Truck Congestion on Uphill Grades

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● WITH the end of World War II in 1945 and the resumption of near-normal activities in 1946, everyone connected with highway construction faced many problems. The Bureau of Public Roads realized there would be various states working on many divergent tangents of the same problem unless a coordinated effort was made to channel research activities along well-organized lines. One of the problems confronting the Arizona Highway Department was the matter of building new highways, as well as remodeling old ones, through very rough mountainous areas. We were concerned with such things as percentage of grade, truck speeds, sight distance, passing opportunity, roadway width, congestion, and uphill truck lanes.

In July of 1947, Arizona was visited by Bureau of Public Roads officials from San Francisco and Washington, who explained the various types of most-urgent and most-desired research projects on which additional basic data were needed. O. K. Normann, of the Traffic Operations Division of the Washington office of the Bureau of Public Roads, made several suggestions as to the type of studies that Arizona could best participate in. One of these, and the one on which we have spent most of our effort, had to do with truck operational speed characteristics on mountainous highways. The original suggestion was that we combine a loadometer survey with a speed study on various percentages of grades under different conditions of traffic, alignment, elevations, etc.

During the 2-day conference a total of 15 different research projects were discussed. Four were finally accepted by the Arizona Highway Department as being well within its limited capabilities of personnel and finance. It was decided that the department would check into the uphill speed characteristics of heavy trucks on long, steep mountain grades, then go to the downhill characteristics, and finally study the congestion caused by slow-moving vehicles on uphill grades. This presentation represents the final phase of the original program.

In 1948 the project was begun by observing the minimum speeds of heavy trucks on grades ranging from 2 percent to 7 percent. The study disclosed a crawl speed of 7 mph. on a 6-percent grade, with an entrance speed of 47 mph. and after traveling 1,700 feet up the grade. We said at that time it would be desirable if we could set 25 mph. as the minimum speed of passenger vehicles on uphill grades under all conditions. It was also pointed out that the speeds of trucks due to improved motors and higher horsepower would perhaps increase; however, it was felt that the minimum crawl speed would not be raised much in the near future. In other words, the only way to speed up the travel of passenger cars through the hills was to provide a means of removing the slow vehicles from the normal path of travel negotiated by the faster automobiles. The obvious answer was to build uphill truck lanes.

The matter of economics and general lack of overall highway revenue prompted further investigation into evaluating the congestion caused by these slow-moving motor vehicles. By slow-moving vehicles we do not mean heavy trucks alone but include passenger cars pulling house trailers as well as older vehicles that become limited in power and speed because of overheating. Only trucks of a capacity of 1½ tons or greater were considered in this study, however. A heavily loaded vehicle was defined as one loaded to capacity or nearly to capacity.

The results of the first study were presented to the Highway Research Board at the annual meeting in Washington on December 16, 1949. The title of the report was, "Survey of Uphill Speeds of Trucks on Mountain Grades." It is recorded in the proceedings of the Twenty-Ninth Annual Meeting. While we were engaged in the study of speed it was felt advisable to check into the downhill speed of heavily loaded trucks as well as the uphill speed characteristics. During 1950 the field investigations were made and the analysis was completed soon thereafter. In January of 1951 the report was read at the annual meeting of the Highway Research Board. The title of the second paper was, "Survey of Downhill Speeds of Trucks on

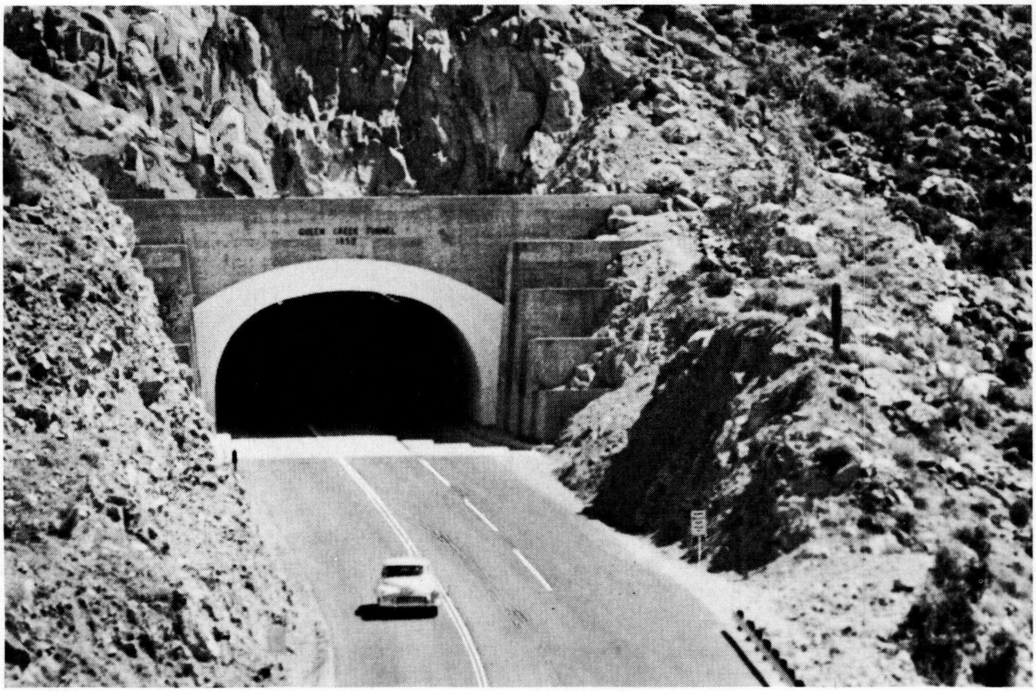


Figure 1. Queen Creek Tunnel, showing striping for uphill truck lane.

