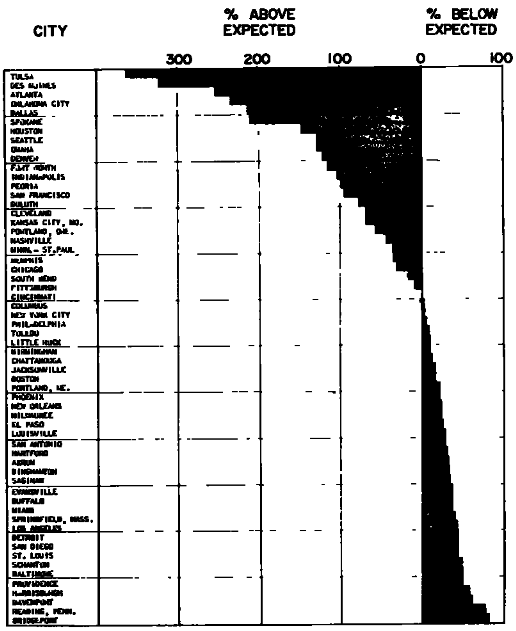

Figure 31. Deviation status of cities, 1956; CBD office space.

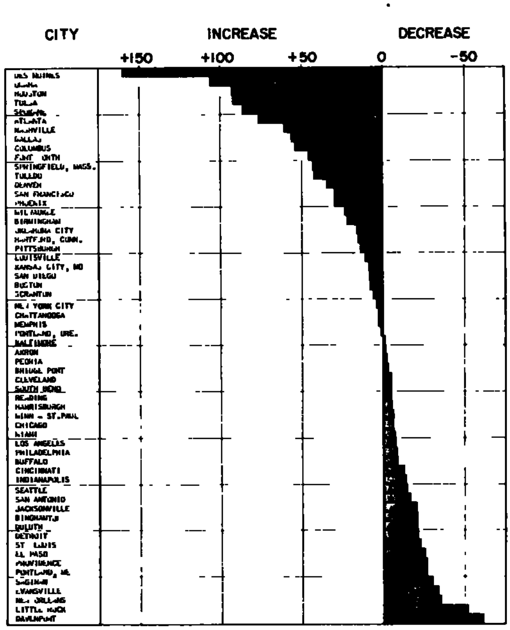

Figure 32. Relative change in CBD office space, 1946-1956.

TABLE 1

CITIES WITH SIGNIFICANT CBD CHANGES[1]

Retail Sales		Office Space	
City	Relative Change 1948-1954	City	Relative Change 1946-1956
Flint	29	Des Moines	160
Rochester	25	Omaha	106
New Haven	20	Houston	93
Charlotte	16	Tulsa	92
Louisville	12	Spokane	86
Houston	12	Atlanta	76
Corpus Christi	12	Nashville	60
El Paso	12	Dallas	56
San Jose	12	Columbus	54
Montgomery	11		
Erie	-11	Little Rock	-52
Youngstown	-11	Davenport	-62
Memphis	-12		
Des Moines	-12		
Pittsburgh	-13		
Worcester	-14		
Reading	-16		

[1] See (7).

central city transportation facilities, that an equilibrium between the forces of retail centralization and decentralization will soon be reached. Any realistic appraisal of the future status of CBD retail sales would be one closely based on the changing central city labor force.

The core labor force is derived mainly from office use rather than retail sales. And unlike retail sales, there has been an absolute increase in CBD office space during the past decade. This reflects the emerging role of the CBD as the center of regional intelligence functions. Although this research has shown evidence of the decentralization of certain office activities which do not require extensive inter-establishment linkages, such as the decentralization of insurance headquarters offices, it is also evident that there is a continual increase and new formations of intelligence, management, and service activities in the CBD core.

Generally, thinking on the CBD has been conditioned in recent years by the retail outlook. Trends have been expressed predominantly by the gain or loss in retail sales. The research indicates that the basic role of the CBD core is changing from a retail-oriented complex to an office-oriented one. By and large, the absolute gain in the office labor force, as determined by space change, has more than offset the loss in retail sales employees. Further, if the increasing trend in office space continues, it is bound to have a secondary effect on the retention of CBD retail sales because of purchases by the central labor force.

