TOLL BRIDGE INFLUENCE
ON
HIGHWAY TRAFFIC OPERATION

by

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A THESIS

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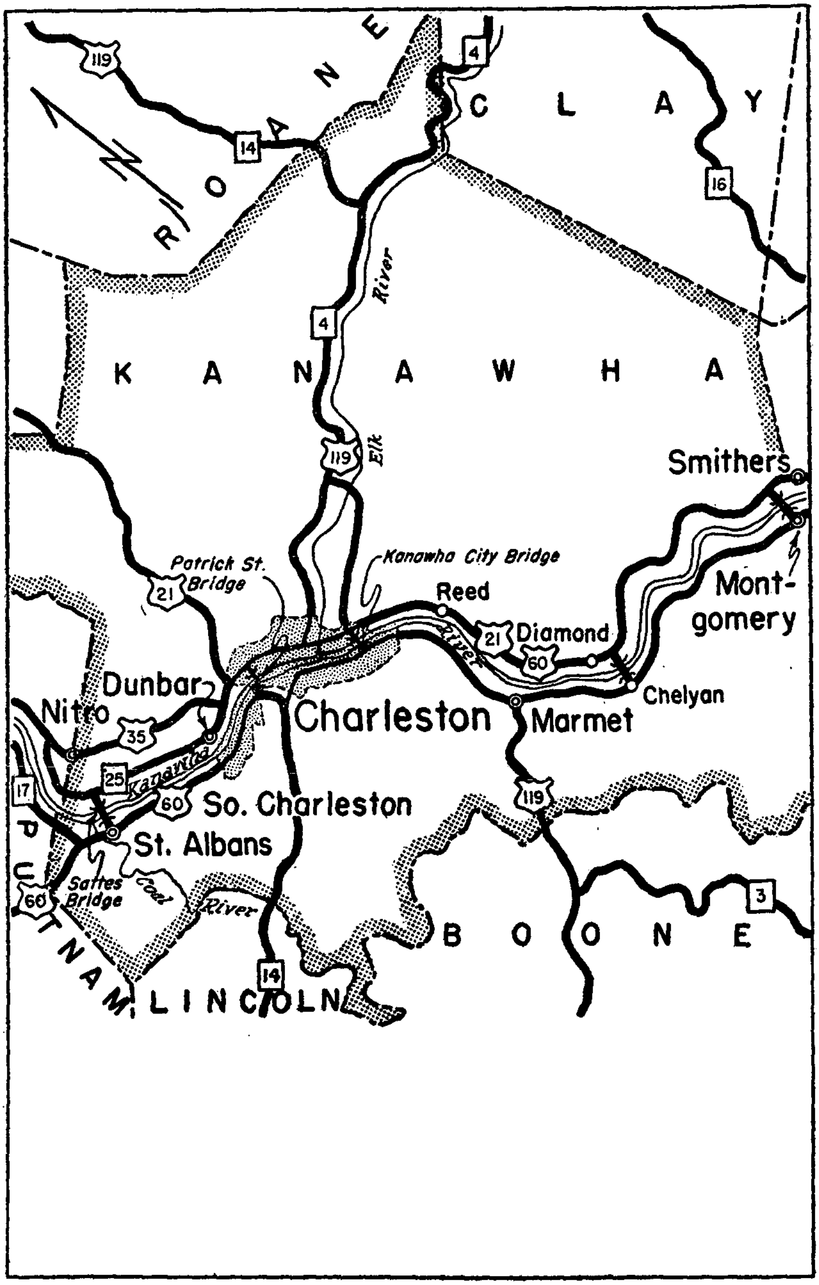

KEY MAP—Showing Bridge Sites and Major Highways.
Kanawha County, West Virginia.

FOREWORD

Each student attending the graduate course in Traffic Engineering at the Bureau of Highway Traffic, Yale University, is required to develop a thesis based on his individual investigations. Severe limitations on time and resources normally restrict the scope of these projects but it is felt that many of them are of sufficient interest and value to warrant their publication and distribution to those concerned with highway traffic.

In this thesis Mr. M. Earl Campbell, the author, was able to draw on the resources of the West Virginia State Road Commission. This made it possible to broaden his study beyond the scope normally possible in student theses. He has dealt with the subject of toll facilities with special reference to developing a mathematical method of measuring the influence of tolls on bridges on the flow of traffic. He has drawn a correlary, which shows the translation of additional monetary costs for time saved into the monetary value of time per minute. The study is unique in that it deals with conditions which rather closely simulate laboratory control—a situation not often found in traffic. It is noteworthy that he took advantage of scientific procedure by use of "before" and "after" data, a comparison of which showed the effect of change on traffic flow.

This is the second of a series of technical reports being issued by the Bureau of Highway Traffic. The first was "Traffic Performance at Urban Street Intersections" by Bruce D. Greenshields, Donald Schapiro, and Elroy L. Ericksen.

The Bureau of Highway Traffic is indebted to the Eno Foundation for Highway Traffic Control, Inc., for furnishing funds for this and other publications of this technical report series.

THEODORE M. MATSON, *Director*
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PREFACE

Are toll bridges warranted? This is not a unique question. It is not a new question. But it is a captivating and intriguing question because its answer is found not only in mathematical formulas but in the biographies of human personalities: in their frustration, in their hope, in their realization, in their disappointment, in their bitterness,—in the repetition of this cycle through the centuries.

Are toll bridges warranted? This poses the question with a brutal frankness. Yet, stripped of all embellishment, the subject resolves itself into this query. And this query is basic in the narrative, in the analysis, and in the conclusions which follow. It is basic because people are asking this question. It is basic because the right answer will salutarily affect community life.

This thesis attempts to answer the question by two distinct methods of treatment. The first method is by a presentation of the subject in retrospect from which the logic of the toll system is traced. The second method develops a mathematical basis for measuring the effect of the toll system on traffic operation, presenting and interpreting some recent field studies.

Sincere gratitude is felt in the opportunity afforded for this study by the Automotive Safety Foundation, and the State Road Commission of West Virginia. Genuine appreciation is expressed for the interest and assistance of the faculty under whose auspices this study was accomplished.

M. Earl Campbell

Yale University
New Haven, Conn.
May, 1946

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CHAPTER I

INTRODUCTION

A very notable revival of interest in the toll bridge question is making itself evident today. From National level to State level, from State level to Community level, and from Community level to the individual there is a serious inquiry into this subject. Divergent opinions and policies on this vital problem are manifested and demonstrated. It would seem that even in our National Government the policy of assisting in the freeing of old toll bridges while at the same time assisting in the financing of new ones, subscribes to the tenet of "Let not thy left hand know what thy right hand doeth."[1]

1. The Problem Defined

This study ventures to discover whether there is an answer to the question—"Are Toll Bridges Warranted?"; and if the answer should be both "YES" and "NO" to discover the appropriate conditions for each answer. The study attempts a review of cause and effect in the success and failure of toll projects together with an objective field measurement of the relative effect of toll facilities on highway traffic. The object of the study is directed toward (a) a reconciliation of conflicting opinions on basis of historical and mathematical disclosure, and (b) the resolution of the toll system philosophy into a consistent, practicable policy.

2. Specifics of the Study

The specific objectives of this thesis are enumerated as follows:

A. Amount of community traffic "stranded" by tolls.

B. Amount of community traffic driven a longer distance to neighboring free bridges.

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[1]Tucker and Leager, *Highway Economics*, *pp.* 84-86. (Scranton, Pennsylvania: International Textbook Co., 1942.)

c. Amount of "foreign" traffic barred from entry into the community.

d. The effective sphere of toll bridge influence in terms of travel distance.

e. The effective sphere of toll bridge influence in terms of travel time.

f. The advantages and disadvantages of toll bridges upon social and economic life.

g. Desirable prerequisites of toll bridges.

h. Objective method of measurements.

i. A monetary evaluation of vehicle time—a correlary of item e.

3. The Need of an Answer

That the subject is timely is evidenced by these facts:

Whereas on the one hand Federal and State agencies are pledged to a program of purchasing and freeing toll bridges,[2] yet on the other hand the impetus for building more new toll facilities reached record levels by 1941[3] (at which time World War II halted all construction except that necessary to the war effort).

The subject is timely because it is alive. During the past year (1945) there were an estimated total of 205 toll bridges and 7 toll tunnels operating in the United States. Of the toll bridges 103 were publicly owned and 102 were privately owned; of the toll tunnels 5 were publicly owned and 2 were privately owned. Since 1940, 6 new toll bridges have been opened to traffic, 41 toll bridges were eliminated and 11 toll bridges changed from private to public ownership.[4]

From the standpoint of needs the following excerpt is quoted—"The American Association of State Highway Officials conducted a survey to determine the extent of deterioration or obsolescence, and

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[2]Tucker and Leager, *Op. Cit.*, pp. 84-86.

[3]Byron W. Shimp, *Financing Public Improvements*, p. 1 and 62 (New York: Van Ingen and Co.)

[4]H. S. Fairbank, Deputy Commissioner, Public Roads Administration, Washington, D. C. Personal letter, March 7, 1946, Mr. Fairbank states: "The above data have not been verified and the Public Roads Administration cannot at the present time take responsibility for their accuracy."

those studies showed . . . over 30,000 bridges should be widened or rebuilt at a cost of more than $800,000,000."[5]

Thus, it is timely to review the situation now, at the beginning of an era that portends to be the greatest highway construction period in American History.

4. Opportunity for Research

The opportunity to review the subject was presented in a most tangible method. The Legislature of the State of West Virginia in regular session in 1945 authorized the purchase of two toll bridges on the Kanawha River for the purpose of making them toll free. At the same time the State Road Commissioner authorized the Planning Division of the State Road Commission to make studies of traffic transfer across the Kanawha and New Rivers to determine the need for and the proper location of additional bridges.

The potentialities of making origin and destination surveys both before and after the bridges were freed was recognized with respect to answering certain pertinent questions relative to toll bridge influence on highway traffic operation.[6]

Proposals were submitted to the Public Roads Administration for concurrence in making this a joint project. Approval was obtained on January 22, 1945.

In the meantime bonds were retired on a state owned toll bridge on the Kanawha River at Point Pleasant and the bridge was freed of tolls on July 4, 1945. The induced traffic added amounted to 38% of the previous toll traffic. This fact lent additional appreciation to the value of the proposed before and after origin and destination studies.

5. Scope of Research

The first phase of the study was that of library research to try to discover from historical accounts the effect of toll facilities in general

[5]Hon. Ed. Martin, Gov. Pennsylvania. Address to Pennsylvania Contractors Association, *Highway Builder* (December 1944) p. 7 Published by Associated Pennsylvania Constructors.

[6]The review of the opportunity was obtained from records of correspondence on file in the office of the Planning Division, and from the personal knowledge of the writer who was State Planning Engineer at that time, and is at this date consulting engineer for the Commission.

on American economic and social life. No objective measurements were discovered, and although a wealth of bibliography exists the reading in large part is slanted by the prejudice of the author. Chapters Two and Three resulted from this survey.

The second phase of the study called for "before" and "after" O and D surveys on the Sattes toll bridge and "before" surveys on Patrick Street, Kanawha City, and Montgomery free bridges, and Chelyan toll bridge, with an analysis of the results. (Schedules of these surveys are included in the Appendix.) These surveys are the basis of Chapters Four and Five.

CHAPTER II

IN RETROSPECT

The quickening interest in the proposition of tolls may lead the casual observer to the conclusion that the subject is a new one,—and unique. It may be quite natural to suppose that this revived system is a product of Twentieth Century economics. On the contrary, the system is almost as old as English History, and stems pre-eminently from the English speaking people who intensified the use of this fiscal device. A mirrored view of the influence causing and caused by toll bridges of the past will clarify and lend appreciation to the issues involved in the question of today.

1. Free Roads—Our Heritage

"There is little evidence in antiquity of the use of the toll system upon roads."[1] "Roman roads were free roads and so were Roman bridges."[2] Of unusual interest is the following excerpt from The Encyclopedia Americana:

> ". . . by the Roman law the right of the use of roads was inherent in the public. The roads could become the exclusive property of no one. The emperors, or other chief magistrates

[1]H. H. Kelly, "Toll Roads." *Public Roads*, Vol. 12, No. 1 (March 1931) p. 1.

Author's Note—Kelly mentions the early collection of tolls in Babylonia and Palestine, which apparently were tariff collections or tribute money.

With further reference to this subject L. W. Page in *Roads, Paths, and Bridges* (New York—Sturgis and Walter Co., 1913) p. 6, says: "Strabo states that there were two branches of the great road leading from Babylon to Syria about 2000 B.C. on one of which only a moderate toll was exacted, and it was, therefore, much more frequented by travellers than the other branch. This is probably the earliest record of the collection of tolls."

[2]*Roads and Railroads* (London: Parker, 1839) p. 27, "There were no turnpike gates (those objects so angrily decried upon their first introduction into England . . ." is the further comment in this book.

Page, *Op. Cit.*, p. 14, states: "Tolls as a means of repairing [Roman] highways appear to have been seldom resorted to."

> were their conservators. The majority of the great highways were built by contract at public expense. A few were built, however, at least in part from the spoils of war, the private munificence of emperors, or great personages ambitious for public approval or acclaim. Their maintenance was in part by the labor of soldiers and slaves or by enforced labor which sometimes took the form of taxation. But in whatever form the maintenance was made it was at the expense of the district through which it passed."[3]

Following the "Glory that was Rome" the Dark Ages descended upon mankind. "History presents the period as an almost complete blank that carried through from about A.D. 500, to something like A.D. 1100, devoid of any constructive human accomplishment.[4]

2. The Beginning of Tolls

Then came the toll bridge. If not the first, nevertheless one of the "earliest traceable" toll bridges was the historic Old London Bridge over the Thames. It was first built of wood about 993 A.D. under King Ethelred II, and tolls were imposed on the users. Rebuilt, repaired, and widened during the near thousand years since, this bridge was finally freed of tolls in 1782 A.D.[5]

Thus, began in England an era of toll bridge construction and operation that continued unabated until about the time of our Civil War.[6]

But after the first toll bridge was built 353 years passed by before England saw a toll road. Then King Edward III granted permission for the establishment of the first toll road in 1346 A.D.[7] But nearly 300 more years passed before the turnpike era began. Then in the year 1663 A.D., during the fifteenth year of the reign of Charles II, the first turnpike act was passed by Parliament.[8]

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[3]A. H. McDannald, Ed. in Chief, "Roads and Highway," *The Encyclopedia Americana,* Vol. 23, p. 558 (New York: The Americana Corporation, Ed. 1943).

[4]Archibald Black, *The Story of Bridges* (New York: McGraw-Hill Book Co., 1936) p. 44.

[5]Mark Searles, *Turnpikes and Toll Bars* (London: Hutchinson and Co., 1930) p. 1.

[6]*Ibid.*

[7]H. H. Kelly, *Op. Cit.*, p. 1.

[8]*Roads and Railroads, Op. Cit.*, p. 67.

"The first toll bridge in America was erected by Richard Thurlow in 1654 over Newbury River at Rowley, Massachusetts. The bridge remained a toll bridge until 1860."[9] In New England when covered wooden bridges were the vogue in bridge design, tolls were charged as the usual procedure.[10]

3. The Turnpike Period

"Near the close of the Eighteenth Century the toll road movement, then at its height in England,[11] made its appearance in the United States. Charters were first granted to toll road companies in Virginia in 1772, and what was said to have been the first toll road in the United States was established in this state between Alexandria and Sniggins Gap [Little River Turnpike] in 1785. "The Philadelphia-Lancaster Turnpike which was begun in 1792 was the first toll road in the United States surfaced with broken stone."[12]

Thus began the turnpike movement in the United States, a movement which flourished between the years 1800 and 1830. This period has been called the Turnpike Era.[13]

"A rage for construction of improved roads . . . swept the country. In 1807, when Gallatin, Secretary of the Treasury, made his famous report on roads and canals, he described sixty-seven companies in New York which had already constructed 900 miles of improved roads."[14]

By 1811 the State of New York had granted charters to 137 turnpike companies which had built 1,400 miles of road;[15] and the State of Pennsylvania by 1828, had 3,110 miles of chartered turnpike.[16]

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[9]Joseph Nathan Kane, Ed., *More First Facts.* (New York: H. W. Wilson Co., 1935) p. 70.

[10]Clara E. Wagemann, *Covered Bridges of New England.* (Rutland, Vermont: The Tuttle Co., 1931) p. 27.

[11]H. H. Kelly, *Op. Cit.,* p. 1, states that by 1836 in England there were 1,100 turnpike trusts operating 20,000 miles of road.

[12]*The Encyclopedia Americana, Op. Cit.,* p. 559.

[13]Joseph Austin Durrenberger, *Turnpikes,* Thesis, 1931 (Valdosta, Georgia: Southern Stationery and Printing Co.) p. 45.

[14]Edward C. Kirkland, *A History of American Economic Life.* (New York: F. S. Crofts and Co., 1934) p. 262.

[15]Minneapolis Board of Education, *Transportation,* 1941, p. 35 (W.P.A. Social Studies Research Proj. No. 8944).

[16]Franklin M. Reck, *The Romance of American Transportation* (New York: Thomas Y. Crowell Co., 1938) p. 195.

Co-incident with the growing supremacy of the toll system there was agitation for a free superhighway to connect the East with the West. Acting upon recommendations first proposed in 1806, and because of popular demand, Congress authorized the construction of the "famous National Pike," or "Cumberland Road." The main section of this road was completed from Cumberland, Maryland, to Wheeling, West Virginia, in the year 1818.[17]

Beyond Wheeling little was done on this project, and finally the Federal Government washed its hands of this and other contemplated projects and withdrew from road construction. And the National Pike soon changed from a free to a toll road.[18]

4. The Wane of the Toll System

After the National Pike experience four score years passed before the Federal Government could be induced to re-enter the field of highway construction.[19] But before this came to pass the turnpike era in the United States had ended and the toll bridge era had waned.[20]

Shaler, in 1896, commented as follows regarding the turnpikes:

". . . such roads [turnpikes] have been completely abolished in the greater part of the prosperous eastern sections of this country, as well as in the Old World."[21]

Taken from the Report of the Toll Road Commission of the Commonwealth of Pennsylvania under the date of January 1, 1911, is this excerpt:

"Resolved that we unanimously recommend that the Commonwealth acquire all such toll roads and abolish the payment of tolls thereon . . ." (Author's note—at that time according to this report there were

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[17] *Transportation, Op. Cit.*, p. 35.

[18] Frederic J. Wood, *The Turnpikes of New England.* (Boston: Marshall Jones Co., 1919) p. 21 (Excerpt: . . . ownership . . . transferred to state through which it passed . . . Each of the states . . . converted the free road into a toll road." [about 1834].)

[19] Edward C. Kirkland, *Op. Cit.*, p. 428.

[20] D. Philip Locklin, *Economics of Transportation* (Chicago: Business Publications, Inc., 1938) p. 34.

[21] N. S. Shaler, *American Highways* (New York: The Century Co., 1896) p. 95.

H. H. Kelly. *Op. Cit.*, p. 2, "The peak of the turnpike development occurred about 1830, and the decline began soon afterward with the rapid extension of railroads and canals."

108 toll roads in Pennsylvania covering 722 miles of road, appraised at $1,584,813).[22]

5. A Revival of Interest in Tolls

Before the first World War began the first cycle of the toll system had ended. But the war had hardly ended before the toll movement—first for bridges and tunnels, and later for roads deluxe began afresh.[23] This time the major emphasis was placed on public sponsored self liquidating projects. Government created "Authorities," of which the Port of New York Authority was the first in the United States, have been responsible for the financing, constructing, and operating of many of the present day toll facilities.[24]

Outstanding examples of the toll facilities constructed during this new cycle of toll movement are:[25]

		Opened
1.	The Holland Tunnel	1927
2.	The Arthur Kill Bridges	1928
3.	The George Washington Bridge	1931
4.	The Bayonne Bridge	1932
5.	The Lincoln Tunnel	
	First tube	1933
	Second tube	1945
6.	San Francisco-Oakland Bay Bridge	1936
7.	The Golden Gate Bridge	1938
8.	Merritt Parkway	1938
9.	Pennsylvania Turnpike	1940
10.	Lake Washington Bridge	1940

[22] Toll Road Commission, Commonwealth of Pennsylvania. Report. Harrisburg, Pa., January 1, 1911.

[23] Kelly, *Op. Cit.*, p. 6, states that the public press began about 1925 to make suggestions for construction of toll superhighways.

[24] The Port of New York Authority—Report Submitted to the New Jersey Legislative Committee, June, 1940. pp. 3, 4, 20, 42, and 46.

H. H. Allen, "Engineering Responsibility for the Successful Planning, Construction and Operation of Revenue Bond Projects," in Lecture on *Financing Public Improvements*, 1939 (New York: B. J. Van Ingen & Co., 1939) pp. 61, 62.

[25] The examples cited were selected largely from *Toll Bridges and Toll Tunnels*, Compiled by Public Roads Administration, Washington, D. C., (1940), from *Financing Public Improvements* published by B. J. Van Ingen & Co. of New York (1939) and from the Report Submitted to the New Jersey Legislative Committee by the Port of New York Authority (1940).

During the period 1928 to 1939 about one-half billion dollars of Revenue Bonds were issued for financing toll bridges, tunnels and highways,[26] and at the end of that period there were in operation 62 toll bridges which had been built with revenue bonds.[27]

6. Cycles of Ascendency

By way of summation: In England the first toll bridge began operating in 993 A.D. and the turnpike movement got underway in 1663 A.D. The movement reached its peak in England near the close of the Eighteenth Century and died away about the time of our Civil War.

In America the first toll bridge began operating in 1654 A.D. and the turnpike movement got under way near the close of the Eighteenth Century. The movement reached its peak in America about 1830 but kept its grip on the highway system until the close of the Nineteenth Century. Whether the turnpike trusts were wrecked by public opposition, or by advent of the railroads and canals, or by a combination of all is a debated question.[28]

Beginning in the Nineteen and Twenties, the toll movement for specific projects is in the acendency. And as in the preceding cycles in England and America, the present potential demand for trade and travel is in great excess of the supply of safe and expeditious facilities.

[26] B. J. Van Ingen, Preface, *Financing Public Improvements* (New York: B. J. Van Ingen and Co. 1939).

[27] Geo. W. Burpee, "Forecasting Traffic and Revenues," in lectures on *Financing Public Improvements,* 1939 (New York: B. J. Van Ingen & Co., 1939) p. 52.

[28] Robert Moses, Commissioner of Parks for the City of New York in an article entitled "Unsnarling America's Road Jam," PIC Vol. 18, No. 4 (April 1946) p. 24, remarks as follows: "The so-called turnpike trusts or companies of olden days were wrecked, not by Public opposition, but by the advent of the railroad. By a curious reversal of trends, the highway is now the railroad's most formidable competitor, and toll roads, bridges and tunnels under public instead of private auspices, have revived."

CHAPTER III

LOGIC OF TOLL FACILITIES

A great body of conflicting argument justifies toll facilities on the one hand and condemns them on the other. An examination of the arguments will reveal some as mere prejudice and specious, whereas others command analytical consideration.

The arguments advanced are cited herewith in the form of advantages and disadvantages with a discussion of significant points.

1. Advantages of Publicly Owned Toll Facilities (Proponent Philosophy)

a. *Makes Financing Possible*—"The plan of charging tolls for the privilege of using roads and bridges is one of the first fiscal devices invented by man. Indeed, it is hard to imagine how the earliest roads could have been built without the aid of tolls."[1]

Shaler[2] comments thusly on the problem of financing transportation facilities: ". . . it is a noteworthy fact that the early successes in road-making were limited to the Roman Empire, in which there was a strong central government controlling all matters relating to public ways . . .," and quoting from Shaler again, "The system of toll roads under the authority of charters has hitherto proved the principal resource of decentralized governments in improving the ways of the people."

The Port of New York Authority[3] in outlining the warrant for the method of financing the Arthur Kill Bridges states: ". . . the interested communities established the need for the facilities they desired but could not point the way to any practicable method of constructing the proposed crossings. None of the communities adjoining the desired

[1]Tucker and Leager, *Highway Economics* (Scranton, Pa.: International Textbook Co., 1942) p. 84.

[2]N. S. Shaler, *American Highways* (New York: The Century Co., 1896) pp. 88, 89.

[3]The Port of New York Authority. Report submitted to the New Jersey Legislative Committee. June 1940. p. 46.

structures could undertake to finance the bridges out of real estate or other taxes, nor were any state appropriations for this purpose in prospect."

At this point a comparison of annual gas tax revenues with annual amortization costs of typical bridges will indicate the nature of the fiscal problem—

With gas tax assumed at 5¢ per gallon, and the average vehicle obtaining 12.5 miles per gallon of gas it is found that the gas tax revenue derived per linear foot of road per year from 20,000 vehicles (assumed optimum for 4 lane highway) amounts to about $5.50 per year. With money valued at 4% per year, this amount of revenue would pay the annual interest charges on an investment of $137.50 per linear foot of highway; or pay annual charges on a 25 year amortization schedule on a capital investment of about $90 per linear foot.

