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# Public Roads

## A JOURNAL OF HIGHWAY RESEARCH

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS

# Public Roads

## A JOURNAL OF HIGHWAY RESEARCH

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Eastbound lanes of Interstate Highway 80 near Donner Lake, Calif. Westbound lanes are near the right edge of the photograph.


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*Trailer-on-flatcar (TOFC) is an expanding form of freight service that combines the established efficiencies of different modes of transportation.*

# Intermodal Freight Transportation in the United States

BY THE OFFICE OF
RESEARCH AND DEVELOPMENT
BUREAU OF PUBLIC ROADS

Reported by **EARLE S. NEWMAN,**
**Economist, Economics and Requirements Division**

*Intermodal freight transportation is dealt with in this article as it is in the United States today and as it is expected to evolve in the next decade or two. Rather than provide only a single-mode service, the carriers, through increased coordination, now offer the public an improved intermodal service, the inherent advantages of which are a strong impetus to further its growth. Competitive modes of transportation are benefiting from this coordinated service by capturing the best features of each mode. Containerization, creating a new role for motor and rail carriers, has enabled them to develop a more convenient, faster, and versatile service. New cost-saving efficiencies will assure the continued growth of trailer-on-flatcar service, and may produce a surge of traffic in its second or third decade of operation. What eventually is best for the shipper will govern the rate of intermodal-transportation growth. Continued close relations among competitive regulated carriers and shippers may reverse the trend to operate privately owned equipment. Trailer-on-flatcar service has the potential to increase the efficiency of basic transport resources and reduce accidents, fatalities, and injuries on the highways.*

## *Introduction*

IN recent years, coordination between highway and railroad transportation has progressed notably. Since it was revived in 1954, Trailer-on-flatcar (TOFC) service has probably expanded faster than any other transportation service. Should TOFC service continue to expand markedly, it will affect the use of the Interstate highway system by altering the role of highway carriers in the transportation of long-haul intercity freight.

The need for more coordination among different segments of the transport industry has been apparent for a long time. With the passage of the Hepburn Act in 1906, Congress recognized the importance of coordination among carriers. Under the provisions of the Act, carriers were to establish through-routes and joint rates. The Transportation Act of 1920 also provided for coordination in the use of transportation support facilities.

The need for coordinated transportation service is also evident in the national transportation policy which states that the Interstate Commerce Act is to bring about ". . . development, coordinating, and preserving a national transportation system by water, highway and rail, as well as other means . . ." In his message on *The Transportation System of Our Nation*, submitted to Congress on April 5, 1962, the President stated ". . . we must now consider the Nation's transportation network as an articulated and closely linked system rather than an uncoordinated set of independent entities." The Presidential Message submitted to Congress in March 1966 again emphasized the need for a ". . . coordinated transportation system that permits travellers and goods to move conveniently

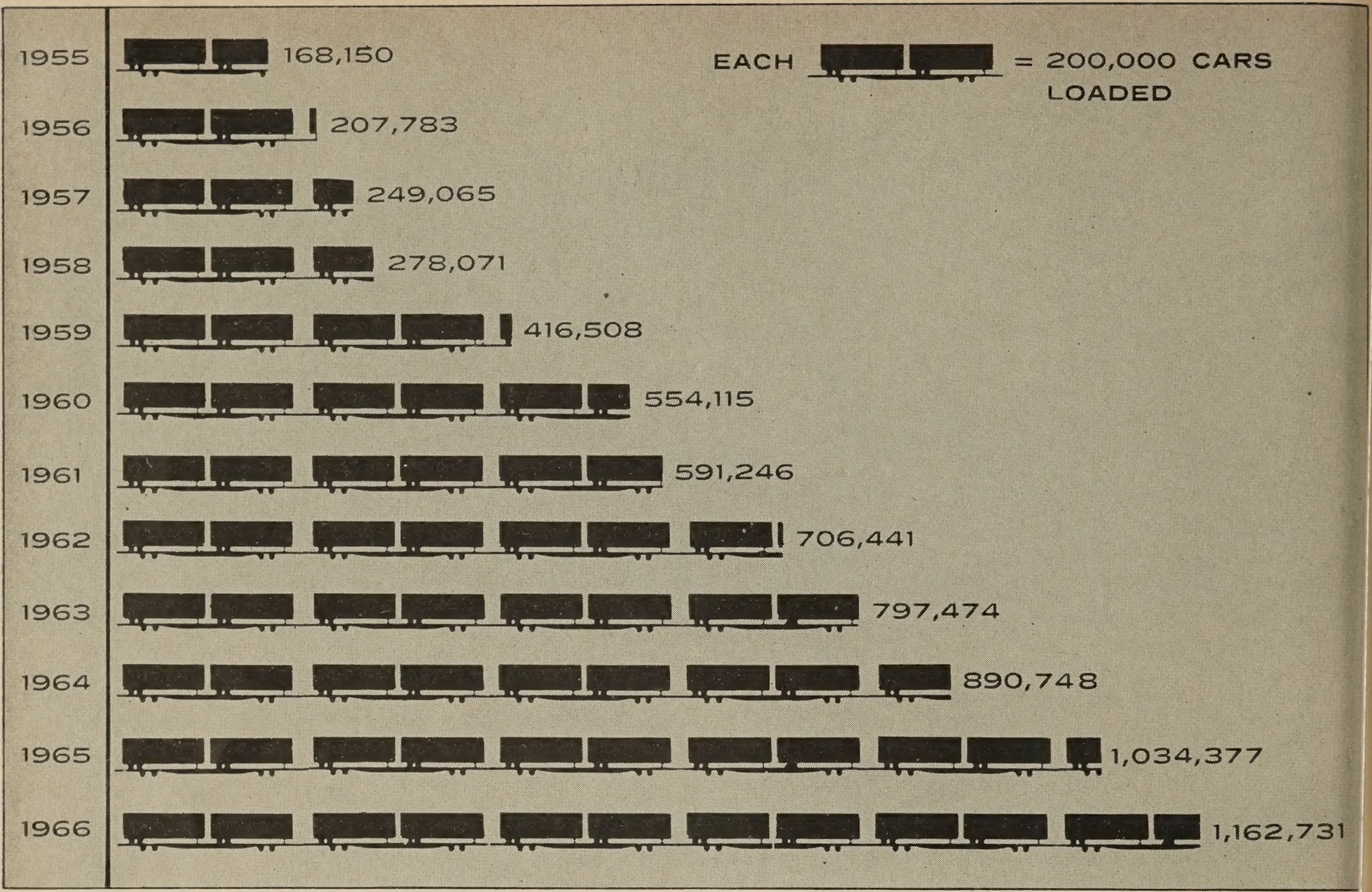


*Figure 1.*—**Piggyback** ***revenue carloadings, 1955–66.***

and efficiently from one means of transportation to another, using the best characteristics of each."

The total cost of transportation for the Nation is approximately 20 percent of the Gross National Product (GNP) or about $150 billion annually (*1*).[1] Approximately half of the expense for freight transportation may go toward paying for what one member of the transportation industry calls the "grand tiddly-winks game of shuffling goods on docks, platforms, between vehicles, and in other side expenses like packaging, damage claims, insurance and the like".(*2*)

Regardless of the fact that coordination between modes of transportation has been held to be essential, there was very little intermodal coordination until 1954, when TOFC service gained momentum. This service has experienced continuous growth since that time, proving beneficial to both carriers and shippers.

The purpose of this article is to consider possible shifts in intercity freight traffic to TOFC service by assessing the relation of this service to the land transport system and shippers and determining its present status and potential growth.

[1] Italic numbers in parentheses identify the references listed on p. 114.

## *Progress of TOFC Service*

It is generally recognized that the growth of TOFC service did not begin until 1954. Since that time, the annual revenue carloadings have increased from 168,150 in 1955 to approximately 1,207,000 in 1967, representing a 618-percent increase, as shown in table 1. Since 1955, annual carloadings have increased each year over the preceding year, as reflected in figure 1.

Although the law has long permitted joint service by various types of carriers, TOFC did not develop as a major transportation service until a variety of arrangements that met the needs and requirements of the shipping public were available. Accordingly, the future growth of this service will probably be contingent on continual flexibility of service and variety of pricing systems.

The Interstate Commerce Commission (ICC) fostered the initial growth of TOFC service by permitting it to develop over a 10-year period, giving it sufficient time for the principal issues to crystalize, before conducting its investigation and proposing rules. In 1954, the ICC conducted an investigation in the so-called New Haven case (293 I.C.C. 93) in which certain practices had been slowly developing in TOFC service. The ICC's approval of these practices resulted in a strong renewal of interest in coordinated transportation by the common carriers and in particip[a]tion of additional carriers in specific plans.

With the steady growth of TOFC servi[ce], problems have arisen; some have been resol[ved] and others will require long and deliber[ate] consideration (*3*). Problems still exist in [the] terminal areas, standardization of equipme[nt], stabilization of rates, and utilization [of] equipment. However, to cope with probl[ems] that confront the railroad industry, a Natio[nal] Railroad Piggyback Association (NRPA) [has] been organized.

The bylaws of NRPA state that its a[ims] are to "foster, protect and promote [the] interests of railroads engaged in the busi[ness] of handling traffic by piggyback, to adva[nce] such interests throughout the United St[ates] and elsewhere through cooperation [and] organization, to stimulate the widespread [use] and recognition of such railroads and to a[ssist] in the solution of problems affecting [the] membership." The NRPA will deal [with] significant sales, operations, terminals, [con]tainerization, car equipment, and trailer[s]. It is too early to appraise NRPA's contribu[tion] to the solution of problems or to assess [what] future part this organization will pla[y to] promote intermodal freight transporta[tion]. The organization is not intermodal i[n its] membership, nor does it have any enforce[ment] powers among its members.

Developments in TOFC service thus far have left little doubt that there are opportunities for additional growth as a result of the advantages that exist in coordinated transportation. In the ICC's investigation Ex Parte 230, of TOFC service, the examiners described *piggyback* as "one of the most dynamic formulas for transportation this country has ever seen." They also stated that "the bounds of this service and its total effect on transportation are as wide and long as the imagination of the men who are providing this service to the Nation."

At this time however, when much effort is being made to stabilize practices into fixed patterns of operation, the potential of TOFC service is difficult to assess because of frequently occurring internal and external changes.

*Piggyback* service may have a tremendous potential for both motor and rail common carrier segments of the transportation industry. It could be the motivating factor in reversing the following predominant trends:

- The use of privately-owned transportation equipment instead of public carriers.
- The lack of cooperation among highly competitive common-carrier modes of transportation.
- Increasing private-carrier transportation costs.

## *Major Categories of Traffic Adaptable to TOFC Service*

During the period following World War II, the trend in the use of private transportation in lieu of public transportation has been substantial. The common carrier industry, both rail and motor, continues each year to lose an appreciable volume of intercity freight traffic to the unregulated private operators. The Nation's estimated freight bill for intercity domestic surface transportation in 1966 was approximately $39 billion. This revenue was distributed among the different modes of transportation as follows:

| Mode: | Amount (billions of dollars) |
|---|---|
| Motor—unregulated, intercity | 17.34 |
| Motor—ICC regulated | 10.15 |
| Railroads | 10.92 |
| Railway Express | .40 |
| Bus | .08 |

Approximately 44 percent of the freight bill was for unregulated highway transportation.

Some of the inherent advantages in *piggyback* service, such as reduction in damage, elimination of pilferage, reduction in labor requirements, greater utilization of carrier equipment, lower freight costs, and contribution to reduction of highway accidents, should substantially help reverse the trend to use private equipment.

During the past three decades, the motor carrier industry has continually grown, and it has been responsible for generating much new traffic and for diverting traffic from competitive modes of transportation. Motor carriers have demonstrated an ability to meet the entire transportation requirements of certain industries. Industry now considers proximity to good highways a major factor in selecting plant locations (*4*).

**Table 1.—Increase in revenue carloadings of trailer-on-flat-car traffic—class I railroads, 1955–67**

| Year | Number [1] | Increase: Over preceding year | Increase: Over preceding year | Increase: Over 1955 |
|---|---|---|---|---|
| | *Carloads* | *Carloads* | *Percent* | *Percent* |
| 1955 | 168,150 | -------- | -------- | ------ |
| 1956 | 207,783 | 39,633 | 23.6 | 23.6 |
| 1957 | 249,065 | 41,282 | 19.9 | 48.1 |
| 1958 | 278,071 | 29,006 | 11.6 | 65.4 |
| 1959 | 416,508 | 138,437 | 49.8 | 147.7 |
| 1960 | 554,115 | 137,607 | 33.0 | 229.5 |
| 1961 | 591,246 | 37,131 | 6.7 | 251.6 |
| 1962 | 706,441 | 115,195 | 19.5 | 320.1 |
| 1963 | 797,474 | 91,033 | 12.9 | 374.3 |
| 1964 | 890,216 | 92,742 | 11.6 | 429.4 |
| 1965 | 1,034,377 | 144,161 | 16.2 | 515.2 |
| 1966 | 1,162,731 | 128,354 | 12.4 | 591.5 |
| 1967 | 1,207,242 | 44,511 | 3.8 | 618.0 |

[1] Source: Association of American Railroads, Form CS 54A.

Because *piggyback* service offers many potential advantages to both modes of transportation, a much higher degree of coordination between railroads and motor carriers should result. The burden is on the regulated carriers—both motor and rail—to further develop programs capable of meeting private carrier competition. TOFC services offer the greatest opportunity to accomplish this.

Many freight movements require no separate containers, such as volume shipments of bulk commodities—coal, iron ore, grain and liquids—for which the walls of the vehicles serve as the containers. Other examples of commodities requiring little, if any, containerization are new automobiles, structural steel, and building stone.

Although commodities that do not have to be containerized make up a large portion of the total tonnage transported in intercity freight service, they do not represent as large a portion of the total cost paid for transportation. Package goods, small shipments, and volume shipments of manufactured items, which are readily adaptable to TOFC service, are far more costly to handle, and therefore offer larger potential savings in handling and transportation costs.

National Transportation Policy Report No. 445, prepared in 1961 by the Committee on Commerce, U.S. Senate, stated that approximately three-fourths of the intercity Interstate freight carriage is by regulated carrier. However, much of the post-war expansion in transportation has accrued to the benefit of the unregulated carriers. It was estimated that 25 percent of the freight moving over the highway was moving in illegal service. It was predicted that by 1975, only 61 percent of the intercity freight will be handled by regulated carriers, and that the principal impact will be on the railroads. The report projected that the regulated carriers will be handling 1,111 billion ton-miles and the unregulated carriers 718 billion ton-miles of freight in intercity service.

The requirement for intercity freight transportation is usually related to the output of goods and construction, which represents about two-thirds of the GNP. Based on this relationship, United Research, Incorporated, Cambridge, Mass., made the projections of intercity freight ton-miles through 1985, shown in table 2.

The year 1962 marked the first post-war year that the collective intercity traffic (total ton-miles) of regulated carriers (rail, highway, and water) gained on their unregulated competitors. Compared with 1962, the relative percentage of distribution remained about the same in 1963 and 1964; there was a slight change in favor of the regulated carriers in 1965 and 1966.

The best opportunity for motor and rail common carriers to generate additional volumes of remunerative traffic is to offer a sufficiently attractive coordinated service to divert freight from the exempt and private carriers. Outside the bulk commodity area there is a great deal of high-revenue-producing traffic currently being handled in unregulated transportation which lends itself to TOFC service. It is possible that much of this freight is being handled in equipment loaded in one direction at an unreasonable cost to the shipper.

**Table 2.—Projection of intercity freight**

| Year | Value of goods and construction | Transportation required: Per dollar of goods and construction | Transportation required: Total |
|---|---|---|---|
| | *Billions of dollars* | *Ton-miles* | *Billions of ton-miles* |
| 1970 | 457 | 3.8 | 1.737 |
| 1975 | 500 | 3.7 | 2.012 |
| 1980 | 631 | 3.6 | 2.271 |
| 1985 | 754 | 3.5 | 2.639 |

Source: *Future U.S. Transportation Needs* by A. H. Norling, United Research, Inc., Cambridge, Mass., 1963, p. VIII-4.

During the past 25 years, the unregulated transportation industry has grown tremendously. Operating independently, neither the motor- nor rail-regulated carriers seems to be able to cope with this competition to the extent that either mode can any longer control the majority of the intercity tonnage or revenue. The traffic handled in unregulated service represents the largest market of potential remunerative traffic adaptable to TOFC service. There has been a relative decline in railroad use, as a factor in surface transportation, and a noticeable inability of the regulated motor carriers alone to significantly reverse the trend in traffic handled by unregulated motor carriers. To make substantial inroads on unregulated competition, and capture or recover a significant part of the intercity freight from the unregulated carriers, the regulated carriers apparently will have to participate to a greater extent in coordinated TOFC service.