HIGHWAY IMPACT IMPLICATIONS

The only possible clue as to urban highway impact on the CBD from the foregoing research requires an analysis of those cities which have had marked CBD changes in relation to transportation improvement. To select these cities retail sales and office space were used as criteria for change. Ranges of significant change were selected for both criteria on the basis of distribution curves of relative change over the time spans studied. Specifically, an increase in relative change of over 10 percent for retail sales and over 50 percent for office space was considered significant. Roughly these changes of significance correspond to the upper and lower deciles of the cities examined. Table 1 lists the cities meeting these requirements. (See Figures 27 through 32 for graphical results.)

Changes in both CBD sales and office space are bound to be reflected in core rents and land values. CBD retail sales changes are generally indicative of internal city shifts in marketing, whereas changes in CBD office space reflect regional trends. In terms of traffic generation, however, office space accounts for approximately three times as many work trips to the core as does retail sales.

The question now arises as to whether any of the cities shown in Table 1 owe their high relative change, either positive or negative, to urban freeways. Of these only Houston had an urban freeway in operation servicing the CBD over most of the time span studied (6). Dallas had a radial freeway operating only in the latter year or two of the time interval (5). The Atlanta freeway, as late as 1956, had no CBD distribution facilities, nor was Pittsburgh's Penn-Lincoln Parkway anywhere near completion as late as 1953 (12). In Connecticut the Wilbur Cross Parkway does not serve central New Haven, nor is the Connecticut Turnpike complete.

In any event, transportation-induced changes would be minimal because of few urban freeway routes and particularly the absence of networks. It is worthwhile to note that Houston is the only city in Table 1 to have improved its CBD's relative position in both retail sales and office space, however, the significance of this is lessened when the nature of the associated cities with high relative change in office space is considered. All of these cities are regional capitals. Not only do they exhibit high relative change between 1946 and 1956, but they were exceptionally high on the scale of office space per capita in 1946. The chances are more than likely that Houston's increased CBD improvement is more a result of its central place importance than its Gulf Freeway.[8]

SUMMARY AND CONCLUSIONS

There are many variables, both related to and independent of the urban freeway network, which make it an extremely difficult task to isolate the effects of highway development on the CBD. Furthermore, the many findings derived from single freeway elements cannot logically be extrapolated to cover network effects.

Although the utility of this research is limited in the sense that it does not reflect the effects of completed urban freeway networks, which are still in the early stages of development, they nevertheless supply a basis for some deduction as to the nature of freeway effects on the CBD.

The most significant deduction is that situational factors relating to the central place importance of cities far outweighs any other factor in contributing to CBD change. The CBD core daytime population is geared to the regional importance of the city, not to intracity considerations. Furthermore, the concentration of central activities relates more to CBD establishment linkage than to intracity transportation amenity.

Undoubtedly intercity transportation improvement will have a greater impact on the CBD than improvement in intracity transportation; and this impact will vary according to the position of the city in the regional structure. In this respect, the regional capitals should experience more CBD growth from intercity transportation improvements than the economically dominated cities in their hinterlands. This relative change should not be attributed to intracity freeway or mass, rapid transit development. True, there has been, and continues to be, decentralization of non-retail activities which no longer require extensive linkages with other establishments, but there is also a continual formation and concentration of new activities in the CBD which require central linkages.

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[8]The following study is the only highway impact research which includes the core of the CBD as a distinct study area. This study reveals that of the 22 areas delimited for land value analysis the CBD core, by one method of analysis, ranked ninetheenth in land value improvement during the 15-yr time span, and fifteenth by another. In fact, the CBD actually lost in value by the first method. On the other hand, the zone of study nearest the Gulf freeway and closest to the CBD ranked seventh in land value increase by one method. Not knowing the size of the sample or the specifics of the study, its validity in respect to these findings cannot be fully evaluated (6).