Mountain Grades." The findings of this phase of the truck project are in the proceedings of the Thirtieth Annual Meeting.

It was ascertained from the downhill study that trucks need little special consideration on downgrades and generally assume speed characteristics commonly associated with passenger vehicles. Ex-

Figure 2. Texas Canyon, showing end of truck passing bay.

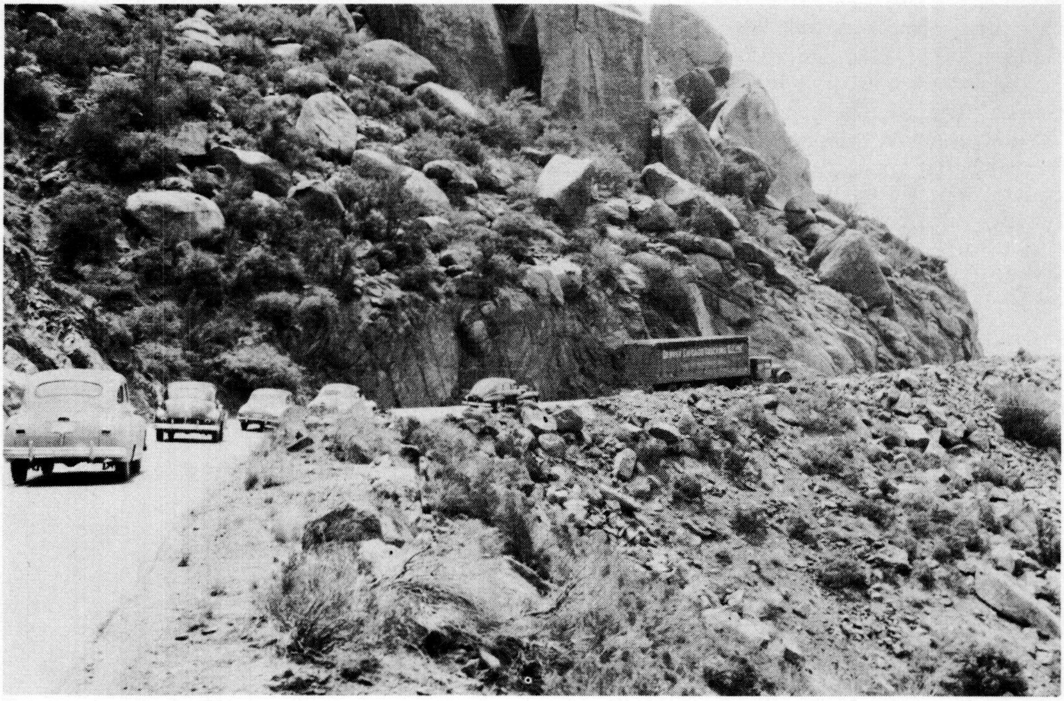


Figure 3. Congestion on Yarnell Hill.

cept under congested traffic conditions, it may be said that downhill truck speeds are largely controlled by the mental attitude of the driver. This is in sharp contrast with uphill speeds, which are determined by the hill-climbing ability of the truck. On the downhill study we could not find any correlation between speeds, weight, or grade.

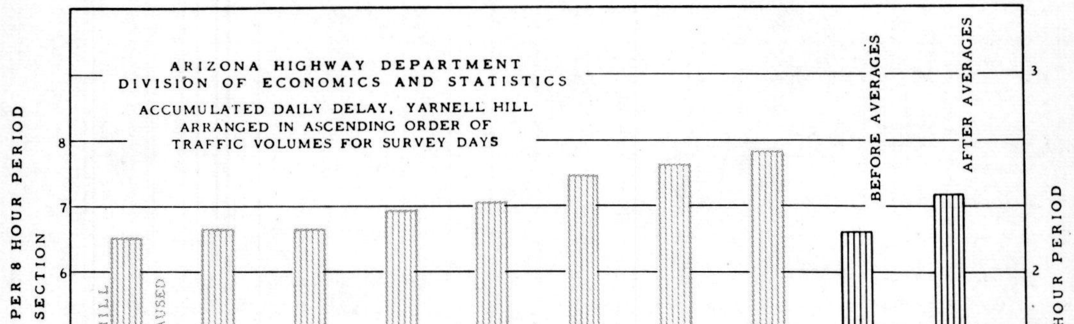


Figure 4.

