Roadway Vehicle Delay Costs at Rail-Highway Grade Crossings

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The purpose of this research was to develop a practical methodology for computing the lengths of delays and costs of delays to roadway vehicles at rail-highway grade crossings (RHGCs). A practical methodology is defined here as one using only United States Department of Transportation Rail-Highway Grade Crossing Inventory (Inventory) data or other data known to be readily available to agencies responsible for RHGCs. The methodology developed makes use of Inventory data and a common deterministic delay model. Default values were developed for train length, diurnal distribution of roadway traffic, directional distribution of roadway traffic, and roadway speed limit. Costs were computed through the use of a procedure developed by the Federal Highway Administration in 1980. The methodology was applied to 1985 conditions for all public RHGCs in Maryland. The results of this application indicate that annual delay costs at RHGCs cover a wide range, from a minimum of $0 to a maximum of $407,441. Comparison of annual delay costs and annual accident costs indicate that accident costs are generally higher than delay costs.

The purpose of this research was to develop a practical methodology for computing lengths of delays and costs of delays to roadway vehicles at rail-highway grade crossings (RHGCs). A practical methodology is defined here as one using only those data known to be easily accessible to the agencies responsible for RHGCs and easily used by those agencies.

Although some agencies certainly maintain additional information about their RHGCs, the only known data base readily available to all agencies is the United States Department of Transportation Rail-Highway Grade Crossing Inventory (Inventory), a computerized description of every public and private crossing in the country. The Inventory provides a great deal of information for each crossing, with most of the information pertaining to the characteristics of the traffic control devices and railroad elements of the crossing. Relatively little information pertains to the highway elements of the crossing.

Conventional queuing theory would allow for straightforward computation of delays at RHGCs, if accurate data were available regarding the diurnal distribution and lengths and speeds of trains, and if accurate data were available regarding diurnal distribution and speeds of roadway traffic. Unfortunately, the Inventory does not provide all these data. Therefore, data collection efforts were undertaken, and analyses conducted, in an effort to develop values to be used in the methodology.

DELAY PARAMETERS

Train Length Analyses

Naturally, one of the key factors in determining delay to roadway vehicles at an RHGC is the length of each train; the longer the train, the greater the delay, all other factors being equal. Unfortunately, the Inventory provides no information regarding train lengths. In addition, the very nature of railroad operations works against any type of systematic prediction of train lengths, particularly in the vicinity of railroad yards, where trains are assembled and dismantled. During assembly of a single train, for example, one locomotive might cross an RHGC several times, with the number of attached cars ranging from zero to the maximum number of cars in the final train.

Figure 1 illustrates this problem, showing the variation in lengths of the 87 trains that, on July 31, 1986, travelled on one or more of the Old Main Line, Washington, Alexandria, Metropolitan, or Georgetown subdivisions of CSX Transportation's Baltimore division. (These data were obtained from CSX Transportation records; the date was selected at random from weekday records). As Figure 1 shows, more than half the trains were quite short, consisting of seven or fewer cars. However, 25 trains had 60 or more cars. The mean length was 35 cars.

Based upon these data, it was decided that 35 cars would be used as the average train length. Based on discussions with CSX personnel, it was decided that 60 feet, a very representative car length, would be used as an average length for each car in a train.

Train Speed Analyses

The Inventory provides three pieces of information regarding train speeds: maximum timetable speed, typical maximum speed, and typical minimum speed. For the purposes of these analyses, it was decided that the arithmetic mean of the typical minimum speed and the typical maximum speed would be used as the default speed at each RHGC.

Diurnal Distribution of Trains

The Inventory provides four pieces of information regarding the diurnal distribution of trains: number of daylight through trains, number of daylight switch trains, number of night through