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The Shoppers' Paradise Concept

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Springfield, Oregon in 1957 tried an experiment utilizing a shoppers' mall within the Central Business District. This experiment was for a short duration, as has been the case with other cities trying similar experiments. During the period of the experiment, sales promotion and advertising activities were stressed, and businesses extended their shopping hours to encourage residents to do their shopping in the CBD. A review of the evaluation of shoppers' comments indicates that shoppers generally favor the mall operation, however, reactions were not unanimous. Many unfavorable comments were indicated.

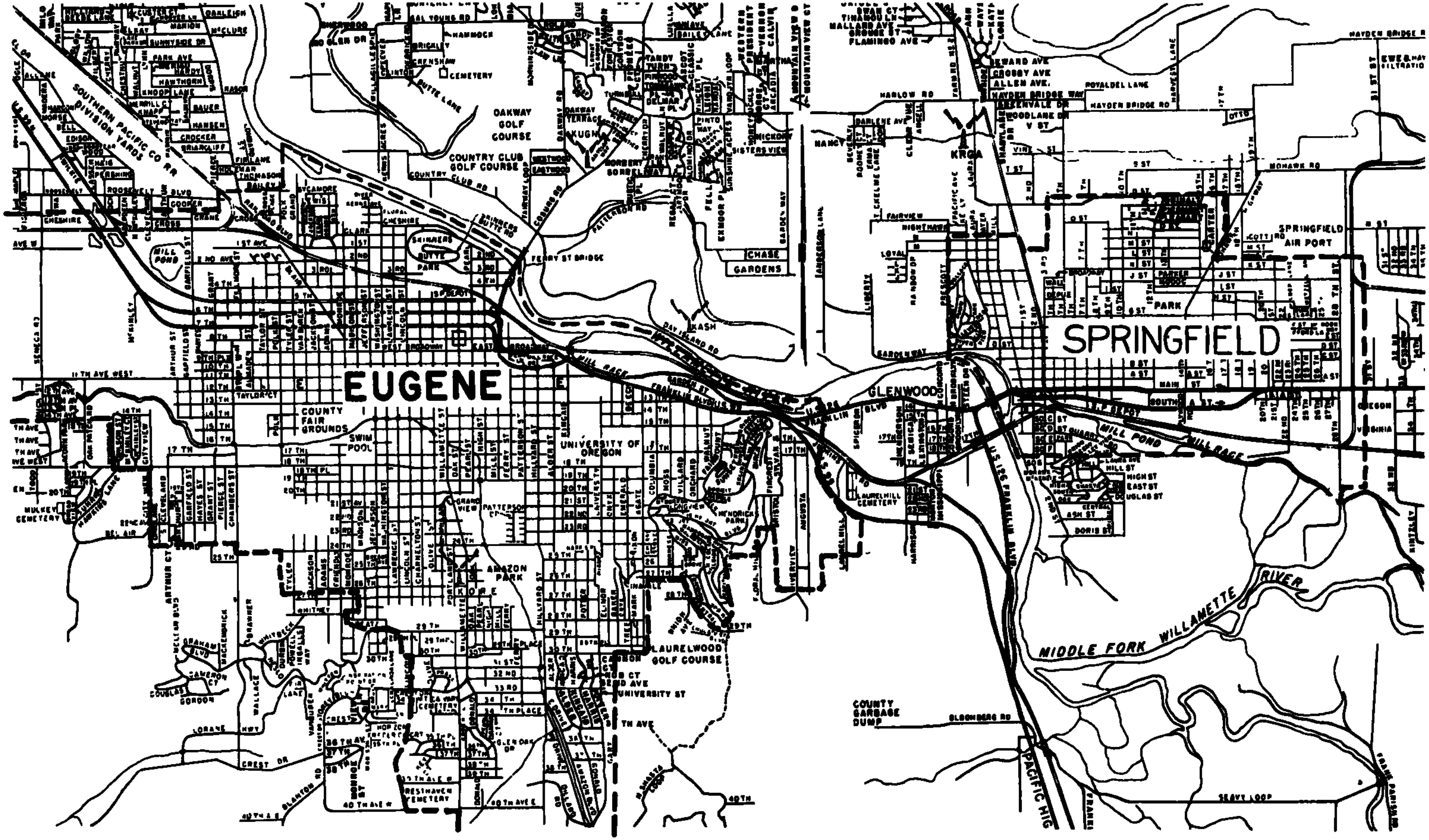
A review of similar experiments in other cities indicates that other cities who have tried the "Shoppers' Paradise" concept utilize almost the same pattern of inception, procedure and accomplishment. The name given to the experiment may be different and the results may vary to a slight degree; however, the analysis of one could almost be used as an analysis of all.