Assuming it possible to build a 4 lane bridge for $10 per square foot of floor area, the construction cost plus maintenance cost over a 25 year period will probably exceed $500 per linear foot.

Comparative figures for a two lane bridge will show a reduction in gas tax revenue to approximately one-fourth that of the four lane bridge whereas the reduction in cost of construction of the bridge will be closer to one-half that of the four lane bridge. Thus, the revenue derived and the amortization rate required diverge still farther apart.

b. *Makes Financing Feasible*—Publicly owned toll bridges which become free bridges upon payment of principal and interest are in effect *self-maintaining* and *self-liquidating* projects. Commonly financed by the revenue bond, the user traffic bears the whole cost without recourse to general taxation.

"The very essence of a revenue bond is that the purchaser may look only to the revenues of a project for the payment of interest and the principal of the debt incurred . . ."[4]

c. *Makes Financing Equitable*—From Highway Economics (p. 85) by Tucker and Leager the following three quotations are taken—

(1) "The charging of tolls . . . was . . . an application of the benefit theory of cost allocation."

(2) "The gasoline tax is in a sense, a new and usable form of the old toll principle."

[4]The Port of New York Authority, *Op. Cit.*, p. 65.

(3) "The toll principle is economically sound when it is applied to structures that furnish extra services . . ."

With respect to the circumstances leading to the beginning of the turnpike era in England, 1663 A.D., The Encyclopedia Americana[5] has this comment—

". . . the argument that 'every person ought to contribute to the roads in the proportion to the use he makes or the benefit he derives from them' found favor with Parliament and the toll road era began."

Mitchell[6] puts the argument succinctly in terse statement—

"There is a strong feeling today that those who use a utility should pay for it," while the Port of New York Authority[7] reasons in parallel vein—

"In creating it (The Port of New York Authority) the states developed a new concept in American governmental life . . .

"The *new* concept was this—an agency was selected to perform the work, finance it on its own credit, and charge the cost to the *users* of the project rather than to the taxpayers in general."

Qualifying this general principle with the idea that special or extra benefits should reward the toll payer Shortridge[8] says—"Today's tolls are charged for use of improvements of considerable benefit to the tollpayers."

d. *Secures Immediacy of Benefit*—The toll bridge plan parallels that of purchasing on the installment payment plan—it procures the benefit of usage *while* paying for the benefit,—a concurrent arrangement,—rather than awaiting benefit until payment is made which in some instances would require many years of delay. In this manner the economic benefits derived from the facility may pay the amortization costs.

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[5]A. H. McDannald, Ed. in Chief, "Roads and Highways," *The Encyclopedia Americana*, Vol. 23, p. 558 (New York: The Americana Corporation, Edition 1943).

[6]Robie Mitchell, of Masslich & Mitchell, Municipal Bond Attorneys, N. Y. City, in Lecture "Legal Security of Public Revenue Bonds." *Financing Public Improvements*, 1939 (New York: B. J. Van Ingen & Co. 1939) p. 15.

[7]Port of New York Authority. Report submitted to the New Jersey Legislative Committee, 1940. pp. 3, 4.

[8]Fearson Shortridge, Manager of New York City Tunnel Authority, "More Public Toll Routes?", The American City, (New York: American City Magazine Corp.) Vol. LIX, No. 5, p. 105 (May 1944).

Cherniack,[9] poses this question—"What would be the reaction of the farmer in upstate New York to the financing of a fifty million dollar facility for the City of New York when this money would construct 500 miles of modern road?"

e. *Supplies Need for Rapid Expansion in Transportation*—A study of the circumstances surrounding the ascendant cycles of toll facility movements shows a rapid expansion in actual and potential travel and trade greatly out-distancing adequate and available roadway facilities.

We read that "as travel and trade increased . . . the toll road era began [1663.]"[10]

The following quotations relating to the beginning of the turnpike era in America about 1790 bears out this premise by implication—

"The improved turnpikes unshackled highway traffic." And "a rage for construction of improved roads, . . ., swept the country."[11]

From the Encyclopedia Americana[12] the following excerpt is taken showing the high potential need for travel ways in America at the beginning of the first turnpike era in the early 1800's—

"The growth of the toll-road movement in the United States was at first extremely rapid and a large amount was invested."

Pertinent to the revival of interest in the toll system in our own day the Port of New York Authority[13] comments as follows—

"The World War [I] period and the post-war period saw a remarkably rapid expansion in the motor car industry. But while the industry mushroomed and people were soon to think of a motor car in every back yard, highways were still in the horse and buggy stage. The very ferries which antedated the horse car were still plying the Hudson and they afforded the only means of crossing that River . . ."

Thus it is recognized that toll facilities may serve in opening and spurring initial development in virgin territory where economic benefits are considerable; and provides communications to an expand-

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[9]Nathan Cherniack, Economist, Port of New York Authority, in a Seminar at Yale University, March, 1946, Bureau of Highway Traffic.

[10]The Encyclopedia Americana, *Op. Cit.*, p. 558.

[11]Edward C. Kirkland, *A History of American Economic Life* (New York: F. S. Crofts & Co. 1934) pp. 261, 262.

[12]The Encyclopedia Americana, *Op. Cit.*, p. 558.

[13]The Port of New York Authority, *Op. Cit.*, p. 42.

ing and shifting population and economy. As Shaler[14] states—". . . in opening a country to settlement the system of toll roads is often advantageous."

f. *Equalization of Cost*—The toll schedule and traffic volume by classification is given constant study for possibility of reducing rates and increasing aggregate revenue.[15] The optimum rate which the traffic will bear is the goal. By this method the cost is equalized to various classes of users at the maximum based on the law of supply and demand. "You can't translate into tolls *all* the savings that the motorist may realize."[16]

g. *Sets Precedent in Geometric Design*—The toll facility as a competitive facility must attract traffic by offering as an offset against toll charges, every possible advantage from standpoint of time and distance saving, convenience, and reduced hazard to travel. In providing these special benefits it acquaints the public with the minimum desirable standards of improvement, and becomes the goal of achievement for "free" facilities, thus advancing engineering progress all along the line.

As Kirkland[17] says of early turnpike construction—"The Lancaster Turnpike was their proto-type."

And quoting from Hilaire Belloc[18]—"It (turnpike) was not without its good effect. It began to create before the middle of the Eighteenth Century an acquaintance in the general mind of the country with what a road surface should be."

Moses[19] of New York City makes this significant statement which argues for the premise—

"The Germans modeled their autobahnen after our parkways, and the Italians drew on our plans largely for their strada."

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[14]N. S. Shaler, *Op. Cit.*, p. 83.

[15]Billings Wilson, of Port of New York Authority, Lecture entitled, "Operation of Bridges and Tunnels," delivered 1941 at Yale University, Bureau for Street Traffic Research.

[16]Geo. W. Burpee of Coverdale & Pitts, Consulting Engineers, New York City, Lecture "The Problem of Forecasting Traffic and Revenues," *Financing Public Improvements*, 1931 (New York: B. J. Van Ingen & Co., Inc., 1939) p. 37.

[17]Edward C. Kirkland, *Op. Cit.*, p. 261.

[18]Hilaire Belloc, *The Highway and Its Vehicle*, p. 29. Studio Limited, London, Date 1926.

[19]Robert Moses, Commissioner of Parks for the City of New York. Article in PIC for April 1946, entitled "Unsnarling America's Road Jam," p. 26 (New York: Street and Smith, Inc.).

2. Advantages of Privately Owned Toll Facilities

a. *Governmental Risk Removed*—The operating company assumes risk of securing traffic diversion and generation as well as adverse changes in volume resulting from changes in competitive free facilities.

b. *Operate Facility at Minimum Cost*—Where toll rates are subject to regulation by Public Service Commissions, the minimum operating cost may be translated into a savings to the motorist.

c. *Prevents Delayed Governmental Action*—The building of toll facilities by private corporations in the early period of settlement is advantageous for it induces capital to provide for the needs of the area earlier than government, thus spurring initial development.[20]

3. Disadvantages of Publicly Owned Toll Facilities (Opponent Philosophy)

a. *Effects Additional Expense of Financing*—The cost of promotion and interest charges may be a considerable amount of added cost, particularly when interest rates are high. (If bonds are callable, advantage may be taken of reduced interest rates.)

b. *Effects Additional Expense of Operating Costs*—Construction and maintenance of collection stations plus the salaries of the operators even on profitable ventures may amount to a considerable extra sum. Kelly[21] reports expense of collecting tolls to cost from 15% to 27% of tolls collected.

c. *Risk in Estimating Usage*—Two notable examples of erroneous predictions of usage were those made of the Detroit International Bridge and the Staten Island Bridges in which cases the actual usage was substantially lower than the predicted usage.[22]

Construction of free facilities in the future near the toll facility may establish a competitive facility which will divert traffic from the toll facility. If such a diversion is quite considerable it may result in the undesirable requirement of refinancing the project on a longer term basis, or if the residual traffic will bear it (which is unlikely), an increase in the toll rate.

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[20] N. S. Shaler, *Op. Cit.*, p. 94.
[21] H. H. Kelly, *Op. Cit.*, p. 7.
[22] Geo. W. Burpee, *Op. Cit.*, p. 55.

d. *High Cost of Facility vs. Low Rate of Toll*—Facilities proposed for toll are usually those which have not already been built as free structures because of the excessive construction costs. Adding to excessive costs also is the demand (in many cases) that toll facilities be built to higher standards than free, with respect to site, convenience and adequacy.

At the same time recognition is had of the fact that toll rates must be low enough to attract necessary amount of traffic to pay the cost. This combination often tempts the promoters to amortize the cost over an extremely long period of time which seems an unwise procedure.

e. *Eventual Retardation of Full Development*—A toll facility precludes a complete, full and free economic and social intercourse. It circumscribes a community with an ecomonic and social barrier. Trade and travel will by-pass a toll bridge unless it becomes profitable to use this facility. The traffic induced when a toll bridge is freed is a measurement of the restriction at the time the bridge is freed; but this restrictive influence felt over a period of many years hampers community expansion and development in an immeasurable amount. Potential outflowing traffic is stranded, potential inflowing traffic is diverted.[23]

"The consideration of the toll system may be shortly made by a slight study as to the effect which it has on the development of a community, and the tolerance by that community of the method. . . The roads are mostly held by the capitalists of the towns, and administered solely with reference to dividends. In this way the free intercourse of the people is obstructed; the country folk of the poorer sort cannot afford to make any journeys save those which are certain to bring them a good money return. Even the attendance on schools is hindered by the fact that children cannot be transported by these institutions, which in a sparsely settled country such as Kentucky are often remote from the dwellings . . . the eventual influence is to retard, or even to completely arrest full development of the economic life of those who dwell on the land."[24]

[23]When the Point Pleasant-Henderson Bridge was freed of tolls in 1945 the induced (previously stranded and diverted) traffic amounted to approximately 40% of the toll traffic. (Letter of September 11, 1945, addressed to W. Va. State Road Commission) [The toll system bars the community with tariff, and circumscribes the populace with toll—writer].

[24]N. S. Shaler, *Op. Cit.*, p. 89.

"'Rivals' says Dr. French, 'are those who dwell on the opposite banks of the same stream, and a toll bridge brings them no nearer'."[25]

f. *Charges Motorist Twice for Same Facility*—"In my opinion, the collection of cash tolls is a reversion to the primitive form of highway finance, not at all in keeping with the ingenuity inherent in motor vehicle license fees and the gasoline tax. In its favor, I can offer the point that only as a last resort is it an expedient method of securing more income . . . it is a costly and unfair method of charging the motorist twice for his use of the highway."[26]

g. *Adds Density and Travel Distance to Neighboring Free Bridges*—The free bridge attracts that traffic which finds it more profitable to travel a longer distance to avoid toll payment—the nearer the bridges are situated with respect to each other the greater the pull or competition of the free bridge. This may cause congestion on the free bridge and reduce revenue on the toll bridge. The longer distances travelled to use the free bridge unduly increases the sphere of influence of the free bridge to the point of making it a toll bridge to some traffic.

The sphere of influence of the *Patrick Street* (Charleston, West Virginia) free bridge was extended westerly about 1½ miles beyond its natural sphere due to the effect of tolls on its next neighboring bridge to the West. The sphere of influence of the *Montgomery*, West Virginia, free bridge was similarly extended westerly 1½ miles beyond its natural sphere of influence due to effect of tolls on its next neighboring bridge to the West. The sphere of influence of the Kanawha City (Charleston, West Virginia) free bridge was likewise extended easterly about two miles beyond its natural sphere of influence due to the effect of toll on its next neighboring bridge to the East. (See graphs of Critical Areas of these three bridges, pp. 54, 62 and 67.)

h. *Public Opposition to Long Amortization Period*—Public impatience for eliminating tolls on a bridge increases as years go by. Likewise their demand for decrease in toll rates mounts as years lengthen into

[25]Clara E. Wagemann, *Covered Bridges of New England.* (Rutland, Vermont: The Tuttle Co., 1931) p. 32.

[26]Bertram H. Lindman, Engineer-Economist, National Highway Users Conference, Washington, D. C., Article entitled, "Highway Financing," *1939 Proceedings*, (New York: Institute of Traffic Engineers, 1939) p. 16.

decades.[27] (Generally the rates are predicated upon the amount that the traffic will bear and amortization period determined accordingly.) The same argument advanced in paragraph e, page 17 (Eventual Retardation of Full Development) operates to cause public opposition to tolls after the first few years.

i. *Paying Toll Delays and Annoys*—Harking back to the early days of the toll era in England we read that "the public was strenuously opposed to paying to use the highway. Many toll gates were torn down by mobs, and several people died in toll gate riots."[28]

Such expressions as "tedious obstruction to movement"[29] "hopeless confusion at the toll gates,"[29] "Shun pikes,"[30] "That Publican,"[31] "The Toll Gatherer,"[31] appear in writings about the early toll roads both in England and America.

"The sentiment against these (bridge) tolls was so strong in the early days that occasionally our forefathers asserted a sportive independence by chopping down the toll gate, and adding insult to injury, the town meeting usually refused to make restitution for damage to the bridge owners."[31]

The following excerpt represents the opinion of at least one legislative body during the early days of the Twentieth Century.[32]

". . . . the payment of such tolls is burdensome to the public." Representative of opinion expressed at the present time is the following—"Except in the case of costly bridges or tunnels, I cannot imagine the public long permitting the annoyance of the toll gate and its interference with the free use of the American highway."[33]

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[27]The Report of the Port of New York Authority to the New Jersey Legislative Committee in June 1940, covers these questions comprehensively. Also see Lecture entitled "Operation of Bridges and Tunnels" given at Yale in 1941 by Billings Wilson, of the Port of New York Authority.

[28]A. L. Bouton, *An Outline History of Transportation.* (Detroit: Fisher Body Craftsman's Guild, 1934) p. 22.

[29]Mark Searles, *Turnpikes and Toll Bars.* (London: Hutchinson and Company, 1930).

[30]Joseph Austin Durrenberger, *Turnpikes.* (Columbia University) Thesis, 1931 (Valdosta, Georgia: Southern Stationery and Printing) p. 78.

[31]Clara E. Wagemann, *Op. Cit.*, pp. 30 and 45.

[32]Report of Toll Road Commission, January 1, 1911. Harrisburg, Pennsylvania.

[33]Bertram H. Lindman, *Op. Cit.*, p. 16.

4. Disadvantages of Privately Owned Toll Facilities

a. *Usurpation of Government Function*—Opposition to privately owned toll facilities arose because of the "contention that management of roads was a 'governmental function and should not be given over to private enterprise' and because of the prejudice of farmers and other users 'who objected to the payment of tolls to these usurpers of public roads'."[34]

"The unusualness of these business methods aroused popular hostility" comments Kirkland in reviewing the early history of turnpike corporations in America. "Road-making had previously been a governmental function; now it was surrendered to private individuals with the right to invade property and charge tolls."[35]

b. *Private Profit from Public Highway Operation Inimical to Public Interest*—Thomas H. MacDonald in an address before the American Association of State Highway Officials in the year 1928 on "Freedom of the Road"[36] had this to say with respect to privately owned toll facilities—

"Seventy-five Federal Authorizations to build toll bridges have been granted to private interests by the present Congress . . .

"The real question is the very simple one of whether it is sound public policy to grant the right to collect a private profit from the user of the highway. The answer ought to be a vigorous and authoritative "No." There is no place on the public highway today for the privately owned toll bridge."

c. *Toll Rates Higher, and Non-Terminating*—Because of the added element of profit necessary to private enterprise it is probable that toll corporations will establish a higher toll rate than a governmental agency. And there is no surcease from toll payments unless the government purchases the facility, which sells very often not at replacement cost but according to its earning power.

Durrenberger[37] comments as follows—"Public owned roads could be maintained cheaper than turnpikes because of the elimination of tolls and the expense of collecting tolls."

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[34]Joseph Austin Durrenberger, *Op. Cit.*, p. 81.

[35]Edward C. Kirkland, *Op. Cit.*, p. 261.

[36]Thomas H. MacDonald (Now Comm. Public Roads Admin.) in Address on "Freedom of Road." Vol. 8, No. 1, *American Highways* (Washington, D. C.: A.A.S.H.O.) January 1929.

[37]Joseph Austin Durrenberger, *Op. Cit.*, p. 162.

5. Desirable Prerequisites for Successful Toll Operations

a. A definite economic need as well as social need for toll facility, must be manifest—need must exceed adequacy of existing facilities.

b. The community to be served must make known their desire for toll facility.

c. Potential traffic must be sufficient to bear costs of amortization without undue risk.

d. Amortization period should be shorter than life expectancy of facility (Period based on predicted traffic densities and optimum toll rates).

e. Assurance should be had that a competitive facility will not be built during the amortization period of the original facility which would reduce its revenues below requirements.

f. Facility should be publicly owned and financed on self-liquidating basis.

g. Benefits to users must outweigh costs.

h. Should not be a part of the presently constituted primary road system.

6. Trend of Attitude Toward Toll Facilities

As discussed under advantages and disadvantages of toll facilities, the reaction to the toll system in the early days of the toll movement both in England and America was antagonistic.

The public today uses a nice discrimination in its choice of facility, and accepts toll facilities as a matter of course, or choice, where benefits exceed cost of toll, and conversely chooses the free facility when benefits from the toll bridge do not exceed their cost.

Notable examples of successfully operated toll facilities have been listed in Chapter One. Many more could be listed. In many cases where a choice is possible between competing toll and free facility, enough traffic supports the toll facility to make successful operation possible.

The Engineering News-Record of January 10, 1946, makes the following observation—

"Despite the fact that the Public Roads Administration in its 1939 report on 'Toll and Free Roads' had declared against toll road systems, strong forces in Congress and in the country still urged such construction."[38]

"Today the trend is definitely away from the use of tolls for bridges and structures that are part of the regular system"[39] is the interpretation of today's attitude by Tucker and Leager. Continuing with their interpretation the authors define the Federal and State attitude.

"*Federal Attitude Toward Toll Structures*—Federal loaning agencies have recognized the desirability of individual toll structures, and in the past have loaned to public bodies upwards of 150 million dollars for that purpose. The Federal Government is, in general, opposed to toll bridges, as evidenced by the 1937 Act, which aids the states in the purchasing of such bridges for the purpose of freeing them from tolls.

"*State Attitude*—State Governments are beginning to realize that blanket policies in regard to toll structures are not feasible on account of the varying local conditions. The tendency is toward analyzing each situation on its own merit, and adopting a policy that is suitable for specific conditions."

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[38]Article entitled "Design Standards for National System Interstate Highways," Vol. 136, No. 2, *Engineering News-Record* (January 10, 1946) p. 131.

[39]Tucker and Leager, *Op. Cit.*, p. 86.

CHAPTER IV

DEVELOPMENT OF AN ANALYTICAL METHOD

1. The Problem Analyzed

Interpretation of "Sphere of Influence"—Prerequisite to its measurement "Sphere of Influence" must be defined. To begin, and for purpose of illustration only, assume a series of three *free* bridges to be serving a certain geographical area. It is desired to determine the sphere of influence of the central structure.

An origin and destination survey shows trips across the central bridge with origins and destinations beyond the other two bridges. It also shows trips across the other two bridges with origins or destinations farther from these two bridges than from the central bridge. In

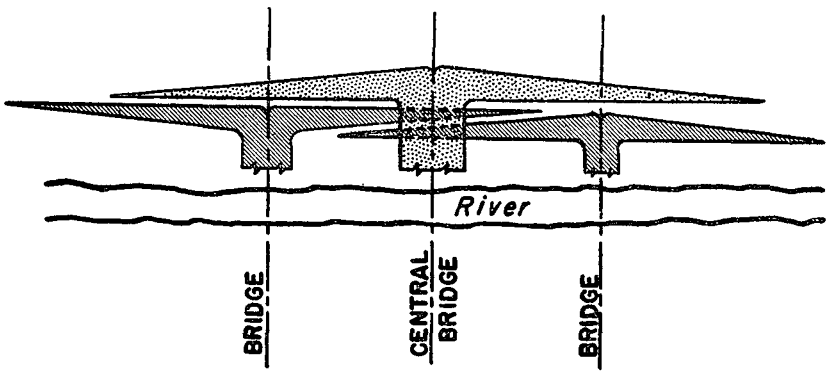

FIGURE 1—Typical Trans River Traffic Flow Diagram.

effect, vehicles have passed by the near bridge to cross one farther distant, and all in all, a great amount of trip overlap is revealed. In the over-all picture the sphere of influence of the central bridge appears to comprehend a substantial part of the spheres indicated in Figure 1 entitled "Typical Trans River Traffic Flow Diagram."

Inasmuch as the central bridge may be used by vehicles whose origins and destinations are beyond the two other bridges, it becomes necessary to analyze the usage, or trip type, in order to delimit the sphere of influence and eliminate the extensive overlap of adjacent spheres, and apportion to each bridge its contingent share of influence.

An analysis of transfers across the river disclose two general types of trips, namely:

1. The "U" type, with "J" type as a variant.
2. The "S" type, with the "L" type as a variant.

An analysis of these two types of trips discloses that the trip with origin and destination beyond the adjacent bridges is usually of the "S" type, whereas the "U" type trip usually has both origin and destination between the bridge crossed and the adjacent bridge.

A comparison of these two trip types reveals the fundamental concept for evaluating the contingent influence of adjacent bridges, namely:

(a) The "S" trip, with its variant, includes no "out-of-way" travel distance between origin and destination, therefore it makes no difference (in distance) which bridge a vehicle crosses as long as the trip maintains its characteristic "S" shape (i.e. it does not change to the "U" type). And inasmuch as there is no difference with respect to which bridge is crossed by the "S" type trip, we may at once eliminate this type of trip from the place of first emphasis in determining the sphere of influence of free bridges.

(b) The "U" trip, with its variant, always includes "out-of-way" travel distance between origin and destination, therefore it always makes a difference in distance with respect to which bridge a vehicle crosses, EXCEPT in certain cases where the "out-of-way" distance is equal regardless of bridge crossed. This exception may occur when both origin and destination are equidistance between bridges, or when each is spaced opposite and equally distant between the midpoint (in distance) between bridges. The "U" type trip, then, must receive the first emphasis in determining the sphere of influence.

Before proceeding further in development of the method of analysis it would be well to assign a name to that direction of travel, every part of which contributes toward reducing the initial relative distance between origin and destination (i.e. that travel which includes *no* "out-of-way" distance). The term "apposite" has been chosen to designate this type of travel. Apposite travel may be defined as that travel which is an attribute of relative position and is independent of constraint.

Conversely, "inapposite" was chosen to represent "out-of-way" or irrelevant travel, and may be defined as travel resulting from constraint of fixed facilities, and is, therefore, dissociated to relative positions.

As applied to the problem at hand the "S" trips represent "apposite" travel. Whereas "U" trips (with variant "J" clipped down to a "U") represent the inapposite. (Refer to Figure 2 entitled "Apposite and Inapposite Travel Distance.")

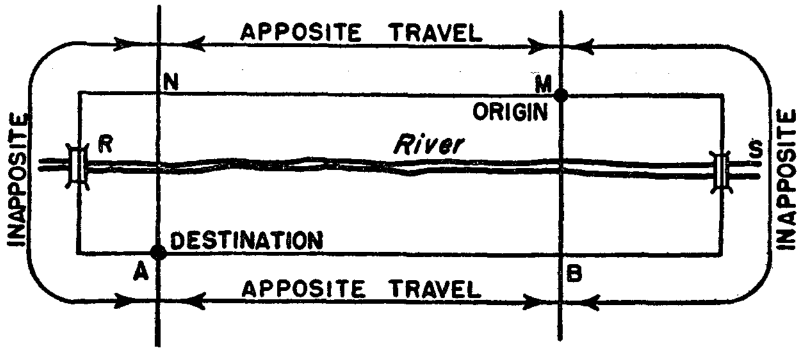

FIGURE 2—Apposite and Inapposite Travel Distance.