It is the freight that is usually the most costly to transport that justifies the inaugura-

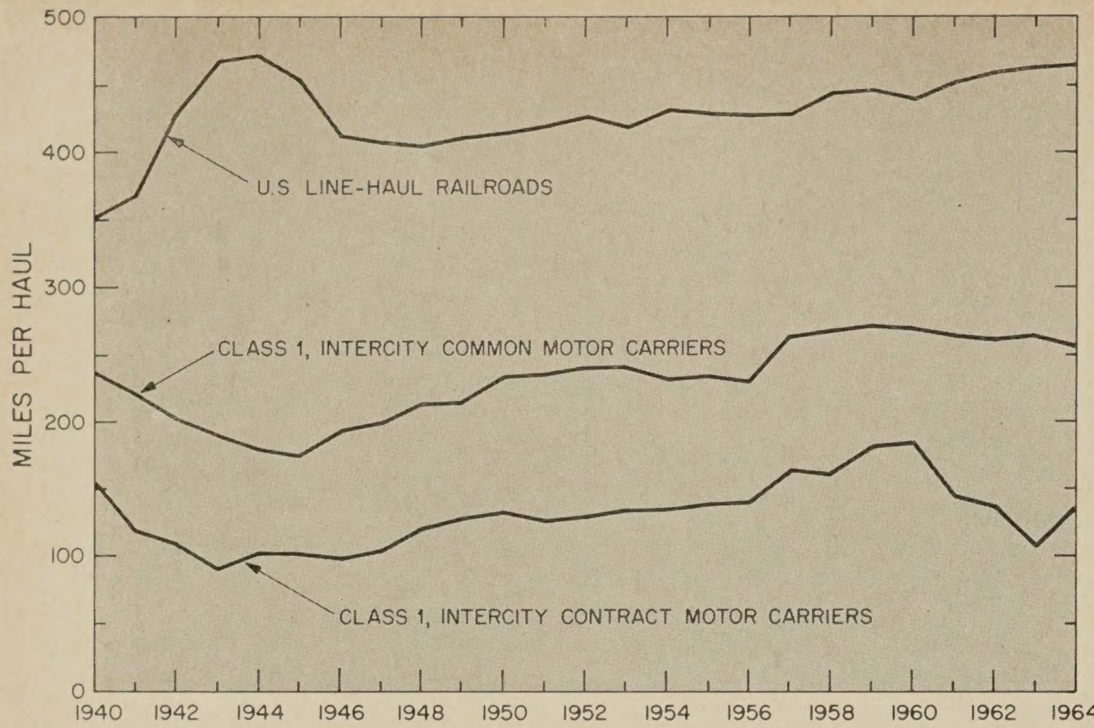


*Figure 2.—Length of haul by truck and rail, 1940–64.*[2]

tion and operation of privately-owned motor service. Because it consists of high-revenue-producing traffic and represents about 40 to 45 percent of the intercity freight, this traffic should provide a strong impetus to regulated motor and rail carriers to expand and perfect their coordinated TOFC services to recapture a larger portion of this market.

Although the motor carriers have grown rapidly because of their important part in the economic development of the United States, about half of their ton-mileage consists of shipments of more than 400 miles, which is subject to being handled in TOFC service. In figure 2 is shown the length of haul by class I intercity motor carriers (common and contract) and all U.S. line-haul railroads, for the years 1940–64. Between 1940 and 1964, the length of haul for the class I common motor carriers increased 9 percent, while the railroads increased 33 percent and the contract motor carriers declined 10 percent. Comparable data are not readily available for private motor carriers, but it is reasonable to believe that during the same period, their average length of haul has increased substantially.

## *Service and Rates*

The inauguration of TOFC service was the first time that two different modes of transportation, motor and rail, combined the best features of their respective services into a large-scale transport operation. This coordinated transportation offers considerable flexibility to shippers, an improvement in reliability of service over a single mode of transportation and, most important, simplified rate structures. The shipper has the combined advantage of door-to-door service by motor carriers, and economical long-haul service by the rail carriers.

In their production and distribution processess, industrial firms weigh the costs of inventory, warehousing, and handling to price their products on a competitive basis. Accordingly, any transit-time saving also saves money and can reduce the overall costs of manufacturing and marketing products. This affords the carriers an opportunity to pass these advantages on to consumers.

Another significant advantage of TOFC service is single-carrier control, whereby the shipper can obtain reports on the status of the shipment from the originating carrier. There has also been a substantial reduction in freight damage when goods are shipped by TOFC service. Although there is probably no measure of the extent of damage reduction, it is the consensus of both shippers and carriers that considerably less damage occurs than when goods are shipped in partial loads—less carload or less truckload service.

Faster service, fewer losses, less damage, and high utilization of equipment will substantially influence the quality of service and the rates in TOFC transportation. If TOFC service enables the motor carriers to keep their rising costs in check, and at the same time provides a margin of profit for the rail carriers, these two modes of common carrier transportation will recapture more of the present traffic handled over-the-road in private transportation; working together, they should be able to slacken the rate of growth and reverse the trend in the use of private transportation.

Before World War II, railroads enjoyed a distinct advantage in freight transportation. During the war a major impetus was given to the growth of the motor carrier industry. Following the war, these two modes of transportation competed for traffic, primarily on a service basis rather than on a cost basis. The greater flexibility of the motor carrier services enabled them to generate much new traffic and to divert an appreciable amount of the more remunerative traffic from the railroads. However, with the establishment and growth of TOFC service since World War II, emphasis has shifted from service competition to rate competition.

Prior to TOFC service, much of the litigation before the ICC involved the question of whether rates were too high; now the litigation usually involves the question of whether rates are too low. For the regulated carriers this litigation has exerted a downward pressure on the rate structures, which, if continued, should result in attracting more traffic from the private carriers.

One of the most significant aspects o TOFC services is the economic implication of the new departures in rate-making tha accompanied the inauguration of TOF( operations on a large scale. The rates provide under the TOFC plans are based on simpl principles, compared to the conventiona procedures and factors which previousl entered into rate-making. Consequently, sub stantial advantages from both administrativ and monetary standpoints are accruing to th participants in TOFC service.

## *Coordination Between Motor Carrier and Railroads*

While some transportation coordinatio has been permitted under the provisions c the Interstate Commerce Act—through-rout and joint-rate arrangements—generally, the was very little actual coordination in th country between rail and motor carrie prior to 1954, when *piggyback* service bega

The ICC has contended that addition authority is needed for the establishment through routes and joint rates. Under t existing statutes, the ICC cannot comp motor common carriers of property to ent into joint-rate and through-route arrang ments with each other, or with comm carriers of other modes. This gap in authori has probably been one of the reasons w there has not been greater coordinati among unlike modes of transportation. Wh in the public interest, however, the ICC h repeatedly requested authority from Congr to require through routes and joint ra between motor common carriers of proper and between motor carriers and comm carriers by rail, express, and water.

The development of TOFC service rep sents an appreciable step forward by t motor and rail carriers to reap the potent benefits of coordinated services. Thus f coordination between motor carriers and r road industries in TOFC service may be d cussed briefly under four topics—manager marketing, technological, and operationas.

### Managerial coordination

The further advancement of TOFC serv will depend, to a considerable extent, on t degree of managerial coordination betw the motor and rail carriers. Within the fra work of the five TOFC plans exists

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[2] Source: *Transportation Statistics in the United States*, Bureau of Transport Economics and Statistics, Interstate Commerce Commission.

maximum opportunity for such coordination. A motor carrier, for example, may solicit the freight traffic, provide the documentation, labor, motor power for pickups, delivery of trailer, and collect the transportation charges, thereby depending on the railroad only to provide the power and railcar for the rail-haul portion of the movement. This represents a nigh degree of coordination between two unlike modes of transportation.

This coordination offers certain inherent advantages to carriers. Managers gain greater knowledge of the operating characteristics of other forms of transportation and become more familiar with the managerial and eco-nomic aspects of competitive modes of trans-portation. The continual growth of TOFC service during the past 10 years is due to this coordination, which has not only resulted in substantial advantages for both modes of transportation, but also has provided the public with improved service.

### Marketing coordination in TOFC service

TOFC service offers considerable latitude for coordination in marketing a *packaged transportation service.* It represents a new era for the shipping public, as it affords an opportunity to consolidate the advantages of each mode of transportation, thereby making available the best service to suit the shipper's requirements at a reduction in cost for furnishing the transportation. The major customers do not rely exclusively—from a service and cost standpoint—on either mode of transportation. The services that the two modes render within the sphere of their respective operations provide transport capability, but single mode capability does not provide all the inherent advantages of both modes.

### Technological coordination

The third area of coordination in TOFC service is the technological area. The potential of combining the technical features of each mode of transportation has been recognized for many years, but only recently have the carriers begun to take advantage of the opportunity. *Piggyback* focuses attention on the advantage of trucking flexibility to perform pickup and delivery of short-haul and medium-haul service, as well as on the cost advantage of rail in some medium-haul and most long-haul service.

It has been necessary for the motor and rail carriers to modify existing equipment and to develop new equipment, including the *piggyback* car and storage and loading facilities, to meet the technological requirements for an efficient service. Management of both modes of transportation has been receptive to a high degree of coordination in technological areas, as they have received the benefits of lower operating costs.

### Operations coordination

Since 1954, a general atmosphere of coordination between motor and rail carriers has developed. It can be concluded that the shipper advocates the maximum amount of coordination between modes of transportation to provide direct, expeditious service with a minimum of administrative expense at the most economical rate.

To attract the traffic, each mode of transportation endeavors to render a superior service at sufficiently compensatory rates. Both the rail and motor carriers have certain inherent advantages to offer regarding service and rates. Much freight traffic is susceptible to movement by either mode of transportation, and it is within this area that the greatest opportunity for coordination between the modes exists. By unifying the advantages of each mode, the carriers are capable of offering a combination service heretofore not readily available to the public.

Through cooperative operations and development of the respective modes, the carriers are reaching new peaks of efficiency. Collectively, they are capable of rendering a superior service in many categories of long-haul traffic. However, the continual growth of private transportation has had a significant impact in promoting coordination between regulated motor and rail transportation. Generally, private transportation affects the most desirable traffic—the type that would produce the highest rate of revenue for the regulated carriers.

To illustrate the effect of private transportation, meat and dairy products are high-revenue producing traffic for both rail and motor carriers. In the 1963 Census of Transportation, the Commodity Transportation Survey on meat and dairy products revealed that about 43 million tons of this commodity were shipped beyond the local area. Private trucks handled more than half of the total tonnage shipped distances of less than 200 miles; motor carriers dominated the middle-distance range—from about 200 to 800 miles—and railroads transported more than half of total shipments over longer distances. Percentage distribution of this traffic among modes on a tonnage and ton-mile basis is shown by the following tabulation:

| Mode of transportation: | *Tons (percent)* | *Ton-miles (percent)* |
|---|---|---|
| Private | 42 | 16 |
| Motor | 30 | 36 |
| Rail | 28 | 48 |

More of this long-haul traffic could have been handled by coordinated rail-motor service.

Once a shipper is committed to private transportation because of his heavy investment in equipment, he is not easily persuaded to abandon his carrier operations. Although it is not evident that any large shippers have discontinued their private transport operations because of TOFC service, many have refrained from increasing the size of their transport operations because of the availability of TOFC service.

The potential overall advantages that accrue to regulated motor and rail carriers should enable them to offer a coordinated service capable of prompting the operators of private carriage to rely, to a greater extent, on public transportation.

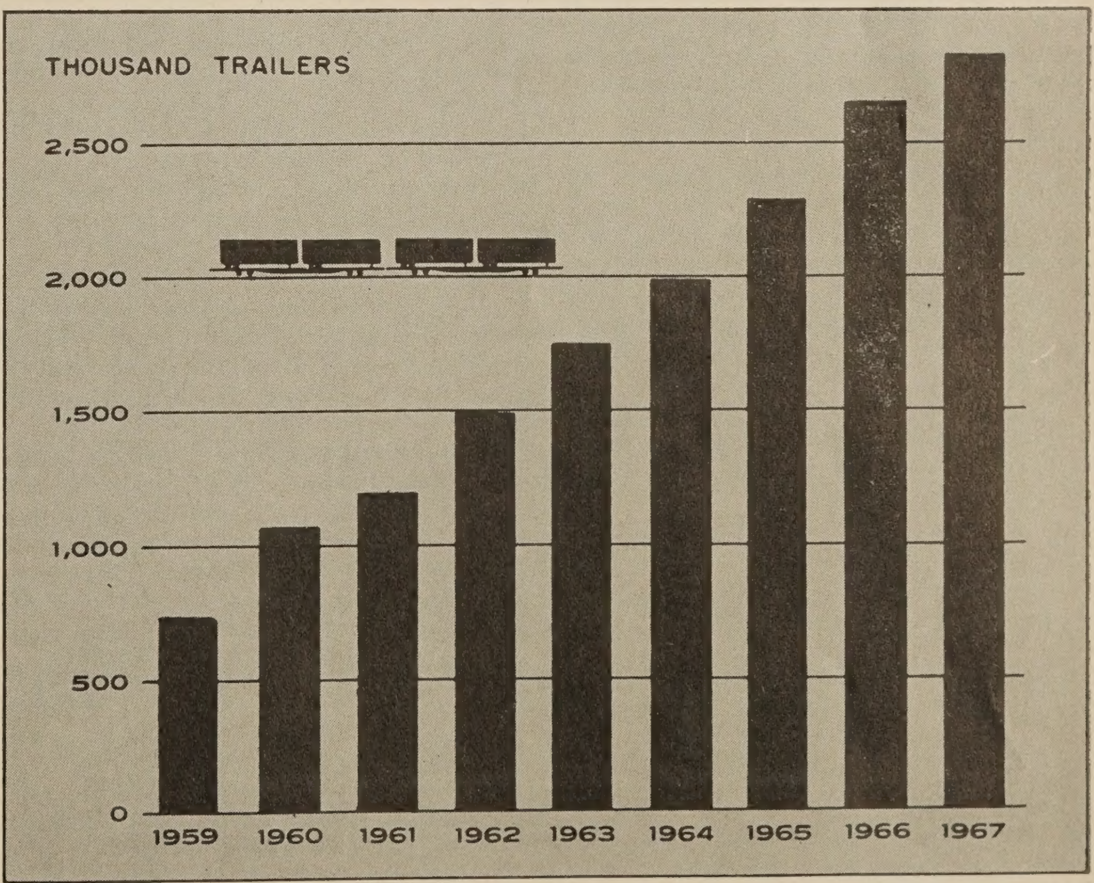


*Figure 3.*—**Piggyback growth, 1959–67—class 1 railroads.**

## *Growth of TOFC Service*

As recorded in table 1, the revenue carloadings handled by TOFC service since 1955 have continually increased. The approximately 1,200,000 carloads of *piggyback* freight, transported in 1967, represent approximately 2 million loaded truck-trailers. Additionally, more than 800,000 empty trailers were handled for a total of about 2,800,000 trailers moved in rail service. The carriage of trailers in rail service increased from approximately 740,000 in 1959, to 2,800,000 in 1967, approximately a 400 percent increase.

TOFC service expanded about 24 percent between 1955 and 1956. (See table 1.) In 1959, it reached an annual growth peak of approximately 50 percent over the preceding year. There have been variations in the annual percentage increases over the preceding years, from a low of 3.8 percent in 1967 to a high of 49.8 percent in 1959. The large percentage gain between 1958 and 1959 was caused by more carriers offering TOFC service and the increased total volume of freight traffic.

During the last five years, TOFC service has grown an average of approximately 11 percent annually. The trend of *piggyback* service—even though fluctuating in rate of growth—is still in a stage of considerable expansion. (See fig. 3.) In each of the past 12 years, except 1961 and 1967, growth has exceeded 11 percent (table 1).

A conceptual approach to the growth of TOFC service has been developed showing increases in carloads and truckloads, based on an annual growth of 6, 8, and 10 percent respectively, predicated on an average of 1.7 trailers per flatcar (table 3). The validity of these projections should be accepted in terms of the principal factors directly affecting TOFC service. The ICC rules governing TOFC service, enactment of the Trade Simplification Act and the size and weight legislation, are significant factors that will affect the future growth rate of this service.

It is estimated that at least 6 million and possibly 12 million trailers will be transported in TOFC service by 1986—a three to sixfold increase. This is a conservative projection, as it represents a range of from considerably less than the fivefold increase of the past 10 years to a maximum of a sixfold increase in the next 18 years.

Once the pattern of TOFC operations is established under the factors identified above, it will undergo a sustained period of stable expansion.