The experiments to date do not provide comprehensive evidence of the long-range effect which might be expected from a shoppers' mall. Therefore, there is a need for an experiment on a long-range basis, with adequate planning and procedures developed to provide realistic indications of the true effect of a shoppers' mall before valid conclusions can be drawn or operational criteria recommended.

●THE PROBLEMS confronting the CBD of urban centers with the advent and the increased promotion of shopping centers removed from the established downtown areas, have increased to a point where city officials as well as merchants are becoming alarmed. Psychology is having its day. The average merchant doing business in the established core of the city is pessimistic about the future, confused as to what can be done to alleviate the situation, and is either actively or passively looking for a site to relocate. The city officials are concerned because the CBD represents the economic base for the community, and as such must be preserved. Officials do not seem to be as pessimistic as the merchant, but are as equally uncertain as to what could be done.

Historically, the downtown area has been the hub of the community, and virtually all retail transactions were conducted within its well-defined limits. To "go to town" on Saturday night was synonymous with a pleasant social evening. People shopped for the sheer enjoyment of meeting and chatting with friends and neighbors, and as a utilitarian means of purchasing the requirements for the coming week. Shopping was an event looked forward to by young and old alike, the young to spread their nickel allowance as far as it would go, and the old to barter gossip and currency for goods. Everyone enjoyed this and was happy. Then came the war years with their industrial expansion. Communities grew into towns, towns grew into cities, and cities grew even larger. The post war years saw the greatest migration from farm to city that has ever been experienced.

The shift in the population from the farm to the city, along with the general increase in the economic standing of the general public has brought about the large increase in automobile ownership. The availability of the private motor vehicle and the desires of individuals to express their feeling for freedom of movement has reduced the emphasis in usage of mass transit for transportation to the use of the private automobile resulting in traffic volumes which are multiples of the pre-war traffic and which has congested the central portions of cities. The resulting congestion developed an attitude on the part of local residents of refusing to enter the congested zones except when absolutely necessary.



MAP OF EUGENE–SPRINGFIELD AREA

Figure 1. Map of Eugene-Springfield area.

Figure 2. Scene in the CBD showing physical deterioration and vacant buildings.

Farsighted merchants speculating on the permanency of existing attitudes and conditions expanded their businesses to the heretofore restricted realm of the residential area. Shopping centers were formed, designed to serve an area rather than the city as a whole. Many located near new or anticipated residential areas where real estate values were correspondingly low and where the purchase of more land than currently needed would allow additional retail expansion and provide convenient parking areas. One of the primary criticisms of the shopper to the downtown area was the lack of parking facilities—these criticisms were answered by the shopping centers through their construction of expansive, free parking lots. Shoppers deserted the CBD. Shopping at the centers was convenient and merchandising was generally as good as that downtown. It was not long after that a hue and cry was heard from businesses still functioning in the CBD. Sales were down, overhead remained high, and the cream of the consumer dollar was being separated and funneled to the shopping centers. Wailing as such, however, did not alleviate the situation. It still existed, and no one knew how to attack the problem, much less solve it. Recently, however, perhaps through desperation, attempts have been made to seek a solution. Led by individuals generally youthful in age as well as in spirit, experiments have been spontaneously undertaken in various cities throughout the country. One form of experimentation has been the establishment of shopping malls within the CBD such as the "shoppers' paradise."