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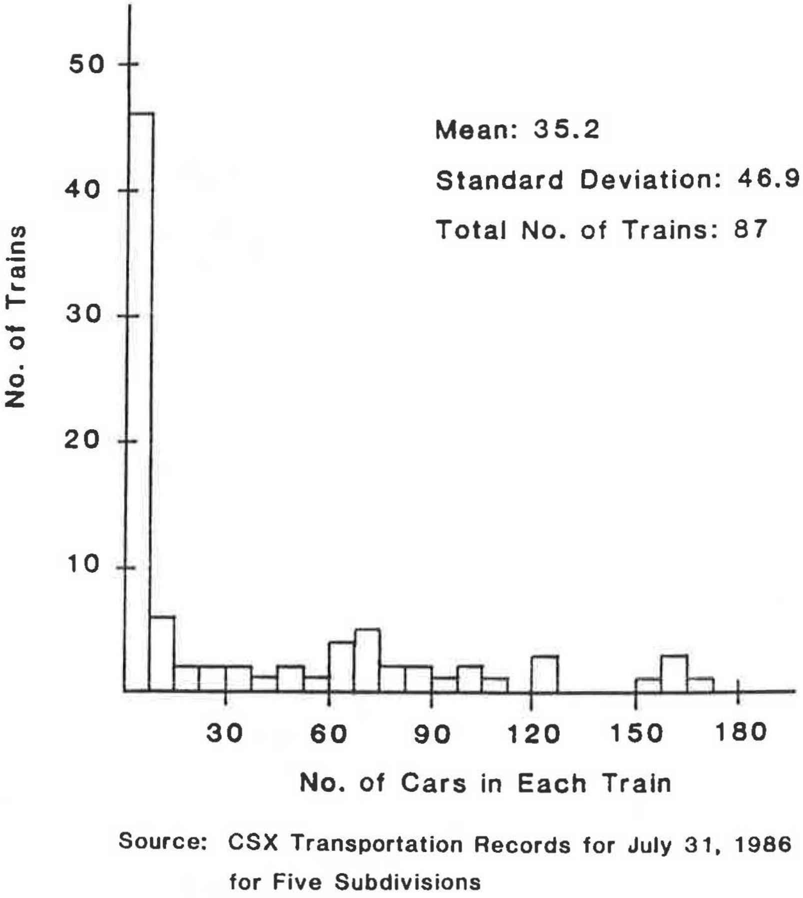


Source: CSX Transportation Records for July 31, 1986 for Five Subdivisions

FIGURE 1 Train lengths.

trains, and number of night switch trains. A more detailed breakdown would show wide variation among crossings, with part of that variation depending upon location. In Maryland, for example, according to CSX Transportation, train activities tend to occur earlier in the day in the western part of the state than in the eastern part, as trains bring loads to the east for further shipment later in the day. There is also some variation in the number of trains per day in each subdivision, with activity typically being lowest on weekends and Mondays, and then gradually increasing through the remainder of the week.

Based upon this information, the following assumptions were made for the methodology:

- All trains cross RHGCs on weekdays (Mondays through Fridays).
- Daylight trains cross RHGCs from 6 a.m. to 6 p.m.
- Night trains cross RHGCs from 6 p.m. to 6 a.m.
- Train arrivals are distributed uniformly across the given 12-hour period.

Diurnal Distribution of Roadway Traffic

As discussed previously, the Inventory provides very little information regarding roadway or traffic characteristics. In terms of traffic, only the annual average daily traffic (AADT) and the percentage of trucks in the AADT are provided.

Data collection and analysis efforts were undertaken in an attempt to develop a diurnal distribution for roadway traffic. The first group of RHGCs for which data were requested consisted of the RHGCs in the Philadelphia and Washington subdivisions of the B&O Railroad. This group was supplemented by a number of RHGCs in Baltimore City, Maryland, and Baltimore County, Maryland, for which data were readily available. All the data came from the files of the Maryland State Highway Administration (SHA), Prince George's County, Howard County, Baltimore County, and Baltimore City.

Analyses were conducted to determine if the diurnal distribution for one type of RHGC differed significantly from that for a different type of RHGC. A total of 42 RHGCs were used in these analyses. The AADTs at these RHGCs ranged from a low of 244 to a high of 28,590.

Because the diurnal distribution of train traffic can only be broken into daylight or night components, the diurnal distribution of roadway traffic as well need only be broken into those two components. The percentages of the AADT that occurred during each hour were computed for each RHGC; the percentages of the AADT occurring during daylight hours (6 a.m. to 6 p.m.) and during night hours (6 p.m. to 6 a.m.) were computed for each RHGC by adding the appropriate hourly percentages. Four groupings of the RHGCs were established: RHGCs in cities, RHGCs not in cities, urban RHGCs (as defined by the functional classification of the roadway in the Inventory), and rural RHGCs (as defined by the functional classification of the roadway in the Inventory). Then, *t*-tests were performed on the in city versus not in city groups and urban versus rural groups. The results of these analyses are shown in Table 1. Examination of Table 1 reveals that none of the values of *t* are significant at the 0.05 level and that the values for the in city versus not in city groups are substantially closer to the 0.05 level than the values for the urban versus rural group.