Pursuing the illustration still further in which free bridge spheres of influence are subjected to analysis, it may be assumed as axiomatic, all other things being equal, that the natural sphere of influence of a free bridge located between two other free bridges will extend out to a division line midway in distance between the adjacent bridges. Hereinafter this division line will be referred to as the "isometric line."

Actually, however, equal adequacy and attractiveness of bridges and facilities is seldom realized. In particular, the time of travel varies between bridges so that the division line midway in time between bridges (hereinafter referred to as the "isochronic line") is seldom coincident with the isometric line.

Since the sphere of influence of a bridge is determined both by time and distance factors (supplemented also by intangible psychological factors), the sphere will be fixed by a line (disregarding intangibles) of equal economy, or a natural line of equity (for free bridges) which would fall between the isometric and isochronic lines. (Refer to Figure 3 entitled "Natural Sphere of Bridge Influence.")

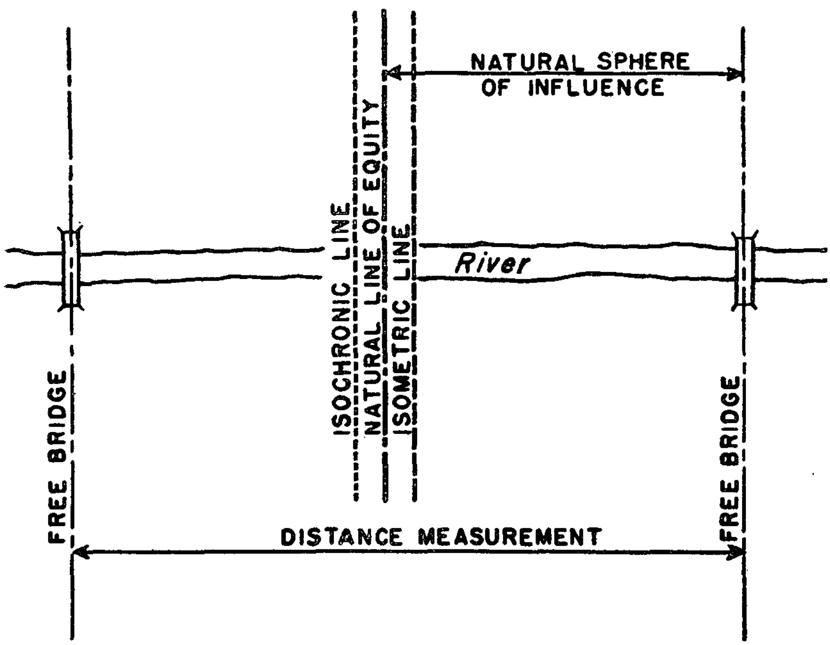

FIGURE 3—Natural Sphere of Bridge Influence.

Now, assume that one of these free bridges becomes a toll bridge. Proceeding with the development of method of analysis, there is now, in addition to items of time and distance, a third tangible item of economy; that of tolls. Immediately, the line of equity is transferred from its original position to a new position nearer to the toll bridge, thus developing assymetry between the trip centroids related to the toll bridge and the free bridge. This new position of the line establishes the "actual" sphere of influence of the toll facility and for convenience will be referred to hereinafter as the actual line of equity.

(Refer to Figure 4 entitled "Natural and Actual Lines of Equity.")

The "Sphere of Influence" may be interpreted as: The actual line of equity enveloping a facility.

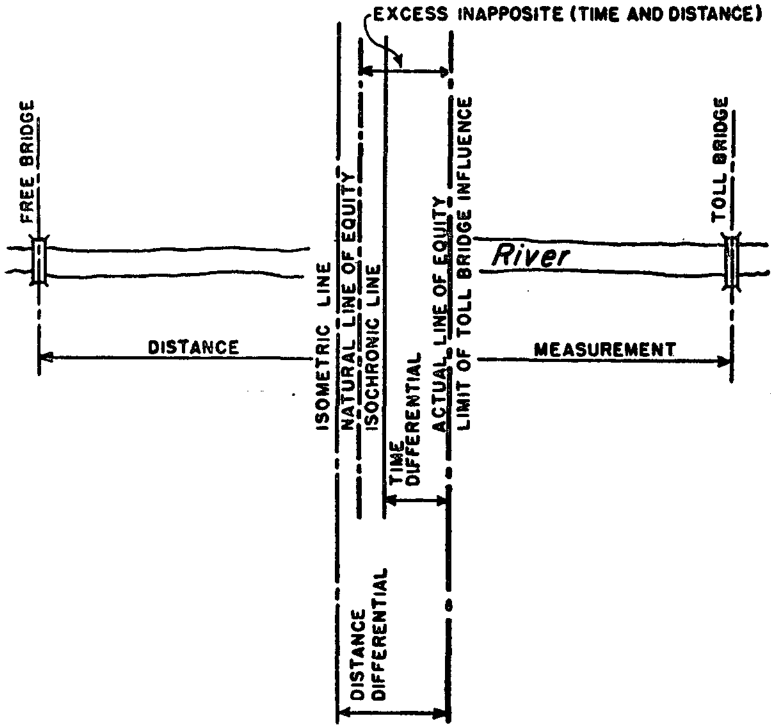

FIGURE 4—Natural and Actual Lines of Equity.

Influence of Constraint—The general theorem relative to influence of constraint may now be stated:

The measurement of assymetry between the natural line of equity and the actual line of equity evaluates the influence (in magnitude) of the constraint.

Referred to the free bridge this assymetry may be called the excess inapposite travel (time and distance).

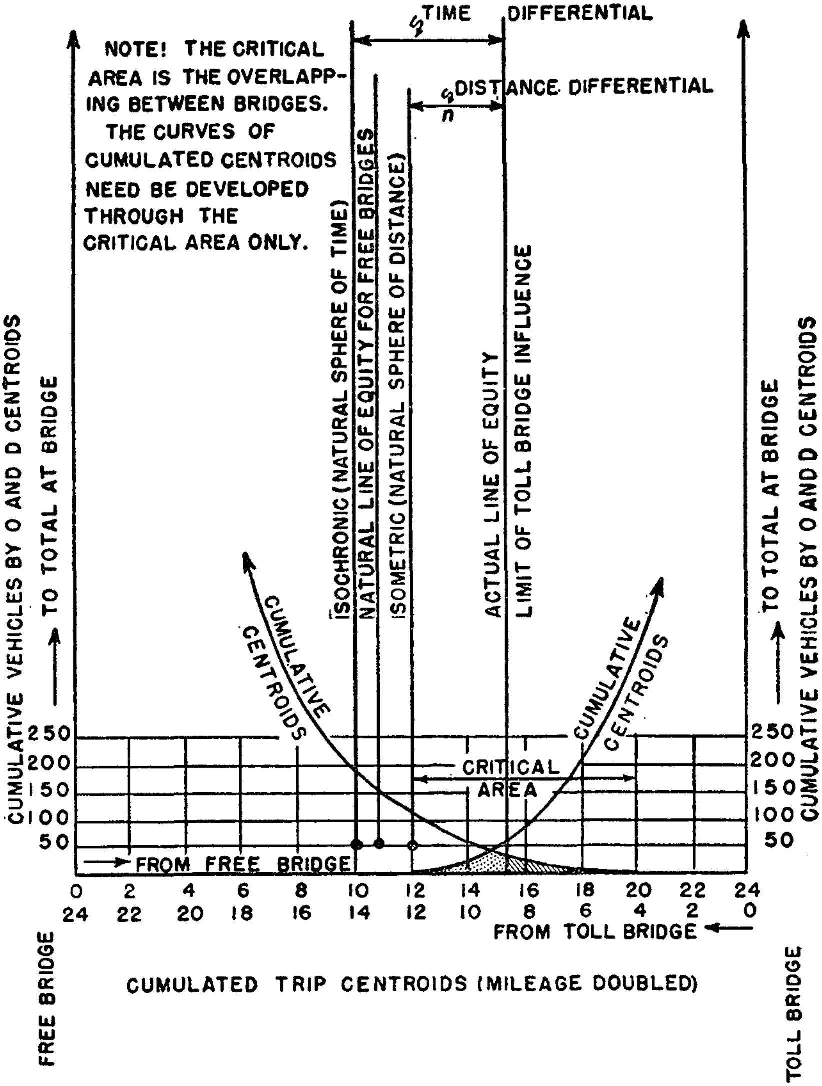

FIGURE 5—Method of Locating Actual Line of Equity.

Defining Differential Measurements—The measurement of excess inapposite travel is a differential measurement in that it is a measurement in terms of distance of the composite value of the time and distance differentials equated against the toll (or other constraint) cost.

The composite differential value may be represented, then, by the out-of-pocket (toll cost) which is assumed to be equal in amount to the aggregate value of total operating costs plus value of total travel time saved; or additional cost (Toll ± operating cost) equals value of total travel time saved.

Measuring Time and Distance Differentials—In order to evaluate time and distance differentials separate measurements must be made for each. The time differential may be obtained by measuring from the actual line of equity to the isochronic line. The distance differential may be obtained by measuring from the actual line of equity to the isometric line.

Correlation of Differentials—Correlation is established on a common monetary basis. Toll costs are known. Distance costs (commonly referred as vehicle operating costs per mile) can be closely calculated. Time value is determined from formula developed in following pages.

Calculating Locus of Actual Line of Equity—Before proceeding further with the method of translating the time differential into terms of monetary cost per minute, the method of determining the location of the actual line of equity will be developed. The mechanics will be presented in detail in the section entitled "Mechanics of Analysis." An understanding of underlying principles, however, is in order in this development of method of analysis.

Reference is made to Figure 5 on page 28, entitled "Method of Locating the Actual Line of Equity."

That point in the overlapping area of travel between the bridges (the "critical area") where the vehicular miles of travel by way of the toll bridge equals the vehicular miles of travel by way of the free bridge establishes the actual line of equity between the bridges. (See item No. 12, Basic Assumptions, page 33.)

Hence, the area under the curves representing equal cumulative travel by way of each bridge establishes the point fixing the actual line of equity.

ACCRUED TRAFFIC[1]

Diverted Traffic—Traffic crossing the free bridge and with centroid of origin and destination farther distant from the free bridge than the natural line of equity is diverted from the toll bridge for reason of cost or convenience. When toll charge is removed it is assumed that this traffic will return to the free structure. Therefore, those trips crossing the natural line of equity to use the free bridge with centroid of origin and destination beyond natural line of equity may be combined with the trips crossing the toll structure when it is made free.

Establishing Locus of Natural Line of Equity—Using the general formula (see Correlary Study, page 36).

$$x = \frac{T - 4\,cn}{d\,(k - 1) + 2n\,(k + 1)} \left(\frac{V}{60}\right)$$

we may now substitute for x the value of time in terms of cost per minute, and substitute O for value of T. The average speed values may now be taken to the isochronic line (approximately correct). Solving for n the differential distance is obtained. A positive value is directed toward the toll bridge, a negative value toward the free. In any event the locus should fall between the isochronic and isometric lines. (See Figure 14, page 57, "Patrick Street-Sattes: Trip Centroid Distribution.")

Induced Traffic—This traffic is variously referred to as induced, generated, stranded or potential traffic. It is traffic with centroid of origin and destination within the sphere of influence of the facility considered, but which is dormant or stranded because the total cost of use of the facility (including toll, time and vehicle operation) is greater than the return (economic or social) justifies.

A decrease or increase in toll rate or travel time or travel distance will be reflected in a respective increase or decrease in induced traffic.

Induced traffic can be measured as that residual of traffic after the original and diverted traffic is subtracted from the total traffic pursuant to an economic change resulting from toll, time or distance change.

Observation—Diverted traffic volume can be computed closely, but induced traffic can only be estimated on the basis of previous experience of comparable situations.

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[1]See Figure 6, page 31.

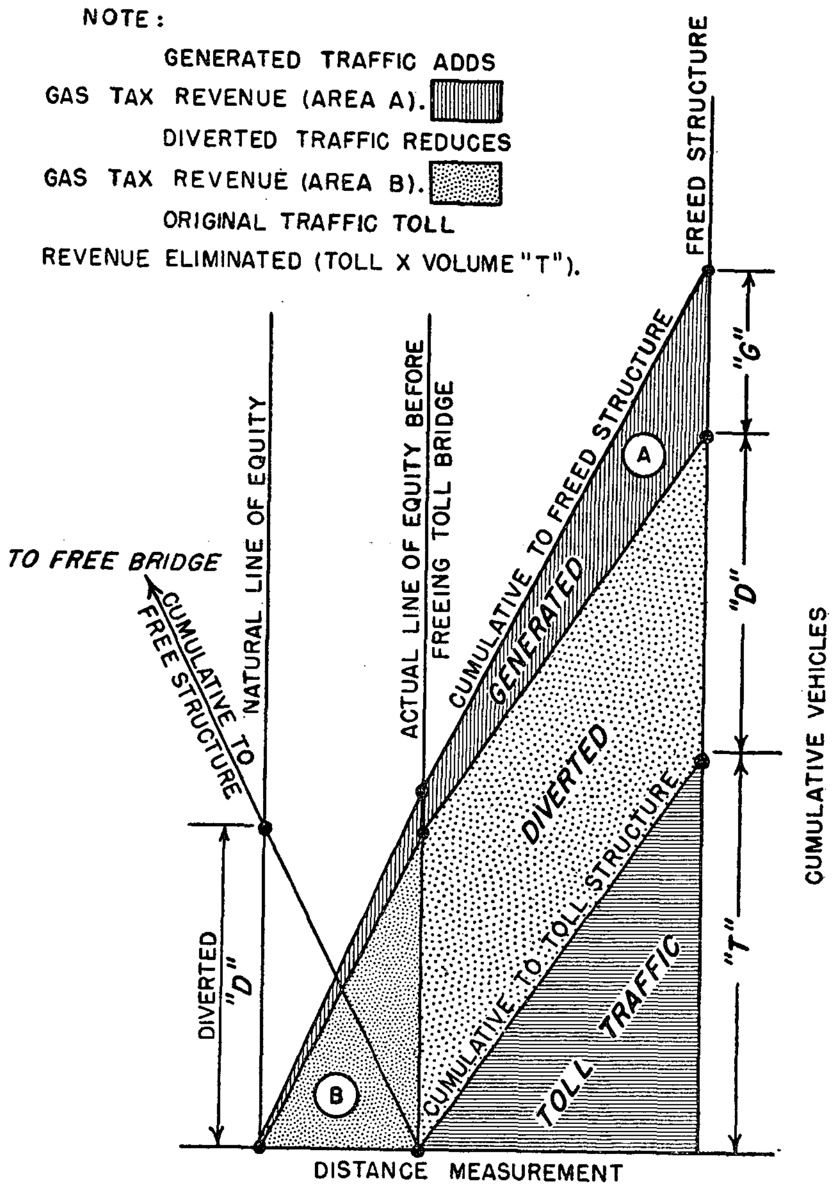

FIGURE 6—Illustration of Accrued Traffic Upon Freeing a Toll Structure.

It is likely that the magnitude of induced traffic will be greater in the area nearer the freed facility, since the population density generally increases as bridge is approached; and the use of the bridge in its immediate environs does not involve substantial time and operation costs.

2. Field Procedures

Basic Information Required—The previous discussion indicates that (a) the trip centroid loci, (b) average speed of travel, (c) operating costs per mile and (d) toll rates per vehicle must be determined. The usual method of procuring this data is by (a) origin and destination surveys, (b) time-delay studies, (c) route inspection and operating cost analysis, and (d) from published toll rates. Each procedure is treated herewith:

(a) Origin and Destination Survey—Origin and destination surveys were made of traffic travelling both directions across each bridge during a 24 hour week-day period. An approximate 100% sample was obtained for each hour period in order to obtain as true a portrayal of travel as practicable. Each trip origin and destination was precisely determined by interviewer so that pin-pointing to the nearest tenth mile could be obtained. Standard procedure was used in outlining and conducting procedures. (See Interview and Code Sheets in Appendix.)

(b) Time-Delay Study—This study was made by the floating car method. Runs were made over the courses to locate control points, which were selected at frequent intervals. (See Time-Delay Field Sheets in Appendix.)

Trips were run to insure an average of traffic conditions. From 7:00 A. M. until midnight not less than one round trip was made in each hour, and as many as three round trips were secured in the hours of heavy traffic. The hours from midnight to 7:00 A. M. were considered to be represented by the other trips which had been accomplished without delay, under similar light traffic conditions.

(c) Route Inspection and Operating Cost Computation—Fairly level grades with little traffic congestion, and few required stops led to the assignment of the commonly accepted 3¢ per mile operating cost as appropriate for passenger vehicles operating in the areas studied.[2]

[2]Coverdale and Colpitts, *Report on Traffic and Revenues, Lake Washington Bridge Project.* (New York: Coverdale and Colpitts) 1938. p. 27.

See also Jorgensen's "Origins and Destinations of Highway Traffic, the Basis for Connecticut Planning," Vol. 23, p. 372, *Proceedings of the Twenty-third Annual Meeting.* (Washington, D. C.: Highway Research Board, 1943).

(d) Published Toll Rates—Toll rates as published by the bridge companies and on file in the office of the Public Service Commission of the State of West Virginia were adopted for use in this study. (See Log of Bridges in Appendix for toll rates.)

3. Mechanics of Analysis

Basic Assumptions in Analyzing Origin and Destination Study

1. The measurement of excess inapposite travel evaluates the constraint.

2. Apposite travel will always be the same regardless of bridge crossed.

3. Without the influence of constraint trips will follow route with least inapposite travel.

4. A vehicle will not cross a toll facility when it can cross a free facility and by so doing avoid both toll and inapposite travel.

5. Conversely, only those trips which have less inapposite travel and time by way of toll bridge can find it profitable to use toll facility

6. A vehicle will cross a toll facility to avoid extra inapposite travel as long as the cost of toll is less than the cost of extra inapposite travel and extra time by way of a free facility.

7. A vehicle will cross a toll facility and include inapposite travel in the trip up to the point where toll cost plus inapposite travel cost plus time cost balances the inapposite travel cost plus excess time cost in travelling by way of the toll bridge.

8. Inapposite distance is equal at the isometric line regardless of travel direction.

9. Excess time is equal at the isochronic line regardless of travel direction.

10. When trip centroids from the free bridge extend beyond the natural line of equity to overlap with trip centroids from the toll bridge they enter the critical area.

11. When trip centroids from the toll bridge overlap the trip centroids from the free bridge, they enter the critical area.

12. That point within the critical area where the cumulative travel by way of the toll bridge equals the cumulative travel by way of the free bridge establishes the actual line of equity between the bridges, which is the limit of their respective spheres of influence (equals the point of maximum inapposite travel with respect to each bridge).

13. Drivers whose daily trips have origin within or near the critical area on one side of the river and destination within or near the critical area on the opposite side of the river are assumed to have evaluted the cost of inapposite travel and excess time as applicable to their individual circumstances, and then travel by the most economical route.

14. Toll paid is measurement of monetary value of tangible and intangible benefits.

15. When a toll bridge is freed, the sphere of its influence will ultimately coincide with the natural line of equity.

16. The differential measured between natural sphere of influence and actual sphere of influence after a toll bridge is freed (and traffic pattern stabilized) may be due to force of habit, or other psychological constraint.

17. Where centroid of trip falls in the line of equal equity, it is as cheap to travel one direction as the other.

Selection of Trips for Analysis—Predicated upon the Basic Assumptions, the trips selected from the O and D study for analysis may be limited to:

1. Free Bridge Interviews
   (a) "U" turns having at least one crossing of the isometric line.
2. Toll Bridge Interviews
   (a) "U" turns with trip centroids overlapping, or approaching, the centroids of trips selected from free bridge interviews.
   (b) "S" turns, with one terminus overlapping inapposite travel of trips selected from free bridge interview.

(Note: Actually all "U" and "S" trips on toll bridge must be reviewed to see whether they meet these conditions, and centroids of each trip calculated and compared for overlapping possibilities.)

Elimination of Irrational Trips—If the driver passes by a toll bridge to use a free bridge and then repasses the same toll bridge, again on the other side of the river, and in so doing the distance and time costs exceed the cost of travel via toll bridge, this trip is not used in analysis.

If driver passes free bridge to use toll bridge and then repasses the same free bridge again on the opposite side of the river, he had other reasons than cost and convenience in using toll bridge, and this trip is deleted.

"S" Trip Analysis—If a driver makes an "S" trip across the toll bridge, having one terminus between toll bridge and free bridge the trip is included as an "L" type, with the other terminus at the opposite end of the toll bridge.

The basis for this is the fact that as the driver approaches a toll bridge with destination between the toll bridge and the adjacent free bridge, he can take no choice of bridges until he reaches the toll bridge. which becomes in effect the origin of route choice.

Expansion Factors for Origin and Destination Study—Since the development of the critical area depends upon the number of trips overlapping, the "Before" and "After" studies must be expanded to a common basis.

This may be done by eliminating the seasonal influence, or by expanding to a known normal ADT for a specific year.

This study is expanded to the normal 1940 ADT for the reason that it is to be used again in another study[3] in which the data must be projected to 1965. The 1940 base is used because factors for expanding 1940 traffic to 1965 traffic have been derived, but such factors are not readily derived from a 1946 base. Expansion was performed by using a fixed recorder in the same area for deriving factors of expansion. The traffic figures shown in the Appendix have been expanded for hourly and seasonal adjustment and to 1940 ADT.

Zoning for Study—Reference is made to Figure 11 showing zoning layout. In the analysis each trip is considered individually, and for that reason the interviews were "pin-pointed" for origin and destination. Zones, however, of a mile in length along the river were resorted to for convenience in grouping interviews for analysis. Nevertheless, travel distances were measured to the nearest one-tenth mile, and thusly, coded. (The isometric line was used as a dividing line between the contiguous zones.)

Time-Delay Analysis—The hourly average travel time for each zone was tabulated and weighed according to the proportional density of the traffic for each hour, thus obtaining average speed of travel between control points applicable to the 24 hour traffic density. Speeds via the

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[3]"Warrants for Additional Bridges in the Kanawha Valley (West Virginia)"—by Planning Division of the State Road Commission of West Virginia.

several bridges to lines of natural and actual equity were obtained by interpolation and accumulation.

4. Correlary Study

In the following study (which translates additional monetary costs for amount of time saved into monetary value of time per minute) the development is based on the method in Analytical Geometry of determining the locus of a point at the intersection of lines of given slopes. (Comparable to a problem in intersection of grades.)

The slopes in the immediate problem are the rates of cost per mile for travel via a toll bridge and via the adjacent free bridge. The rate of cost per mile includes the (vehicle) operating cost per mile of travel plus the (vehicle) time cost per mile of travel. The offset distance of the locus of the point of intersection from the isometric line is the distance differential = n.

In the case at hand the locus is known, the relative rates of slope per mile are known and their points of intercept on the Y axis are known. The solution consists of finding the absolute rates of slope (cost) per mile of travel. With these values determined, the vehicle cost per mile of travel is found by simply deducting the operating cost per mile. The residual values are translated into cost per minute by multiplying by speed of travel, in miles per hour, and dividing by sixty.

In the development of the Correlary Study specific values of operating cost, travel time, travel distance, differential distance and toll charge are assumed and a graph drawn in accordance with these assumptions; then the analysis is developed and proved by using the assumed values. This procedure is used in order to provide a concrete illustration of a somewhat abstract theory.

Translation of Time and Distance Differentials into Cost per Minute— Two cases are analyzed as follows for passenger vehicles:

Case 1

Hypothesis: Isometric and Isochronic (Lines Coincident)

Based on an assumed toll charge of 25¢ per passenger vehicle, operating cost of 3¢ per vehicle mile, cost of 1¢ per minute for time value of passenger vehicle, 12 mile travel distance between bridges, and average speed of 30 miles per hour between bridges, Figure 7 was drawn to influence of toll facility.

It will be noted that the differential measurement between actual line of equity and natural line of equity is 1.25 miles (equals assymetry of inapposite travel).

Development of Formula—(Refer to Figure 7, page 38).

The formula for intersection of slopes (when speeds and operating costs are equal in each sphere of influence) may be expressed as follows:

$$\frac{y}{2s} = 2n$$

or transposing

$$\frac{y}{2n} = 2s$$

where

- y equals toll charge (also equals T)
- n equals assymetry of bridge influence
- s equals sum of operating and time cost per mile (= Slope)
- 2n equals distance differential (total excess inapposite travel on both sides of river)

Now let

- x equal time cost per minute
- c equal operating cost per vehicle mile
- t equal time cost per vehicle mile
- V equal average speed in miles per hour

Whence (substituting and rearranging):

$$\frac{y}{2n} - 2c = 2t$$

$$t = \frac{y}{4n} - c$$

where t equals time cost per mile.