EXPERIMENT IN OREGON

What constituted a "shoppers' paradise?" Is it something more than being able to park within one block of the destination? Is it well-displayed merchandise at lowest prices? Is it a pleasant atmosphere and a leisurely pace? Is it one, some, or all of these things that would cause a shopper to stop and sigh, "This is Paradise"?

In August of 1957 the City of Springfield, Oregon, tried an experiment using a shoppers' mall in the CBD. Springfield is a city of approximately 13,000 population located in Lane County near the south end of the Willamette River Valley. The primary industry of Springfield is wood and wood products.

The City of Eugene is located within a few miles of Springfield. Eugene, which has a population of approximately 45,000 people, is the major trading area for the metropolitan area which includes Springfield, Eugene, and the surrounding area and contains approximately 100,000 people. Figure 1 shows the relative location of the two cities and the suburban development within the metropolitan area.

TABLE 1

POPULATION AND RETAIL SALES FOR SELECTED OREGON CITIES

City	Population[1] 1950 Census	1957 Est.	% Increase	Retail Sales ($1,000)[2] 1954 Census	1956 Est.	% Increase
Albany	10,115	12,800	26	$25,745	$27,258	6
Astoria	12,331	12,331	-	20,732	21,589	4
Corvallis	16,207	18,500	14	23,963	25,657	7
Roseburg	8,390	13,000	55	35,197	40,255	14
Springfield	10,807	13,500	25	16,036	19,192	20
Eugene	35,879	46,480	30	98,253	108,631	11
Lane County	125,776	151,690	21	163,915	182,523	12

[1]Source: 1950 Data, U. S. Bureau of the Census, 1950 Census of Population; 1957 Data, Official estimates by the Oregon State Board of Census.

[2]Source: 1954 Data, U. S. Bureau of the Census, 1954 Census of Business; 1956 Data, Estimates by Sales Management Magazine.

During the past several years, the CBD of Springfield has experienced considerable physical deterioration. Buildings have been vacated and maintenance and upkeep of the establishments have been poor. Evidence of this physical deterioration and the vacation can be seen in Figure 2. During this same period of time the volume of retail trade in the CBD has shown some decrease. Comparative data as shown on Table 1 indicate that Springfield during the period from 1954 to 1956 has shown increases in retail sales. These increases, however, have been experienced primarily in shopping centers and not in the CBD. The loss of retail sales in the CBD has resulted in a low confidence in the future by the merchants in the area.

Late in 1956, the Springfield Chamber of Commerce and the City Planning Commission recognized these symptoms of physical deterioration and initiated a preliminary study to evaluate the functions of the CBD and to note its physical limitations. The following four points were concluded:

1. The McKenzie Highway, US 126, traversed the CBD over a one-way couplet and carried approximately 10,000 vehicles per day on each leg of the couplet. The relatively high traffic volume and the high percentage of log truck traffic in the traffic stream was causing congestion in the CBD.
2. Parking due to the congestion was difficult and hazardous.
3. Ribbon-like development of the business district discouraged pedestrian shopping.
4. The downtown area was physically unattractive and did not provide a pleasant shopping environment.

Figure 3 shows the congestion on Main Street prior to the establishment of the shoppers' mall.

Upon completion of the initial analysis, the suggestion that a shoppers' paradise experiment be conducted was advanced and agreed upon. The purpose of the experiment was initially aimed at the restoration of confidence in the downtown business community.

Permission was sought and granted from the City of Springfield and the Oregon State Highway Commission to initiate the experiment. The City Council passed the necessary ordinance, and the Highway Commission agreed to reroute the westbound leg of the US 126 one-way couplet one block north of the CBD.

It was decided by the working committee to conduct the experiment in conjunction with a retail promotion in an attempt to attract as many shoppers as possible.

The experiment in downtown revitalization was conducted between August 15-26, 1957. Three blocks in the CBD had traffic taken off to form a mall. Figure 4 shows details of the shoppers' mall and its relation to the CBD. The area took on a carnival atmosphere. The street was landscaped by bringing in small trees, rides for the children, and various exhibits were interspersed throughout the area, benches were provided for leisure, and music was piped in during the day and live entertainment was featured in the evenings. Figure 5 shows street scenes within the mall area during shoppers' paradise.