It is interesting to note, that in connection with passing lane studies and because of brake failure on long downgrades, many states are studying, and some are constructing such things as runaway ramps, braking barriers, or walls that trucks may be driven against in case of an emergency. Runaway ramps are generally steep, adverse upgrades adjacent to the downhill lane onto which a truck out of control may be diverted and stopped.

ance from the minimum crawl speed of 7 mph. recorded in 1949 to 12.5 mph. in 1952, on a 6 percent grade.' This improvement bears out the original conclusion that relief from congestion must be provided by highway construction rather than larger truck motors. Furthermore, in 1954 with the construction of passing bays and because of improved alignment, truck speed was increased only 1.2 mph. to an average of 13.7 mph. or only 50 per-

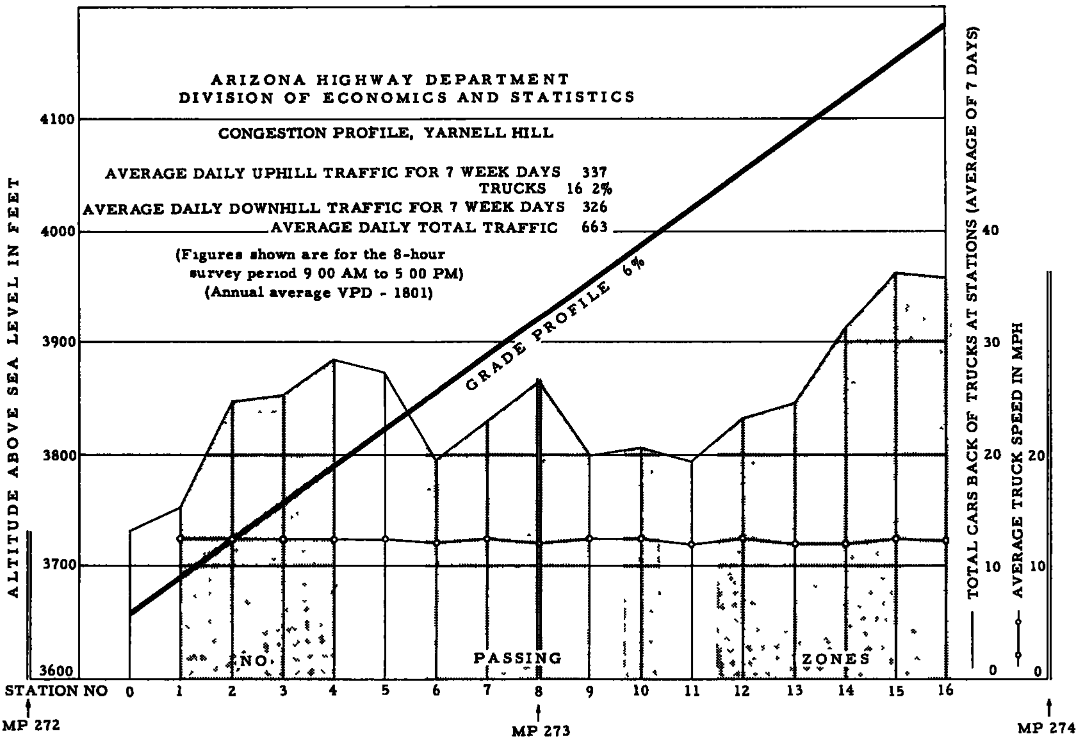


Figure 5.

By the end of 1951 data were available relative to uphill speeds and downhill speeds that definitely indicated the following conclusions: (1) upgrades of 4 percent and for a length of 3,600 feet—and for a 6-percent upgrade with a length of 1,700 feet—uphill passing lanes or bays should be investigated; (2) on the descent, extra passing lanes are not warranted, in most cases, inasmuch as all vehicle speeds are about uniform, except over the crest of the hill; and (3) on uphill passing lanes the lane should be extended over the crest of the hill to a point approximately at which the truck speed builds up to the normal passenger car operational speed.

Modern design has improved perform-

cent of an overall desirable minimum road speed. With this thought in mind we moved our research to the field of congestion, which was the third and final phase of this project. We undertook to show that the congestion caused by slow-moving vehicles on certain lengths of various uphill grades, within definite traffic volume groups, when eliminated, would result in sufficient saving to the motorist to pay for the cost of construction of an uphill lane, or of passing bays as required at certain critical points.

While conducting the uphill survey a limited amount of data were noted on the work sheets regarding the delay caused to other vehicles by slow-moving trucks. The time and location of a car back of a truck were noted. If passing became possible farther up the hill, this also was noted. Serious study was given these data in 1949, and a definite need for more factual information became evident. It was not until late in 1951 that finances and personnel became available, so that we could observe and record what happens when trucks or other slow-moving vehicles cause delay on uphill grades under actual operational conditions.

It was decided to conduct the congestion investigation on one of the hills that had previously been studied relative to uphill truck speeds, inasmuch as some preliminary data were available and observation stations had been designated for the hill. The length of hill was 4 miles and the grade was a continuous 6 percent. It is located on US 89 between Wickenburg and Prescott, Arizona, and is known locally as Yarnell Hill. The highway was of a narrow, two-lane type with a roadway only 22 feet wide; a surface width of 20 feet and with very-poor alignment. The Arizona Highway Adjusted Sufficiency Rating totaled 41 points, a very-low score. Average daily traffic was 1,800 vpd. including 290, or 16.2 percent, heavy trucks. Sight distance was substandard and passing opportunity was almost nonexistent. Slow-moving vehicles operating over such inadequate highways, present a real challenge to highway safety as well as a menace to the ever-increasing problem of congestion.