**Table 3.—Projections of number of carloads and truckloads in trailer-on-flatcar revenue service, 1967–87**

**[Based on an annual increase of the percentages shown]**

| Year | Projected loads hauled | | | | | |
|---|---|---|---|---|---|---|
| | Annual increase—6 percent | | Annual increase—8 percent | | Annual increase—10 percent | |
| | Carloads | Truckloads [1] | Carloads | Truckloads [1] | Carloads | Truckloads [1] |
| | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* |
| 1967 | 1, 207, 242 | 2, 052, 311 | 1, 207, 242 | 2, 052, 311 | 1, 207, 242 | 2, 052, 311 |
| 1968 | 1, 279, 677 | 2, 175, 451 | 1, 303, 821 | 2, 216, 496 | 1, 327, 966 | 2, 257, 542 |
| 1969 | 1, 356, 458 | 2, 305, 979 | 1, 408, 127 | 2, 393, 816 | 1, 460, 763 | 2, 483, 297 |
| 1970 | 1, 437, 845 | 2, 444, 337 | 1, 520, 777 | 2, 585, 321 | 1, 606, 839 | 2, 731, 626 |
| 1971 | 1, 524, 116 | 2, 590, 997 | 1, 642, 439 | 2, 792, 146 | 1, 767, 532 | 3, 004, 789 |
| 1972 | 1, 615, 563 | 2, 746, 457 | 1, 773, 834 | 3, 015, 518 | 1, 944, 275 | 3, 305, 268 |
| 1973 | 1, 712, 497 | 2, 911, 245 | 1, 915, 741 | 3, 256, 760 | 2, 138, 703 | 3, 635, 795 |
| 1974 | 1, 815, 247 | 3, 085, 920 | 2, 069, 000 | 3, 517, 300 | 2, 352, 573 | 3, 999, 374 |
| 1975 | 1, 924, 162 | 3, 271, 075 | 2, 234, 520 | 3, 798, 684 | 2, 587, 830 | 4, 399, 311 |
| 1976 | 2, 039, 612 | 3, 467, 340 | 2, 413, 282 | 4, 102, 579 | 2, 846, 613 | 4, 839, 242 |
| 1977 | 2, 161, 989 | 3, 675, 381 | 2, 606, 345 | 4, 430, 787 | 3, 131, 274 | 5, 323, 166 |
| 1978 | 2, 291, 708 | 3, 895, 904 | 2, 814, 853 | 4, 785, 250 | 3, 444, 401 | 5, 855, 482 |
| 1979 | 2, 429, 210 | 4, 129, 657 | 3, 040, 041 | 5, 168, 070 | 3, 788, 841 | 6, 441, 030 |
| 1980 | 2, 574, 963 | 4, 377, 437 | 3, 283, 244 | 5, 581, 515 | 4, 167, 725 | 7, 085, 133 |
| 1981 | 2, 729, 461 | 4, 640, 084 | 3, 545, 904 | 6, 028, 037 | 4, 584, 498 | 7, 793, 647 |
| 1982 | 2, 893, 229 | 4, 918, 489 | 3, 829, 576 | 6, 510, 279 | 5, 042, 948 | 8, 573, 012 |
| 1983 | 3, 066, 823 | 5, 213, 599 | 4, 135, 942 | 7, 031, 101 | 5, 547, 243 | 9, 430, 313 |
| 1984 | 3, 250, 832 | 5, 526, 414 | 4, 466, 817 | 7, 593, 589 | 6, 101, 967 | 10, 373, 344 |
| 1985 | 3, 445, 882 | 5, 857, 999 | 4, 824, 162 | 8, 201, 075 | 6, 712, 164 | 11, 410, 679 |
| 1986 | 3, 652, 635 | 6, 209, 480 | 5, 210, 095 | 8, 857, 162 | 7, 383, 380 | 12, 551, 746 |

[1] Based on an average of 1.7 trailers per carload.

## *Conclusions*

Today, the competitive situation in intermodal transportation is intensified. Since World War II, improved highways and technological progress have resulted in longer and heavier truck hauls. The highway trailer has grown to the point of having the appearance and nearly the capacity of a boxcar. Industry is no longer attached exclusively to the rail heads. However, TOFC is a modern method of transferring containers and providing industry, regardless of its location, with adequate, efficient, and economical transportation, the further growth of which is now assured.

The past 10-year period has brought forth sufficient developments in TOFC service to support some conclusions and forecasts regarding its continued growth for the future. Although TOFC service, in a sense, may still be a transportation infant, it has considerable potential for substantial additional growth. Further experience will provide more improvements in service, pricing patterns, and coordination between competitors.

*Piggyback* is definitely a breakthrough in the barrier of cooperation that existed between the regulated railroads and motor carriers, both of which have a common, influential competitor in the unregulated carriers.

During this transitional period, the available statistical data on TOFC operations and services throughout the Nation is not sufficiently refined to reveal the precise answer to many questions such as: (1) To what extent has *piggybacking* meant the actual diversion of traffic from competitive modes of transportation? (2) Is traffic being handled at noncompensatory rates? (3) How much revenue is derived by the respective modes from TOFC traffic? and (4) What long-range impact will this rapidly developing system of coordinated transportation have on the Federal-aid highway system?

Thus far, there is no sign of total TOFC traffic leveling off. But neither have all the major factors that will influence its development settled into a sufficiently definite pattern to permit forecasting its future rate of growth, other than in the general manner shown here.

A true indication of the initial impact of TOFC service on highway freight is not yet in sight. It is reasonable to conclude that there will be considerably more coordinated service and in the reasonably near future it should be possible to measure the impact of TOFC service on highway freight and its potential effect on the highway system.

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(*2*) *Containers: The Right Track?* Railway Age, vol. 148, No. 22, May 30, 1960, p. 9.

(*3*) *Piggyback—Progress Has Its Problems*, Railway Age, vol. 158, No. 22, May 31, 1965, pp. 54–66.

(*4*) *Highways, Trucks, and New Industry*, by Dept. of Research and Transport Economics, American Trucking Association, Inc., Washington, D.C., May 1963.


*When highway trailers are hauled on rail flatcars in* **piggyback** *operations, highway transportation is an essential part of the overall service.*

# Highways and Rail Piggybacking

BY THE OFFICE OF PLANNING
BUREAU OF PUBLIC ROADS

**Reported by[1] ALEXANDER FRENCH,**
**Chief, Planning Services Branch,**
**Current Planning Division**

***Although the trend to transport freight by hauling highway trailers on flatcars, piggybacking, has been steadily upward, this intermodal freight service apparently has not retarded the growth of highway freight transportation. As pointed out in this article, it is unlikely that piggyback will replace highway transportation for moving freight over short distances; it is more likely to eliminate a substantial amount of intercity highway freight movement over long distances. Even though a large part of the long-distance highway freight travel would be converted to piggyback transportation, short distance highway travel should increase to handle movement to and from piggyback terminals. Highway planners must be attentive to the need for a high level-of-service on the arterial highway networks providing access between piggyback terminals and the origins and destinations of shipments.***

## *Introduction*

THE transportation of highway semitrailers and interchangeable highway rail containers by rail flatcar provides efficient long-distance transportation of commodities. In the study reported here, this intermodal form of freight transportation, called *piggyback*,[2] was analyzed to determine whether a substantial shift in the highway share of total intercity ton-miles or other significant effects on highway administration, planning, or design are likely. It was concluded that *piggybacking* did not significantly dampen the growth of highway freight transportation during the past 10 years, nor is it likely to have a retarding effect in the future.

Special planning and design analyses are recommended for highways serving *piggyback* terminals to assure efficient intermodal operation. Special, highly localized problems could be caused by the concentration of semitrailer combinations on highways serving *piggyback* terminals during the periods immediately before and after loading and unloading of trailer trains. These problems can be readily identified and analyzed as part of the highway planning process. Roadways can then be designed to provide the necessary capacity for traffic flow and, where necessary, pavements affected by a high frequency of heavy axles can be strengthened.

## *National Trends*

Trends in intercity rail and highway cargo transportation since 1945, based on a 1961 index, are shown in figure 1. Data on *piggyback* ton-miles can be estimated, beginning

[1] Assisting in collecting and analyzing the material were T. S. Dickerson and W. J. Page, Highway Research Engineers; J. F. Petring, Highway Engineer Trainee; and A. J. Simms, Statistical Assistant.

[2] *Piggyback* refers to the transportation of highway trailers on railroad flatcars (TOFC) and to the transportation of interchangeable containers—similar to semitrailer van bodies—that are designed for transportation by railroad and highway semitrailer (COFC).

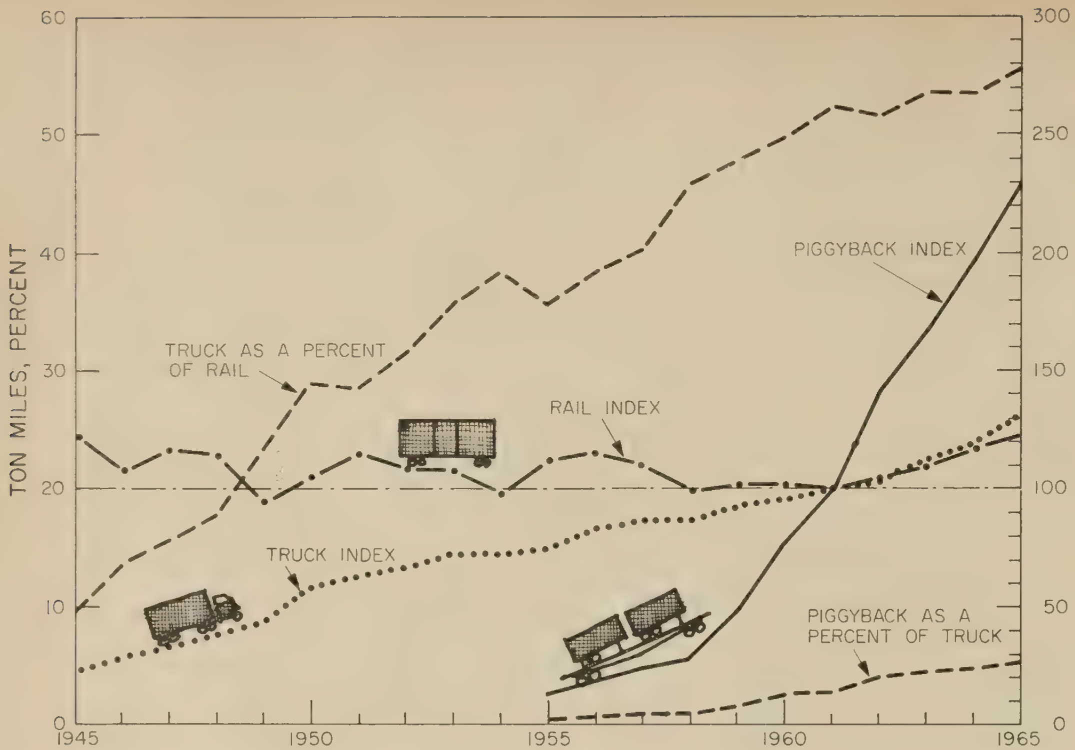



***Figure 1.—Trends in intercity cargo transportation by piggyback, rail, and highway.***

in 1955, as shown in table 1. From the index lines in figure 1, it is evident that since World War II, rail traffic has remained nearly constant, while truck and *piggyback* have increased—truck traffic increasing steadily and *piggyback* at a much higher rate. The line representing truck ton-miles as a percent of rail, when compared with the line for *piggyback* ton-miles as a percent of truck, indicates that while *piggyback* is growing at a very rapid rate, truck ton-mileage continues to grow faster with respect to rail than does *piggyback* with respect to truck.

Trends in relationships of intercity ton-miles hauled by rail, highway, and *piggyback* are shown in table 1. The share hauled by rail and *piggyback* together has declined from nearly 75 percent in 1955 to about 65 percent in 1965, while the highway share has increased from about 26 percent to 35 percent in the same period. The annual increase for total ton-miles and ton-miles by each of the three categories is also shown in the table. *Piggyback* has been gaining an increasing share of the annual increase of land vehicular ton-miles. Although *piggyback* operations have apparently served to hold the rail share, it has not had a very large effect on highway cargo movements.

The procedure for estimating annual rail *piggyback* ton-miles in table 1 is represented by the equation:

$$TM_p = O_p \times P \times H \times L,$$

Where,

$TM_p$ = estimated ton-miles of cargo hauled by rail *piggyback*.

$O_p$ = number of *piggyback* rail cars originating (see "Effect of Piggyback Operation on Volume of Highway Truck Traffic," Alan C. Flott, Highway Research Board Record Number 153, 1967).

$P$ = estimated average number of loaded *piggyback* trailers and containers per originating rail car ranging from $P$ = 1.10 in 1955–59 to $P$ = 1.64 in 1964.

$H$ = average haul, in miles, estimated for rail *piggyback* cars, based on the ratio of *piggyback* car average in I.C.C. Statement No. 66–1 to the all-flatcar average computed by mileage block from Statement TC–1, then applied to similar flatcar data for 1955–65.

$L$ = average load per loaded *piggyback* semitrailer body or container estimated to be approximately 16 tons based on I.C.C. Statement No. 66–1 and confirmed by 1963 truck weigh data for long-haul van body, fully loaded semitrailer combinations.

Although the values and assumptions are based on extensive discussions with experts in the field, the author takes full responsibility for the estimates, which were intended to be realistic but assure a reasonably high *piggyback* ton-mile series.