The rerouting of the McKenzie Highway, US 126, around the CBD during shoppers' paradise for the establishment of a pedestrian haven by the elimination of vehicles also eliminated the parking facilities located within the mall. Prior to the experiment, parallel parking was permitted along both sides of Main Street. During shoppers' paradise, additional parking facilities were provided by using one block of Main Street at either extremity of the mall and converting parking from parallel to diagonal. In addition to these two blocks of Main Street changed to diagonal parking, three of the four north-south cross-streets traversing through the mall area were changed to diagonal parking for one block on each side of Main Street. The additional parking provided from the change from parallel to diagonal parking compensated for the parking spaces lost due to the createion of the mall. On those streets for which diagonal parking was

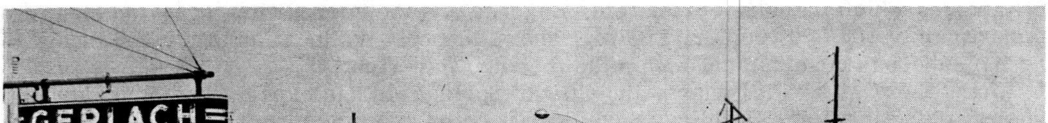
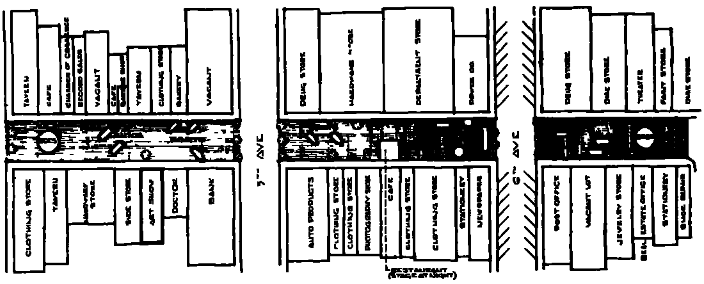


Figure 3. Congestion on Main Street prior to the shoppers' mall.



The Mall In Detail

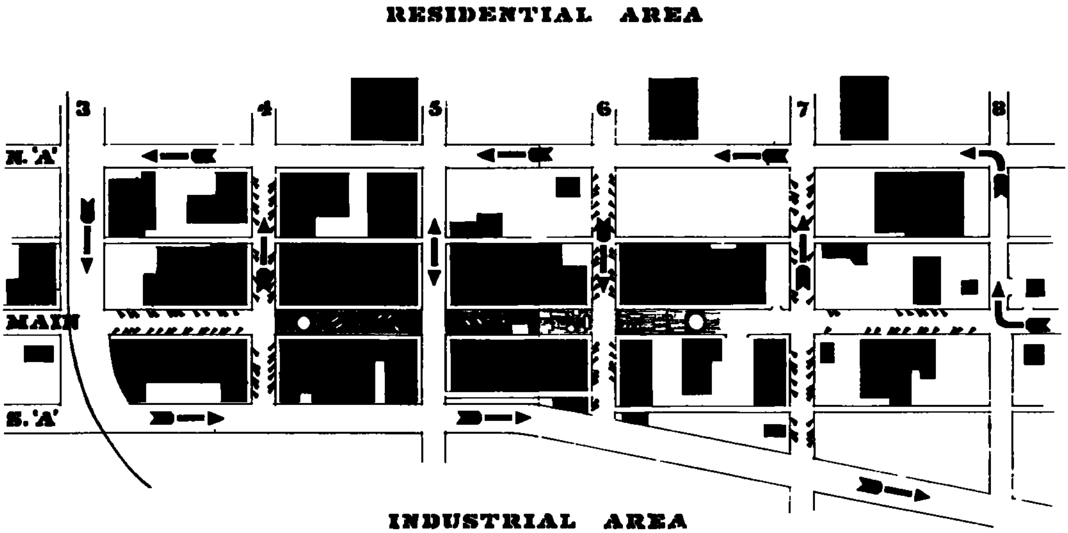


Figure 4. Map of downtown Springfield—Shoppers' Paradise.

allowed, one-way traffic was established. These changes resulted in the elimination of congestion in the parking areas by eliminating the conflict with fast moving traffic and by bringing the shopper to the edge of the shopping area and not into it. Figure 6 is an aerial photograph of the mall area and indicates the extent of the mall area and the parking available adjacent to the mall area.