Thus, based on these data, there is no reason to believe that the diurnal distribution of roadway traffic at one type of RHGC is different from that at another. For this reason, the arithmetic means of the percentage of AADT occurring during each hour at all 42 RHGCs were computed and then used in the methodology. These default values are shown in Figure 2.

Because the diurnal distribution of railroad traffic cannot be determined from the Inventory with any more accuracy than to be broken into day or night groups, the diurnal distribution of roadway traffic needs to be used in the same fashion. Thus, for the methodology, the percentages of daily traffic occurring from 6 a.m. to 6 p.m. were averaged to obtain the average daylight hourly volume; the percentages from 6 p.m. to 6 a.m. were averaged to obtain the average nighttime hourly volume.

TABLE 1 *t*-TESTS: DIURNAL DISTRIBUTION OF ROADWAY TRAFFIC

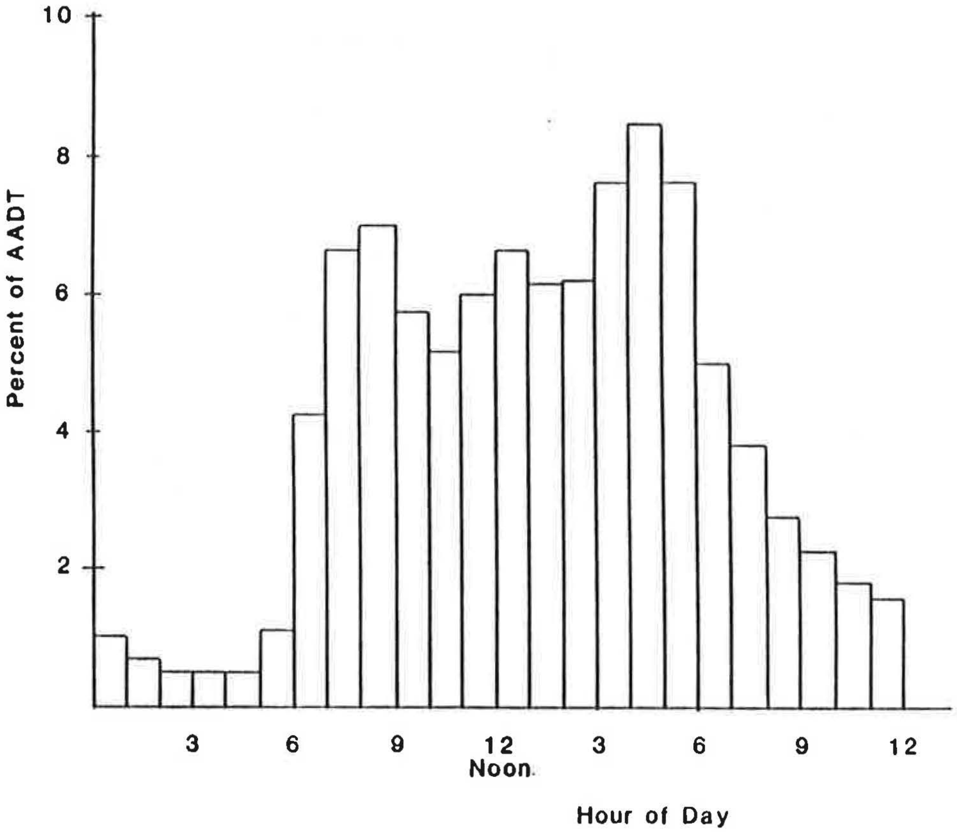
		Day Percentage		Night Percentage	
Inventory Parameter	Number of Cases	Mean	t-Test Prob.	Mean	t-Test Prob.
In City	20	80.0		19.7	
Not in City	22	76.3	0.088	23.7	0.068
Urban	38	78.4		21.5	
Rural	4	75.1	0.373	24.9	0.359

Source: Files of Maryland State Highway Administration, Baltimore City, Baltimore County, Howard County and Prince George's County

RHGC Blockage Time

The amount of time that a given train blocks an RHGC is comprised of two elements: the amount of time the train physically blocks the RHGC, and the amount of time the RHGC is "blocked" by traffic control devices or flaggers prior to the train's arrival. The physical blockage time at each RHGC is determined simply by dividing the length of each train by its average speed. The advance blockage time is somewhat more difficult to obtain.