**Table 1.—Trend in the amount and share of intercity cargo transportation by railroad, piggyback, and highway**

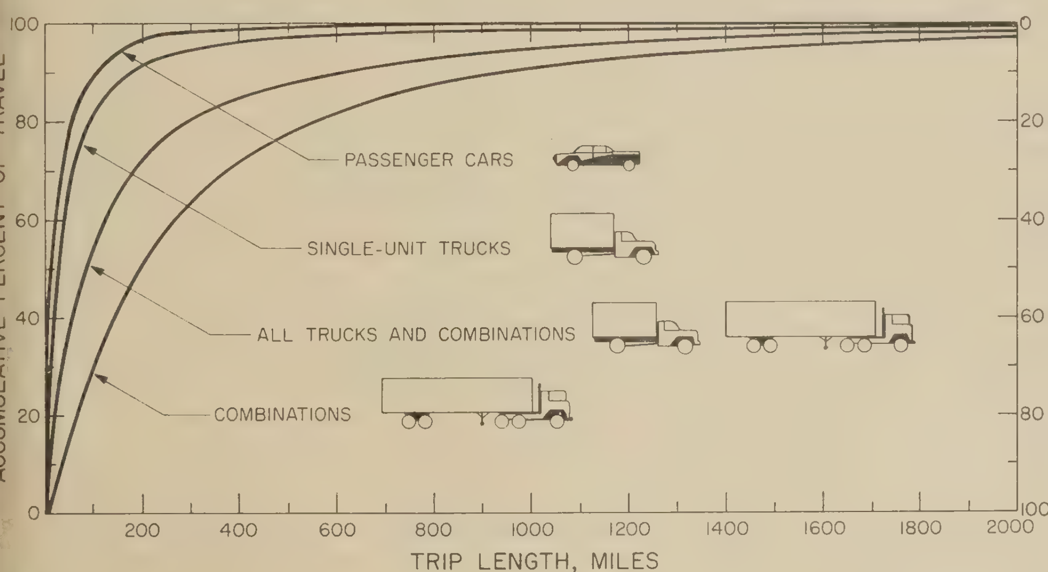
| | 1945 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ton-miles, millions: | | | | | | | | | | | | |
| Railroad excluding piggyback | 684,148 | 625,588 | 649,486 | 619,721 | 552,010 | 574,349 | 568,638 | 557,534 | 583,423 | 610,486 | 644,793 | 685,584 |
| Piggyback, TOFC [1] and COFC [2] | ........ | 1,305 | 1,702 | 2,186 | 2,524 | 4,288 | 6,722 | 8,761 | 12,351 | 14,684 | 17,296 | 20,120 |
| Total railroad | 684,148 | 626,893 | 651,188 | 621,907 | 554,534 | 578,637 | 575,360 | 566,295 | 595,774 | 625,170 | 662,089 | 705,704 |
| Highway | 66,948 | 223,254 | 248,846 | 254,174 | 255,544 | 278,934 | 285,483 | 296,485 | 309,407 | 336,170 | 356,298 | 388,438 |
| Total ton-miles | 751,096 | 850,147 | 900,034 | 876,081 | 810,078 | 857,571 | 860,843 | 862,780 | 905,181 | 961,340 | 1,018,387 | 1,094,142 |
| Percent of total ton-miles: | | | | | | | | | | | | |
| Railroad excluding piggyback | 91.09 | 73.58 | 72.16 | 70.74 | 68.14 | 66.97 | 66.06 | 64.62 | 64.45 | 63.50 | 63.32 | 62.66 |
| Piggyback, TOFC [1] and COFC [2] | ........ | 0.15 | 0.19 | 0.25 | 0.31 | 0.50 | 0.78 | 1.02 | 1.36 | 1.53 | 1.70 | 1.84 |
| Total railroad | 91.09 | 73.73 | 72.35 | 70.99 | 68.45 | 67.47 | 66.84 | 65.64 | 65.81 | 65.03 | 65.02 | 64.50 |
| Highway | 8.91 | 26.27 | 27.65 | 29.01 | 31.55 | 32.53 | 33.16 | 34.36 | 34.19 | 34.97 | 34.98 | 35.50 |
| Total percentage | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Change from previous year, percent: | | | | | | | | | | | | |
| Railroad excluding piggyback | ........ | 13.29 | 3.82 | −4.58 | −10.93 | 4.05 | −0.99 | −1.95 | 4.64 | 4.64 | 5.62 | 6.33 |
| Piggyback, TOFC [1] and COFC [2] | ........ | ........ | 30.42 | 28.44 | 15.46 | 69.89 | 56.76 | 30.33 | 40.98 | 18.89 | 17.79 | 16.33 |
| Total railroad | ........ | 13.53 | 3.88 | −4.50 | −10.83 | 4.35 | −0.57 | −1.58 | 5.21 | 4.93 | 5.91 | 6.59 |
| Highway | ........ | 4.70 | 11.46 | 2.14 | 0.54 | 9.15 | 2.35 | 3.85 | 4.36 | 8.65 | 5.99 | 9.02 |
| Total change | ........ | 10.90 | 5.87 | −2.66 | 7.53 | 5.86 | 0.38 | 0.22 | 4.91 | 6.20 | 5.93 | 7.44 |
| Piggyback-highway ton-mile percentages: | | | | | | | | | | | | |
| Piggyback as percent of other rail | ........ | 0.21 | 0.26 | 0.35 | 0.46 | 0.75 | 1.18 | 1.57 | 2.12 | 2.41 | 2.68 | 2.93 |
| Piggyback as percent of highway | ........ | 0.58 | 0.68 | 0.86 | 0.99 | 1.54 | 2.35 | 2.95 | 3.99 | 4.37 | 4.85 | 5.18 |
| Highway as percent of all rail | 9.78 | 35.61 | 38.21 | 40.87 | 46.08 | 48.21 | 49.62 | 52.36 | 51.93 | 53.77 | 53.81 | 55.04 |
| Indices, 1961—100: | | | | | | | | | | | | |
| Railroad excluding piggyback | 123 | 112 | 116 | 111 | 99 | 103 | 102 | 100 | 105 | 109 | 116 | 123 |
| Piggyback, TOFC [1] and COFC [2] | ........ | 15 | 19 | 25 | 29 | 49 | 77 | 100 | 141 | 168 | 197 | 230 |
| Total railroad | 121 | 111 | 115 | 110 | 98 | 102 | 102 | 100 | 105 | 110 | 117 | 124 |
| Highway | 23 | 75 | 84 | 86 | 86 | 94 | 96 | 100 | 104 | 113 | 120 | 131 |
| Total | 87 | 99 | 104 | 102 | 94 | 99 | 100 | 100 | 105 | 111 | 118 | 127 |

[1] TOFC = trailer on flatcar.
[2] COFC = container on flatcar.

**Table 2.—Number of trailer-on-flatcar (TOFC) movements according to four prescribed plans, 1963** [1]

| | Plan | | | | | | | | Totals | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | I [2] | | II [3] | | III [4] | | IV [5] | | | | |
| | Origin | Termination | Origin | Termination | Origin | Termination | Origin | Termination | Origin | Termination | Both |
| State: | | | | | | | | | | | |
| Massachusetts | 109 | 94 | ----- | ----- | 175 | 112 | ----- | ----- | 284 | 206 | 490 |
| New Jersey | 233 | 245 | 89 | 198 | 248 | 330 | 60 | 68 | 630 | 841 | 1,471 |
| New York | 119 | 123 | 236 | 260 | 155 | 102 | ----- | ----- | 510 | 485 | 995 |
| Pennsylvania | 116 | 80 | 166 | 176 | 142 | 121 | ----- | ----- | 424 | 377 | 801 |
| Florida | ----- | ----- | ----- | ----- | 132 | 357 | ----- | ----- | 132 | 357 | 489 |
| Illinois | 783 | 723 | 802 | 574 | 615 | 554 | 173 | 215 | 2,373 | 2,066 | 4,439 |
| Ohio | ----- | ----- | 236 | 135 | 125 | 25 | ----- | ----- | 361 | 160 | 521 |
| Minnesota | 36 | 104 | 178 | 194 | ----- | ----- | ----- | ----- | 214 | 298 | 512 |
| Missouri | ----- | ----- | 195 | 257 | ----- | ----- | ----- | ----- | 195 | 257 | 452 |
| Texas | ----- | ----- | 129 | 224 | ----- | ----- | ----- | ----- | 129 | 224 | 353 |
| Colorado | 142 | 148 | ----- | ----- | ----- | ----- | ----- | ----- | 142 | 148 | 290 |
| California | ----- | ----- | 371 | 279 | ----- | ----- | 168 | 152 | 539 | 431 | 970 |
| Percent of waybills | 75 | | 65 | | 72 | | 78 | | 68 | | |

[1] Source—appendix C. *Piggyback Traffic Characteristics*, Statement No. 66-1, Interstate ommerce Commission, December 1966; includes only data for States having at least 5 per- ent of originating or terminating waybills.
[2] Plan I—Railroad transports motor carrier trailers over a portion of the motor carrier's ip. Motor carrier deals with shipper and furnishes pickup and delivery service charging otor carrier rates to shipper.
[3] Plan II—Railroad furnishes all equipment, both flat cars and trailers, and provides pickup and delivery service charging railroad rates to shipper.
[4] Plan III—Railroad transports trailers either owned or leased by the shipper at a flat rate per mile. Shipper is responsible for pickup and delivery.
[5] Plan IV—Railroad transports trailers owned or leased by the shipper on flatcars also owned or leased by shipper at a flat charge per car, loaded or empty. Shipper picks up and delivers, loads and unloads.




*igure 2.—Accumulative percentage of travel from trips of increasing length for passenger cars, single-unit trucks, and combinations.*

## *Characteristics of Piggyback Operation*

The Interstate Commerce Commission eport, *Piggyback Traffic Characteristics*,[3] conains extensive information on *piggyback* perations. Data from appendix C of that eport was used to compile table 2 in which is shown that shipments were concentrated 12 States. Although data relating *piggyback* rigins to destinations are not readily availble, a substantial proportion of these movements are east-west between the major rail and ea transportation hubs. Because the data in he table are from the Interstate Commerce Commission's (I.C.C.) *1 percent waybill ample*, the total number of shipments can be pproximated by multiplying the sample data by 100. Accordingly, it is estimated that 443,900 trailers were shipped by rail to or from Illinois, the State with the maximum number of shipments in 1963. This is an average of 1,216 trailers per day or 51 trailers per hour. Even if all these shipments going through all the *piggyback* terminals in the State had been concentrated on a single major highway, there would have been fewer trailers on that highway than are usually carried by a typical heavy-truck route. On U.S. 66 southwest of Chicago, the number of trailer combinations in 1963 averaged 1,957 vehicles per day. This figure is based on counts obtained by the Illinois Division of Highways.[4] The trailer volume on this one highway was 60 percent more than all TOFC movements originating or terminating in the State.

Several comparisons can be made to determine the portion of present highway truck cargo that might be served by *piggyback*. There would be no advantage to transporting goods by *piggyback* if transportation by tractor truck semitrailer combination alone is less costly than having the trailer moved part of the way by rail. Depending on the orientation of *piggyback* terminals with respect to actual origin and destination of shipments, there are minimum distances for which all-highway hauling is more economical than *piggyback*. "Average short-line length of haul for all *piggyback* rail waybills, was 711 miles per car; the local average haul was 589 miles, and for interline service, 929 miles. Plans I and II had the lowest average short-line hauls per car; plan IV had the greatest. Average short-line hauls ranging 600 miles and upward suggest that *piggyback* competes effectively for relatively long haul traffic. The average hauls computed from the sample exceed distances of 300 to 425 miles which, based on early cost analyses by different transportation interests, were thought to be the shortest distances at which *piggyback* might be competitive with highway operations. They also exceed 1963 average hauls per ton of 464 miles for class I railroads, and the average haul for class I motor common carriers and common carriers of general freight, 267 and 342 miles, respectively." [3]

As shown in figure 2, approximately 37 percent of all travel by all highway trailer combinations consists of trips 300 miles or longer. Only about 27 percent consists of trips longer than 425 miles. As indicated above, the minimum shipping distances for which *piggyback* is likely to be competitive with highway transportation has been estimated to be 300 to 425 miles. More detailed trip-length data by vehicle type is given in table 3. Interpolating between the 300- and 500-mile entries on the line *all trailer combinations*, it is estimated that less than 3 percent of all trips are longer than 425 miles, although these trips account for 28 percent of all travel by combinations. As these are

[3] *Piggyback Traffic Characteristics*, Statement No. 66-1, nterstate Commerce Commission, December 1966.

[4] *Traffic Characteristics on Illinois Highways, 1963*, Department of Public Works and Buildings, station No. 24BX, p. 100.



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**Table 3.—Cumulative percentages of trips and travel by different types of vehicles**

| Vehicle type | Category | One way trip length, miles: 5 | 10 | 20 | 30 | 40 | 50 | 100 | 250 | 500 | 700 | 1,000 | 1,500 | 2,000 | 2,500 | 2,500 and over |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Passenger cars [1] | Trips | 56.4 | 76.8 | 91.3 | 95.8 | 97.3 | 98.0 | 99.5 | 99.9 | ----- | ----- | 100.0 | ----- | ----- | ----- | 100.00 |
| | Travel | 14.2 | 31.0 | 54.5 | 67.4 | 73.7 | 77.8 | 89.9 | 97.7 | ----- | ----- | 100.0 | ----- | ----- | ----- | 100.00 |
| Single unit trucks: [2] | | | | | | | | | | | | | | | | |
| Panel and pickups | Trips | 51.26 | 75.24 | 89.29 | 94.01 | 96.38 | 97.61 | 99.44 | 99.90 | 99.97 | 99.98 | 99.99 | 100.00 | 100.00 | 100.00 | 100.00 |
| | Travel | 14.38 | 30.89 | 50.70 | 62.22 | 70.40 | 75.90 | 88.08 | 94.76 | 96.88 | 97.59 | 98.32 | 98.96 | 99.36 | 99.62 | 100.00 |
| Other 4-tire trucks | Trips | 50.14 | 74.51 | 88.44 | 93.46 | 96.08 | 97.48 | 99.44 | 99.93 | 99.98 | 99.99 | 99.99 | 100.00 | 100.00 | 100.00 | 100.00 |
| | Travel | 13.51 | 30.00 | 49.28 | 61.26 | 70.17 | 76.32 | 89.35 | 96.34 | 97.91 | 98.49 | 98.78 | 99.25 | 99.47 | 99.67 | 100.00 |
| 2-axle, 6-tire trucks | Trips | 40.57 | 64.09 | 81.42 | 88.17 | 91.99 | 94.24 | 98.34 | 99.77 | 99.95 | 99.98 | 99.99 | 100.00 | 100.00 | 100.00 | 100.00 |
| | Travel | 7.75 | 18.58 | 34.69 | 45.54 | 54.29 | 60.93 | 79.36 | 93.19 | 97.04 | 98.20 | 98.97 | 99.55 | 99.77 | 99.91 | 100.00 |
| 3-axle or more | Trips | 31.40 | 17.04 | 79.53 | 87.26 | 91.47 | 93.77 | 98.25 | 99.69 | 99.94 | 99.97 | 99.99 | 99.99 | 100.00 | 100.00 | 100.00 |
| | Travel | 5.69 | 58.85 | 34.76 | 46.05 | 54.74 | 60.92 | 79.14 | 91.80 | 96.67 | 97.94 | 98.88 | 99.46 | 99.65 | 99.84 | ----- |
| Truck with light trailer | Trips | 39.51 | 59.96 | 79.81 | 87.39 | 90.67 | 92.06 | 95.53 | 98.21 | 99.17 | 99.50 | 99.74 | 99.89 | 99.99 | 100.00 | ----- |
| | Travel | 4.06 | 8.64 | 18.85 | 25.34 | 29.52 | 31.83 | 40.63 | 56.40 | 68.90 | 76.32 | 83.73 | 90.68 | 97.64 | 99.96 | 100.00 |
| Subtotal | Trips | 45.11 | 69.17 | 85.11 | 90.95 | 94.10 | 95.86 | 98.88 | 99.84 | 99.96 | 99.98 | 99.99 | 100.00 | ----- | ----- | ----- |
| | Travel | 10.08 | 23.15 | 40.81 | 51.98 | 60.54 | 66.73 | 82.74 | 93.70 | 96.95 | 97.95 | 98.71 | 99.31 | 99.60 | 99.79 | 100.00 |
| Semitrailer combinations: [2] | | | | | | | | | | | | | | | | |
| 3-axle | Trips | 27.39 | 44.73 | 59.31 | 67.53 | 73.88 | 78.22 | 89.20 | 96.93 | 99.02 | 99.46 | 99.73 | 99.86 | 99.92 | 99.95 | 100.00 |
| | Travel | 1.66 | 4.23 | 8.70 | 13.03 | 17.73 | 21.89 | 38.54 | 64.23 | 79.77 | 85.35 | 90.24 | 93.93 | 95.86 | 97.63 | 100.00 |
| 4-axle | Trips | 18.68 | 33.02 | 47.33 | 54.66 | 61.24 | 65.87 | 81.19 | 94.30 | 98.33 | 99.17 | 99.71 | 99.93 | 99.97 | 99.98 | 100.00 |
| | Travel | .77 | 2.22 | 5.24 | 7.83 | 11.15 | 14.15 | 30.15 | 59.82 | 79.95 | 87.25 | 93.73 | 96.67 | 98.61 | 99.17 | 100.00 |
| 5-axle or more | Trips | 18.76 | 30.84 | 40.66 | 47.13 | 53.73 | 59.20 | 76.18 | 90.67 | 96.91 | 98.23 | 99.05 | 99.63 | 99.82 | 99.94 | 100.00 |
| | Travel | .56 | 1.42 | 2.93 | 4.59 | 6.99 | 9.57 | 22.08 | 46.25 | 69.17 | 77.27 | 84.50 | 92.05 | 95.63 | 98.32 | 100.00 |
| Subtotal | Trips | 20.88 | 35.41 | 48.66 | 56.00 | 62.52 | 67.29 | 81.94 | 94.05 | 98.15 | 99.01 | 99.55 | 99.84 | 99.92 | 99.97 | 100.00 |
| | Travel | .85 | 2.28 | 5.03 | 7.59 | 10.82 | 13.88 | 28.79 | 55.91 | 76.22 | 83.51 | 89.98 | 95.12 | 97.13 | 98.62 | 100.00 |
| Truck and full trailer combinations: [2] | | | | | | | | | | | | | | | | |
| 4-axle or less | Trips | 39.88 | 63.59 | 78.43 | 85.05 | 88.94 | 91.32 | 95.88 | 98.73 | 99.53 | 99.75 | 99.84 | 99.94 | 99.98 | 99.99 | 100.00 |
| | Travel | 4.45 | 11.56 | 20.36 | 26.86 | 32.16 | 36.82 | 50.15 | 68.82 | 81.00 | 86.42 | 89.44 | 94.59 | 97.52 | 98.76 | 100.00 |
| 5-axle | Trips | 12.06 | 22.02 | 33.15 | 41.80 | 51.83 | 54.29 | 78.37 | 95.57 | 98.83 | 99.34 | 99.84 | 99.97 | 99.99 | 100.00 | ----- |
| | Travel | .54 | 1.51 | 3.83 | 6.97 | 11.90 | 15.43 | 36.57 | 73.26 | 88.96 | 93.21 | 97.02 | 99.16 | 99.61 | 99.88 | 100.00 |
| 6-axle or more | Trips | ----- | ----- | 10.25 | 16.84 | 32.84 | 34.74 | 71.25 | 95.56 | 99.67 | ----- | ----- | ----- | ----- | ----- | ----- |
| | Travel | ----- | ----- | 1.85 | 3.67 | 10.16 | 11.08 | 40.71 | 81.50 | 97.22 | ----- | ----- | ----- | ----- | ----- | ----- |
| Subtotal | Trips | 25.24 | 42.25 | 55.20 | 62.81 | 69.90 | 17.79 | 86.92 | 97.13 | 99.20 | 99.55 | 99.84 | 99.95 | 99.98 | 99.99 | 100.00 |
| | Travel | 1.50 | 3.96 | 7.88 | 11.82 | 16.94 | 20.62 | 40.03 | 72.35 | 87.18 | 91.63 | 95.21 | 98.05 | 99.10 | 99.61 | 100.00 |
| Two-trailer combinations: [2] | | | | | | | | | | | | | | | | |
| 5-axle or less | Trips | 2.73 | 7.61 | 25.53 | 39.04 | 47.00 | 54.00 | 75.93 | 95.16 | 99.04 | 99.49 | 99.82 | 99.96 | 99.99 | 100.00 | ----- |
| | Travel | .12 | .62 | 3.96 | 8.23 | 11.78 | 15.79 | 35.90 | 72.06 | 89.84 | 93.31 | 96.83 | 98.99 | 99.69 | 99.95 | 100.00 |
| 6-axle | Trips | 23.08 | 31.36 | 43.17 | 62.09 | 65.69 | 68.00 | 85.89 | 96.84 | 99.28 | 99.76 | 99.92 | 100.00 | ----- | ----- | ----- |
| | Travel | ----- | 1.30 | 4.35 | 12.73 | 15.36 | 17.56 | 41.37 | 73.56 | 90.31 | 95.60 | 98.24 | 100.00 | ----- | ----- | ----- |
| 7-axle or more | Trips | 59.70 | 64.62 | 66.52 | 74.29 | 78.04 | 79.40 | 94.86 | 99.81 | 99.99 | ----- | ----- | ----- | ----- | 100.00 | ----- |
| | Travel | 1.32 | 2.60 | 3.91 | 11.79 | 17.03 | 19.65 | 65.77 | 96.07 | 98.69 | ----- | ----- | ----- | ----- | 100.00 | ----- |
| Subtotal | Trips | 7.50 | 12.65 | 29.20 | 42.81 | 50.20 | 56.51 | 77.77 | 95.55 | 99.11 | 99.54 | 99.84 | 99.96 | 99.99 | 100.00 | ----- |
| | Travel | .13 | .69 | 3.98 | 8.54 | 12.07 | 15.96 | 36.74 | 72.58 | 90.03 | 93.53 | 96.94 | 99.04 | 99.69 | 99.95 | 100.00 |
| All trailer combinations | Trips | 20.66 | 34.99 | 48.34 | 55.93 | 62.53 | 67.30 | 82.10 | 94.30 | 98.25 | 99.06 | 99.58 | 99.85 | 99.93 | 99.97 | 100.00 |
| | Travel | .85 | 2.29 | 5.11 | 7.81 | 11.14 | 14.26 | 29.60 | 57.29 | 77.26 | 84.27 | 90.49 | 95.40 | 97.32 | 98.72 | 100.00 |
| All trucks and trailer combinations. | Trips | 41.58 | 64.23 | 79.80 | 85.90 | 89.54 | 91.74 | 96.46 | 99.04 | 99.71 | 99.85 | 99.93 | 99.98 | 99.99 | 99.99 | 100.00 |
| | Travel | 5.66 | 13.18 | 23.75 | 30.87 | 36.93 | 41.65 | 57.34 | 76.30 | 87.54 | 91.41 | 94.78 | 97.44 | 98.51 | 99.28 | 100.00 |