Since $x = t \cdot \frac{V}{60}$ and $t = \frac{y}{4n} - c$

by substituting, and letting y equal T:

$$x = \frac{V}{60}\left(\frac{T}{4n} - c\right)$$ See Equation 3, page 43

Proof (use numerical values assumed and solve for x):

$$x = \frac{30}{60}\left(\frac{25}{5} - 3\right) = 1¢ \text{ per minute}$$

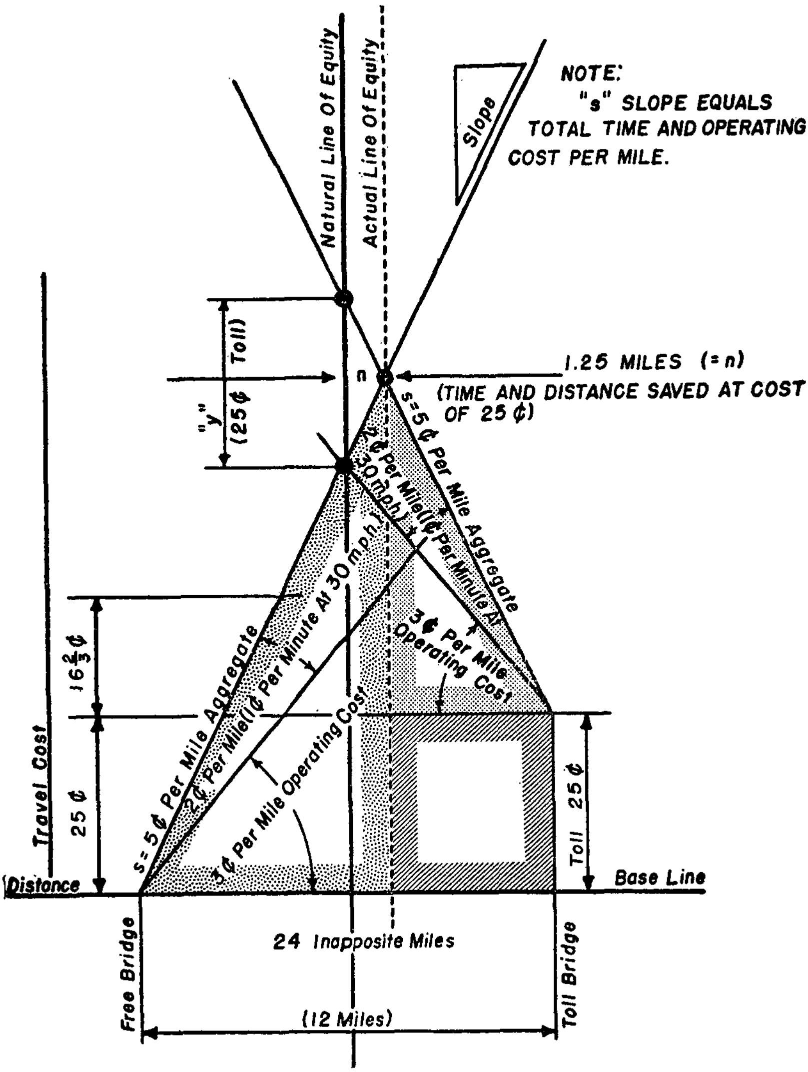


FIGURE 7—Graphical Analysis with Equivalent Speeds. Isometric and Isochronic Coincident (Speed = 30 m.p.h.).

CASE 2

Hypothesis: Isometric and Isochronic (Lines Non-coincident)

Assumption: Average speed of travel via free bridge is 20 M.P.H. and via toll bridge 30 M.P.H. Other conditions same as in Case 1, namely: Average toll paid by vehicles in critical area 25¢, operating cost of vehicle 3¢ per mile, 1¢ per minute for time value, distance of 12 miles between toll and free facility. Refer to Figure 8 which was drawn upon basis of above assumptions.

It will be noted that the distance between the actual line of equity and

(a) Isometric line is 0.59 miles (1.18 inapposite miles)

(b) Isochronic line is 1.79 miles (3.58 inapposite miles)

Development of Formula—Refer to Figure 8:

Let X = time cost per mile.

Then from relations shown in Figure 8,

$$y = (2)\,(1.79)\left[(2)(3) + \frac{5X}{2}\right];$$

in which 1.79 equals m (by method of intersection of slopes).

$b = [12 - 2\,(0.59)\,(3+X)]$ in which 0.59 equals n
and $b = 32.46 + 10.82X$
$y = y_1 + y_2$
$y_1 : b + 25 = 2\,(1.79) : 12 + 2\,(0.59)$ (similar triangles)

$$y_1 = \frac{2\,(1.79)\,(32.46 + 10.82X + 25)}{13.18} \text{ Where } 32.46 + 10.82X = b$$

$y_2 : b = 2\,(1.79) : 12 - 2\,(0.59)$ (similar triangles)

$$y_2 = \frac{(2)\,(1.79)\,(32.46 + 10.82X)}{10.82}$$

Equating values of $y = y_1 + y_2$:

$$2\,(1.79)\left[(2)\,(3) + \frac{5X}{2}\right] = 2\,(1.79)\left[\frac{(57.46 + 10.82X)}{13.18}\right] + 2\,(1.79)\left[\frac{32.46 + 10.82X}{10.82}\right]$$

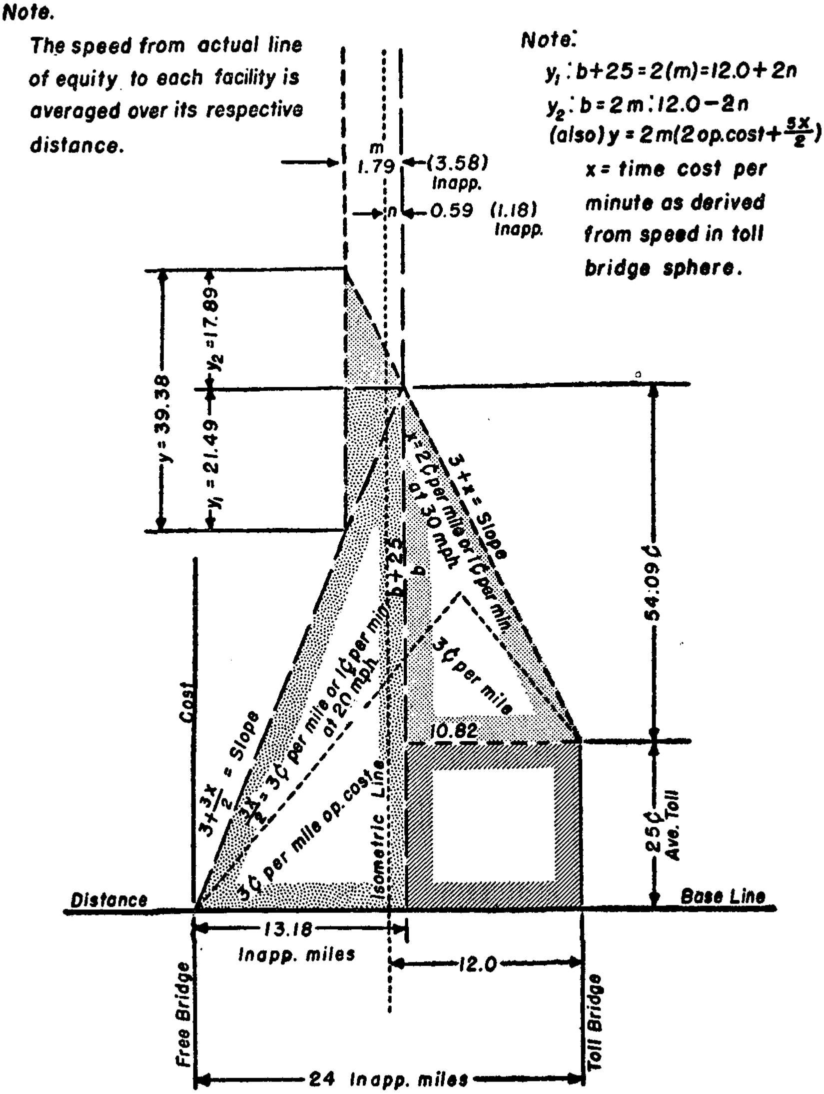


FIGURE 8—Graphical Analysis with Variable Speeds. Isometric and Isochronic Lines Noncoincident.

Simplifying: [dividing through by 2(1.79)]

$$(2)\ (3) + \frac{5X}{2} = \frac{57.46 + 10.82X}{13.18} + \frac{32.46 + 10.82X}{10.82} \quad \text{Equation 1}$$

$$35.6519\ (12 + 5X) = 5.41\ (57.46 + 10.82X) + 6.59\ (32.46 + 10.82X)$$

$$427.8228 + 178.2595X = 310.8596 + 58.5362X + 213.9114 + 71.3038X$$

$$48.4195X = 96.9482$$

$X = 2$ equals time cost per mile for the average speed via toll bridge.

Since the speed of this group is given as 30 M.P.H. then,

$$\frac{30}{60} \times 2 = 1¢ \text{ per minute.}$$

Now let:

- c equal average vehicle operating cost per mile
- k equal $\frac{V_1}{V_2}$
- V_1 equal average speed in toll bridge sphere of influence
- V_2 equal average speed in free bridge sphere of influence
- d equal distance between bridges (or one-half complete fixed circuit)
- 2n equal distance differential
- T equal toll cost

Translating equation (1) in terms of data given:

$$2c + (X + kX) = \frac{(d - 2n)\ (c + X) + T}{d + 2(n)} + \frac{(d - 2n)\ (c + X)}{d - 2(n)}$$

$$X\ (1 + k) = \frac{2d\ (c + X) + T}{d + 2n} - 2c$$

$$X = \frac{2d\,X - 4cn + T}{(d + 2n)\ (1 + k)}$$

Multiply by denominator and assemble factors in X to left of equality sign:

$$X\ (d + 2n)\ (1 + k) - 2d\,X = -4\,cn + T$$

$$dX + dkX + 2nX + 2knX - 2dX = -4\,cn + T$$

$$X\ (dk + 2n + 2\,kn - d) = -4\,cn + T$$

$$X = \frac{-4\,cn + T}{dk + 2n + 2\,kn - d}$$

$$X = \frac{T - 4\,cn}{d\,(k - 1) + 2n\,(k + 1)}$$

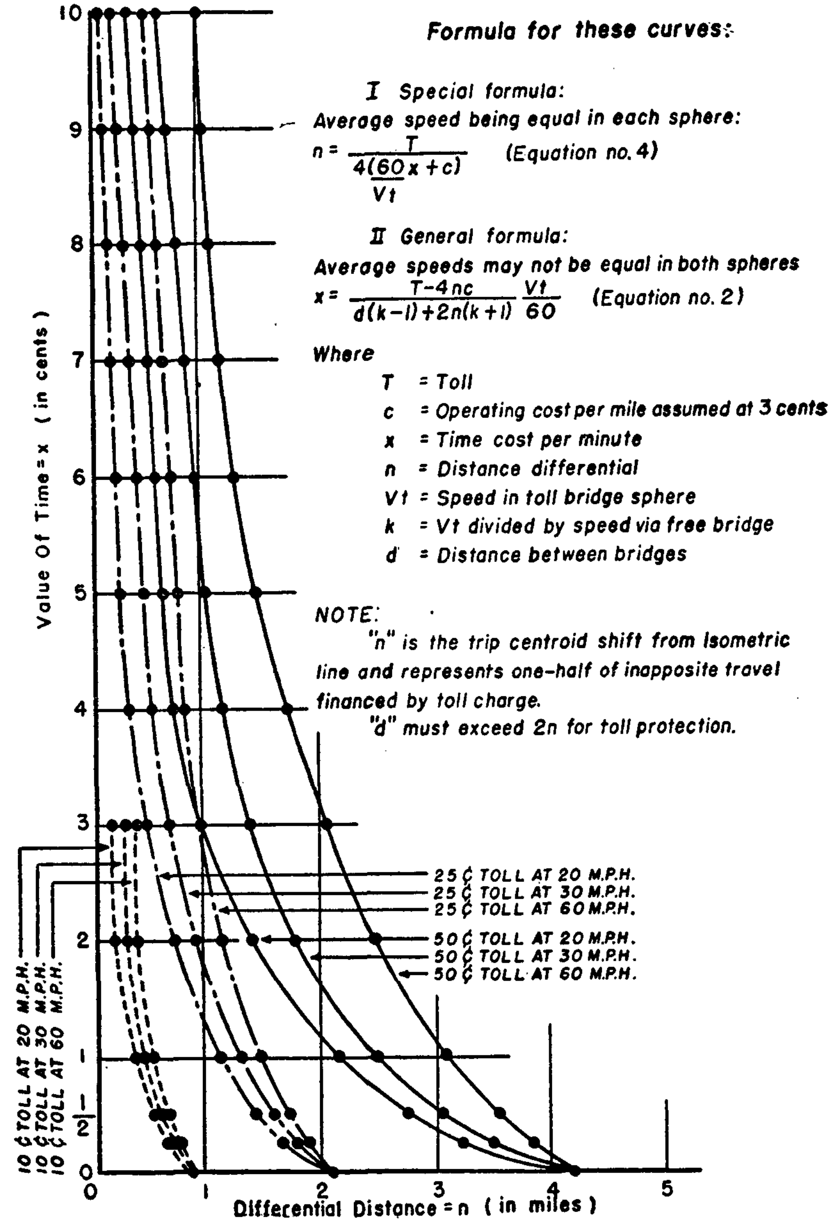


FIGURE 9—Families of Curves for Specific Toll Rates and Speeds Related to Time Value and Distance Differential.

Now, if we let x equal time cost per minute, we must multiply by $\frac{V_1}{60}$ to reduce to cost per minute, and

$$x = \frac{T - 4\,cn}{\left[d\,(k-1) + 2n\,(k+1)\right]\frac{60}{V_1}} = \frac{\text{Extra Cost}}{\text{Time Saved}} \qquad \text{Equation 2}$$

which becomes $x = \frac{V_1}{60}\left[\frac{T}{4n} - c\right]$ Equation 3

$$\text{or } n = \frac{T}{4\left[\frac{60}{V_1}x + c\right]} \qquad \text{Equation 4}$$

when speeds are equal and K equals 1 (See Case 1, page 36).

Interpreting and Investigating Formula

1. When speeds are equal via both toll bridge and free bridge and there is no positive differential measurement the value of x becomes infinitely large–the driver "has more dollars than sense."

2. When value of x equals 0, speed of travel is cancelled out, and differential distance equals T/12 equals maximum value of n.

3. When speeds are equal via both toll and free bridges, n is directly proportional to T for any specific value of x.

4. When k equals 1, T equals 0, and n equals 0, x is nideterminate.

5. When k is greater than 1, or less than 1, x is a function of d (distance between bridges).

6. When k equals 1, x is independent of d.

Applying Formula

1. The value of x is determined for Patrick Street-Sattes, Chelyan, Kanawha City, and Montgomery-Chelyan Bridges in Chapter Five.

2. By supplying values for x, c, and T, the value of n may be found which measures the influence of, or delimits the sphere of influence of a toll bridge.

3. By plotting families of curves and correlating with O and D data, and stranded and diverted traffic data, adjustments may be made in toll schedules to secure optimum traffic with maximum rates. (Classifi-

cation by type must be made in this analysis.) See Figure 9 entitled "Families of Curves."

4. By solving for value of n for a given set of conditions, it may be determined how close a toll bridge may be placed to a free bridge and still maintain required traffic density to pay amortization costs.

CHAPTER V

DIVERTED, BARRED AND STRANDED TRAFFIC

An Application of Spheres of Influence and Differential Measurements

1. Introduction

The spheres of influence and differential measurements with resultant effects are treated by bridge couples in the following order:

1. Patrick Street-Sattes.
2. Chelyan-Kanawha City.
3. Montgomery-Chelyan.

The amount of diverted, barred and stranded traffic is shown for the Sattes Bridge, where an origin and destination survey was made both before and after it was freed of tolls. Value of time per passenger vehicle minute is also determined.

The amount of diverted traffic and value of time per passenger vehicle minute is determined for the Chelyan Bridge on the basis of an origin and destination survey made while it was a toll bridge. Although the bridge is scheduled to be freed in the immediate future, it will be too late to include an after study in this thesis. It is believed, however, that the propriety of the method of analysis, which is the object of this treatise, is established by application to the before and after study of the Sattes Bridge traffic and the omission of the Chelyan "after" study will not vitally detract from the essential development.

Speed Values—After the actual line of equity was determined, the speed via each bridge to this line was calculated from the time-delay data. The time-delay data was obtained by floating car method in which sufficient trips were made during each of the 24 hours of the day to provide a stable speed pattern for each hour. The average speed was obtained by weighting the hourly average speeds by the respective hourly density of traffic.

Class of Traffic Studied—Only passenger vehicle traffic is included in this thesis, in order to bring out the essential development with simplicity. This type of traffic paid the same toll per vehicle, regardless of occupancy, at the Sattes Bridges, thus enabling the study of all passenger vehicles in a unified group.

Commercial vehicle behavior and costs can be studied by grouping vehicles in brackets with respect to speeds, operating costs and toll charge.

Bridge Logs—Pertinent information relative to each of the bridges studied is included in the Appendix 1.

2. Patrick Street-Sattes Bridges

General—The *Patrick Street Bridge* crosses Kanawha River at the west corporate limits of Charleston, carrying US 60, W.VA. 4, and W.VA. 13 traffic, and providing a connecting link between the City of Charleston (Pop. 67,914 in 1940) and City of South Charleston (Pop. 10,377 in 1940). The ADT on this bridge amounted to 19,500 vehicles in 1940.

The *Sattes Bridge* crosses the Kanawha River to connect St. Albans (Pop. 3,558 in 1940) with Sattes (unincorporated) and Nitro (Pop. 2,983 in 1940). The 1940 ADT was 1,162 vehicles.

Scope of Study—This study includes the trips with centroids of origins and destinations between the Patrick Street Bridge and Sattes. The Sattes-Winfield couple is not included for the reason that the Winfield Ferry (about 14 miles west) serves about 40 vehicles a day—such a small volume as to be relatively insignificant.

Accuracy of Study—A force of inexperienced interviewers were employed on this project and, although under excellent supervision, it was difficult to obtain perfection in answers, particularly with reference to pin-pointing of the Origin and Destination of each trip.

The repeat survey was delayed until six weeks after the bridge was freed (from February 7 until March 19) to allow the traffic to stabilize in its use of the bridge couple at the optimum usage of the Sattes bridge. Referring to Figure 10, page 49, it will be noted that the percentage increase on the Sattes Bridge after the repeat survey is less than the seasonal increase at the area (automatic) recorder.

I—Sattes Bridge from North Side of River Looking South.
Freed February 7, 1946.

II—Patrick Street Bridge from North Side of River Looking West.

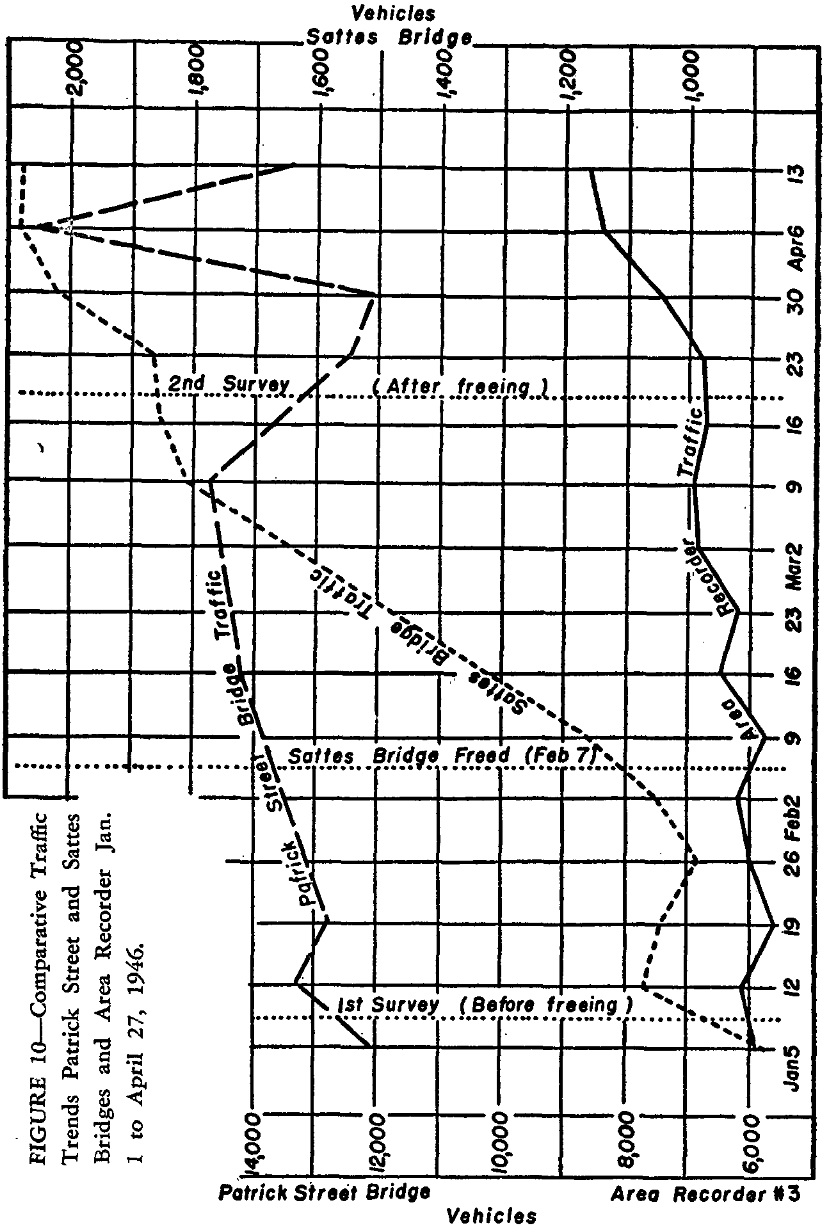


FIGURE 10—Comparative Traffic Trends Patrick Street and Sattes Bridges and Area Recorder Jan. 1 to April 27, 1946.

Portable recorder tubing was frequently cut on both bridges, making an accurate day by day density count almost impossible. The erratic fluctuations in the Patrick Street Bridge graph possibly reflects inefficiency in the machine counts.

Total Before and After Portrayal—The accompanying bar graph, Figure 11, shows the comparable before and after traffic by origin and destination for each zone between the Patrick Street Bridge and Winfield Ferry. Trucks are included in the total traffic in this portrayal.

Analysis of Before and After Origin and Destination Study—The analysis will be treated in the following divisions:

a. Diverted Traffic
b. Barred Traffic
c. Stranded Traffic
d. Sphere of Toll Bridge Influence
e. Correlary: Monetary Evaluation of Vehicle Time
f. Solution for Natural Line of Equity

a. *Diverted Traffic*—(Refer to Table No. IV entitled "Estimated East to East Traffic via Sattes Bridge after Freeing," also Table No. VIII entitled "Sattes Bridge Travel Centroids Before and After Freeing.") The Estimated East to East Traffic that would use the Sattes Bridge after tolls were eliminated was based on the amount of traffic that travelled out of the way to avoid a toll charge. This traffic, with centroid of origin and destination West of the Natural Line of Equity, amounted to 150 vehicles. (See Figure 12, page 52, and Figure 14, page 57.)

With respect to West to West Traffic: No origin and destination study was made on the toll ferry 14 miles to the West of Sattes for the reasons: it carries less than 50 vehicles per day; it has a 25 cent toll charge, and adds to travel time due to an appreciable delay. It was believed, therefore to divert little traffic from the Sattes Bridge.

With respect to "S" trips having terminus East of Sattes: Those trips with centroid between East terminus and Sattes Bridge East of actual line of equity would probably be diverted over Patrick Street Bridge and are, therefore, included in the 150 diverted vehicles enumerated above.