In the early phase of this congestion study there were a number of items that were outlined as being pertinent to the problem: (1) Can the need for uphill passing lanes or bays be determined by volume of traffic when related to percentage of trucks? (2) On any particular upgrade where should the widening begin and where should it end? (3) Is there a definite point or area on a mountain grade where the delay factor is an important item and for how long does it continue? (4) Can passing bays 1,000 feet long help relieve congestion? (5) Original highway locations in most cases have been in service some 30 years. Such roads are probably those where this type of delay is most frequently found and where relief is most needed. Can this extra lane be economically justified? Will the life of the improvement be such that the savings to the motorist will offset the cost? Basically, from an engineering economic standpoint the savings in dollars should exceed the capital investment plus maintenance if a favorable benefit ratio of greater than one is obtained. (6) With the addition of uphill lanes will the number of accidents decrease?

As a preliminary step in this study we were able to have the district engineers stripe some uphill lanes on existing roadways where there was at least a minimum width for three lanes. These sections should not be confused with three-lane highways but rather as a roadway with two uphill lanes, the inside for fast travel and the outside for slow travel with one downhill lane. At all of the locations where this expedient has been tried it has worked exceptionally well and has materially reduced congestion.

Any study of congestion, whether it be on a level highway or on a 6-percent grade, is quite involved. That is, when does congestion actually set in? Is it when moving along on an open highway at the normal rate of speed and someone passes you? Did the driver pass because he felt that the car ahead was an obstruction and he was being delayed or congested? A dictionary defines the word "congest" as: "to aggregate; accumulate, to affect with over-crowding, to gather; become congested." It might also have said aggravate or irritate when considering long queues of passenger cars delayed by slow-moving vehicles through mountainous areas. It was our decision to consider that all vehicles delayed behind any slow-moving truck were congested, inasmuch as the truck speed, at its best, was only half of the minimum desired passenger-car speed of 25 mph. under any condition of grade or alignment. It might also be said that perhaps there are two causes of congestion, i.e., voluntary and involuntary. The voluntary type appears when a driver intentionally slows down through mountainous area so that his passengers may view the scenery or, perhaps, because the driver is fearful of mountain grades and prefers to go very slowly. The involuntary type is when a driver is forced to proceed slower than his desired rate of speed, of course. With the problem being discussed this occurs when a vehicle must decelerate and follow one traveling at a lower than normal rate of speed where there is little or no opportunity to pass. This lack of opportunity to pass depends not only on the traffic in the same lane but also upon the volume and type of opposing traffic.

For this project a field party consisting of four men was used. One man recorded and classified all traffic, while the others tabulated congestion data. The grade under observation was divided into 1/10-mile intervals with panels of high visibility cloth used as station markers. Since the observation posts could not be perpendicular to the roadway at all points, a line of sight from the observation point was used to adjust the roadside interval markers. This method assured that a vehicle passing behind the marker represented a distance of 1/10 mile of roadway traveled.

Each truck was considered as a single unit, and the following data were recorded: (1) classified manual traffic count by 15-minute intervals; (2) time at which a truck or vehicle passed the 0-mile point on the hill, at which time the stop watch was started; (3) stop-watch time as each station marker was passed; (4) stop-watch time when overtaking vehicles either piled-up or passed without delay; (5) approximate meeting point with opposing traffic; (6) stop-watch time of completion of passing movement of delayed vehicle; and (7) miscellaneous data such as test section location, type of vehicles, date.

During the course of this study two test sites were examined. The second location was at Ashfork Hill on US 66 in the northern part of the state. For the purpose of this presentation only the data obtained at Yarnell Hill will be discussed because of time