[1] Nationwide Automobile Use Study conducted April 1961 for Bureau of Public Roads by Bureau of the Census based on one current population survey panel of approximately 4,000 dwelling units.

[2] 1963 Special Truck Weight Study data obtained by the State highway departments i cooperation with the Bureau of Public Roads in the summer of 1963.

minimum distances for *piggyback* usage, and because the percentages are small for longer distances, it appears that less than 20 to 25 percent of all travel by highway trailer combinations can be considered for eventual diversion to *piggyback*.

**Piggyback terminal areas**

In or near larger cities, where the majority of shipments originate—either *piggyback* or all-highway hauling—and where the concentrations of the truck combinations are largest, the diversion from highway transportation to *piggyback* theoretically would not reduce the amount of travel by trailer combinations on the highways at all; it would more likely increase the travel by truck combinations on urban streets and highways. The reason for this is that the shipments must be transported by highway to and from the *piggyback* terminal. Why this is likely to occur is shown in figure 3. Shipment A represents a situation in which both origin and destination are within the urbanized area boundary; shipment B represents a situation in which both origin and destination are outside the periphery of the urban area. In situation A, *piggyback* shipment would eliminate the highway travel as shown by the symbol (−), and add the highway travel, as shown by the symbol (+). Careful location analysis would tend to minimize (+) and maximize (−) on the basis of existing and future locations of shipment origins and destinations.

In most areas, choices for *piggyback* terminal locations are limited, as sites where existing rail lines are near freeway interchanges are preferred. Location of plants and warehouses near the *piggyback* terminal can contribute to efficient operation, but commodities must move through, to, and from other parts of the urban area and the surrounding region. Consequently, the moving of commodities by highway to and from ultimate origins and destinations, whether in the *piggyback* container or in another vehicle, cannot be eliminated. Within the urbanized area, the sum of highway travel eliminated, shown in figure 3 by symbol (−), cannot be substantially more than the sum of the added travel to and from the *piggyback* terminal indicated by symbol (+). However, a substantial amount of highway travel between cities can be eliminated.

Shipment B represents a situation in which all-highway movement would not travel through either the origin or destination urban areas. In this situation, the shift to *piggyback* would produce additional urban travel by trailer combination and reduce rural travel. By shifting to *piggyback*, the reduction of the long highway trailer trips would be most noticeable in the more remote rural areas between major terminal cities separated by 300 miles or more. At such locations, these larg highway vehicles may constitute 25 percer or more of all traffic; but the total traffic vo ume is usually quite low.

Spatial and temporal concentrations ( urban trailer combination movements ma cause problems. In figure 3, the sectior identified as *connection* are intended to repr sent the sections of highways, streets, inte changes, and intersections that provide tl connecting links between the *piggyback* te minal and the expressway network. With limited number of *piggyback* terminals, it w be necessary for *piggyback* shipments from a parts of the urbanized area to traverse the connecting links. The all-highway shipmen will traverse a variety of routes througho the urban area, but in rural areas, the majori will use the principal intercity routes. The spatial dispersions and concentrations ha little significance, except that pavements connecting links must be adequate for t frequent, heavy loads. It is the concentrati of trailer combination movements during t periods immediately before departure a after arrival of the rail trains that can crea highway capacity problems, particularly the periods coincide with morning or eveni peak hour periods. Because time costs mon in commodity transportation, shipppers a consignees often arrange to deliver and pi up their trailers or containers close to t

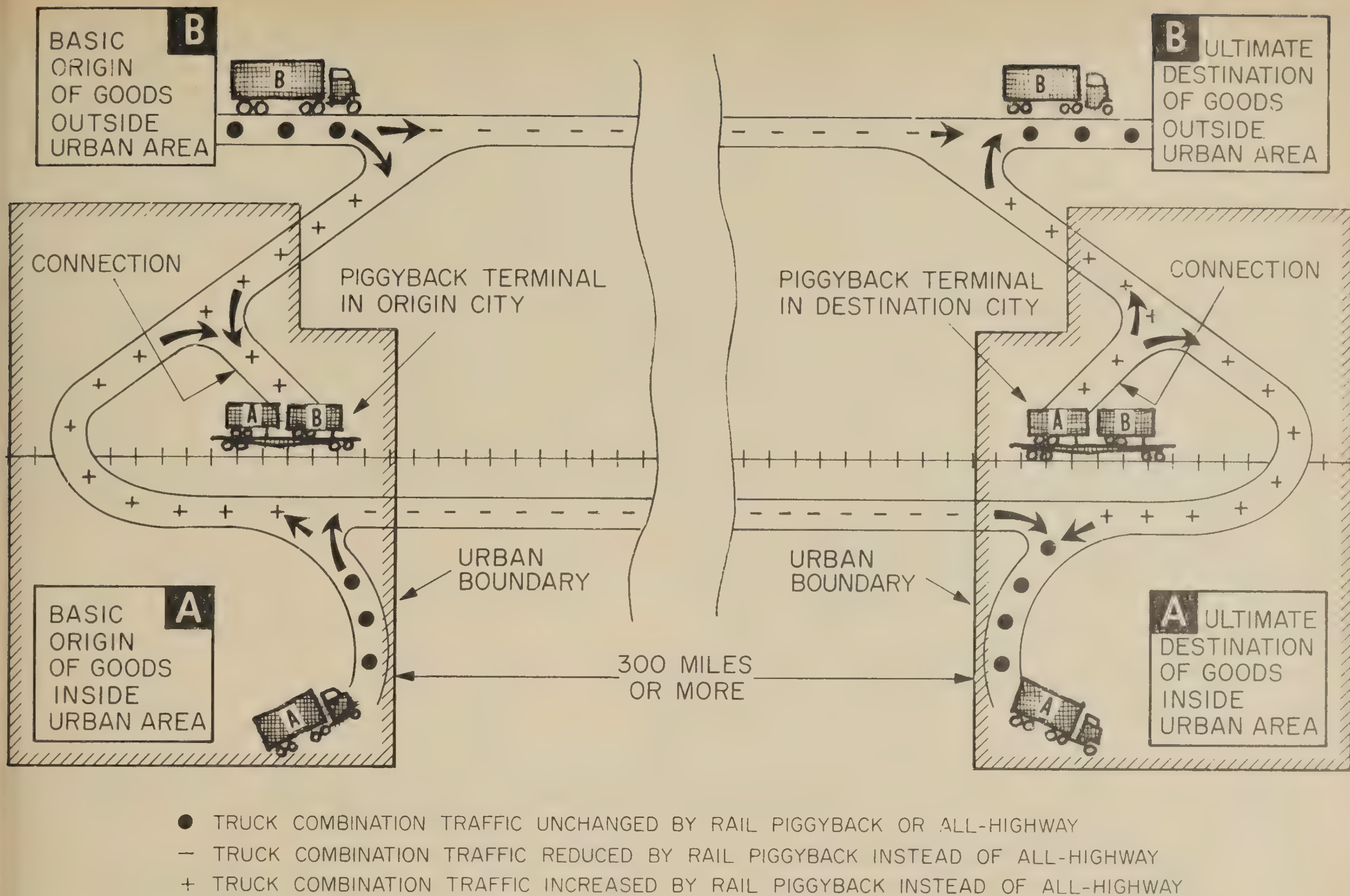



*Figure 3.—Hypothetical changes in highway travel patterns caused by* **piggyback.**

scheduled train time. As unloading rates exceed one trailer per minute, it is not unlikely that several semitrailer combinations will be added to the traffic stream during each signal cycle or equivalent time interval at certain connecting link intersections. If near-capacity traffic already exists at the intersections, serious congestion may result. Because excessive delays would tend to discourage use of the *piggyback* terminal, it is important that adequate traffic capacity be provided on the connecting links.

Accordingly, rail *piggybacking*, although tending to relieve the rural portions of intercity routes by as much as 25 percent of travel by trailer combinations, will have little effect on the amount of such travel in the urban areas served by the terminals. Some increase in total urban travel and the possible concentration of trailer combination movements near *piggyback* rail terminals warrants the attention of transportation planners. Additional lanes of highway for increased capacity at the terminals is one problem. If from one to two more than a half dozen combinations each minute—as limited by rail loading and unloading—entered or left a highway that serves a *piggyback* terminal, a level 4-lane expressway would experience added congestion during peak hours. A more critical problem is the effect on an adequate 4-lane urban expressway of arrivals and departures during off-peak hours. The need is for a sufficiently high level of service on all sections of the urban arterial network so that cargo can be moved expeditiously between the *piggyback* terminal and the ultimate origins and destinations.

**Legal and regulatory considerations**

A decision by the Interstate Commerce Commission in 1954 signaled the succeeding rapid growth of *piggybacking*.[5] In 1967, a Supreme Court decision established the right of motor carriers to avail themselves of railroad *piggyback* services at the same rates charged to other customers,[6] which should encourage *piggyback* to be used on a larger scale for shipments of sufficient length. As indicated previously, this increased use could affect a maximum of about 25 percent of all combination vehicle miles. To approach this maximum would require railroads to be properly located to serve all these long truck movements.

The point at which *piggyback* becomes economical is related to the distance that a trailer unit can be moved on highways during one 8-hour work shift. While practices vary according to the type of operation and geographic location, it is evident that once a trailer or semitrailer is connected to a power unit and is underway, the cost for each additional mile driven is small. The owner's costs for capital investment in the vehicle and the driver wages are the same whether the vehicle is being hitched, driven to a *piggyback* terminal, unhitched, returned empty, or continuing down the road toward the destination. Usually, the driver must be employed for a full shift even if only one or two units are to be moved. When several units are to be loaded at about the same time, near the end of a work shift and shortly before scheduled departure of the trailer train, then several power units may be required to move them all to the loading point on time. If these power units must stand idle except for the

[5] *The New Haven Case*, Interstate Commerce Commission Docket No. 31375, Movement of Highway Trailers by Rail, 293, Interstate Commerce Commission 93, July 30, 1954.

[6] No. 57, American Trucking Association, Inc., et al., versus the Atchison, Topeka and Sante Fe Railway Company, et al.; No. 59, National Automobile Transportation Association of Detroit, Mich., versus Atchison, Topeka and Santa Fe Railway, et al.; and No. 60, United States, et al., versus the Atchison, Topeka and Santa Fe Railway Company, et al.

few hours required each day for moving trailers to and from the loading point, it may be more economical to run some or all of the combinations through to the destination.

The capital cost of the power unit and the driver wages represent a large part of the cost of highway cargo movement, and substantial economies can be achieved when more cargo can be moved by a single power unit. Recent changes in State laws have brought about the changes shown in figure 4. The States shown with dark shading have permitted the use of combinations with a semitrailer and full trailer 65 feet in length since January 1964. The lightly shaded States have subsequently revised their laws and now permit use of these vehicles. In many States these large combinations are restricted to travel only on the major highways, including the Interstate System. In New York and Massachusetts, the combinations are permitted only on certain toll roads, as indicated by the shading. Hence, 4 years ago these large combinations, called *double bottoms*, were permitted in only a few areas; today, except for the Appalachian barrier, it is legal to drive them almost coast to coast. The increased use of *double bottoms* has increased, by 30 to 50 percent, the amount of cargo that can be transported by a single power unit and driver. Additional economics result for operations in which a full load in a smaller body increases loading and other efficiencies. These changes increase the economy of long distance highway transportation.