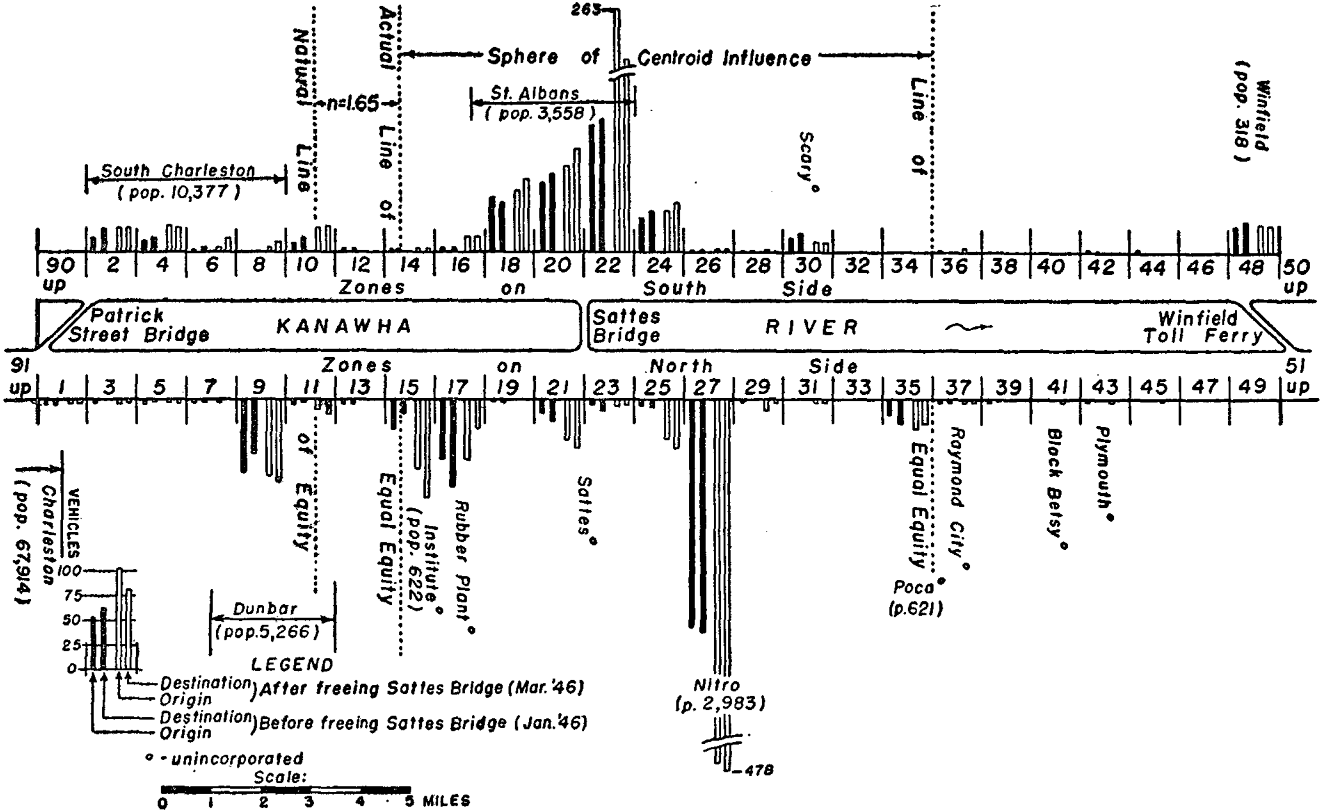


FIGURE 11—Schematic Diagram Showing Origin and Destination of Travel Crossing Sattes Bridge by Zones.

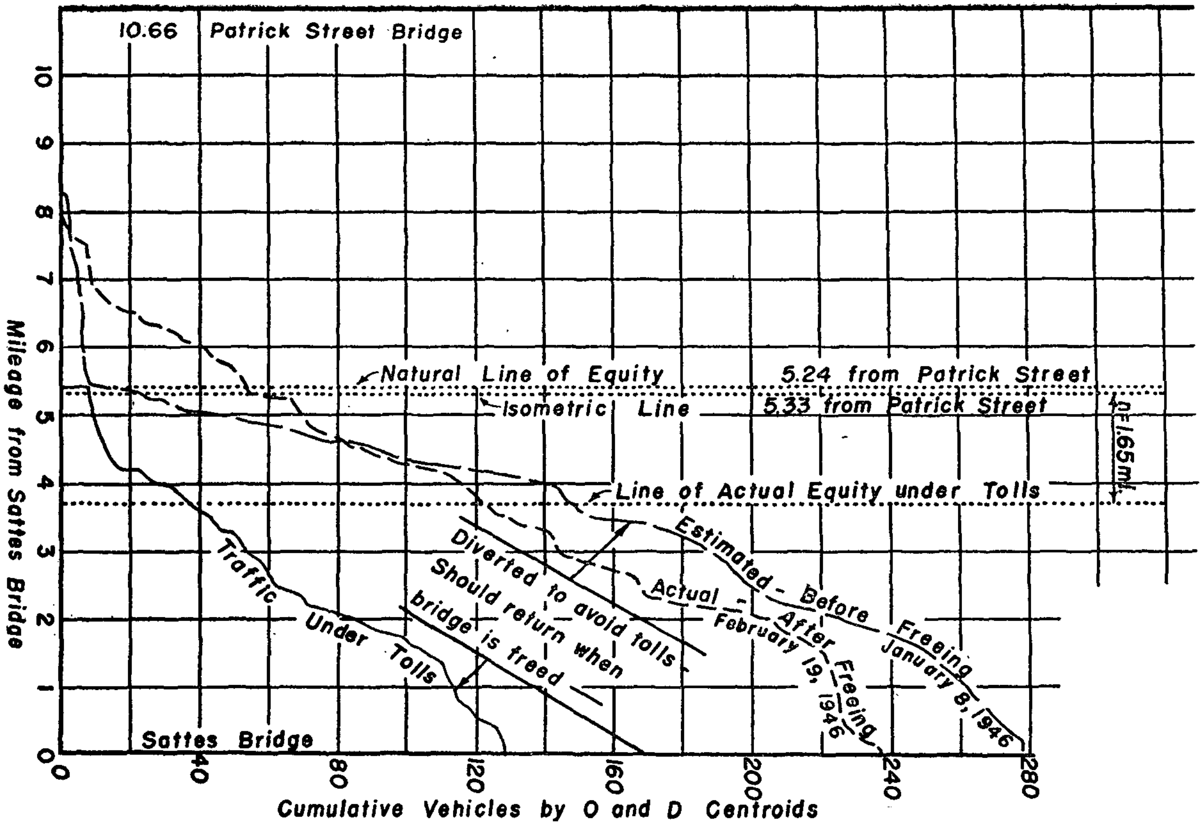


FIGURE 12—Accrued Traffic: East to East U Turns Estimated and Actual After Freeing Sattes Bridge

It is not believed that any diversion of "S" type trip occurs via Winfield Ferry since the Sattes Bridge is probably the more attractive from time standpoint.

The freed bridge should divert a few cars from the Ferry, but there are but few that can be diverted.

Thus, probably all told, there were between 150 and 200 passenger vehicles diverted from the Sattes Bridge by way of other facilities. For purpose of further analysis the diverted traffic is assumed to be 175 vehicles—15 per cent of the total 1940 ADT toll traffic, but about 9 per cent of hypothetical 1940 ADT "freed" traffic.

b. *Barred Traffic*—This traffic consists of the "foreign" vehicle or vehicle having terminii beyond the sphere of influence of the toll bridge, which did not use the bridge until it was freed of toll. It is closely allied to stranded traffic, the limitation being that barred traffic has centroid terminii beyond natural line of equity. Computing this by a zone to zone transfer by I.B.M. and excluding trips previously used in computing diverted traffic—practically all of the barred traffic is found with terminii in the "S" trips—about 35 new trips were found, in addition to 14 trips previously using the toll facility from areas entirely outside sphere of influence.

c. *Stranded Traffic*—(See Table No. VIII in Appendix.) Traffic which previously did not exist except as a static reservoir is referred to as "stranded" traffic. As previously defined all "new," induced, or generated traffic with centroid of origin and destination (or one terminus of an "S" trip) within the natural sphere of influence of the freed facility may be termed toll stranded traffic; or total traffic in this area less original, diverted and barred traffic equals stranded traffic.

Patrick Street-Sattes Bridges

Summation of Accrued Passenger Traffic

TYPE	AMOUNT	PER CENT OF PASSENGER TOLL TRAFFIC
Diverted	175 veh.	20%
Barred	35 veh.	4%
Stranded	445 veh.	53%
Total Accrual	655 veh.	77%

The total passenger vehicle traffic expanded to 1940 ADT under tolls was 845. The expansion after freeing the bridge to the 1940 ADT raises this total to about 1,500, or an increase of about 655 vehicles per day. (Note that commercial vehicles are not included. The aggregate ADT was raised from 1,162 vehicles to approximately 1,800 vehicles.)

The diverted traffic (175 trips) plus the barred traffic (35 trips) plus the original traffic (845 trips) makes a total of 1,055 trips, which

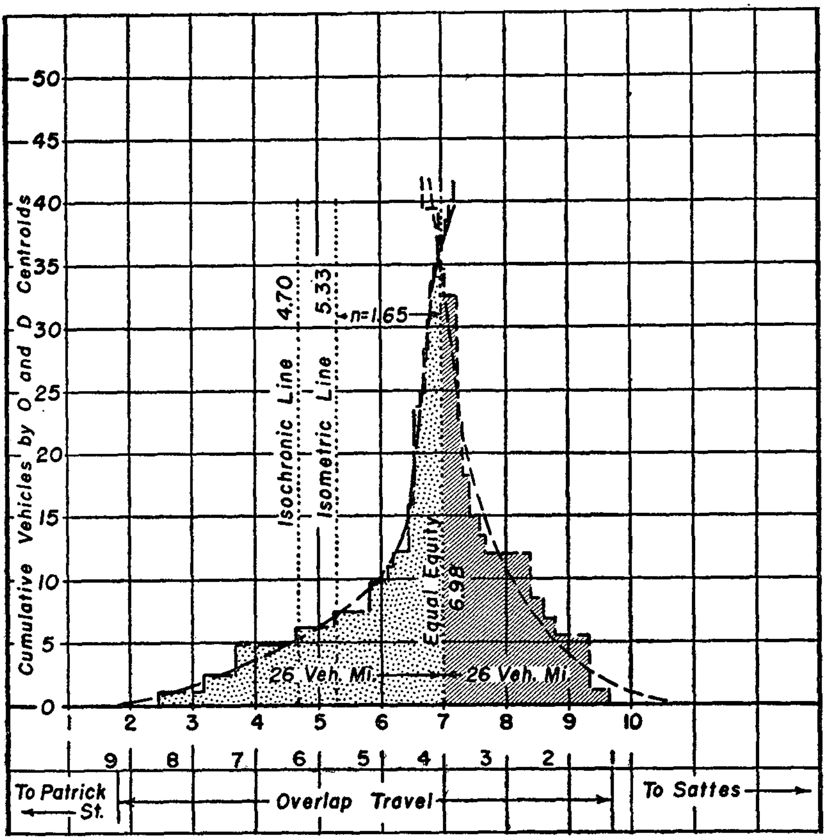


FIGURE 13—Patrick Street-Sattes: Critical Area and Line of Equity.

subtracted from 1,500 trips, leaves 445 trips per day as the stranded traffic,—53 per cent of the (passenger) toll traffic. It will be noted that most of the stranded traffic increase is "close in."

d. *Sphere of Influence*—Calculation of Line of Equal Equity. (Vehicle volume and distance taken from Table No. III in Appendix.)

Cumulative Vehicular Mileage
(Using 7.0 Mi. from Pat. St. as Ref. Line)

VIA TOLL BRIDGE			VIA FREE BRIDGE		
VEHICLES	MILES	VEH. MI.	VEHICLES	MILES	VEH. MI.
1.2	4.55	5.46	1.2	2.65	3.18
1.3	3.80	4.94	4.3	2.35	10.10
2.4	3.30	1.92	1.3	1.80	2.34
1.3	2.35	3.05	1.8	1.60	2.88
1.2	1.75	2.10	3.4	1.40	4.76
2.4	1.15	2.76	1.4	0.70	0.98
1.2	0.90	1.08	1.5	0.60	0.30
1.2	0.80	0.96	3.4	0.40	1.36
3.7	0.55	2.03	4.3	0.30	1.29
1.3	0.50	0.65	10.3	0.25	2.51
6.6	0.45	2.97	1.5	0.05	0.07
1.2	0.35	0.42			
3.6	0.30	1.08	34.4		29.77
2.4	0.25	0.60			
2.0	0.20	0.40			
1.2	0.10	0.12			
1.2	0.05	0.06			
35.4		30.60			
plus:					
35	0.03	1.05	Difference		2.08
		31.65			

Adjusting:

Minus:

35 × .025 = 0.88

30.77

Plus:

39 × 0.025 = .97

30.74

7.00 − 0.025 = 6.975, Say 6.98

Observation—Thus, a distance of 6.98 miles from Patrick Street Bridge locates the limit of spheres of influence of the two bridges. But, this is an "imaginary" line derived by statistical process. Few individual motorists place a precise value upon their time, apparently, for the extreme values indicated on the graph vary from an extreme negative value to an extreme positive value. (See Fig. 13, page 54.)

e. *Correlary: Monetary Evaluation of Passenger Vehicle Time per Minute.*

$$x = \left[\frac{T - 4cn}{d\,(k-1) + 2n\,(k+1)}\right]\frac{V}{60}$$

Substituting values determined, assuming operating cost at 3¢ per mile: (See Figure 14, page 57).

$$x = \frac{25 - 4 \times 3 \times 1.65}{10.66\,(0.16) + 2 \times 1.65\,(1.16 + 1)} \cdot \frac{38.2}{60} = \frac{5.20}{8.83}\,(.637)$$

$$x = .375\ ¢ \text{ per minute}$$

Distribution of costs per vehicle: Before Freeing. (See Figure 15, page 58.)

via toll bridge

$\frac{60}{38.2} \times .375 = .589$ ¢ equals time cost per mile

.589 × 3.68 (2) = 4.33 ¢ = total time cost

3.0 × 3.68 (2) = 22.08 ¢ = total operating costs

25.00 ¢ = toll cost

51.41¢ Total costs to line of equity

via Patrick Street free bridge

$\frac{60}{33} \times 3.75 = .682$ ¢ = time cost per mile

.682 × 6.98 (2) = 9.52 ¢ = total time cost

3.0 × 6.98 (2) = 41.88 ¢ = total operating cost

51.40¢ Total costs to line of equity

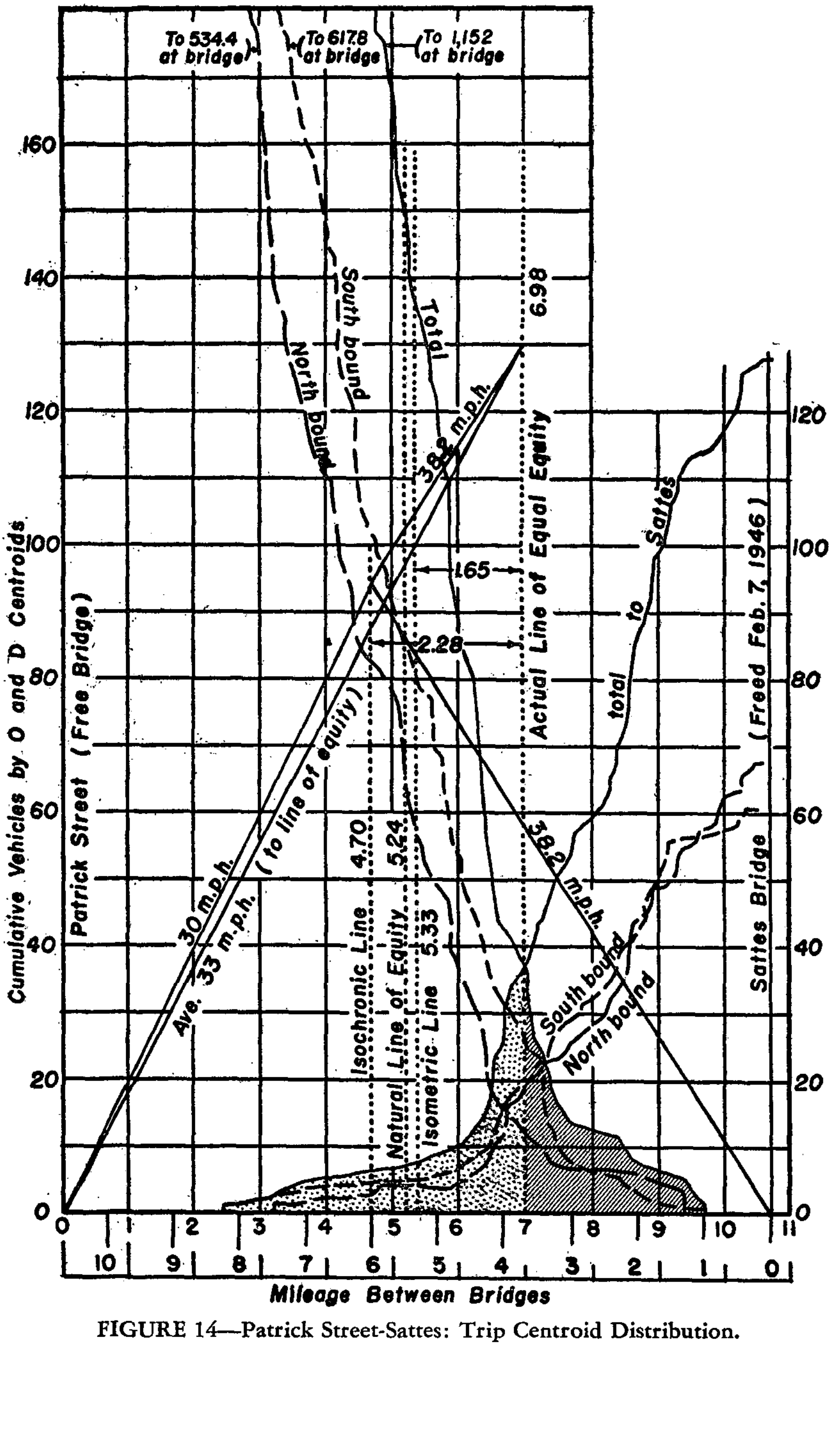


FIGURE 14—Patrick Street-Sattes: Trip Centroid Distribution.

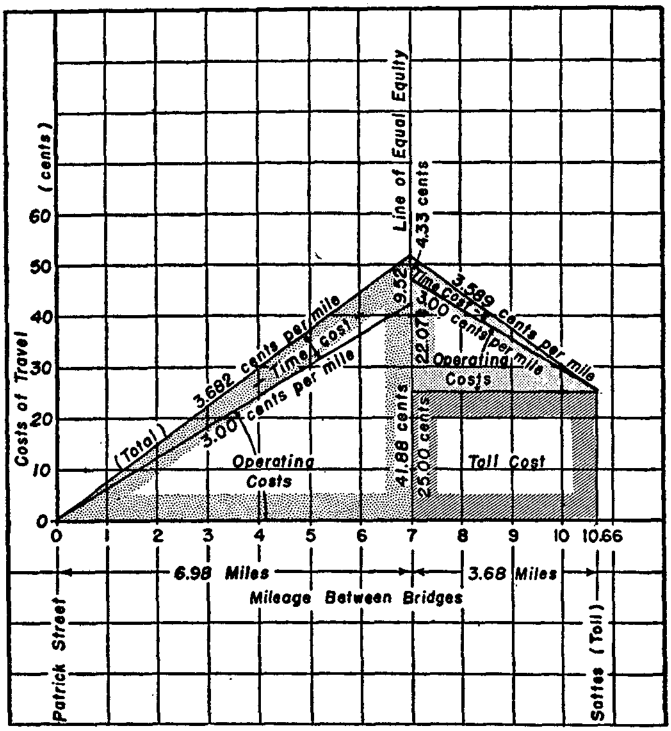


FIGURE 15—Distribution of Travel Costs—Via Patrick Street Bridge, Charleston and Sattes Toll Bridge.

f. *Solution for Natural Line of Equity*—(See Figure 12, page 52).

$$x = \frac{T - 4\,cn}{d\,(k - 1) + 2n\,(k + 1)}$$

$$x = \frac{0 - 4\,cn}{10.66\,(0.27) + 2 \times n\,(1.27 + 1)} \cdot \frac{38.2}{60}$$

Substituting value of x (page 56).

$$.375 = \frac{0 - 4 \times 3 \times n}{2.88 + 4.54\,n}\,(.637)$$

$$1.08 + 1.70\,n = -7.64\,n$$

$$9.34\,n = -1.08$$

$$n = -0.09$$

$5.33 - 0.09 = 5.24$ natural line of equity

Distribution of costs: After Freeing.

via Patrick Street

$\frac{60}{30} \times .375 = 0.75$ ¢ per mile

5.24 (2) × 0.75 =	7.86 ¢	Time cost
5.24 (2) × 3.0 =	31.24 ¢	Operating cost
	39.00 ¢	Total cost

via Sattes

$\frac{60}{38.2} \times 3.75 = 0.6$ ¢ per mile

5.42 (2) × 0.6 =	6.50 ¢	Time cost
5.42 (2) × 3.0 =	32.52 ¢	Operating cost
	39.02 ¢	Total cost

(Note: This is a sample procedure—the same method would be followed for Chelyan-Kanawha City, Montgomery-Chelyan or any other bridge couple.)

3. Chelyan-Kanawha City Bridges

General—The *Chelyan (Toll) Bridge* crosses the Kanawha River about 13 miles above Charleston. It connects US 60 and W.VA. 61, serving as a link between the North Side and South Side of Cabin Creek Magisterial District. It is situated in the Town of Chelyan, which had a 1940 population of 1,397. The hypothetical 1940 ADT of this bridge was 723 vehicles.

The *Kanawha City Bridge* crosses the Kanawha River near the East Corporate Limits of Charleston, carrying US 119 traffic to a junction with US 60, and US 19, and linking Kanawha City (a Charleston district) with Charleston proper. The 1940 ADT on this bridge was 10,420 vehicles.

Scope of Study—A "Before" O and D survey was made for each bridge. The Chelyan Toll Bridge will be freed about June 1946.

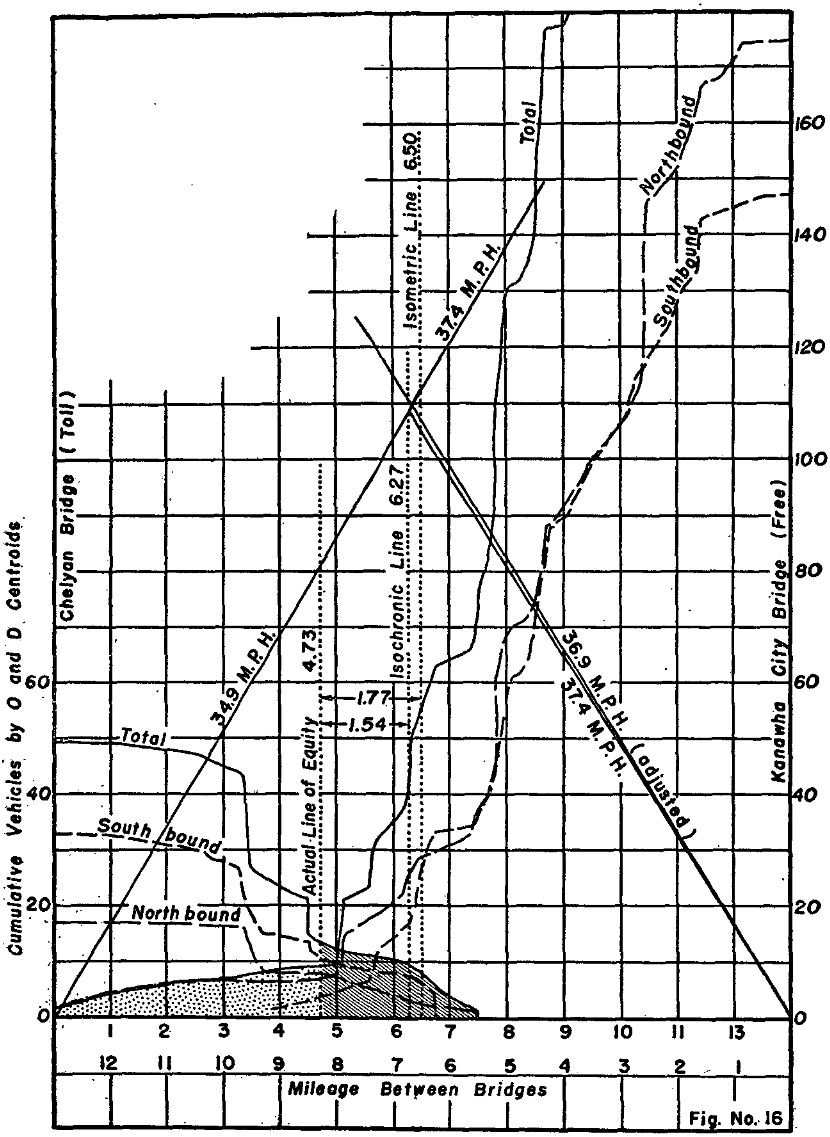


FIGURE 16—Chelyan-Kanawha City: Trip Centroid Distribution.

Analysis of Study—The analysis will be treated in the following divisions:

(a) Diverted Traffic

(b) Sphere of Toll Bridge Influence

(c) Correlary: Monetary Evaluation of Vehicle Time

a. *Diverted Traffic.* The same general remarks included under Patrick Street-Sattes Bridges apply here. Reference to Figure 16 indicates that at the natural line of equity 40 vehicles are being diverted to the Kanawha City Bridge.

b. *Sphere of Influence*—Calculation of Line of Equal Equity. (Vehicle volume and distance taken from Tables XIV and XV in Appendix.)

Cumulative Vehicular Mileage

(Using 5.0 Mi. from Chelyan Bridge as Reference Line)

VIA TOLL BRIDGE			VIA FREE BRIDGE		
VEHICLES	MILES	VEH. MI.	VEHICLES	MILES	VEH. MI.
1.2	3.00	3.60	1.1	4.5	4.95
4.1	2.25	9.22	1.4	4.2	5.88
1.6	2.10	3.36	4.0	1.6	6.40
1.2	2.00	2.40	1.6	0.6	0.96
1.4	1.85	2.60			
1.2	1.25	1.50			18.19
1.2	0.50	0.60			
1.2	0.25	0.30			
1.2	0.05	0.06			
		23.64	Difference		5.45
Adjusting:					
Minus:			Plus:		
	12 × 0.27	−3.24		8.1 × 0.27	2.19
		20.40			20.38

Line of Equal Equity: (See Figure 17, page 62).