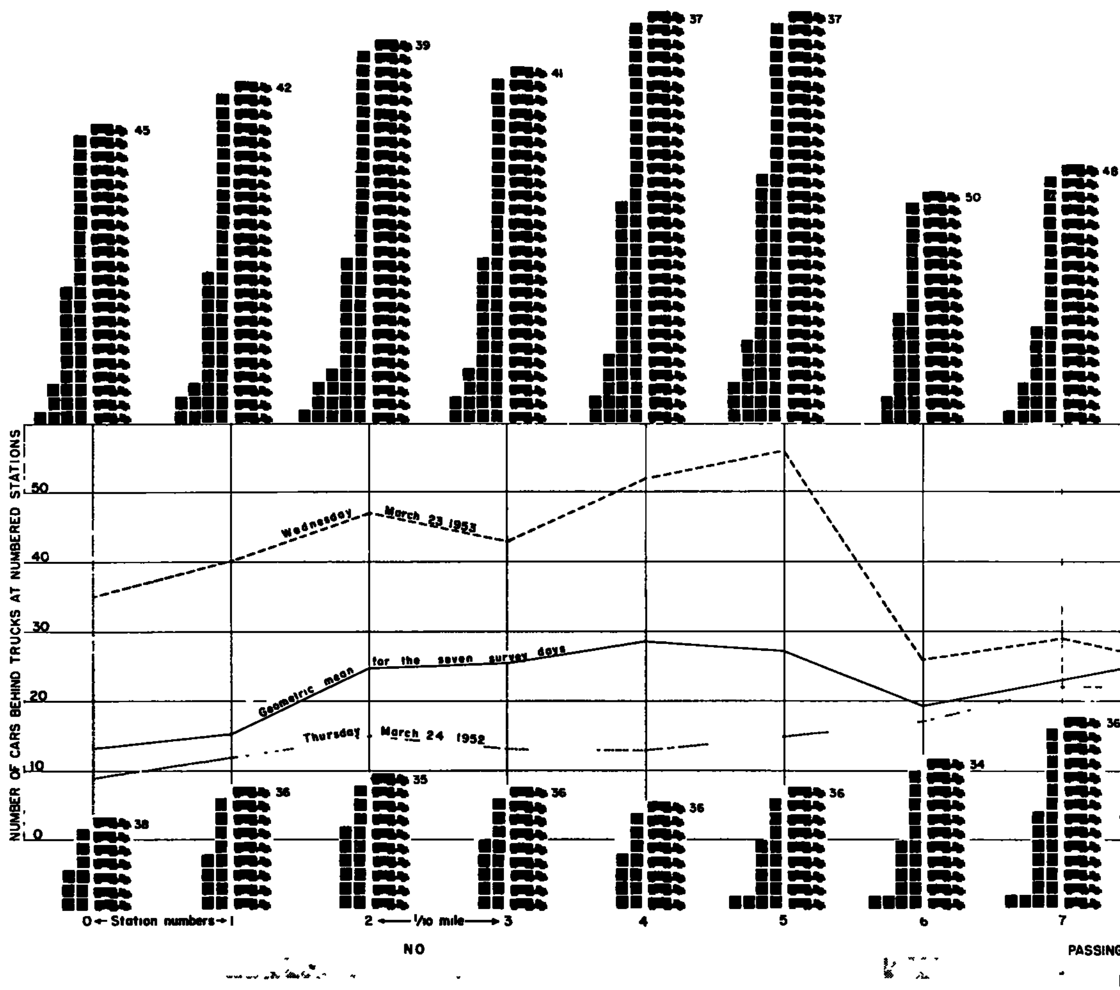
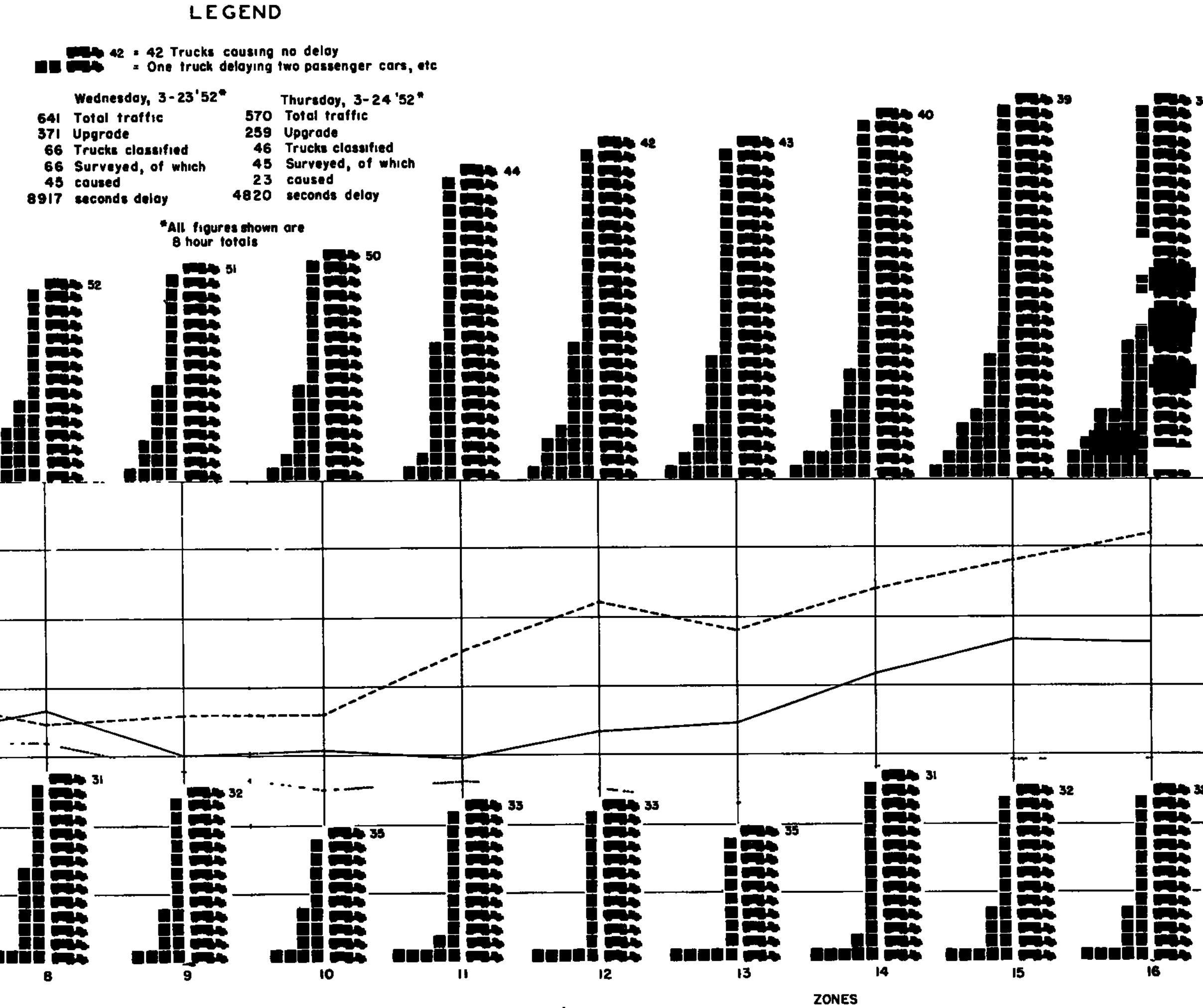