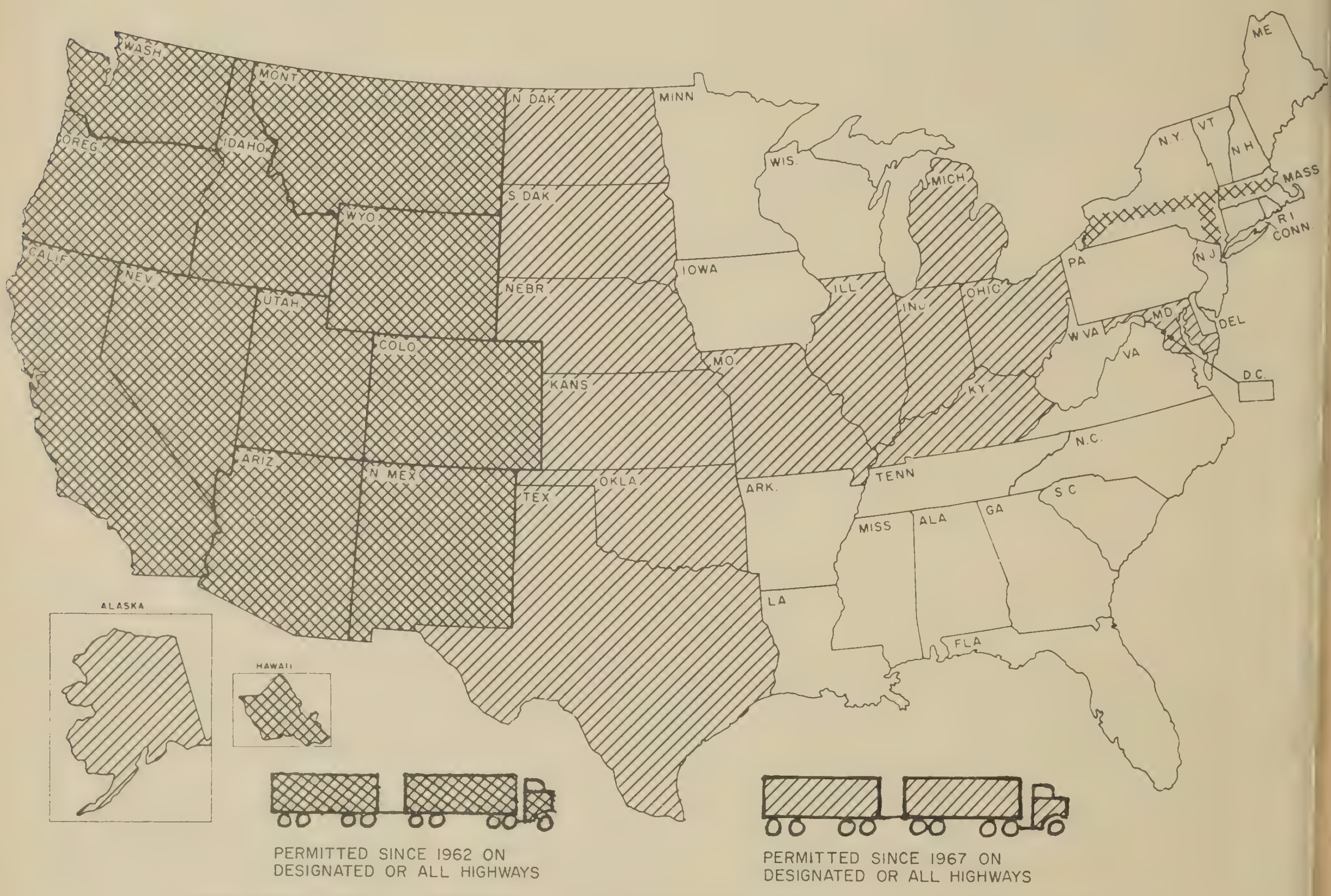
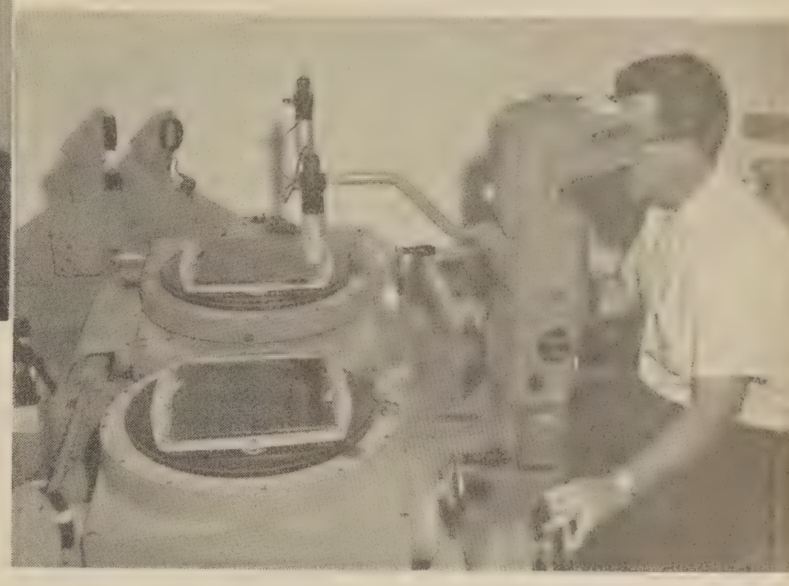



*Figure 4.—States that have permitted use of tractor semitrailer-full trailer combinations since 1962 and currently (from data summarized by American Trucking Association).*

*Two of the photogrammetric instruments, point transfer device (left) and sterocomparator (below), that were used in the evaluation presented in this article. The point transfer device was used to drill pass points on photographic plates; the sterocomparator was used to measure photogrammetric x and y plate coordinates.*



# Analytic Aerial Triangulation for Highways— A Comparison of Two Methods


3Y THE OFFICE OF
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3UREAU OF PUBLIC ROADS

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***Results of a comparison of two methods of analytic aerial triangulation are presented in this article. Accuracies of the Canadian National Research Council (NRC) and the U.S. Coast and Geodetic Survey (CGS) systems are compared. The evaluation was performed with 1:4,800- and 1:9,600-scale photographs. Strip coordinate computations and strip adjustments for the two methods were tested using the same measured plate coordinates and ground control.***

***Although the error propagation within each strip computation is undoubtedly different, the resultant computed ground coordinates are not significantly affected. Either the NRC or the CGS method of analytic aerial triangulation will provide acceptable results for highway location and design.***


## *Introduction*

ANALYTIC aerial triangulation has been established as a useful method of obtaining ɔcurate topographic data that can be used ı highway planning, location, and design, ıd several methods have been developed for ıis approach to photogrammetric bridging. wo of the more prominent methods for com-ıting the positions and elevations of points ı the ground, those developed by the Na-onal Research Council of Canada (NRC) , *2*) [4] and the U.S. Coast and Geodetic Survey (CGS) (*3*, *4*), were evaluated in the investigation reported here. The coordinates obtained from either method can be used for many purposes in highway location and design, but State highway personnel and others who are concerned with photogrammetry and are interested in this method of bridging often question the accuracy of the methods.

Two scales of photographs were used in the investigation to evaluate the accuracy of computed ground coordinates, and the errors in the two methods were compared and evaluated. The information presented should assist State highway organizations and others in selecting the method of analytic strip triangulation that will best suit their individual requirements.

Two previous investigations [5] (*5*) have been conducted to determine the feasibility of

[1] Mr. Chaves was with the Office of Engineering and ɔerations when the project reported here was initiated.
[2] Presented at the Annual Convention of the American ciety of Photogrammetry, Washington, D.C., March 1968.
[3] Previously published by Photogrammetric Engineering, l. XXXIV, No. 7, July 1968, pp. 697-704.
[4] Italic numbers in parentheses identify the references listed p. 126.

[5] *Survey Control Extension by Analytic Aerotriangulation for Highways*, by J. R. Chaves, unpublished thesis, Syracuse University, September 1965.

using analytic aerial triangulation in highway engineering. These included evaluating computed ground coordinates for supplemental control for large-scale, small contour interval mapping employed in highway location and design. In the previous work, coordinate measurements were made with monocular comparators—in this investigation, a stereocomparator was used.

### *Aerial Photography*

Aerial photographs, used in a mapping project for the extension of Colonial Parkway near Williamsburg, Va., were provided by Regional Office 15 of the Federal Highway Administration. Two photographic flight strips, used for the comparative evaluation experiment, were taken with a Wild RC–8 mapping camera equipped with a 6-inch focal length Aviogon lens. The first flight strip of an area about 12,000 feet long consisted of 10 photographs at a scale of 1:4,800. The second flight strip of an area about 16,000 feet long, consisted of six photographs at a scale of 1:9,600. The larger scale photographs were used for map compilation and bridging; the smaller scale photographs were used exclusively for analytic bridging. Diapositive plates were printed emulsion-to-emulsion from the aerial negative film by an automatic-dodging printer.

### *Ground Control Survey and Photographic Targets*

Basic horizontal control was surveyed to better than second-order accuracy using a Tellurometer and Wild T–2 theodolite; vertical control was surveyed to second-order accuracy using a Zeiss N–2 automatic level. Ground positions of 39 points and elevations of 42 points were surveyed on the ground. Ground coordinates of these points were available for controlling the triangulated strips and for testing the accuracy of the analytically computed coordinates.

All but four surveyed points were premarked by photographic targets. The other four points were natural objects that could be readily identified in the aerial photographs. Three types of target designs (fig. 1) were used as markers of surveyed ground control. Nine of the type A targets were placed throughout the photographed area by the mapping contractor. Seven targets of the type B and 23 of the type C targets were placed throughout the project by personnel of the Bureau of Public Roads. The legs of the type A targets were made of white muslin. The centers of the type B targets consisted of alternating colored cloth wedges of either blue and black or brown and black. The centers of the type C targets were solid black squares. Whenever targets were placed in wooded areas, the legs were extended somewhat to facilitate locating them on the aerial photographs.

### *Photogrammetric Instruments and Measuring Procedure*

Photographic $x$ and $y$ plate coordinates were measured with a Wild STK 1 Stereocomparator equipped with a Wild EK 4 Electric Coordinate Printer that recorded coordinate measurements to the nearest even micron. Comparator output was recorded on punched cards that could be used as computer input data. Measurements were made at 70° F. ±1° in a temperature controlled room using 11 diameter magnification and a 40-micron diameter measuring mark.

A Wild Pug 3 Point Transfer Device was used to drill six pass points, perpendicular to the flight axis, along the center of each photographic plate. Two holes were drilled in the vicinity of the customary pass-point locations. Wherever feasible, these were located in areas of relatively flat topography so that $x$ and $y$ parallaxes at the time of coordinate measurement could be accurately and readily removed. Although a three-dimensional view was available for selection of pass-point locations, all holes were actually drilled monocularly, using the same drill.

During measurement, each plate was oriented with its emulsion side down and the photographic $x$-axis nearly parallel to the comparator $x$-axis. The $x$ and $y$ coordinates were measured on the left-hand stage while the parallaxes, $px$, and $py$, were recorded from the right-hand stage.

Each of the image points was measured four times. Because the fiducial marks in the camera had open centers, it was necessary to measure each of the four legs and then mathematically intersect for the center of the fiducial. Five measurements were made on each leg.

### *Analytic Systems*

It is beyond the scope of this article to present the mathematical basis of the analytic aerial triangulation systems used in th investigation; however, the theoretical bas can be pursued by consulting the reference literature (*1, 2, 3, 4, 6, 7, 8, 9*). Document FORTRAN computer programs are al included ln the referenced literature (*1, 2,* *4, 9*).

### *Computers*

Because of their availability, four IB computers, were used in the investigatio 7030 (STRETCH), 7010 (60K), 7090 a 360 Model 50. To avoid unnecessary dela no computer program conversions we attempted during the investigation but programs are now operational on the IB 360.

The STRETCH computer used for comp ing the strip coordinates by the triplet meth was made available through the courtesy the CGS. The NRC strip computations we performed on the IBM 7010 system using 18-digit mantissa. The CGS strip adjustme were computed on the IBM 7090 and the N strip adjustment with the IBM 360.

### *Computer Program Features*

For the CGS strip computation pho graphic $x$ and $y$ coordinates of each ima point occur on separate cards. Measureme from one to 10 can be made for each point, all the cards must be together. In multi observations, coordinates that deviate m than 25 microns from the mean are reject If two such rejections occur in a given set, computation is stopped and a new triang tion is started. Coordinates of pass points each photograph of the triplet must be i

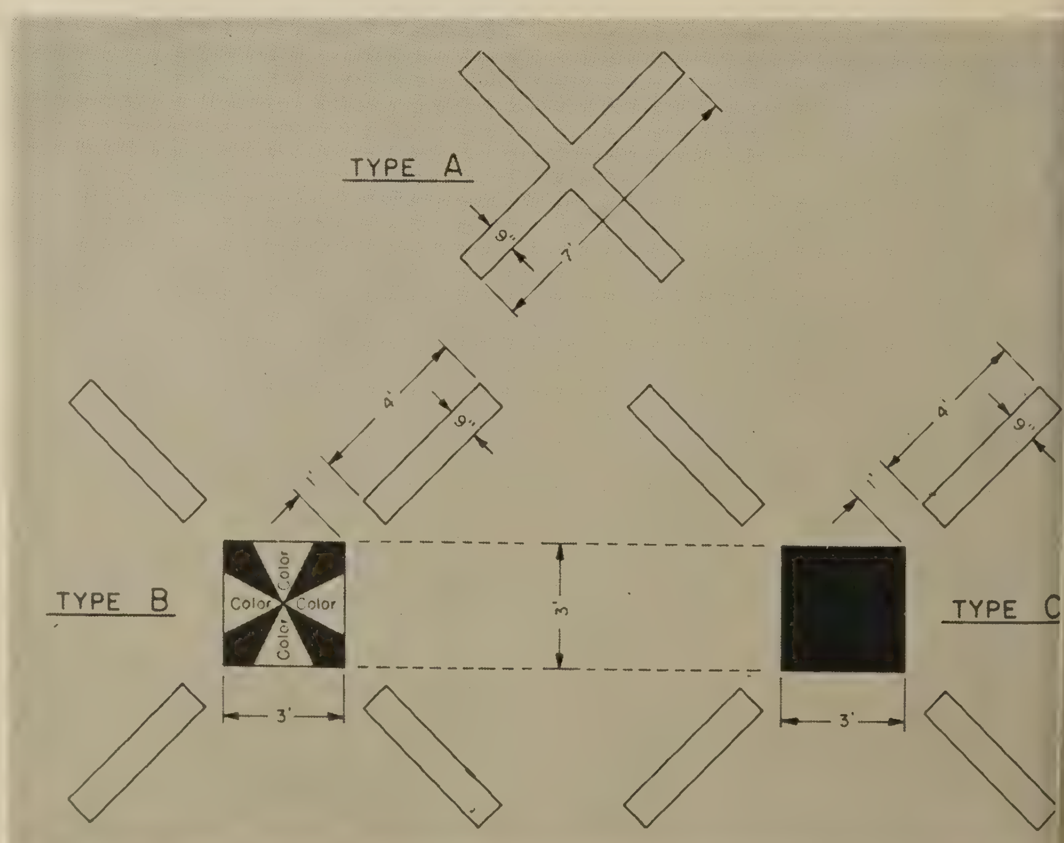


*Figure 1.—Photographic target designs.*

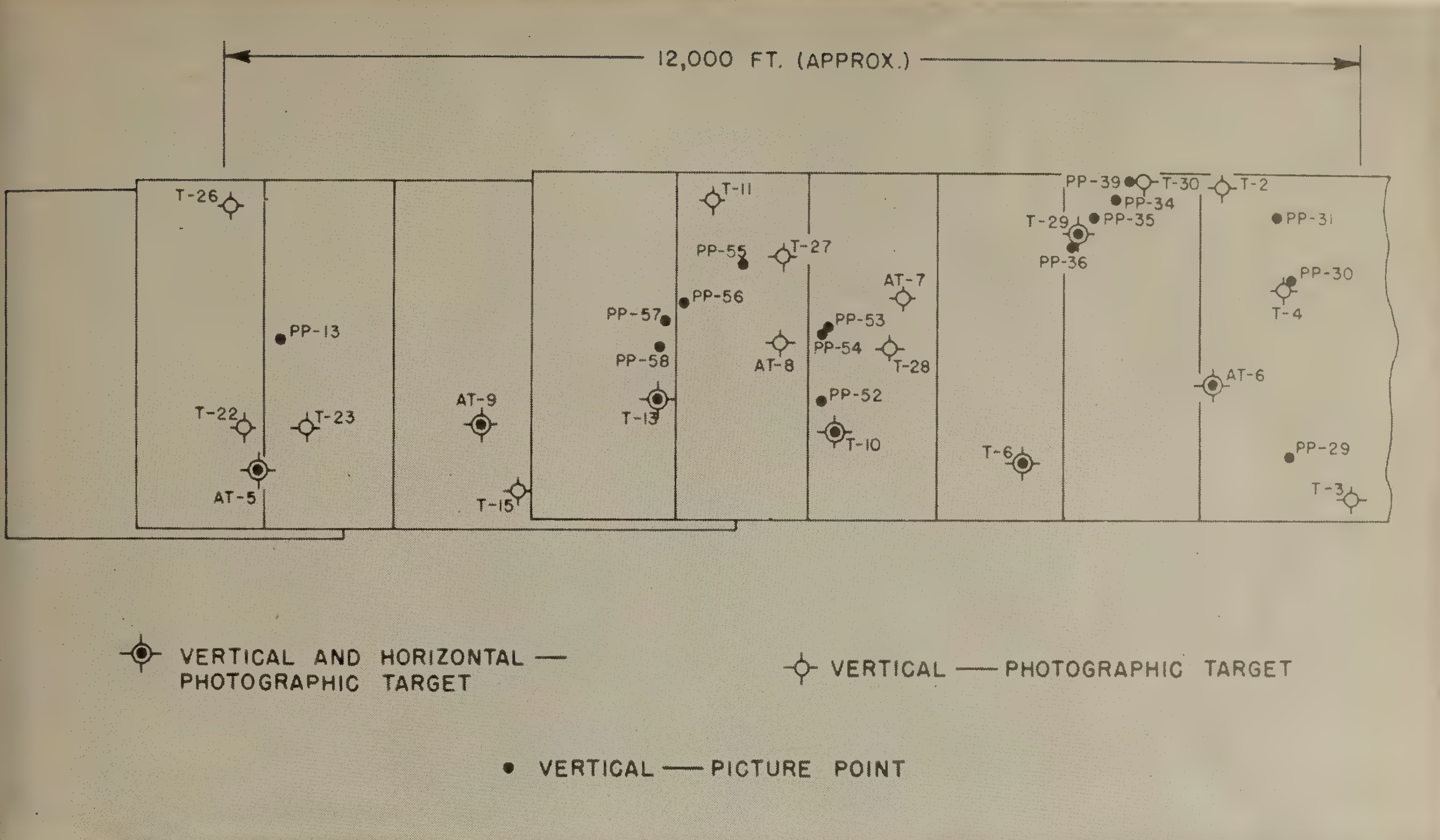


*Figure 2.—Ground control distribution, 1:4,800-scale photography.*

rict sequence, and a card sort is performed insure the proper order. In the triplet solu-on, a given pass-point image is rejected if its sidual parallax exceeds the limit set by the ser. The companion pass point in the same ea is then substituted for it. If two pass oints, for a given model in the same area e rejected, the solution is terminated.