Within the limits of the mall pedestrians were given complete freedom of movement between establishments. There were two cross-streets traversing through the mall which were left open to vehicular traffic, however, traffic volumes were relatively light and the conflict with vehicles and pedestrians was not serious. Landscaping, exhibits, and other attractions made walking a more enjoyable experience. Benches were erected for shopper use and traffic noise was replaced by relaxing music. Stores remained open until 9:00 p. m. for shopper convenience and business establishments outside the mall were invited to participate with street displays. The shoppers' paradise was continued for 10 days during and after which shoppers were interviewed to determine their opinions on different aspects of the experiment.

OTHER EXPERIMENTS

Springfield, Oregon, was not alone in its concern about revitalizing the CBD. Over the past several years other cities have made an attempt along similar lines. These include such cities as Stockton and Pomona, California; Waco, Texas; and Grand Haven, Michigan, to name a few. Meanwhile, the list of cities making plans for shoppers' malls continues to grow.

Figure 5. Street scenes within the shoppers' mall.

In reviewing accounts of other attempts along the "shoppers' paradise" concept, it is amazing how regular the pattern of inception, procedure, and accomplishments become. The name given to the experiment may be different. In Stockton, California it was "Vacation Playtime," in Pomona it was used in conjunction with the Christmas season, and in Waco, Texas, it was "The Cotton Mall" but the presentation and the effect are virtually identical.

A review of information available of other experiments indicated that some cities are more adaptable because of their physical layout, and that in general, most studies have been conducted over a short period of time.

SUMMARY OF FINDINGS

In evaluating the shoppers' statements from the Springfield experiment, the following conclusions were derived:

Favorable to shoppers' paradise—

1. Truck traffic was detrimental to the CBD.
2. Elimination of traffic noises impressed more people than any other single aspect of the experiment.
3. Traffic moved through Springfield 3 to 5 minutes faster than normal.
4. Parking was more convenient.
5. Elimination of parking meter fees during the experiment though stressed by few shoppers was credited by many merchants as a factor in the success of the experiment.
6. Shoppers appreciated the ease of movement between establishments.

Figure 6. Aerial photograph of CBD and shoppers' mall.

7. More "family" shopping was noted.
8. One-fourth of shopper comments related to the enjoyable shopping atmosphere.

Unfavorable to shoppers' paradise—

1. Changed traffic pattern was confusing and appeared to affect some businesses.
2. Merchants were unable to accept the elimination of vehicular traffic as well as parking facilities in front of their establishments.
3. Parking facilities were too few and some shoppers complained of the distance between parking and shopping.
4. Some businesses in the mall do not benefit from exclusively pedestrian traffic.
5. Businesses outside the mall either lost business or failed to profit from the increased number of shoppers in town.
6. Exhibits were well-patronized, but failed to pull shoppers into low pedestrian count areas as anticipated.
7. Entertainment may draw crowds but does not necessarily promote sales.
8. The carnival approach would not lend itself well to a long term program.

Table 2 summarizes the shoppers' opinions in cities of Springfield, Oregon, Grand Haven, Michigan, and Waco, Texas.

TABLE 2

SHOPPERS' OPINIONS OF SHOPPER MALL

Shoppers	Liked or Thought Mall Should Be Continued (%)	Did Not Like Or Thought Mall Should Not Be Continued (%)
Springfield, Oregon	77	23
Grand Haven, Michigan	63	37
Waco, Texas	76	24

A study of gross retail income indicates that the mall did not confer equal or equivalent benefits on all the retail merchants involved. During the ten days the merchants on the mall reported a 14 percent increase while those off the mall reported a 5 percent decrease compared to any 10-day period of the previous August.