Figure 6. Delay pattern

limitations. The terrain at Yarnell Hill made it possible to view the entire section under consideration from one observation station. Because of this favorable situation, it was possible to make records on as many as four trucks at the same time. The truck traffic was such that we were able to observe and survey 95.4 percent of the total truck traffic. All trucks did not create congestion, since only 41.5 percent of the total caused delay to other vehicles. The survey data was accumulated during approximately eight normal showed the number of trucks· (1) causing no delay through the entire test section; (2) causing no delay at the corresponding station; (3) charged with delaying one car as it passed the corresponding station: and (4) delaying two cars, three cars, etc.

The chart also noted the number of cars added to or subtracted from the existing stack or queue between stations. From this chart the maximum and minimum days of traffic congestion were related to number of cars being delayed, as well as the total hours of delay during the day.



for Yarnell Hill

working days. The first step in the office was to organize the field data in a convenient and usable form.

This was done on a delay chart which

The next step was to compute the delay to each vehicle caused by slower-moving traffic in the same lane. This analysis involved: (1) time at which the car (or

Figure 7. Illustration to accompany Yarnell Hill afterstudy, before.

cars) became a tail to the slower moving truck; (2) time when the delayed car finally passed the truck; (3) time interval the car was back of the truck was computed; (4)

Figure 8. Illustration to accompany Yarnell Hill afterstudy, after.

from this was subtracted the time interval the car would have traveled that same distance at the posted speed limit of 30 mph; the difference being considered the delay time.

All delays to each car, whether singly or in a long line, were computed separately. There were some cases where trucks were delayed by other slower-moving trucks. In these instances it was figured that the delayed truck could have made the 12.5-mph. average truck speed rather than the slower speed of the lead truck and the delay was computed accordingly. The time delay is shown by bar graph as Figure 4 relating the delay in hours to the total volume of traffic by days.

was to correlate the delay in numbers of cars to the actual 6-percent profile grade of the highway. These findings are shown as Figure 5.

The next objective of the congestion study was to evaluate the money value of the delays, together with other economic factors, to see if a full-length uphill truck lane could be justified. A cost analysis for construction and maintenance was made and related to savings to the motorist in a benefit ratio comparison. In this computation, passenger-car driver time was listed at $1.10 per hour and overall truck operational costs, based on local fleet records was $5.28 per hour. When the truck desire speed was related to delay