The vector sum of all $x$ and $y$ parallaxes is inted out for each pass point that appears three photographs; only the $y$ parallaxes e output for all other image points. A single ot-mean-square value of all residual paral-xes for the 18 pass points in a triplet is also tput and serves as a reliability number for e triplet.

The NRC strip computation provides for rrecting the measured photographic co-dinates for the effects of differential film rinkage, radial lens distortion, earth curva-re, and atmospheric refraction.[6] Two cor-tion factors for differential film shrinkage applied in the $x$ and $y$ directions. This ngle set of values is applied to all the photo-aphs in the flight strip. Any number of age points may be used for relative orienta-n, and an experimental weighing equation y be applied if the photographs have been tained with a Wild 6-inch Aviogon lens. ith this equation, image points near the ncipal point are given more weight in the ative orientation solution than those located near the corners of the photograph. As many as 10 image points may be used for scaling by an appropriate signal on each scaling point card. Equal weight is given to each scaling point. There are also four standard patterns for the scaling points that can be used, depending on a number punched in the first data card of the strip. This same pattern of image points is used throughout the triangulated strip, but a maximum of four scaling points is permitted with the standard patterns. The program has provisions for discarding anomalous scale transfer points.

[6] The coordinate refinement portion of the NRC program s not used in the investigation.

The measured photographic coordinates for input to the NRC program are arranged in groups according to models. The first card of each model contains the coordinates of the principapl points of the two photographs and a number that determines the number of points to be used in relative orientation. The coordinates of corresponding image points appear on each of the subsequent cards. Immediately following the first card are cards for the relative orientation points. All other object-point cards come last. The residual parallaxes will be at photograph scale, providing the value of the base component $bx$ in the first model has been set equal to the actual distance on the photograph. Residual $y$ parallaxes are printed out for each image point.

Input data for the CGS and NRC strip adjustment programs are similar. They include:

- Strip coordinates and surveyed ground control data.
- Strip coordinates of all the points whose ground coordinates are needed.
- The $x$ and $y$ strip coordinates of two points near each end of the flight strip for defining the axis-of-flight.
- A card containing the degrees of polynomials to be used.

The CGS and NRC methods provide for first, second, and third degree polynomials for correcting the horizontal and vertical coordinates. The NRC program also allows for higher degree polynomials and the use of a separate degree polynomial for correcting scale and azimuth, longitudinal tilt, and transversal tilt. The NRC program can also be used for a block adjustment of parallel overlapping flight strips.

## *Evaluation Scheme*

In testing the accuracy of the analytic computations by the two methods, the following procedure was employed:

- The measured $x$ and $y$ plate coordinates for the 1:4,800- and 1:9,600-scale photographic strips were corrected for film and radial lens distortion. The mathematical formulation is described in reference (*8*). This method of coordinate refinement is included as an integral part of the Three-Photo Aerotriangulation program (*3*).
- The strip coordinates for the two flight strips were computed by the NRC and CGS methods using the same set of refined coordinates. Twelve image points in each model

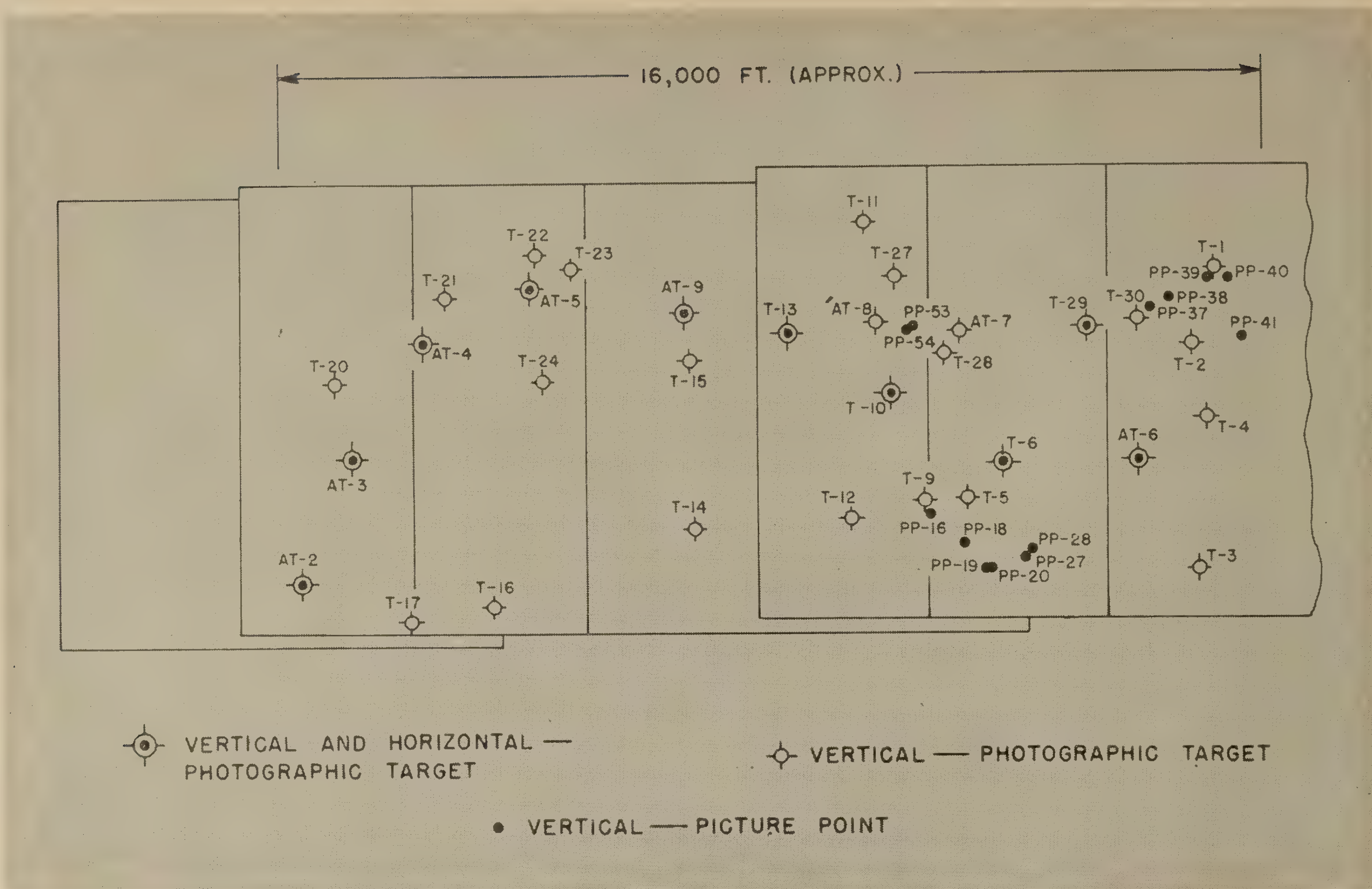


*Figure 3.—Ground control distribution, 1:9,600-scale photography.*

were used to compute the relative orientation. Two of these image points were located in each of the six conventional pass-point locations.

- The computed strip coordinates for each scale of photographs were adjusted and transformed to ground coordinates by the NRC and CGS strip adjustment methods. Second and third degree polynomial adjustments were employed for each of four combinations. The following four combinations of strip coordinates and strip adjustments permitted a comparison between two independent methods of analytic triangulation and enabled determination of the differences caused by either the strip adjustments or the strip coordinate computation:

  NRC-NRC—NRC strip coordinates and NRC strip adjustment.

  CGS-CGS—CGS strip coordinates and CGS strip adjustment.

  NRC-CGS—NRC strip coordinates and CGS strip adjustment.

  CGS-NRC—CGS strip coordinates and NRC strip adjustment.

The standard errors for the *X*, *Y*, and *Z* coordinates were computed for all ground surveyed test points that were withheld from the strip adjustment solution.

The ground control distribution used for controlling and testing the computations for the 1:4,800-scale photographs is shown in figure 2. Four horizontal and seven vertical control points were used for strip adjustment. The horizontal ground control points used are identified in the figure as T–26, AT–9, T–29, and T–4. Vertical control is designated as AT–5, T–26, T–11, T–13, T–28, T–2, and T–3. The ground control distribution for the 1:9,600-scale photographs is shown in figure 3. Four horizontal control points (AT–3, AT–9, AT–7, T–4) and eight vertical control points (AT–4, T–17, T–22, T–9, T–11, T–28, T–1, T–3) were used to adjust this strip.

The *X* and *Y* ground coordinates of 14 points and the elevations of 13 points were available for testing the accuracy of analytically computed coordinates for the 1:4,800-scale flight strip. The horizontal position of 25 ground points and elevations of 23 points were available for testing the computed coordinates for the 1:9,600-scale strip.

## Results

### Triangulation—1:4,800-scale photographs

The standard errors obtained from the different combinations of strip coordinate and strip adjustment computations for the 1:4,800-scale photographs are shown in tables 1 and 2. By the two independent method using second degree polynomials, no signif cant differences in the computed *X* and coordinates were evident in comparison No. table 1. The standard error of the *Y* c ordinates for the CGS method is slight smaller than that for the NRC metho Similarly, in the second comparison, it slightly smaller than that for the NR method. In the second comparison, only slight reduction in the standard error of was caused by the CGS adjustment. comparison No. 3, no significant differenc resulted from the strip adjustments.

In the fourth and fifth comparisons, differences could be attributed solely to t strip computations. Any minor differen that may have existed from the strip ordinates alone are likely to have been co pensated by the adjustment procedure. In trial combinations the standard errors fo were less than those for *X*.

In the first comparison shown in table the CGS computation, compared with NRC method, resulted in standard err that were larger in *X* and smaller in *Y* and In comparisons Nos. 2, 3, 4, and 5, standard errors for *Z* suggest that the slig improvement in the standard error of the coordinates in comparison No. 1 may h been due to the CGS strip computat rather than to the strip adjustment. A sim

**Table 1.—Standard errors for computed ground coordinates from second degree strip adjustments, scale—1:4,800**

| Comparison number | Trial identification [1] | Coordinate errors | | |
|---|---|---|---|---|
| | | X | Y | Z |
| | | *Feet* | *Feet* | *Feet* |
| 1 | NRC-NRC | 0.49 | 0.38 | 0.34 |
| | CGS-CGS | .51 | .27 | .32 |
| 2 | NRC-NRC | .49 | .38 | .34 |
| | NRC-CGS | .48 | .30 | .34 |
| 3 | CGS-CGS | .51 | .27 | .32 |
| | CGS-NRC | .47 | .32 | .30 |
| 4 | NRC-NRC | .49 | .38 | .34 |
| | CGS-NRC | .47 | .32 | .30 |
| 5 | NRC-CGS | .48 | .30 | .34 |
| | CGS-CGS | .51 | .27 | .32 |

[1] NRC—National Research Council; CGS—U.S. Coast and Geodetic Survey.

**Table 2.—Standard errors for computed ground coordinates from third degree strip adjustments, scale—1:4,800**

| Comparison number | Trial identification [1] | Coordinate errors | | |
|---|---|---|---|---|
| | | X | Y | Z |
| | | *Feet* | *Feet* | *Feet* |
| 1 | NRC-NRC | 0.46 | 0.52 | 0.44 |
| | CGS-CGS | .61 | .31 | .37 |
| 2 | NRC-NRC | .46 | .52 | .44 |
| | NRC-CGS | .60 | .34 | .44 |
| 3 | CGS-CGS | .61 | .31 | .37 |
| | CGS-NRC | .48 | .47 | .39 |
| 4 | NRC-NRC | .46 | .52 | .44 |
| | CGS-NRC | .48 | .47 | .39 |
| 5 | NRC-CGS | .60 | .34 | .44 |
| | CGS-CGS | .61 | .31 | .37 |

[1] NRC—National Research Council; CGS—U.S. Coast and Geodetic Survey.

**Table 3.—Error differences resulting from quadratic and cubic polynomials, scale—1:4,800**

| Trial identification [1] | Polynomial | Coordinate errors | | |
|---|---|---|---|---|
| | | X | Y | Z |
| | | *Feet* | *Feet* | *Feet* |
| NRC-NRC | Quadratic | 0.49 | 0.38 | 0.34 |
| NRC-NRC | Cubic | .46 | .52 | .44 |
| CGS-CGS | Quadratic | .51 | .27 | .32 |
| CGS-CGS | Cubic | .61 | .31 | .37 |

[1] NRC—National Research Council; CGS—U.S. Coast and Geodetic Survey.

Analysis of comparisons Nos. 2, 3, 4, and 5 shows that the more accurate *Y* coordinates of the CGS method were primarily due to the CGS strip adjustment. The smaller standard error for *X* in comparison No. 1 was largely a result of the NRC strip adjustment.

For all the trials adjusted by the NRC method, the standard errors for *X* were about the same as those for *Y*, whereas the *Y* coordinates from the CGS strip adjustments were about twice as accurate as the *X* coordinates.

The differences in standard errors resulting from the quadratic and cubic polynomials used in the two strip adjustments are shown in table 3. For both the NRC and CGS method, the second degree strip adjustments gave better overall results, as expected for a relatively short flight strip and dense ground control.

### Triangulation—1:9,600-scale photographs

The standard errors for computed ground coordinates using the 1:9,600-scale flight strip appear in tables 3 and 4. Strip adjustments were performed using second degree polynomials for the comparisons shown in table 3.

The CGS method gave slightly lower standard errors for *Y* and *Z* in comparison No. 1. In comparison No. 2, no significant differences between the computed coordinates resulted from the two strip adjustments. For comparison No. 3, the results do not corroborate those of the previous comparison because the CGS strip adjustment gave slightly smaller standard errors for *X*, *Y*, and *Z*. In the fourth comparison, no significant differences were caused by the method of strip computation. It is suggested in comparison No. 5 however, that the CGS strip computation gave slightly more accurate elevations.

In both the NRC and CGS strip adjustments, standard errors for *X* and *Y* were about equal. This is unlike the standard errors from second degree CGS adjustments for the 1:4,800-scale photographs (table 1) in which the *Y* coordinates were computed more accurately than the *X*.

Standard errors for the ground coordinates, using third degree polynomials, are shown in table 4. In comparison No. 1, the CGS method gave markedly improved *X* and *Y* coordinates and only slightly improved *Z* coordinates. In the second and third comparisons, the improvements in *X* and *Y* were due mainly to the CGS strip adjustment. In these comparisons, it is suggested by the data for the *Z* coordinates that improvement was a result of the CGS strip adjustment. In comparison No. 4 there appeared to be only slight improvement in *X* from the NRC strip computation. In comparison No. 5 a similar indication was shown for *X*, but improvements for *Y* and *Z* were also shown because of the NRC strip coordinates.

It is suggested in comparisons Nos. 4 and 5 (tables 3 and 4) that the third degree NRC strip adjustment has simply *adjusted out* any differences that may have existed between the strip coordinates. The CGS adjustment does this to a lesser extent. It is also possible that the NRC strip computations were more accurate for the 1:9,600-scale strip, but the improvement was insignificant in terms of the coordinate improvements resulting from the CGS strip adjustment (comparison No. 1). Comparisons for the 1:4,800-scale strip (tables 1 and 2) do not, however, substantiate this conclusion. In table 1, no significant differences were indicated between the two methods of strip computation, whereas in table 2, it is suggested that the slight improvement in *Z* coordinates was due to the CGS strip computation.

Both the NRC and CGS strip adjustments resulted in standard errors for *X* that were about equal to those for *Y*. This is the same relationship obtained with the quadratic adjustments. Differences obtained from quadratic and cubic polynomial adjustments for the two independent methods of trianguation are shown in table 6.

A significant difference occurred in the standard errors of the *X* and *Y* coordinates owing to the degree of polynomial for the NRC adjustment. There was little or no difference for the horizontal coordinates regardless of whether a second or third degree CGS adjustment was employed. For both the NRC and CGS methods, slightly lower standard errors for *Z* were obtained with second degree adjustments.