5.0 − 0.27 = 4.73 miles from toll bridge

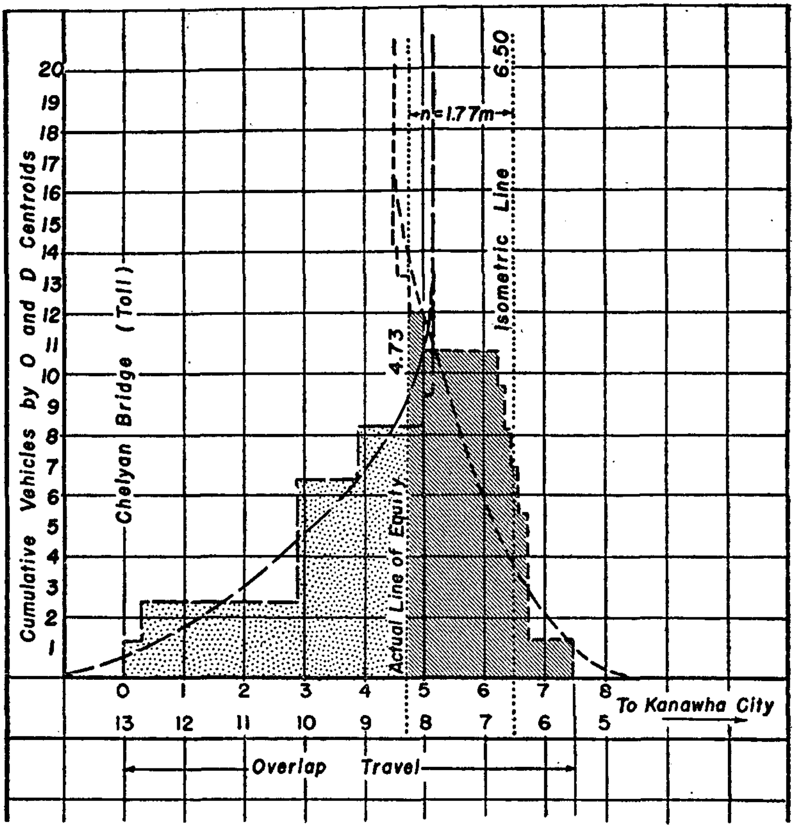


FIGURE 17—Chelyan-Kanawha City: Critical Area and Line of Equity.

c. *Correlary: Monetary Evaluation of Passenger Vehicle Time per Minute.*

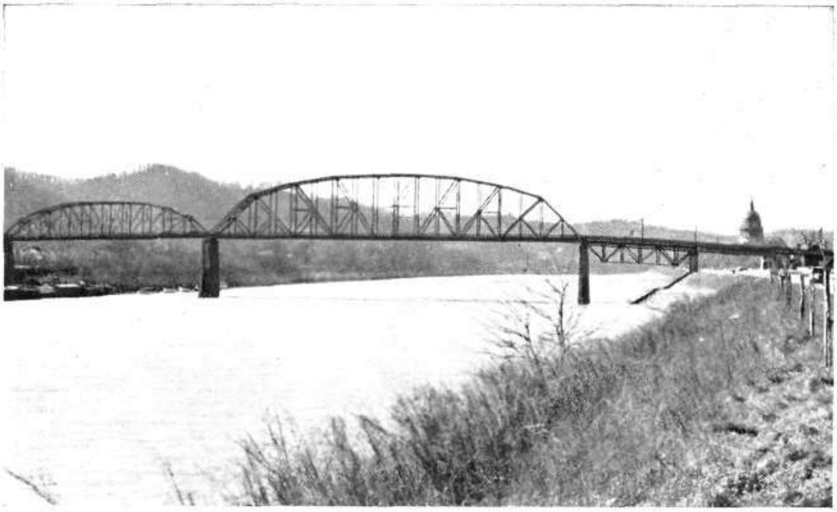
$$\text{Formula:}\quad x = \left[\frac{T - 4cn}{d(k-1) + 2n(k+1)}\right]\frac{V}{60}$$

$$= \frac{29 - 4 \times 3 \times 1.77}{13(.946 - 1) + 3.54(1.946)} \times \frac{V}{60}$$

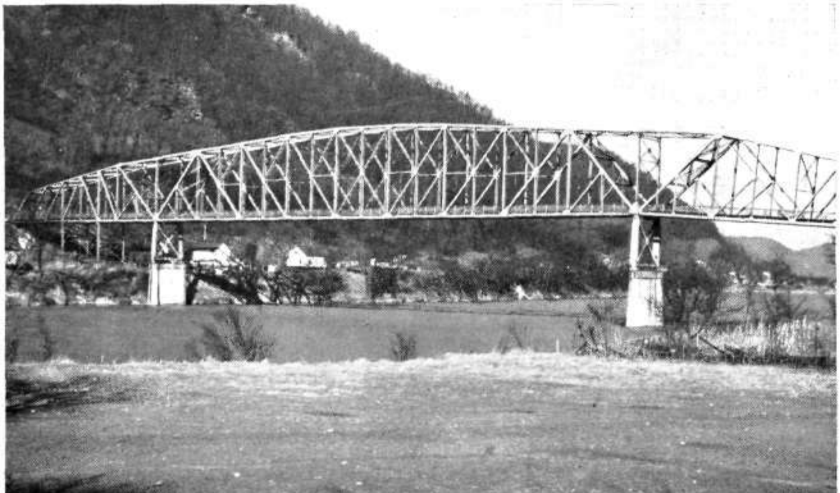
$$= \frac{29 - 21.24}{-.702 + 6.889} \times \frac{34.9}{60}$$

$$= \frac{7.76}{6.187} \times .582$$

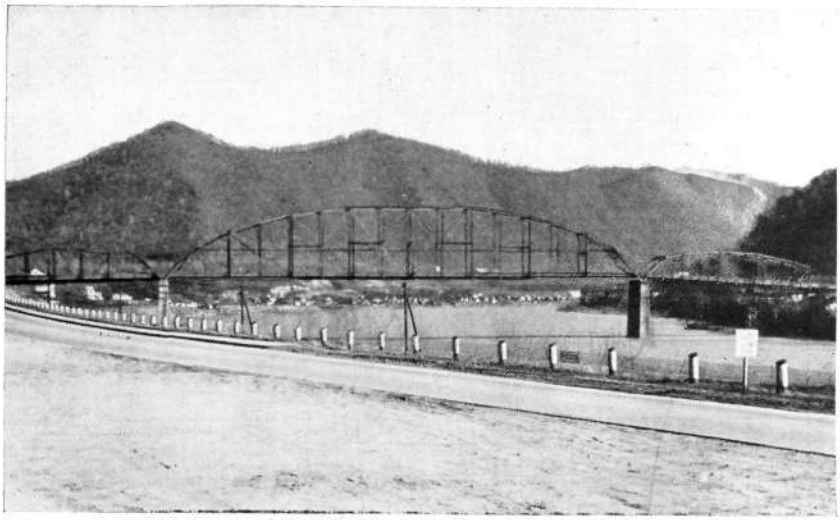
$x = 0.73$ ¢ per minute



III—Kanawha City Bridge from North Side Looking West.



IV—Chelyan Bridge from South Side Looking East (Toll).



V—Montgomery Bridge from North Bank Looking East

Distribution of costs:

via toll bridge

$$.542 \times \frac{60}{34.9} = 1.254 = \text{time cost per mile}$$

$$1.254 \times 4.73\ (2) = 11.87\ ¢ = \text{time cost}$$

$$3.0 \times 4.73\ (2) = 28.38\ ¢ = \text{operating costs}$$

$$29.00\ ¢ = \text{toll cost}$$

$$69.25\ ¢ \quad \text{Total costs}$$

via free bridge

$$0.73 \times \frac{60}{39.9} = 1.187 = \text{time cost per mile}$$

$$1.187 \times 8.27\ (2) = 19.63\ ¢ = \text{time cost}$$

$$3.0 \times 8.27\ (2) = 49.62\ ¢ = \text{operating costs}$$

$$69.25\ ¢ \quad \text{Total costs}$$

4. Montgomery-Chelyan Bridges

General—The *Montgomery Bridge* is situated at Montgomery, West Virginia, 25 miles east of Charleston, and 12 miles east of the Chelyan Bridge. It connects US 60 and US 19, with Montgomery and W.VA. 61. Montgomery had a 1940 population of 3,231. The 1940 ADT of this bridge was 5,056.

The Chelyan Bridge description is under the Chelyan-Kanawha City Bridge couple.

Scope of Study—A "Before" origin and destination survey was made for each bridge.

Analysis of Study—The analysis will be treated in the following divisions:

(a) Diverted Traffic

(b) Correlary: Monetary Evaluation of Vehicle Time

a. *Diverted Traffic*—Reference to Figure 18 indicates that at the natural line of equity 338 vehicles are being diverted to Montgomery. (See Figure 19 for line of equal equity.)

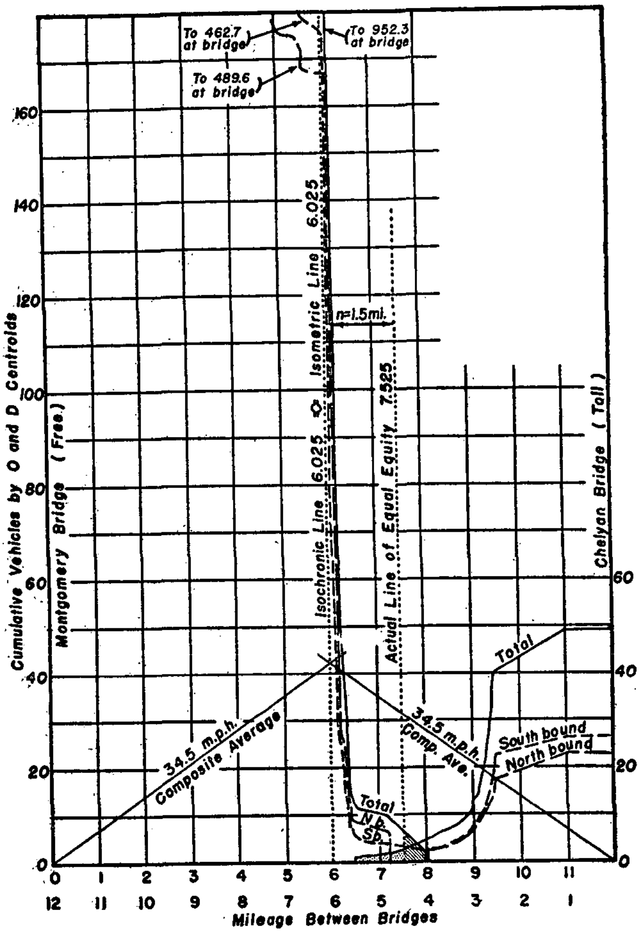


FIGURE 18—Montgomery-Chelyan: Trip Centroid Distribution.

b. *Correlary: Monetary Evaluation of Passenger Vehicle Time per Minute.*

Formula: $$x = \left[\frac{T - 4cn}{d(k-1) + 2n(k+1)}\right]\frac{V}{60}$$

Given $k = 1$

Whence

$$x = \frac{T}{4n} - c\left(\frac{V}{60}\right)$$

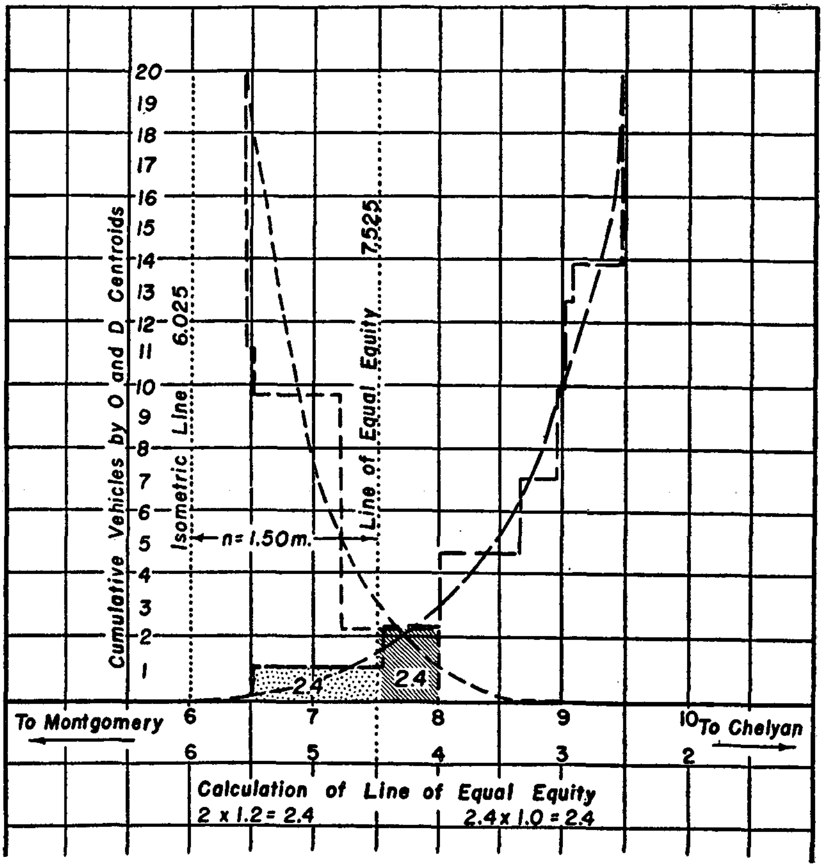


FIGURE 19—Montgomery-Chelyan: Critical Area With Solution for Line of Equity.

Substituting values:

$$= \frac{29}{4 \times 1.5} - 3\left(\frac{34.5}{60}\right)$$

$$= 1.833 \times .575$$

$$x = 1.044 \text{ ¢ per minute}$$

Distribution of costs:

via toll bridge

$$\frac{60}{34.5} \times 1.044 = 1.833 \text{¢ per mile}$$

$$1.833 \times 4.525\ (2) = 16.59 \text{¢} = \text{time cost}$$
$$3.00 \times 4.525\ (2) = 27.15 \text{¢} = \text{operating costs}$$
$$\text{plus } 29.00 \text{¢} = \text{toll cost}$$

$$72.74 \text{¢} = \text{Total costs}$$

via free bridge

Cost per mile same as above.

$$1.833 \times 7.525\ (2) = 27.59 \text{¢} = \text{time cost}$$
$$3.00 \times 7.525\ (2) = 45.15 \text{¢} = \text{operating costs}$$

$$72.74 \text{¢} = \text{Total costs}$$

5. Observations

This Chapter raises the question: "How much is time worth to induced (or stranded) traffic?" Apparently their time is worth less, or their ability to purchase use of the facility is less than that of the original toll traffic.

The ability to pay for a purchase of time must be coupled with the desire to make the purchase. An addition of induced traffic over the freed Sattes Bridge equal to 53% of the original toll traffic resulted from removal of the purchase price on time. Again: "How much induced traffic can be secured with a reduction of 50% in toll charge?"

The line of equal equity balances the value of time with the rate of toll for those who have the desire to purchase time and can afford to do so at the prevailing rate. Now, suppose the rate reduced. "Will the change in position in the line of equity be proportional to the change in toll rate, or will it move so as to indicate a new, lower, value for time, as more traffic is induced?"

These questions can only be answered factually, it would seem, by making an O and D study before and after changes are made in toll rates.

Another question that presents itself, to remain unanswered in this study, is this: To what extent will induced traffic on a freed bridge operate to oppose diversion of traffic from an adjacent toll bridge thus affording protection to the toll bridge financial structure?

CHAPTER VI

SUMMARY

"Are toll bridges warranted?" This is a realistic, direct and simple question. The answer is not as simple. Certainly, it is not a blanket affirmative nor a blanket negative. This study has very significantly indicated that the answer must be a specific "Yes" or a specific "No," each predicated upon a special investigative study of each situation.

1. Findings

The more notable points developed in the preceding chapters are abstracted as follows:

a. *Historical Import*

i. The toll system is not a new device.
ii. Toll system interest is manifested in cycles.
iii. The cycle of ascendency begins with demands and desires for transportation exceeding the ability of the State to publicly finance and build transportation facilities.
iv. The cycle is completed when facilities are adequately provided—although the amortization of the incurred debt may be incomplete.

b. *Advantages and Disadvantages*

i. The toll system implements the State program of securing rapid and immediate expansion of transport facilities.
ii. The toll system distributes the cost of the facility to the user in accordance with his usage (and inferred benefits); and equalizes the cost between character of usage.
iii. The toll system adds additional expense of financing in the form of promotion, interest charges, and system operation.
iv. A long amortization period tends to create a reservoir of stranded traffic.

c. *Human Interest*

I. The toll system, generally, is accepted as an expedient—a questioned resource.

II. Public impatience for eliminating or reducing tolls on a facility increases with time. A toll project which elicits public favor in the beginning may be the object of marked disfavor in the end.

2. Conclusions

An interpretation of the historical implications and a mathematical analysis of cause and effect lead to the following conclusions:

A. There must be a positive economic and social need for the toll facility coupled with an economic environment adequate to support the toll system and amortize the debt in a reasonable length of time.

B. The accrued community benefits from a toll facility must outweigh the economic and social disadvantages which it incurs.

C. Generally, the toll facility should be operated under public ownership, or authority, and should be operated on a self-liquidating basis.

D. The motorist does not place a precise, uniform, monetary value on his time, but selects a route which more nearly accommodates the urgency of immediate demand. Time cost, it appears, is a variable dependent upon individual driver judgment, time of trip (hour and day), together with economic demands upon and economic environment of motorist.

E. Each toll facility has its own peculiar sphere of influence as determined by factors which include toll rate and speeds of travel in the immediate area, together with its economic and social environment.

F. Each toll facility exerts its own peculiar influence upon highway traffic in the nature of diverted, barred, stranded and user traffic.

G. The perpetuation of tolls on a fully amortized facility to protect the financial stability of an adjacent toll structure may not be necessary. Each toll bridge is inherently protected if sufficient distance and travel time separates it from the next adjacent bridge. Each situation should be the subject of a special study in cause and effect.

H. Origin and Destination Surveys, in conjunction with Time-Delay Studies furnish very precise instruments for measuring spheres of influence, lines of equity, values of vehicle time, and diversion of traffic. They also serve a useful purpose in estimating the anticipated change in facility use occasioned by a change in toll rate.

As an epilogue it may be reiterated that toll systems have a profound economic and social effect upon a community.

The public official entrusted with toll system policy may make sure his own position by a familiarity with toll system history and a mathematical analysis of the immediate situation.

APPENDIX I

Bridge Logs

Log I

Sattes Bridge

Across Kanawha River, Kanawha County
Connects US 60 and Primary 25

Kind of Structure — Cantilever
Superstructure — Steel
Substructure — Concrete
Floor — Concrete
Length overall — 1953′
Number of Spans — 14
 1 Span @ 450.0
 2 Spans @ 200.0
 11 Spans @ 46.68
Roadway Width — 20.0
Overhead Clearance — 16.0
Height above Stream — 91.0
Owner — State Road Commission of W. Va. — Free (since Feb. 7, 1946)
Built — 1927
Cost — Substructure $95,405 — Bid Price
 Superstructure $158,607.50
Toll Rates Formerly Effective:

All passenger cars (including passengers)	0.25
Small trucks 1 ton and under	0.25
Trucks over 1 ton	0.35
Pedestrians	0.05
2 Horse wagon	0.20
1 Horse wagon	0.15
Horse and rider	0.10
Motorcycle	0.10
Bicycle	0.05

Building contractor — E. R. Mills
Engineer in charge — J. E. Greiner

Log II

Patrick Street Bridge

Across Kanawha River, Kanawha County
On US 60 at Jct. Primary 3

Kind of Structure – Steel Through Truss
Superstructure – Steel
Substructure – Concrete
Floor – Concrete
Length overall – 1759.5′
1 Main @ 434.0′
2 Mains @ 199.5′
1 Main @ 142.5′
1 Main @ 72.0′
2 Appr. @ 36.0′
20 Appr. @ 32.0′
Roadway Width – 40′
Bridge No. 1139
Built – 1930
Owner – State Road Commission of W. Va. – Free Bridge
Cost – Bonds – $737,163.00
Substructure $177,150.00
Superstructure $469,632.00
Right of Way $45,939.00
Contractor – Fort Pitt Bridge Co.

Log III

Kanawha City Bridge

Across Kanawha River, Kanawha County
On US 119 at Jct. US 21 and 60

Kind of Structure – Steel Through Truss
Superstructure – Steel
Substructure – Concrete
Floor – Concrete
Length overall – 1855.0′
Number of Spans – 34
1 Main @ 415.5′
1 Main @ 233.5′
1 Main @ 120.0′

Log III *(Continued)*

1 Appr. @ 90.0′
1 Appr. @ 65.8′
1 Appr. @ 60.0′
1 Appr. @ 45.0′
8 Appr. @ 31.0′
19 Appr. @ 30.0′

Roadway Width – 23.0′
Overhead Clearance – 15.8′
Surface of bridge to bed of stream – 80.0′
Bridge No. 912-2
Built – 1915
Owner – State Road Commission of W. Va. – Free Bridge
Cost – $351,017.67
Cost of Improvement – $57,850.55 in 1941

Trojan Steel Co.	$25,001.81
Pocahontas Const. Co.	$32,848.74

Log IV

Chelyan Bridge

Across Kanawha River, Kanawha County
Connects US 60 and Primary 61

Kind of Structure – Cantilever
Superstructure – Steel
Substructure – Concrete
Floor – Concrete
Length overall – 868′ + 450′
Number of spans – 3
1 Main @ 450′
1 Appr. @ 200′
1 Appr. @ 218′

Approach viaduct on south end – 450′
Roadway Width – 20′
Overhead Clearance –
Built – 1929
Owner – Midland Trail Kanawha River Bridge Co.
Toll Rates:

Pedestrians	.05
Auto	.25 and .35
1 Ton Truck	.25

LOG IV *(Continued)*

2 Ton Truck	.55
3 Ton Truck	.75
4 Ton Truck	.95

20¢ additional for each ton

No record of construction cost obtainable

Bridge Contractor – General Contracting Co.

Engineer in charge – J. E. Greiner & Co.

Cost reported in "Toll Bridges and Toll Tunnels in the United States" – published by Public Roads Administration as of December 31, 1940 – is in the amount of $488,806.00.

LOG V

MONTGOMERY BRIDGE

Across Kanawha River

On 61A Connects US 60 and Primary 61

Kind of Structure – Steel Through Truss
Superstructure – Steel
Substructure – Stone
Floor – Concrete
Length overall – 864′
Number of Spans – 8

1 Main	@ 416.0
1 Main	@ 175.0
1 Main	@ 150.0
5 Appr.	@ 24.6

Roadway Width – 16.0
Overhead Clearance – 20.0
Bridge No. 1034
Built – 1910
Owner – State Road Commission of W. Va. – Free Bridge
Cost – $106,000.00 ($96,000 Structure, $10,000 Right of Way etc.)
Reconstruction Cost – $39,193.04
Date – 1935
Total Cost – $145,193.04

STATE ROAD COMMISSION OF WEST VIRGINIA
PLANNING DIVISION

Station No. ______ Day ______________

Location ______________________________ Date ______________

Dir. of Travel ______________ O-D FIELD SHEET Hour _____ AM _____ PM

Type of Veh.	Cross Bridge		People in Car or Cap. of Tr.	ORIGIN Exact Point Where Trip Began	DESTINATION Exact Point Where Trip Will End	STOPS Before and After Passing Station		
	Yes	No					PLACE - Exact Point	PURPOSE
						B / A		
						B / A		
						B / A		
						B / A		
						B / A		
						B / A		
						B / A		
						B / A		
						B / A		

FORM I—Origin and Destination Interview Sheet.

Page ____ of ____

O. D. Sheet for ____________ Bridge Survey

No. of Cards ____	Surv. No.		Sta. No.		Year		Month		Day		Hour Pd.	
	1	2	3	4	5	6	7	8	9	10	11	12

Interview Number			Veh. Type	Origin						Destination						Trip Type	Toll Charge		Direction of Travel		Sp. Control	
				Zone			Mileage			Zone			Mileage									
13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35

FORM II—Origin and Destination Code Sheet.

US 60 West of Charleston
Time Delay

Trip East / West — Beginning ______ A.M. / P.M. — Date ______

	Control Points	Time Stopping		Time Going		Delay Period			
	Patrick Street Bridge, South End								
.97	Stop Light, 3rd. Avenue								
.49	Stop Light, Mound								
.22	Stop Light, "E" Street								
.36	Plant Stop Light #1								
.09	Plant Stop Light #2								
.61	Davis Creek Bridge								
.34	Kenna Drive Blinker Light								
.66	Stop Light								
.41	Farmers Super Market								
.34	Entrance, Casto Flying Field								
.23	Green Frog Grocery								
.30	Wig Wam Bar B Q								
.37	Blue Star Tourist Camp								
.20	Mt. State Industries								
.16	Camp Charleston								
.51	Huntington Trailer Sales								
.76	Intersection US 60 (old) on left								
1.34	West End (A&P) Entrance to Ordnance Park								
1.79	Stop Light								
.03	End of Bridge								

(Observer)

FORM III—Time-Delay Field Sheet.