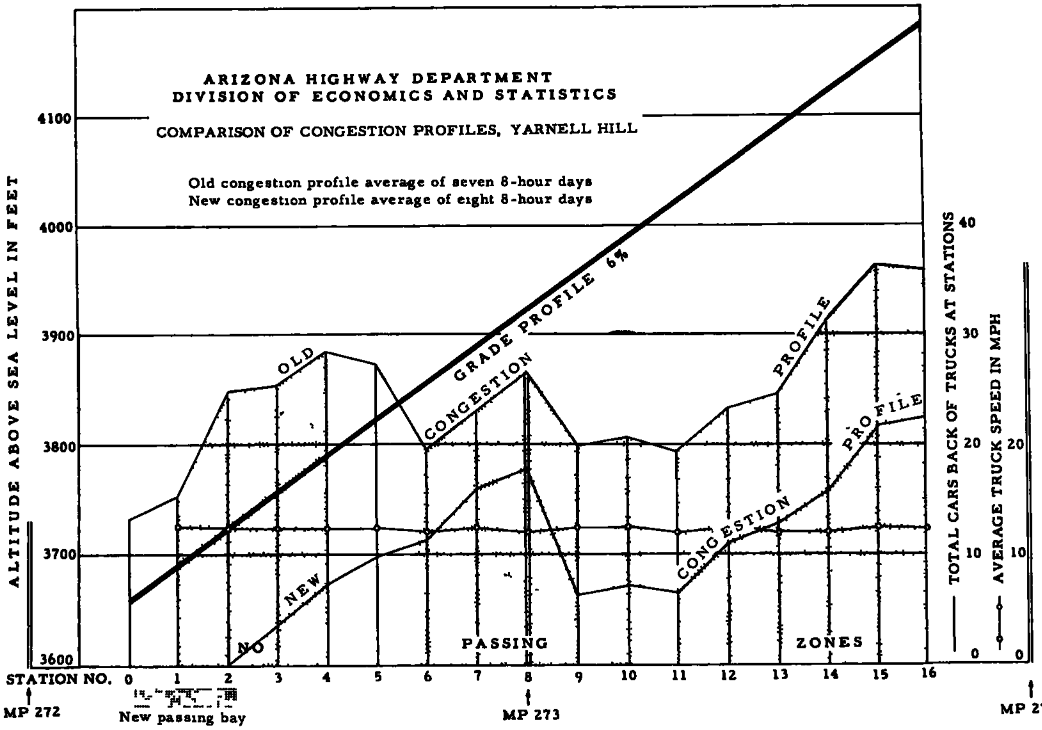


Figure 9.

The next step was to identify the accumulated amount of congestion with the established stations up the grade. This was done in graph form and is illustrated by Figure 6. The chart shows the delay pattern for the low volume day and the high volume day, giving the number of trucks that caused no delays; those that delayed one car, two cars, etc. The arithmetic mean of the number of cars delayed at each station is shown for the 8-day survey period. From this chart, the next step

speed the total truck cost was figured at $5.51 per delay hour. These costs were intentionally made low so as to be on the conservative side when making the economic analysis.

It was not at all surprising, what with solid rock excavation, that the capital costs far exceeded the benefits that could be expected. In other words, the benefit ratio factor was considerably less than one. With the full uphill lane out of the picture economically, the next best thing was to consider the benefits that could be provided by relatively short passing bays located at strategic points.

The congestion profile showing the delays at various stations clearly indicated the areas of greatest congestion buildup. It was a simple matter then to designate by highway stations the best locations for the passing bays. Selling these locations to the field engineers was not such an easy matter, inasmuch as it was their choice to construct the bays where it was easier to dig and not where it was indicated the greatest relief in congestion could be obtained. Differences were finally resolved when a further analysis disclosed that the passing bays would have a benefit ratio of greater than one. Also, by constructing three passing bays at an estimated 15 percent of what a full extra uphill lane would cost, it was found that we could expect to reduce congestion by 70 percent. These figures were obtained by office analysis and could only be checked after the passing bays were constructed and a new study made of the improved situation.

Three bays, each 1,000 feet long, were decided upon and were to be located at the bottom, middle, and near the top of the hill. Because of the bad alignment and sight distance, these locations represented the areas of greatest congestion. The length was determined by an analysis of the average number of trucks causing delay, together with the number of cars that would desire to pass in the wider area pro-