Accompanying the experiment was a sales promotion and advertising program which was not conducted during the previous August. The results of the comparison in retail income, therefore, becomes somewhat questionable, inasmuch as the entire change could have resulted from sales promotion and advertising activities.

From the viewpoint of moving traffic on US 126, the program in Springfield was successful. During the 10-day period there was but one accident involving the rerouted westbound traffic. Traffic flowed much more smoothly than it had on Main Street. Although the four right angle turns slowed traffic some, there was neither the conflict with pedestrians at unsignalized intersections nor with vehicles engaged in parking and un-parking, with a resultant over-all decrease in time necessary to travel around the CBD. Before becoming too enthusiastic about a shoppers' mall, however, it would be well to review the peculiar physical characteristics of Springfield. The shift of traffic from Main Street to North "A" Street had, with the exception of introducing right angle turns, no effect on traffic other than the lengthening of the distance between a pair of one-way streets from one to two blocks. Springfield has very little north-south traffic, so the angle parking on the cross-streets did not interfere with the normal flow of traffic, particularly so with diagonal parking on one-way streets. Furthermore, the business district of Springfield does not have a square pattern as found in most cities, but tends to stretch ribbon-like along Main Street. The ribbon development made it very easy to route traffic on the one-way couplet one block north around the CBD. Many cities would find this adjustment in traffic routing quite difficult. Heavier cross traffic through the mall area might not allow angle parking which in turn might eliminate the possibility of replacing the parking area lost within the mall area. In some cities the loss of parking area would be enough to defeat an experiment of this type.

The results of the experiment in other cities though varying to a slight degree, form such a standard pattern that the analysis of one could almost be used for an analysis of another. Findings as set forth for Springfield serve all cities studied, and City Officials evaluating the experiments agree that the mall even though tending to revitalize business over a short period of time presents four major problems.

1. Parking—amount and quality.
2. Some businesses are not compatible with exclusive shopper mall type operation.
3. Large investments are needed to adapt buildings and adjust traffic routings to the mall layout.
4. The lack of information as to the success which could be anticipated on a long-term mall project when applied to an existing CBD.

SUMMARY

In reviewing all available reports, it appears that the problems found in Springfield were problems elsewhere. Some cities are more adaptable because of their physical layout to the mall operation. There is no indication that success over a short period of time is assurance that this is the answer to the question of revitalizing the heart of the city. The mall may be the answer, but as of now it has failed to achieve complete success even over a short period of time. The Springfield experiment suggests that formidable difficulty stands in the way of the implementation of such a change as the creation of a mall out of the existing business district. A spirit of cooperation is essential between all merchants for the voluntary achievement of such a project and such spirit generally does not exist.

A straightforward answer as to whether the mall arrangements have been successful or unsuccessful cannot be made since so much depends upon individual point of view. A review of the data available indicates that considerable effort remains before an answer can be found with respect to the value of a shoppers' mall. Most cities have entered into the experiment over a short period of time and have not made a comprehensive analysis of the effect of the mall.

Additional research and study is required which must include a long-range operation of a shoppers' mall in the CBD with more adequate planning and research to evaluate the effect of the mall. Some of the items which must be considered in this evaluation would be:

1. The effect on traffic routing.
2. Parking—supply, demand, and usage, and parking-control.
3. Motor vehicle accidents.
4. Use of mass transit.
5. Attitude of shoppers.
6. Attitude of merchants.
7. Adaptability of various types of physical areas.
8. Adaptability of various types of businesses.
9. Gross retail sales.

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Information on the shoppers' malls in other cities was obtained from Harvey Terrill, City Manager, Grand Haven, Michigan; Glen A. Crawford, City Engineer, Pomona, California; W. R. Shroeder, Traffic Engineer, Stockton, California; and R. T. Gregory, Director of Planning and Traffic, Waco, Texas.

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