Primary 25 West of Charleston
Time Delay

Trip East / West   Beginning ____ A.M. / P.M.   Date ________

	CONTROL POINTS	Time Stopping		Time Going		Delay Period			
	Patrick Street Bridge								
.17	N.Y.C. RR Crossing								
.51	Int. US 21								
1.35	Perry Lane								
.78	Int US 35								
.17	N.Y.C. RR Crossing								
1.75	RR Crossing, Fletcher #1								
.10	RR Crossing, Fletcher #2								
.08	Stop Light 12th Street								
.30	N.Y.C RR Crossing								
.35	Int. Roxalana Road								
.19	Int. 19th Street								
.29	Int. Sec. Road on Right near City Limits								
.87	Fairground Road (Center)								
.51	Flashing Caution Light								
.22	Airport Road								
.69	White Inn								
2.62	N.Y.C. RR Crossing								
.17	Int. Bridge Road								
.05	North Bridge Abutment								

________ (Observer)

FORM III a—Time-Delay Field Sheet.

APPENDIX III

Centroid Tabulations

Table I

Chronological Order of O-D Surveys on Kanawha River Bridges

SEQUENCE NUMBER	LOCATIONBOF SURVEY	DIRECTION OF TRAVEL	SURVEY DATES BEGIN	INCLUSIVE
1	Chelyan Bridge	South	6/7/45	6/7/45 & 6/8/45
2	Sattes Bridge	North	6/13/45	6/13/45 & 6/14/45
3	Montgomery Bridge	North and South	7/31/45	7/31/45, 8/1/45, 8/7/45 & 8/8/45
4	Sattes Bridge	South	8/21/45	8/21/45 & 8/22/45
5	Chelyan Bridge	North	8/22/45	8/22/45 & 8/23/45
6	Sattes Bridge	North and South	11/27/45	11/27/45 & 11/28/45
7	Sattes Bridge	North and South	1/8/46	1/8/46, 1/9/46 & 1/18/46
7	Patrick St. Bridge	North and South	1/8/46	1/8/46, 1/9/46 & 1/18/46
9	Kanawha City Bridge	North and South	1/22/46	1/22/46, 1/23/46 & 1/26/46
9	Chelyan Bridge	North and South	1/22/46	1/22/46, 1/23/46 & 1/26/46
9	Montgomery Bridge	North and South	1/22/46	1/22/46, 1/23/46 & 1/26/46
10	Sattes Bridge (Free)	North and South	3/19/46	

TABLE II

SATTES BRIDGE (BEFORE STUDY)

North Bound Cumulative East to East Transfer

CENTRIOD DISTRICT	NO. VEHICLES	CUM.
0.2	1.2	67.1
0.4	2.4	65.9
0.45	1.2	63.5
0.70	1.4	62.3
0.75	1.2	60.9
0.8	1.2	59.7
0.85	1.2	58.5
1.05	1.2	57.3
1.10	1.2	56.1
1.35	2.5	54.9
1.4	2.5	52.4
1.5	1.2	49.9
1.75	2.5	48.7
1.8	1.2	46.2
1.85	1.2	45.0
2.05	4.8	43.8
2.10	3.6	39.0
2.15	4.9	35.4
2.45	2.4	30.5
2.70	1.2	28.1
2.90	1.2	26.9
3.0	2.4	25.7
3.15	1.2	23.3
3.50	2.4	22.1
3.65	1.2	19.7
3.70	1.2	18.5
3.75	1.2	17.3
3.90	1.3	16.1
3.95	2.4	14.8
4.0	1.2	12.4
4.05	1.2	11.2
4.15	2.5	10.0
4.25	3.7	7.5
4.85	1.2	3.8
6.05	1.3	2.6
7.50	1.3	1.3

South Bound Cumulative East to East Transfer

CENTRIOD DISTRICT	NO. VEHICLES	CUM.
0.45	2.1	60.3
0.50	2.4	58.2
1.55	3.6	55.8
1.6	1.5	52.2
1.7	1.2	50.7
1.75	2.4	49.5
1.8	1.3	47.1
1.9	3.6	45.8
2.0	1.2	42.2
2.15	1.2	41.0
2.2	1.2	39.8
2.3	2.4	38.6
2.35	1.2	36.2
2.4	2.4	35.0
2.6	1.2	32.6
2.85	1.2	31.4
2.9	2.4	30.2
3.25	4.0	27.8
3.35	1.2	23.8
3.4	1.2	22.6
3.5	1.3	21.4
3.6	1.2	20.1
3.8	1.2	18.9
3.9	1.5	17.7
4.0	2.4	16.2
4.15	4.1	13.8
4.2	1.3	9.7
4.5	1.2	8.4
4.6	1.2	7.2
4.85	1.2	6.0
5.45	1.2	4.8
7.0	2.4	3.6
8.25	1.2	1.2

Table III

Sattes Bridge (Before Study)
Total Cumulative
East to East Transfer

CENTRIOD DISTRICT	NO. VEHICLES	CUM.	CENTROID DISTRICT	NO. VEHICLES	CUM.
0.20	1.2	127.4	2.70	1.2	59.5
0.40	2.4	126.2	2.85	1.2	58.3
0.45	3.3	123.8	2.90	3.6	57.1
0.50	2.4	120.5	3.00	2.4	53.5
0.70	1.4	118.1	3.15	1.2	51.1
0.75	1.2	116.7	3.25	4.0	49.9
0.80	1.2	115.5	3.35	1.2	45.9
0.85	1.2	114.3	3.40	1.2	44.7
1.05	1.2	113.1	3.50	3.7	43.5
1.10	1.2	111.9	3.60	1.2	39.8
1.35	2.5	110.7	3.65	1.2	38.6
1.40	2.5	108.2	3.70	1.2	37.4
1.50	1.2	105.7	3.75	1.2	36.2
1.55	3.6	104.5	3.80	1.2	35.0
1.60	1.5	100.9	3.90	2.8	33.8
1.70	1.2	99.4	3.95	2.4	31.0
1.75	4.9	98.2	4.00	3.6	28.6
1.80	2.5	93.3	4.05	1.2	25.0
1.85	1.2	90.8	4.15	6.6	23.8
1.90	3.6	89.6	4.20	1.3	17.2
2.00	1.2	86.0	4.25	3.7	15.9
2.05	4.8	84.8	4.50	1.2	12.2
2.10	3.6	80.0	4.60	1.2	11.0
2.15	6.1	77.4	4.85	2.4	9.8
2.20	1.2	71.3	5.45	1.2	7.4
2.30	2.4	70.1	6.05	1.3	6.2
2.35	1.2	67.1	7.00	2.4	4.9
2.40	2.4	65.5	7.50	1.3	2.5
2.45	2.4	63.1	8.25	1.2	1.2
2.60	1.2	60.7			

Note: Out of 174 East to East trips via Sattes Bridge, 46 trips were eliminated on basis that trip was necessary.

TABLE IV
ESTIMATED EAST TO EAST PLUS
Diverted "S" Traffic Via Sattes Bridge (After Freeing)
(Estimated from the Before Study)

CENTRIOD DISTRICT	NO. VEHICLES	CUM.
0.20	1.2	277.2
0.40	2.4	276.0
0.45	3.3	273.6
0.50	2.4	270.3
0.70	1.4	267.9
0.75	1.2	266.5
0.80	1.2	265.3
0.85	1.2	264.1
1.01*	1.2*	262.9
1.05	1.2	261.7
1.10	1.2	260.5
1.31*	4.3*	259.3
1.35	2.5	255.0
1.40	2.5	252.5
1.50	1.2	250.0
1.55	3.6	248.8
1.60	1.5	245.2
1.70	1.2	243.7
1.75	4.9	242.5
1.80	2.5	237.6
1.85	3.2	235.1
1.86*	1.3*	231.9
1.90	3.6	230.6
2.00	1.2	227.0
2.05	4.8	225.8
2.06*	1.8*	221.0
2.10	3.6	219.2
2.15	6.1	215.6
2.20	1.2	209.5
2.26*	3.4*	208.3

CENTROID DISTRICT	NO. VEHICLES	CUM.
2.30	2.4	204.9
2.35	1.2	202.5
2.40	2.4	201.3
2.45	2.4	198.9
2.60	1.2	196.5
2.70	1.2	195.3
2.85	1.2	194.1
2.90	3.6	192.9
2.96*	1.4*	189.3
3.00	2.4	187.9
3.06*	1.5*	185.5
3.15	1.2	184.0
3.25	4.0	182.8
3.26*	3.4*	178.8
3.35	1.2	175.4
3.36*	4.3*	174.2
3.40	1.2	169.9
3.41*	10.3*	168.7
3.50	3.7	158.4
3.60	1.2	154.7
3.61*	1.5*	153.5
3.65	1.2	152.0
3.66*	3.4*	150.8
3.70	1.2	147.4
3.71*	1.6*	146.2
3.80	2.4	144.6
3.95	2.4	142.2
3.96*	3.8*	139.8
4.05	4.8	136.0
4.15	6.8	131.2

TABLE IV—*Continued*

ESTIMATED EAST TO EAST PLUS
Diverted "S" Traffic Via Sattes Bridge (After Freeing)
(Estimated from the Before Study)

CENTRIOD DISTRICT	NO. VEHICLES	CUM.
4.16*	6.5*	124.4
4.20	1.3	117.9
4.21*	6.5*	116.6
4.25	3.7	110.1
4.26*	6.7*	106.4
4.31*	3.7*	99.7
4.36*	4.6*	96.0
4.50	1.2	91.4
4.51*	6.6*	90.2
4.60	1.2	83.6
4.61*	7.0*	82.4
4.66*	5.5*	75.4
4.71*	1.2*	69.9
4.76*	2.0*	68.7
4.81*	15.2*	66.7

CENTROID DISTRICT	NO. VEHICLES	CUM.
4.85	2.4	51.5
4.86*	4.6*	49.1
5.01*	8.2*	44.5
5.06*	1.9*	36.3
5.11*	3.6*	34.4
5.21*	5.3*	30.8
5.26*	3.1*	25.5
5.41*	15.0*	22.4
5.45	1.2	7.4
6.05	1.3	6.2
7.00	2.4	4.9
7.50	1.3	2.5
8.25	1.2	1.2

*Traffic via Patrick Street Bridge diverted from Sattes Bridge to avoid toll payment (apparently) consisting both of diverted "U" and "S" trips.

Table V

Sattes Bridge

North Bound Cumulative (After Study)
East to East Transfer

CENTRIOD DISTRICT	NO. VEHICLES	CUM.
0.15	1.1	125.5
0.20	2.4	124.4
0.40	1.2	122.0
1.25	1.1	120.8
1.50	3.4	119.7
1.65	2.2	116.3
1.70	2.3	114.1
1.80	3.4	111.8
1.90	1.2	108.4
2.05	5.6	107.2
2.10	1.3	101.6
2.15	4.8	100.3
2.20	6.7	95.5
2.25	1.1	88.8
2.60	1.7	87.7
2.65	5.5	86.0
2.95	1.2	80.5
3.00	1.1	79.3
3.15	1.1	78.2
3.30	1.3	77.1
3.35	2.6	75.8
3.40	2.7	73.2
3.50	1.1	70.5
3.55	1.1	69.4
3.60	1.4	68.3
3.70	1.1	66.9
3.80	1.1	65.8
4.00	1.2	64.7
4.05	3.5	63.5
4.15	4.7	60.0
4.25	2.2	55.3
4.30	2.4	53.1
4.40	1.1	50.7
4.55	2.3	49.6
4.60	1.1	47.3
4.75	1.1	46.2
4.85	2.2	45.1
5.10	1.2	42.9
5.20	1.1	41.7
5.25	10.5	40.6
5.30	1.1	30.1
5.50	1.2	29.0
5.65	1.1	27.8
5.75	2.2	26.7
6.00	1.4	24.5
6.10	2.2	23.1
6.30	3.4	20.9
6.45	1.1	17.5
6.50	3.9	16.4
6.60	6.2	12.5
6.90	2.6	6.3
7.50	2.5	3.7
7.85	1.2	1.2

Table VI

Sattes Bridge

Actual South Bound Cumulative (After Study)

East to East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.	CENTROID DISTRICT	NO. VEHICLES	CUM.
0.10	1.1	111.5	4.45	1.2	41.0
0.15	4.0	110.4	4.50	2.3	39.8
0.20	1.5	106.4	4.55	1.2	37.5
0.55	1.1	104.9	4.60	7.2	36.3
1.00	1.2	103.8	4.75	2.4	29.1
1.25	1.2	102.6	5.00	1.1	26.7
1.50	1.1	101.4	5.25	1.2	25.6
1.70	1.2	100.3	5.30	1.2	24.4
2.00	5.8	99.1	5.75	4.8	23.2
2.05	1.2	93.3	5.90	1.2	18.4
2.15	9.1	92.1	6.00	3.6	17.2
2.20	1.1	83.0	6.05	1.1	13.6
2.25	1.2	81.9	6.15	1.1	12.5
2.35	1.2	80.7	6.25	4.5	11.4
2.65	13.9	79.5	6.35	2.2	6.9
2.90	1.2	65.6	6.50	1.2	4.7
3.30	1.2	64.4	7.50	1.2	3.5
3.35	2.4	63.2	7.65	1.1	2.3
3.45	2.4	60.8	7.75	1.2	1.2
3.50	2.5	58.4			
3.75	1.2	55.9			
3.85	2.3	54.7			
4.05	1.5	52.4			
4.15	6.0	50.9			
4.40	3.9	44.9			

Table VII
Actual Total East to East Traffic Via Sattes Bridge
After Freeing
(O and D Survey–March 19, 1946)

Centroid District	No. Vehicles	Cum.	Centroid District	No. Vehicles	Cum.
0.10	1.1	237.0	3.85	2.3	119.4
0.15	5.1	235.9	4.00	1.2	117.1
0.20	3.9	230.8	4.05	5.0	115.9
0.40	1.2	226.9	4.15	10.7	110.9
0.55	1.1	225.7	4.25	2.2	100.2
1.00	1.2	224.6	4.30	2.4	98.0
1.25	2.3	223.4	4.40	5.0	95.6
1.50	4.5	221.1	4.45	1.2	90.6
1.65	2.2	216.6	4.50	2.3	89.4
1.70	3.5	214.4	4.55	3.5	87.1
1.80	3.4	210.9	4.60	8.3	83.6
1.90	1.2	207.5	4.75	3.5	75.3
2.00	5.8	206.3	4.85	2.2	71.8
2.05	6.8	200.5	5.00	1.1	69.6
2.10	1.3	193.7	5.10	1.2	68.5
2.15	13.9	192.4	5.20	1.1	67.3
2.20	7.8	178.5	5.25	11.7	66.2
2.25	2.3	170.7	5.30	2.3	54.5
2.35	1.2	168.4	5.50	1.2	52.2
2.60	1.7	167.2	5.65	1.1	51.0
2.65	19.4	165.5	5.75	7.0	49.9
2.90	1.2	146.1	5.90	1.2	42.9
2.95	1.2	144.9	6.00	5.0	41.7
3.00	1.1	143.7	6.05	1.1	36.7
3.15	1.1	142.6	6.10	2.2	35.6
3.30	2.5	141.5	6.15	1.1	33.4
3.35	5.0	139.0	6.25	4.5	32.3
3.40	2.7	134.0	6.30	3.4	27.8
3.45	2.4	131.3	6.35	2.2	24.4
3.50	3.6	128.9	6.45	1.1	22.2
3.55	1.1	125.3	6.50	5.1	21.1
3.60	1.4	124.2	6.60	6.2	16.0
3.70	1.1	122.8	6.90	2.6	9.8
3.75	1.2	121.7	7.50	3.7	7.2
3.80	1.1	120.5	7.65	1.1	3.5
			7.75	1.2	2.4
			7.85	1.2	1.2

Note: Of 252 East to East trips via Sattes Bridge 15 necessary trips were eliminated.

Table VIII

Sattes Bridge

Usage by O and D Centroids Before and After Freeing

(Approximate 100% Samples Unexpanded)

(Use Expansion Factor of 1.23 for Before Values and Expansion Factor of 1.18 for After Values to Translate to 1940 A-D-T)

O AND D CENTROID DISTANCE	EAST-EAST TRAVEL BEFORE	EAST-EAST TRAVEL AFTER	WEST-WEST TRAVEL BEFORE	WEST-WEST TRAVEL AFTER	EAST TERMINUS BEFORE	EAST TERMINUS AFTER	WEST TERMINUS BEFORE	WEST TERMINUS AFTER
0.25					61.	116.	69.	168.
0.50	6.	10.	6.	6.				
0.75					25.	54.	17.	58.
1.00	3.	1.	2.	21.				
1.25					62.	31.	160.	330.
1.50	16.	4.	72.	196.				
1.75					8.	60.	2.	8.
2.00	26.	37.	27.	39.				
2.25					11.	......	10.	7.
2.50	12.	19.	......	10.				
2.75					11.	40.		
3.00	6.	13.	1.	2.				
3.25					56.	71.	46.	66.
3.50	13.	15.	19.	17.				
	Line of Actual Equity (3.68)							

TABLE VIII—*Continued*

O AND D CENTROID DISTANCE	EAST-EAST TRAVEL BEFORE	EAST-EAST TRAVEL AFTER	WEST-WEST TRAVEL BEFORE	WEST-WEST TRAVEL AFTER	EAST TERMINUS BEFORE	EAST TERMINUS AFTER	WEST TERMINUS BEFORE	WEST TERMINUS AFTER
3.75					3.	10.	3.	3.
4.00	17.	17.	1.	4.				
4.25					30.	19.		
4.50	......	23.	21.	24.				
4.75					4.	31.		
					Natural Equity North Side			
5.00	3.	8.	......	......	48.	183.		
5.25	......	6.	......	......	3.	4.		
	Line of Natural Equity (5.33)				Natural Equity South Side			
5.50	1.	8.	......	2.	17.	64.		
5.75	8.	5.				1.		
6.00	1.	9.						
6.25	9.	5.					2.	......
6.50	1.	4.	8.	4.				
6.75	2.	2.					17.	17.
7.00	......	1.						
7.25							13.	27.
7.50	1.	5.	12.	14.				
			Line of Natural Equity 7.50				Line of Natural Equity	

TABLE VIII—*Continued*

O AND D CENTROID DISTANCE	EAST-EAST TRAVEL BEFORE	EAST-EAST TRAVEL AFTER	WEST-WEST TRAVEL BEFORE	WEST-WEST TRAVEL AFTER	EAST TERMINUS BEFORE	EAST TERMINUS AFTER	WEST TERMINUS BEFORE	WEST TERMINUS AFTER
7.75	1.	1.						
8.00	2.		20.	27.				
8.25	5	7.						
8.50			......	3.				
8.75								
9.00	......	1.						
9.25								
9.50	1.	0.	1.	......				
9.75	......	6.						
10.00			1.	2.				
10.25	1.	1.						
10.50			4.	1.				
10.75								
11:00								
12.00			1.	......				
13.00			1.	......				
14.00			10.	1.				
	141.	213.	207.	373.	339.	684.	339.	684.

Table IX

Patrick Street Bridge
North Bound Cumulative
West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.	CENTROID DISTRICT	NO. VEHICLES	CUM.
0.10	1.8	534.1	2.00	5.5	315.1
0.25	1.8	532.3	2.05	1.8	309.6
0.30	53.6	530.5	2.10	8.2	307.8
0.40	1.8	476.9	2.20	3.5	299.6
0.45	1.6	475.1	2.25	5.3	296.1
0.50	11.8	473.5	2.30	11.9	290.8
0.55	7.0	461.7	2.40	2.3	278.9
0.60	6.4	454.7	2.45	5.0	276.6
0.65	12.6	448.3	2.50	36.3	271.6
0.70	2.3	435.7	2.55	15.9	235.3
0.75	13.5	433.4	2.65	5.0	219.4
0.80	26.9	419.9	2.70	8.6	214.4
0.85	9.0	393.0	2.75	4.9	205.8
0.90	1.4	384.0	2.80	10.0	200.9
0.95	1.2	382.6	2.85	11.7	190.9
1.00	4.7	381.4	2.90	4.9	179.2
1.05	1.2	376.7	2.95	6.5	174.3
1.10	3.4	375.5	3.00	4.1	167.8
1.15	7.3	372.1	3.05	10.1	163.7
1.20	2.8	364.8	3.10	4.1	153.6
1.25	3.0	362.0	3.15	5.3	149.5
1.45	4.9	359.0	3.20	5.8	144.2
1.50	3.5	354.1	3.25	2.8	138.4
1.55	11.0	350.6	3.35	2.3	135.6
1.60	10.0	339.6	3.40	5.2	133.3
1.65	1.8	329.6	3.45	2.3	128.1
1.75	3.4	327.8	3.55	2.8	125.8
1.80	1.2	324.4	3.60	1.5	123.0
1.85	1.5	323.2	3.65	1.2	121.5
1.95	6.6	321.7	3.70	4.1	120.3

TABLE IX—*Continued*

PATRICK STREET BRIDGE

North Bound Cumulative

West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
3.75	1.8	116.2
3.80	1.4	114.4
3.85	2.3	113.0
4.00	1.5	110.7
4.10	2.6	109.2
4.15	8.6	106.6
4.20	2.7	98.0
4.25	1.5	95.3
4.40	2.6	93.8
4.45	6.8	91.2
4.50	5.2	84.4
5.00	1.8	79.2
5.05	5.6	77.4
5.15	15.0	71.8
5.40	1.2	56.8
5.45	4.1	55.6
5.55	3.6	51.5
5.85	8.0	47.9
5.90	2.0	39.9
6.00	3.6	37.9
6.05	1.5	34.3
6.15	3.4	32.8
6.30	1.2	29.4
6.35	3.7	28.2
6.40	3.8	24.5
6.45	3.6	20.7
6.50	1.8	17.1
6.70	3.8	15.3
7.00	1.8	11.5
7.25	1.8	9.7
7.30	1.8	7.9
8.60	1.8	6.1
9.35	4.3	4.3

Table X

Patrick Street Bridge
South Bound Cumulative
West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.	CENTROID DISTRICT	NO. VEHICLES	CUM.
0.25	8.4	617.9	2.10	1.4	327.9
0.30	61.0	609.5	2.20	4.9	326.5
0.40	7.3	548.5	2.25	6.2	321.6
0.50	14.1	541.2	2.30	6.2	315.4
0.55	4.6	527.1	2.35	5.9	309.2
0.60	16.9	522.5	2.40	3.3	303.3
0.65	4.3	505.6	2.45	4.1	300.0
0.70	1.9	501.3	2.50	21.6	295.9
0.75	13.5	499.4	2.55	6.5	274.3
0.80	17.2	485.9	2.60	12.6	267.8
0.85	7.9	468.7	2.65	1.9	255.2
0.95	16.2	460.8	2.70	5.2	253.3
1.00	4.6	444.6	2.75	8.3	248.1
1.05	5.8	440.0	2.80	9.8	239.8
1.10	4.0	434.2	2.85	11.4	230.0
1.20	4.4	430.2	2.90	4.2	218.6
1.25	14.4	425.8	2.95	3.8	214.4
1.30	2.7	411.4	3.00	1.7	210.6
1.35	1.2	408.7	3.05	15.0	208.9
1.40	1.5	407.5	3.10	3.8	193.9
1.45	6.2	406.0	3.15	4.0	190.1
1.50	5.9	399.8	3.20	4.1	186.1
1.55	5.1	393.9	3.25	2.5	182.0
1.60	37.9	388.8	3.30	1.9	179.5
1.65	1.4	350.9	3.35	1.2	177.6
1.75	4.6	349.5	3.40	2.6	176.4
1.80	4.9	344.9	3.45	4.4	173.8
1.85	1.9	340.0	3.50	2.4	169.4
1.95	7.2	338.1	3.55	4.2	167.0
2.05	3.0	330.9	3.60	3.4	163.8

TABLE X—*Continued*

PATRICK STREET BRIDGE

South Bound Cumulative

West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
3.70	1.2	160.4
3.75	1.2	159.2
3.80	8.1	158.0
3.85	2.7	148.9
4.00	1.5	146.2
4.05	1.5	144.7
4.10	3.4	143.2
4.15	8.5	139.8
4.20	4.9	131.3
4.25	4.1	125.4
4.35	1.2	122.3
4.40	2.6	121.1
4.45	7.4	118.5
4.50	51	111.1
4.55	3.4	106.0
4.65	1.2	102.6
4.75	2.9	101.4
4.80	2.4	98.5
4.90	3.4	96.1
4.95	3.1	92.7
5.05	9.3	89.6
5.35	1.9	80.3
5.45	1.2	78.4
5.60	1.9	77.2
5.65	8.2	75.3
5.80	4.6	67.1
5.85	7.2	62.5
5.95	1.2	55.3
6.00	1.9	54.1
6.05	5.5	52.2
6.15	3.2	46.7
6.30	3.4	43.5
6.40	2.8	40.1
6.45	2.9	37.3
6.50	6.5	34.4
6.95	1.6	27.9
7.00	1.6	26.3
7.05	1.5	24.7
7.25	8.5	23.2
7.30	2.5	14.7
7.40	3.4	12.2
7.60	1.5	8.8
7.70	1.4	7.3
8.40	3.4	5.9
8.80	1.3	2.5
9.65	1.2	1.2