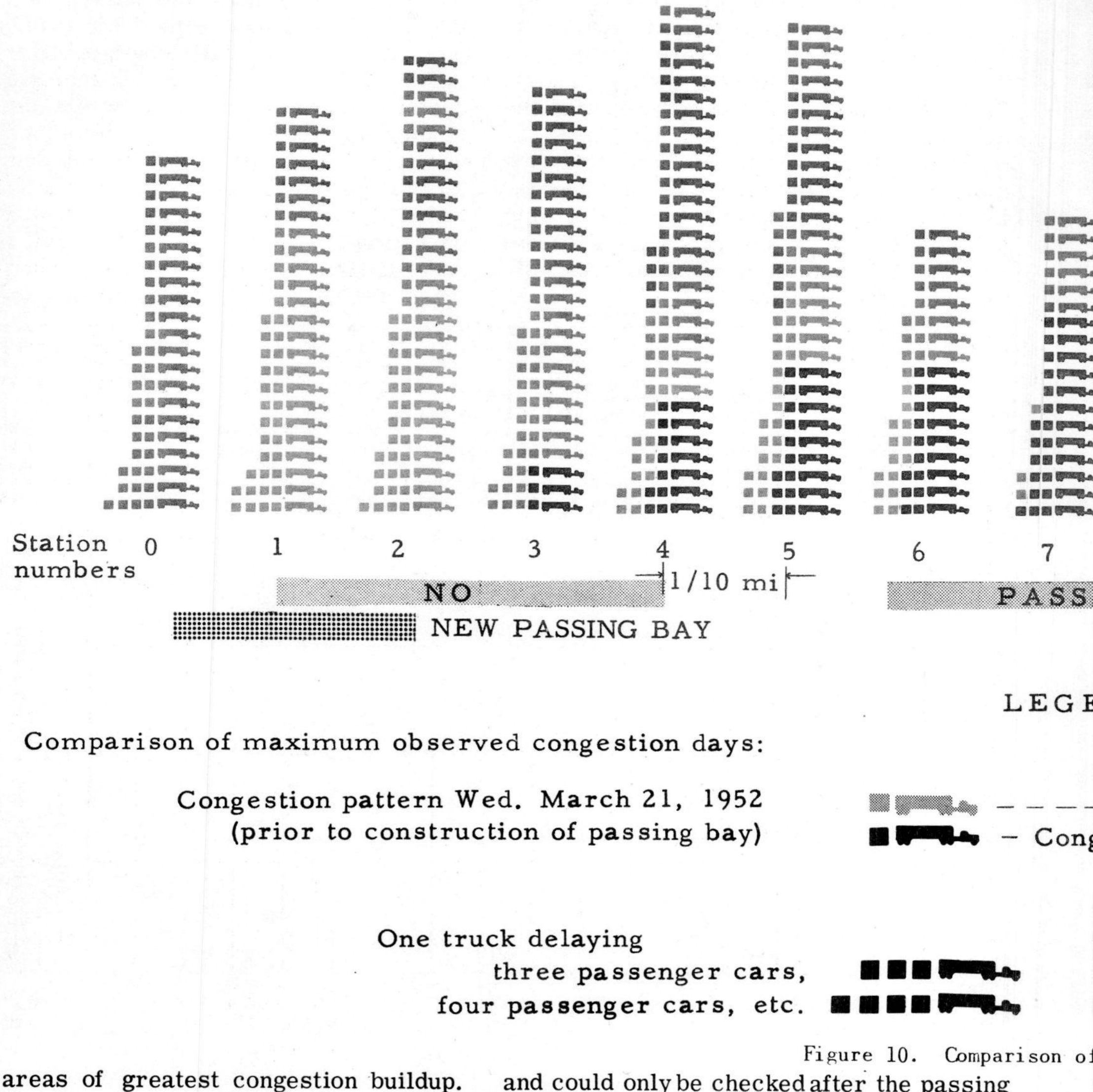


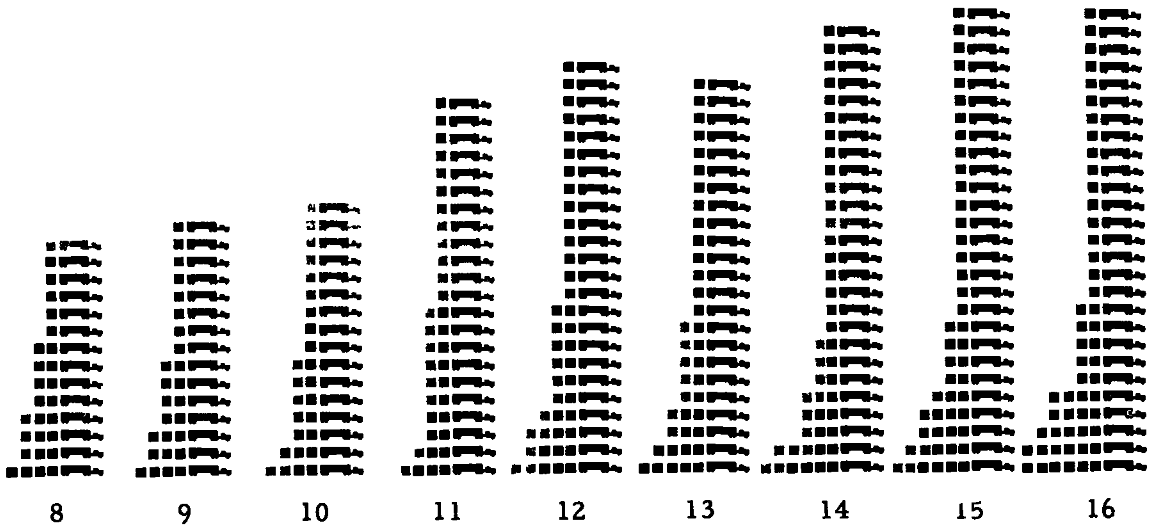
Figure 10. Comparison o

vided by the new bays. This length figured out to be 800 feet with a 100-foot transition at each end, so the total length became 1,000 feet. Table 1 lists the theoretical passing distance for various numbers of motor vehicles on a 6-percent grade, compared to what was actually observed after the bays were constructed.

Cars took longer to pass in the new bays than was previously anticipated. This was especially true of the Number 4 car and those following it. The 1,000-foot bay, under ideal conditions on a 6-percent grade, should allow 14 vehicles to pass a truck moving at the crawl speed. As a practical matter, only nine can expect to clear a truck at any one passing bay on Yarnell Hill. As a commentary on sign observance by drivers, it was noted during the course of this study that of all passing maneuvers 32.6 percent were made in clearly marked no-passing zones. It might well be stated that a 1,000-foot bay properly signed should adequately handle a total daily traffic volume of 3,000 vehicles, with 20 percent trucks.

The field work for the congestion study was supervised by J. W. Dewey, project chief, and H. C. Burnett and A. B. Anthony, project assistants, all of the Arizona Highway Department.

Because of budgetary limitations it was not feasible to construct all three bays under one contract so they were built one at a time. To date two have been built and the third is planned for this year. The relief



NG ZONES

ND

Congestion eliminated by new passing bay

estion pattern Wed. June 9, 1954
(after construction of passing bay)

congestion patterns.