**Table 4.—Standard errors for computed ground coordinates from second degree strip adjustments, scale—1:9,600**

| Comparison number | Trial identification [1] | Coordinate errors | | |
|---|---|---|---|---|
| | | X | Y | Z |
| | | *Feet* | *Feet* | *Feet* |
| | NRC-NRC | 0.58 | 0.61 | 0.62 |
| | CGS-CGS | .54 | .51 | .48 |
| 2 | NRC-NRC | .58 | .61 | .62 |
| | NRC-CGS | .55 | .58 | .62 |
| 3 | CGS-CGS | .54 | .51 | .48 |
| | CGS-NRC | .60 | .64 | .58 |
| 4 | NRC-NRC | .58 | .61 | .62 |
| | CGS-NRC | .60 | .64 | .58 |
| 5 | NRC-CGS | .55 | .58 | .62 |
| | CGS-CGS | .54 | .51 | .48 |

[1] NRC—National Research Council; CGS—U.S. Coast and Geodetic Survey.

**Table 5.—Standard errors for computed ground coordinates from third degree strip adjustments, scale—1:9,600**

| Comparison number | Trial identification [1] | Coordinate errors | | |
|---|---|---|---|---|
| | | X | Y | Z |
| | | *Feet* | *Feet* | *Feet* |
| 1 | NRC-NRC | 0.89 | 0.92 | 0.66 |
| | CGS-CGS | .55 | .45 | .56 |
| 2 | NRC-NRC | .89 | .92 | .66 |
| | NRC-CGS | .45 | .33 | .47 |
| 3 | CGS-CGS | .55 | .45 | .56 |
| | CGS-NRC | .97 | .92 | .66 |
| 4 | NRC-NRC | .89 | .92 | .66 |
| | CGS-NRC | .97 | .92 | .66 |
| 5 | NRC-CGS | .45 | .33 | .47 |
| | CGS-CGS | .55 | .45 | .56 |

[1] NRC—National Research Council; CGS—U.S. Coast and Geodetic Survey.

**Table 6.—Error differences resulting from quadratic and cubic polynomials, scale—1:9,600**

| Trial identification [1] | Polynomial | Coordinate errors | | |
|---|---|---|---|---|
| | | X | Y | Z |
| | | *Feet* | *Feet* | *Feet* |
| NRC-NRC | Quadratic | 0.58 | 0.61 | 0.62 |
| NRC-NRC | Cubic | .89 | .92 | .66 |
| CGS-CGS | Quadratic | .54 | .51 | .48 |
| CGS-CGS | Cubic | .55 | .45 | .56 |

[1] NRC—National Research Council; CGS—U.S. Coast and Geodetic Survey.

### *Photographic Images*

The discussion here largely reflects the observations made by the stereocomparator operator during measurement of the two photographic flight strips used in the investigation. The target designs used in the investigation are illustrated in figure 1. Based on the use of a 40-micron diameter measuring mark (black dot) and 11 diameter magnification, the center of the type *C* target was found to be both too large and too dark for precise measurement. This was true for both the 1:4,800- and 1:9,600-scale photographs. There was a tendency for the black measuring mark to disappear from view within the target center. Under these circumstances, the type *C* target did not appear suitable for analytic triangulation.

The colored wedges forming the center of the type *B* target lacked tonal contrast in the aerial photograph. The center of this type of target had a rather uniform, gray photographic tone and appeared more like a type *C* target except for the lighter tone. The type *B* target is preferred to type *C* because the black floating mark can be seen within the target center.

The center of the type *A* target appeared too large for optimum measuring accuracy on both scales of photographs. It has been suggested that reduction of the leg widths would provide a more suitable target for the two scales of photographs tested.

In general, the picture points selected by the field crew were found acceptable for coordinate measuring. It was impossible to establish any definite correlation between the types of images (picture points or target types) and the errors in position and elevation at these points.

### *Summary and Conclusions*

Differences in computed ground coordinates of the two analytic systems are caused primarily by the strip adjustments. The degree of polynomial used produces significantly different results with the NRC strip adjustment, but it has a lesser effect with the CGS adjustment. Second degree polynomials in both methods gave the better overall results. With the NRC strip adjustment, polynomials higher than second degree appear unwarranted. For the CGS strip adjustment, the degree of polynomial used should depend on the scale of photographs, length and density of flight strip, and distribution of ground control.

Although the error propagation within each strip computation is undoubtedly different, the resulting computed ground coordinates are not significantly affected.

The magnitude of the standard errors obtained for the computed ground coordinates in the investigation do not necessarily represent the utmost in accuracy that can be expected for the scales of photographs and the distributions and densities of ground control used. Regarding optimum densities and distributions of ground control, no conclusions of the effect of using different photographic target designs are possible.

The author believes that the CGS method of compensating for film distortion is superior to the NRC method. In the NRC program, the same average linear scale factors are applied to the entire flight strip. The CGS method, however, is applicable only to cameras with four corner fiducials, or eight fiducials, if additional fiducials are present along the mid-points of the sides. A separate program was written to provide input to the NRC strip computation program whenever photographs with side fiducials are used. This program transforms the origin of the plate coordinates to the principal point and applies linear film distortion compensation to each photograph of the flight strip.

The choice of a particular method of analytic aerial triangulation depends on (1) personal preferences of the user for specific program features, (2) design of aerial camera(s), and (3) size and speed of the available computer. The NRC strip triangulation program requires less computer storage and runs more efficiently than the CGS strip coordinate computation.

For all practical purposes, either the CGS or the NRC method of analytic aerial triangulation will provide acceptable results for highway location and design purposes.

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# NEW PUBLICATIONS

The Bureau of Public Roads has recently published four documents. These publications may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, prepaid. The following paragraphs give a brief description of each publication and its purchase price.

## Highway Condemnation Law and Litigation in the United States

*Highway Condemnation Law and Litigation in the United States* contains a review of highway condemnation law as reflected in the statutes of the States. This publication was prepared for the Bureau of Public Roads by the University of Wisconsin. It consists of two volumes:

*Vol. 1—A Survey and Critique* (70 cents a copy). The survey was conducted on the assumption that there is too much litigation in highway land acquisition programs. One objective of the survey was to determine whether there is a close relation between the percentage of increase of contested highway condemnation cases and the seemingly higher awards that are being made by the courts as compared with appraised valuations.

The author has reviewed the law of condemnation throughout the United States to pinpoint the principal causes of litigation. The report provides a general review of condemnation law, identifies the issues that have arisen and the frequency with which they have arisen. It contains tables of highway and nonhighway condemnation cases, classification of types of proceedings involved, issues raised, and the record of success of parties on appeal.

The statutory authority to condemn property for highway purposes is reviewed, and examples are furnished to indicate the range of issues with which such statutes deal among different States. The subject of compensability is presented under three major categories—specific rights or interests, requirement of taking, and consequential damages. A description of the issues relating to procedure or practice and a review of the constitutional provisions dealing with the subject of eminent domain are provided.

*Vol. 2—State by State Statistical Summary of Reported Highway Comdennation Cases from 1946 through 1961* ($1.75 a copy)—a supplement to the first volume—is a review of 1,890 reported court decisions in the highway condemnation field during the period 1946–61. It contains a State-by-State breakdown of the cases and provides supporting data for some of the findings in the basic report.

## The Role of Third Structure Taxes in the Highway User Tax Family

*The Role of Third Structure Taxes in the Highway User Tax Family* ($2.25 a copy), a 331-page research and development report prepared under contract with the University of Mississippi, increases the factual basis for assessing the place of so-called *third structure* taxes in modern State tax systems for the support of highways. The information it provides is based on personal interviews with tax administrators and with representatives of trucking associations and individual trucking firms, on mailed questionnaires, and on examination of tax laws and public records.

The principal emphasis of the report is on the administrative aspects of third structure taxes. Its series of detailed State case studies representing 10 major types of such taxes should be particularly valuable to State legislatures, administrators, and others concerned with the problems of financing highways.

## Handbook of Highway Safety Design and Operating Practices

The *Handbook of Highway Safety Design and Operating Practices* (40 cents a copy) is intended to serve all jurisdictions of government and designed to attract the attention of administrative and technical personnel who are making decisions bearing on the safety aspects of street and highway design and operations.

The publication is an illustrated guidebook presenting some of the latest safety techniques in such categories as the roadway cross-section and slopes, bridge design, signing, guardrail and barriers, drainage, and railroad grade crossings. Future supplements to the handbook will include other aspects of safety design and operations—construction and maintenance zones, urban streets and highways, light standards, gores, protective screening, etc. The handbook has a loose-leaf format to accommodate revisions and additions as new techniques are developed. Users of the handbook are urged to forward to the Federal Highway Administration, Washington, D.C., any ideas, comments, or new techniques that are appropriate for use in the handbook. The principal responsibility for the continuation of the publication has been assigned to the Bureau of Public Roads.

## Standard Plans for Highway Bridges, Vol. 1, Concrete Superstructures, 1968

*Standard Plans for Highway Bridges, Vol. 1, Concrete Superstructures, 1968* ($1.25 a copy), is a revised edition of the 1962 publication and pertains to bridge widths and current design specifications and geometrics. The plans are intended to serve as useful guides in the development of suitable and economical bridge designs. Sufficient information has been included so that all plans can be readily modified when contract drawings are prepared.

The volume contains plans for reinforced concrete and prestressed concrete superstructures. Reinforced concrete types include precast channel sections from 20 to 30 feet and cast-in-place I-beam and box girder spans from 40 to 120 feet. The precast-prestressed concrete types include voided sections from 25 to 40 feet, box sections from 40 to 70 feet, and I-beam sections from 35 to 90 feet. For optimum economy, the pretensioned I-beam sections have been designed to use the new 270 grade prestressing strands.

Bridge roadway widths used are 28 feet with H15–44 live load for low-traffic volume, low-design-speed roadways and 44 feet with HS20–44 live load for the standard 2-lane, two-directional roadway.

# APPALACHIAN DEVELOPMENT HIGHWAY SYSTEM

## STATUS OF IMPROVEMENT AS OF SEPTEMBER 30, 1968

| STATE | TOTAL DESIGNATED SYSTEM MILEAGE | OPEN TO TRAFFIC: ADEQUATE SEGMENTS-NO APPALACHIA FUNDS EXPENDED | OPEN TO TRAFFIC: INADEQUATE SEGMENTS-IMPROVED WITH APPALACHIA FUNDS | OPEN TO TRAFFIC: TOTAL |
|---|---|---|---|---|
| GEORGIA | 89.0 | 2.6 | 0 | 2.6 |
| KENTUCKY | 579.6 | 163.3 | 40.2 | 203.5 |
| MARYLAND | 82.2 | 4.1 | 9.4 | 13.5 |
| NEW YORK | 260.0 | 29.5 | - 0 | 29.5 |
| NORTH CAROLINA | 199.4 | 1.3 | 14.0 | 15.3 |
| OHIO | 295.3 | 93.0 | 0 | 93.0 |
| PENNSYLVANIA | 489.9 | 58.1 | 3.1 | 61.2 |
| TENNESSEE | 333.3 | 12.8 | 8.6 | 21.4 |
| VIRGINIA | 203.8 | 25.0 | 18.3 | 43.3 |
| WEST VIRGINIA | 421.7 | 9.9 | 6.8 | 16.7 |
| TOTAL | 2,954.2 | 399.6 | 100.4 | 500.0 |

13.5% | 3.4%

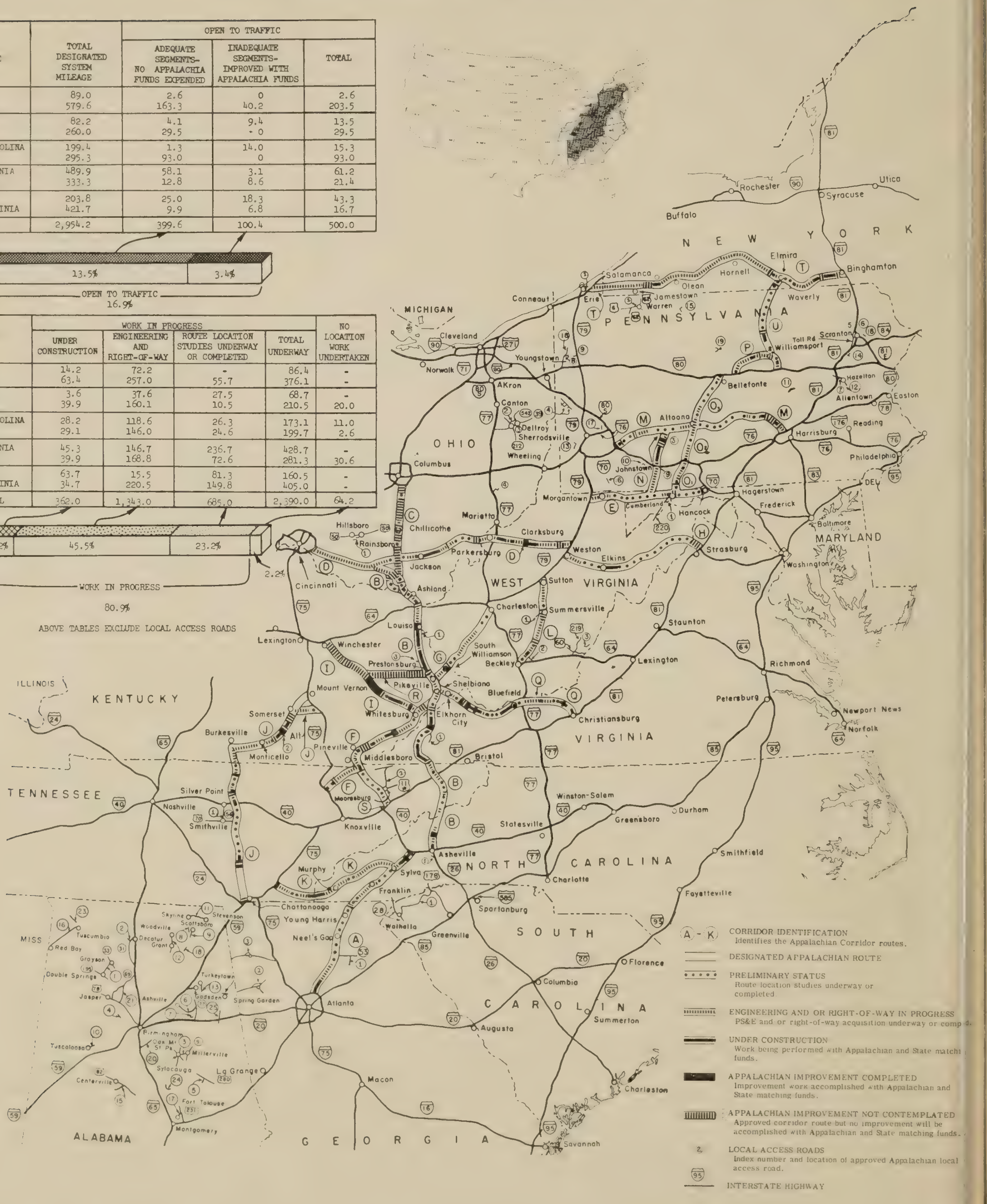
OPEN TO TRAFFIC 16.9%

| STATE | WORK IN PROGRESS: UNDER CONSTRUCTION | WORK IN PROGRESS: ENGINEERING AND RIGHT-OF-WAY | WORK IN PROGRESS: ROUTE LOCATION STUDIES UNDERWAY OR COMPLETED | WORK IN PROGRESS: TOTAL UNDERWAY | NO LOCATION WORK UNDERTAKEN |
|---|---|---|---|---|---|
| GEORGIA | 14.2 | 72.2 | - | 86.4 | - |
| KENTUCKY | 63.4 | 257.0 | 55.7 | 376.1 | - |
| MARYLAND | 3.6 | 37.6 | 27.5 | 68.7 | - |
| NEW YORK | 39.9 | 160.1 | 10.5 | 210.5 | 20.0 |
| NORTH CAROLINA | 28.2 | 118.6 | 26.3 | 173.1 | 11.0 |
| OHIO | 29.1 | 146.0 | 24.6 | 199.7 | 2.6 |
| PENNSYLVANIA | 45.3 | 146.7 | 236.7 | 428.7 | - |
| TENNESSEE | 39.9 | 168.8 | 72.6 | 281.3 | 30.6 |
| VIRGINIA | 63.7 | 15.5 | 81.3 | 160.5 | - |
| WEST VIRGINIA | 34.7 | 220.5 | 149.8 | 405.0 | - |
| TOTAL | 362.0 | 1,343.0 | 685.0 | 2,390.0 | 64.2 |

12.2% | 45.5% | 23.2% | 2.2%

WORK IN PROGRESS 80.9%

ABOVE TABLES EXCLUDE LOCAL ACCESS ROADS








U.S. GOVERNMENT PRINTING OFFICE 1968

# PUBLICATIONS of the Bureau of Public Roads

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