Table XI

Patrick Street Bridge
Total Cumulative
West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.	CENTROID DISTRICT	NO. VEHICLES	CUM.
0.10	1.8	1152.0	1.80	6.1	669.3
0.25	10.2	1150.2	1.85	3.4	663.2
0.30	114.6	1140.0	1.95	13.8	659.8
0.40	9.1	1025.4	2.00	5.5	646.0
0.45	1.6	1016.3	2.05	4.8	640.5
0.50	25.9	1014.7	2.10	9.6	635.7
0.55	11.6	988.8	2.20	8.4	626.1
0.60	23.3	977.2	2.25	11.5	617.7
0.65	16.9	953.9	2.30	18.1	606.2
0.70	4.2	937.0	2.35	5.9	588.1
0.75	27.0	932.8	2.40	5.6	582.2
0.80	44.1	905.8	2.45	9.1	576.6
0.85	16.9	861.7	2.50	57.9	567.5
0.90	1.4	844.8	2.55	22.4	509.6
0.95	17.4	843.4	2.60	12.6	487.2
1.00	9.3	826.0	2.65	6.9	474.6
1.05	7.0	816.7	2.70	13.8	467.7
1.10	7.4	809.7	2.75	13.2	453.9
1.15	7.3	802.3	2.80	19.8	440.7
1.20	7.2	795.0	2.85	23.1	420.9
1.25	17.4	787.8	2.90	9.1	397.8
1.30	2.7	770.4	2.95	10.3	388.7
1.35	1.2	767.7	3.00	5.8	378.4
1.40	1.5	766.5	3.05	25.1	372.6
1.45	11.1	765.0	3.10	7.9	347.5
1.50	9.4	753.9	3.15	9.3	339.6
1.55	16.1	744.5	3.20	9.9	330.3
1.60	47.9	728.4	3.25	5.3	320.4
1.65	3.2	680.5	3.30	1.9	315.1
1.75	8.0	677.3	3.35	3.5	313.2

TABLE XI—*Continued*

PATRICK STREET BRIDGE

Total Cumulative

West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
3.40	7.8	309.7
3.45	6.7	301.9
3.50	2.4	295.2
3.55	7.0	292.8
3.60	4.9	285.8
3.65	1.2	280.9
3.70	5.3	279.7
3.75	3.0	274.4
3.80	9.5	271.4
3.85	5.0	261.9
4.00	3.0	256.9
4.05	1.5	253.9
4.10	6.0	252.4
4.15	17.1	246.4
4.20	7.6	229.3
4.25	5.6	221.7
4.35	1.2	216.1
4.40	5.2	214.9
4.45	14.2	209.7
4.50	10.3	195.5
4.55	3.4	185.2
4.65	1.2	181.8
4.75	2.9	180.6
4.80	2.4	177.7
4.90	3.4	175.3
4.95	3.1	171.9
5.00	1.8	168.8
5.05	14.9	167.0
5.15	15.0	152.1
5.35	1.9	137.1
5.40	1.2	135.2
5.45	5.3	134.0
5.55	3.6	128.7
5.60	1.9	125.1
5.65	8.2	123.2
5.80	4.6	115.0
5.85	15.2	110.4
5.90	2.0	95.2
5.95	1.2	93.2
6.00	5.5	92.0
6.05	7.0	86.5
6.15	6.6	79.5
6.30	4.6	72.9
6.35	3.7	68.3
6.40	6.6	64.6
6.45	6.5	58.0
6.50	8.3	51.5
6.70	3.8	43.2
6.95	1.6	39.4
7.00	3.4	37.8
7.05	1.5	34.4
7.25	10.3	32.9
7.30	4.3	22.6
7.40	3.4	18.3
7.60	1.5	14.9
7.70	1.4	13.4
8.40	3.4	12.0
8.60	1.8	8.6
8.80	1.3	6.8
9.35	4.3	5.5
9.65	1.2	1.2

TABLE XII

KANAWHA CITY BRIDGE
North Bound Cumulative
East to East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.85	4.6	174.6
1.10	1.1	170.0
1.20	1.3	168.9
1.50	1.8	167.6
1.60	2.6	165.8
1.65	11.2	163.2
2.00	1.8	152.0
2.10	1.3	150.2
2.25	1.3	148.9
2.30	1.4	147.6
2.50	31.6	146.2
2.60	1.1	114.6
2.65	3.1	113.5
2.80	2.3	110.4
2.85	8.4	108.1
3.55	2.3	99.7
3.60	10.0	97.4
4.30	2.7	87.4
4.35	6.4	84.7
4.40	1.2	78.3
4.45	1.3	77.1
4.50	2.3	75.8
4.55	2.3	73.5
4.65	1.2	71.2
4.95	1.2	70.0
5.00	1.1	68.8
5.05	3.8	67.7
5.10	2.5	63.9
5.15	7.9	61.4
5.20	10.7	53.5
5.25	2.5	42.8
5.30	2.4	40.3
5.50	5.6	37.9
6.65	1.2	32.3
6.00	1.3	31.1
6.25	1.2	29.8
6.55	1.1	28.6
6.65	1.1	27.5
6.70	1.1	26.4
6.75	3.5	25.3
6.85	1.1	21.8
7.05	1.4	20.7
7.35	2.5	19.3
7.55	1.1	16.8
7.85	8.1	15.7
8.00	1.1	7.6
10.10	4.0	6.5
12.70	1.4	2.5
13.0	1.1	1.1

Table XIII

Kanawha City bridge
South Bound Cumulative
East to East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.40	1.5	147.2
0.85	2.5	145.7
1.60	9.8	143.2
1.65	1.8	133.4
1.75	1.1	131.6
1.90	1.8	130.5
1.95	1.4	128.7
2.00	3.0	127.3
2.05	1.6	124.3
2.15	1.8	122.7
2.30	1.2	120.9
2.45	1.6	119.7
2.50	2.2	118.1
2.65	1.8	115.9
2.75	1.6	114.1
2.80	1.4	112.5
2.85	3.0	111.1
2.90	1.6	108.1
3.00	4.5	106.5
3.30	1.2	102.0
3.45	1.6	100.8
3.55	1.6	99.2
3.60	7.5	97.6
3.90	1.1	90.1
4.30	4.6	89.0
4.35	6.0	84.4
4.40	1.6	78.4
4.45	4.3	76.8
4.50	4.1	72.5
4.55	3.5	68.4
4.60	3.2	64.9
4.75	1.3	61.7
4.95	1.2	60.4
5.00	4.4	59.2
5.05	1.8	54.8
5.10	1.8	53.0
5.15	4.3	51.2
5.20	3.4	46.9
5.25	2.3	43.5
5.30	3.4	41.2
5.50	3.2	37.8
5.60	1.4	34.6
6.25	2.8	33.2
6.40	3.0	30.4
6.50	1.5	27.4
6.60	2.8	25.9
6.65	6.0	23.1
6.75	1.3	17.1
6.80	1.6	15.8
7.05	1.1	14.2
7.25	1.6	13.1
7.35	4.6	11.5
7.40	1.6	6.9
7.85	3.7	5.3
9.10	1.6	1.6

Table XIV
Kanawha City Bridge
Total Cumulative
East to East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.40	1.5	321.8
0.85	7.1	320.3
1.10	1.1	313.2
1.20	1.3	312.1
1.50	1.8	310.8
1.60	12.4	309.0
1.65	13.0	296.6
1.75	1.1	283.6
1.90	1.8	282.5
1.95	1.4	280.7
2.00	4.8	279.3
2.05	1.6	274.5
2.10	1.3	272.9
2.15	1.8	271.6
2.25	1.3	269.8
2.30	2.6	268.5
2.45	1.6	265.9
2.50	33.8	264.3
2.60	1.1	230.5
2.65	4.9	229.4
2.75	1.6	224.5
2.80	3.7	222.9
2.85	11.4	219.2
2.90	1.6	207.8
3.00	4.5	206.2
3.30	1.2	201.7
3.45	1.6	200.5
3.55	3.9	198.9
3.60	17.5	195.0
3.90	1.1	177.5
4.30	7.3	176.4
4.35	12.4	169.1
4.40	2.8	156.7
4.45	5.6	153.9
4.50	6.4	148.3
4.55	5.8	141.9
4.60	3.2	136.1
4.65	1.2	132.9
4.75	1.3	131.7
4.95	2.4	130.4
5.00	5.5	128.0
5.05	5.6	122.5
5.10	4.3	116.9
5.15	12.2	112.6
5.20	14.1	100.4
5.25	4.8	86.3
5.30	5.8	81.5
5.50	8.8	75.7
5.60	1.4	66.9
5.65	1.2	65.5
6.00	1.3	64.3
6.25	4.0	63.0
6.40	3.0	59.0
6.50	1.5	56.0
6.55	1.1	54.5
6.60	2.8	53.4
6.65	7.1	50.6
6.70	1.1	43.5
6.75	4.8	42.4
6.80	1.6	37.6
6.85	1.1	36.0
7.05	2.5	34.9
7.25	1.6	32.4
7.35	7.1	30.8
7.40	1.6	23.7
7.55	1.1	22.1
7.85	11.8	21.0
8.00	1.1	9.2
9.10	1.6	8.1
10.10	4.0	6.5
12.70	1.4	2.5
13.00	1.1	1.1

TABLE XV

CHELYAN TOLL BRIDGE

Northbound Cumulative
West-West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
3.35	8.4	16.6
3.70	1.3	8.2
4.50	4.3	6.9
6.35	1.4	2.6
7.50	1.2	1.2

Northbound Cumulative
East-East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
1.05	5.1	22.5
2.50	3.6	17.4
2.55	7.4	13.8
3.00	2.8	6.4
3.35	1.2	3.6
4.00	2.4	2.4

Southbound Cumulative
West-West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.90	1.5	32.6
2.00	1.2	31.1
2.70	1.2	29.9
2.80	1.8	28.7
3.35	7.5	26.9
3.50	2.4	19.4
3.65	1.5	17.0
3.70	1.2	15.5
4.50	2.6	14.3
4.55	1.2	11.7
4.75	1.2	10.5
5.00	1.2	9.3
5.75	1.2	8.1
6.50	1.2	6.9
6.60	1.6	5.7
6.75	4.1	4.1

Southbound Cumulative
East-East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
1.05	3.8	26.3
2.50	3.7	22.5
2.55	11.2	18.8
2.90	1.2	7.6
3.05	2.8	6.4
3.35	1.2	3.6
4.45	1.2	2.4
5.50	1.2	1.2

TABLE XV—*Continued*

CHELYAN TOLL BRIDGE

Total Cumulative West-West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.90	1.5	49.2
2.00	1.2	47.7
2.70	1.2	46.5
2.80	1.8	45.3
3.35	15.9	43.5
3.50	2.4	27.6
3.65	1.5	25.2
3.70	2.5	23.7
4.50	6.9	21.2
4.55	1.2	14.3
4.75	1.2	13.1
5.00	1.2	11.9
5.75	1.2	10.7
6.35	1.4	9.5
6.50	1.2	8.1
6.60	1.6	6.9
6.75	4.1	5.3
7.50	1.2	1.2

Total Cumulative East-East Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
1.05	8.9	48.8
2.50	7.3	39.9
2.55	18.6	52.6
2.90	1.2	14.0
3.00	2.8	12.8
3.05	2.8	10.0
3.35	2.4	7.2
4.00	2.4	4.8
4.45	1.2	2.4
5.50	1.2	1.2

Table XVI

Montgomery Bridge
North Bound Cumulative
West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.	CENTROID DISTRICT	NO. VEHICLES	CUM.
0.25	1.4	489.6	3.00	6.2	244.5
0.30	3.0	488.2	3.10	1.4	238.3
0.35	3.1	485.2	3.30	24.5	236.9
0.40	7.1	482.1	3.35	12.3	212.4
0.95	1.8	475.0	3.40	5.5	200.1
1.05	43.4	473.2	3.45	3.0	194.6
1.10	16.1	429.8	3.50	1.7	191.6
1.15	9.1	413.7	3.60	1.4	189.9
1.35	3.3	404.6	3.70	5.2	188.5
1.50	81.3	401.3	3.80	1.4	183.3
1.55	17.7	320.0	4.30	1.4	181.9
1.60	14.0	302.3	4.80	1.4	180.5
1.75	1.8	288.3	4.90	1.7	179.1
1.80	4.3	286.5	5.00	1.6	177.4
2.20	4.4	282.2	5.05	1.4	175.8
2.30	1.4	277.8	5.45	1.7	174.4
2.35	4.5	276.4	5.55	4.6	172.7
2.60	1.4	271.9	5.60	1.4	168.1
2.65	2.7	270.5	6.05	51.5	166.7
2.70	9.3	267.8	6.10	65.9	115.2
2.75	2.6	258.5	6.15	21.6	49.3
2.80	3.0	255.9	6.20	1.8	27.7
2.85	5.0	252.9	6.25	1.7	25.9
2.90	1.7	249.9	6.30	7.5	24.2
2.95	1.7	246.2	6.35	7.5	16.7
			6.40	3.2	9.2
			7.20	6.0	6.0

Table XVII

Montgomery Bridge
South Bound Cumulative
West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.30	2.8	462.7
0.40	1.5	459.9
0.80	2.9	458.4
0.85	1.3	455.5
1.05	49.0	454.2
1.10	10.4	405.2
1.15	3.2	394.8
1.20	3.5	391.6
1.25	1.2	388.1
1.30	3.8	386.9
1.35	4.9	383.1
1.40	2.3	378.2
1.45	1.4	375.9
1.50	65.7	374.5
1.55	11.7	308.8
1.60	3.1	297.1
1.70	1.4	294.0
1.85	2.7	292.6
2.20	4.1	289.9
2.30	11.4	285.8
2.35	2.3	274.4
2.65	1.3	272.1
2.80	21.1	270.8
2.85	2.5	249.7
3.00	2.6	247.2
3.25	1.2	244.6
3.30	33.8	243.4
3.35	2.6	209.6
3.40	4.9	207.0
3.45	2.7	202.1
3.50	1.4	199.4
3.60	2.3	198.0
3.65	2.3	195.7
3.70	2.3	193.4
3.75	3.1	191.1
3.85	1.2	188.0
3.95	2.3	186.8
4.35	1.7	184.5
4.85	1.7	182.8
4.95	1.2	181.3
5.25	1.2	180.1
5.55	2.7	178.9
5.95	1.7	176.2
6.05	107.9	174.5
6.10	23.8	66.6
6.15	16.0	42.8
6.20	4.8	26.8
6.25	3.7	22.0
6.30	2.8	18.3
6.35	8.8	15.5
6.40	1.4	6.7
6.50	1.5	5.3
7.20	1.4	3.8
8.00	2.4	2.4

Table XVIII

Montgomery Bridge

Total Cumulative West to West Transfer

CENTROID DISTRICT	NO. VEHICLES	CUM.
0.25	1.4	952.3
0.30	5.8	950.9
0.35	3.1	945.1
0.40	8.6	942.0
0.80	2.9	931.4
0.85	1.3	930.5
0.95	1.8	929.2
1.05	92.4	927.4
1.10	26.5	835.0
1.15	12.3	808.5
1.20	3.5	796.2
1.25	1.2	792.7
1.30	3.8	791.5
1.35	8.2	787.7
1.40	2.3	779.5
1.45	1.4	777.2
1.50	147.0	775.8
1.55	29.4	628.8
1.60	17.1	599.4
1.70	1.4	582.3
1.75	1.8	580.9
1.80	4.3	579.1
1.85	2.7	574.8
2.20	8.5	572.1
2.30	12.8	563.6
2.35	6.8	550.8
2.60	1.4	544.0
2.65	4.0	542.6
2.70	9.3	538.6
2.75	2.6	529.3
2.80	24.1	526.7
2.85	7.5	502.6
2.90	1.7	495.1
2.95	1.7	493.4
3.00	8.8	491.7

CENTROID DISTRICT	NO. VEHICLES	CUM.
3.10	1.4	482.9
3.25	1.2	481.5
3.30	58.3	480.3
3.35	14.9	422.0
3.40	10.4	407.1
3.45	5.7	396.7
3.50	3.1	391.0
3.60	3.7	387.9
3.65	2.3	384.2
3.70	7.5	381.9
3.75	3.1	374.4
3.80	1.4	371.3
3.85	1.2	369.9
3.95	2.3	368.7
4.30	1.4	366.4
4.35	1.7	365.0
4.80	1.4	363.3
4.85	1.5	361.9
4.90	1.7	360.4
4.95	1.2	358.7
5.00	1.6	357.5
5.05	1.4	355.9
5.25	1.2	354.5
5.45	1.7	353.3
5.55	7.3	351.6
5.60	1.4	344.3
5.95	1.7	342.9
6.05	159.4	341.2
6.10	89.7	181.8
6.15	37.6	92.1
6.20	6.6	54.5
6.25	5.4	47.9
6.30	10.3	42.5
6.35	16.3	32.2
6.40	4.6	15.9
6.50	1.5	11.3
7.20	7.4	9.8
8.00	2.4	2.4

Table XIXA
Sattes Bridge—Before Study
Traffic by Origin Zone

Zone of Origin	Passenger	Commercial	Total
1	3.9	1.2	5.1
2	14.3	1.2	15.5
3	....	....	....
4	10.4	2.4	12.8
5	1.3	2.4	3.7
6	....	....	....
7	....	....	....
8	....	1.2	1.2
9	58.5	15.6	74.1
10	9.1	2.4	11.5
11	5.2	....	5.2
12	2.6	....	2.6
13	6.5	....	6.5
14	....	2.4	2.4
15	27.4	3.6	31.0
16	5.2	1.2	6.4
17	53.3	6.0	59.3
18	54.6	....	54.6
19	....	2.4	2.4
20	57.2	13.2	70.4
21	11.7	1.2	12.9
22	104.0	24.0	128.0
23	5.2	1.2	6.4
24	33.8	6.0	39.8
25	3.9	1.2	5.1
26	....	3.6	3.6
27	204.1	28.8	232.9
28	1.3	....	1.3
29	1.3	....	1.3
30	10.4	3.6	14.0
34	44.2	18.0	62.2
35	10.4	3.6	14.0
36	1.3	....	1.3
37	1.3	1.2	2.5
39	1.3	....	1.3
42	1.3	....	1.3
44	1.3	....	1.3
48	31.2	9.6	40.8
Sub Total	777.5	157.2	934.7
51	28.6	7.2	35.8
90	52.0	12.0	64.0
91	28.6	8.4	37.0
Sub Total	109.2	27.6	136.8
Grand Total	886.7	184.8	1071.5

TABLE XIXB

SATTES BRIDGE—BEFORE STUDY
Traffic by Destination Zone

ZONE OF DESTINATION	PASSENGER	COMMERCIAL	TOTAL	ZONE OF DESTINATION	PASSENGER	COMMERCIAL	TOTAL
1	2.6	1.2	3.8	24	33.8	8.4	42.2
2	20.8	1.2	22.0	25	6.5	2.4	8.9
3	....	....	....	26	0	1.2	1.2
4	14.3	2.4	16.7	27	191.1	43.2	234.3
5	1.3	3.6	4.9	28	1.3	0	1.3
6	1.3	1.2	2.5	30	15.6	4.8	20.4
7	1.3	0	1.3	34	52.0	10.8	62.8
8	....	....	....	35	13.0	1.2	14.2
9	54.6	6.0	60.6	37	2.6	0	2.6
10	11.7	1.2	12.9	42	2.6	0	2.6
11	2.6	0	2.6	43	1.3	0	1.3
12	2.6	0	2.6	48	31.2	7.2	38.4
13	3.9	2.4	6.3	Sub			
14	3.9	0	3.9	Total	811.2	168.0	979.2
15	13.0	3.6	16.6	50 & up	1.3	7.2	8.5
16	3.9	0	3.9	51 & up	29.9	12.0	41.9
17	78.0	12.0	90.0	90	37.7	4.8	42.5
18	46.8	2.4	49.2	91	13.0	3.6	16.6
19	0	1.2	1.2	Sub			
20	68.9	10.8	79.7	Total	81.9	27.6	109.5
21	16.9	6.0	22.9	Grand			
22	102.7	32.4	135.1	Total	893.1	195.6	1088.7
23	9.1	1.2	10.3				

TABLE XXA

SATTES BRIDGE—AFTER STUDY

Traffic by Origin Zone

ZONE OF ORIGIN	PASSENGER	COMMERCIAL	TOTAL
1	3.6	3.3	6.9
2	24.0	1.1	25.1
3	2.4	0	2.4
4	22.8	1.1	23.9
5	1.2	0	1.2
6	13.2	2.2	15.4
8	7.2	1.1	8.3
9	69.6	11.0	80.6
10	25.2	2.2	27.4
11	10.8	1.1	11.9
14	0	2.4	2.4
15	88.8	11.0	99.8
16	15.6	1.1	16.7
17	27.6	0	27.6
18	69.6	5.5	75.1
20	94.8	11.0	105.8
21	43.2	8.8	52.0
22	226.8	36.3	263.1
23	6.0	0	6.0
24	42.0	8.8	50.8
25	41.4	8.8	50.2
26	1.2	0	1.2
27	421.2	57.2	478.4
28	2.4	0	2.4
29	1.2	1.1	2.3
30	9.6	1.1	10.7
31	1.2	0	1.2
34	43.2	26.3	69.5
35	24.0	2.2	26.2
37	1.2	0	1.2
41	1.2	0	1.2
43	0	1.1	1.1
45	1.2	0	1.2
48	24.0	6.6	30.6
Sub Total	1367.4	212.4	1579.8
50 & up	7.2	0	7.2
51 & up	26.4	6.6	33.0
90	126.0	26.2	152.2
91	55.2	9.9	65.1
Sub Total	214.8	42.7	257.5
Grand Total	1582.2	255.1	1837.3

Table XXB

Sattes Bridge—After Study
Traffic by Destination Zone

Zone of Destination	Passenger	Commercial	Total
1	1.2	1.1	2.3
2	25.2	1.1	26.3
3	4.8	1.1	5.9
4	26.4	1.1	27.5
5	1.2	1.1	2.3
6	6.0	1.1	7.1
7	2.4	1.1	3.5
8	3.6	1.1	4.7
9	63.6	14.3	77.9
10	25.2	1.1	26.3
11	8.4	3.3	11.7
12	1.2	....	1.2
14	2.4	....	2.4
15	50.4	8.8	59.2
16	14.4	3.3	17.7
17	58.8	1.1	59.9
18	58.8	3.3	62.1
20	76.8	11.0	87.8
21	33.6	4.4	38.0
22	276.0	46.2	322.2
23	4.8	....	3.8
24	32.4	5.5	37.9
25	33.6	6.6	40.2
26	2.4	....	2.4
27	385.2	78.1	463.3
29	9.6	....	9.6
30	10.8	1.1	11.9
31	2.4	....	2.4
34	49.2	16.5	65.7
35	27.6	2.2	29.8
36	2.4	....	2.4
37	1.2	....	1.2
41	1.2	....	1.2
48	37.2	5.5	42.7
Sub Total	1340.5	221.1	1561.6
51	21.6	3.3	24.9
90	122.4	25.3	147.7
91	43.2	4.4	47.6
Sub Total	187.2	33.0	220.2
Grand Total	1527.7	254.1	1791.8

APPENDIX IV

Additional Formula Application

A practical application of the formula derived in the Correlary Study included in Chapter FOUR may be made in determining value placed on time by users of toll roads which are paralleled by free facilities *when origins and destinations are known.*

In the following cases the origins and destinations are *not* known but for purpose of illustration are assumed at a common meeting point at each end of the parallel routes.

1. *New York City to Norwalk*

Given:

Distance by Boston Post Road as 16 miles and by Merritt Parkway as 17.7 miles. Average speed by Boston Post Road 25.0 m.p.h. and by Merritt Parkway 40.0 m.p.h. Toll 10 cents.

Solution:

Substituting values in Equation 2, page 43.

$$x = \frac{10 - 4 \times 3\,(-0.85)}{16.85\,(1.6 - 1) + 2\,(-0.85)\,(1.6 + 1)} \cdot \frac{40.0}{60}$$

$x = 1.28$ cents per minute

2. *New York City to New Haven*

Given:

Distance by Boston Post Road as 70 miles, and by Merritt Parkway as 78 miles. Average speed by Boston Post Road 25 m.p.h. and by Parkway 40 m.ph. Toll 40 cents.

Solution:

Substituting values in Equation 2, page 52—

$$x = \frac{40 - 4 \times 3 \times (-2)}{74\,(1.6 - 1) + 2\,(-2)\,(1.6 + 1)} \cdot \frac{40}{60}$$

$x = 1.26$ cents per minute

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