Advance blockage time depends upon the type of traffic control device used at the RHGC. Passive devices such as crossbucks and stop signs cause little or no advance blockage



Source: Files of Maryland State Highway Administration, Baltimore City, Baltimore County, Howard County, and Prince George's County

FIGURE 2 Diurnal distribution of roadway traffic at 42 RHGCs.

time, while automatic gates without constant warning time capability may cause advance blockage times in excess of one minute. Based on observations of driver behavior at RHGCs and discussions with CSX personnel, the parameters described in Table 2 were established for use in this methodology. The following explanations should help readers understand Table 2:

- "Constant Warning Time Capability" means that the track circuit that detects the presence of a train can determine the speed of that train and adjust the actuation of the traffic control devices accordingly.
- "Crossbucks or Other Signs" category assumes that a driver is made aware of an oncoming train by sight or sound at least 5 sec prior to the arrival of that train at the RHGC. Based on observations of motorist behavior, it is assumed that no driver accepts any gap smaller than 5 sec and that no driver rejects any gap larger than 5 sec.
- "Flagger Disembarking Train" category assumes that, once the flagger has stopped all roadway traffic, 20 sec elapses before the train accelerates from a standing start and reaches the RHGC.
- Flashing light signals must be activated at least 3 sec before automatic gates begin to drop, according to CSX Transportation. Automatic gates must take from 9 sec to 12 sec to drop. A train can occupy an RHGC anytime after the gates finish dropping. The actual time prior to train arrival at which the signals begin flashing is adjusted by a CSX technician on the basis of sight distance or other site-specific conditions. For purposes of this methodology, a value of 15 sec from start of flashing light signal operation to completion of gate drop was assumed, based upon a 9 sec gate drop, a minimum 3 sec interval of flashing light signal operation prior to commencement of gate drop, and an additional 3 sec interval of flashing light signal operation prior to commencement of gate drop due to site-specific conditions.
- Flashing light signals used without gates must be in operation at least 20 seconds prior to the crossing being occupied by a train, according to CSX Transportation.

Directional Split of Roadway Traffic

On most roadways, volume in one direction of travel is heavier than volume in the other direction during peak hours and sometimes during other hours as well. During peak hours, this directional split can be as high as 80 to 20 percent or even higher, in areas with a single type of land use (such as residential), or as low as 55 to 45 percent, or even lower, on major arterial roadways. During off-peak hours, the directional split tends to be more even. Most of the diurnal data analyzed gave no information regarding directional split; thus, an assumption is necessary. Based upon observations of traffic volumes within Maryland, the directional split of traffic is assumed to be 60 to 40 percent during all hours. The direction of heavier flow is immaterial to the methodology.

TABLE 2 ADVANCE BLOCKAGE TIME PARAMETERS

	Advance Blockage Time (sec)	
Highest Protection Class at RHGC	with Constant Warning Time Capability	without Constant Warning Time Capability
Crossbucks	n/a	5
Flagger Disembarking Train	n/a	20
Flashing Light Signals or Highway Signals	20	20 x (Max. Speed)/ (Avg. Speed)
Automatic Gates	15	15 x (Max. Speed)/ (Avg. Speed)

n/a = not applicable

Source: Observations of driver behavior and conversations with CSX personnel

Roadway Speed Limit

Because the delay cost computations (described later) assume that traffic will travel at the speed limit unless forced below that speed by a train or a queue caused by a train, this factor is somewhat important. Unfortunately, the speed limit is not given in the Inventory; thus, some data collection seemed necessary. Data were again collected at the RHGCs in the Philadelphia subdivision and the Washington subdivision of the B&O Railroad. The resulting data are summarized in Figure 3. Examination of Figure 3 reveals that the mean speed was 28.5 mph.

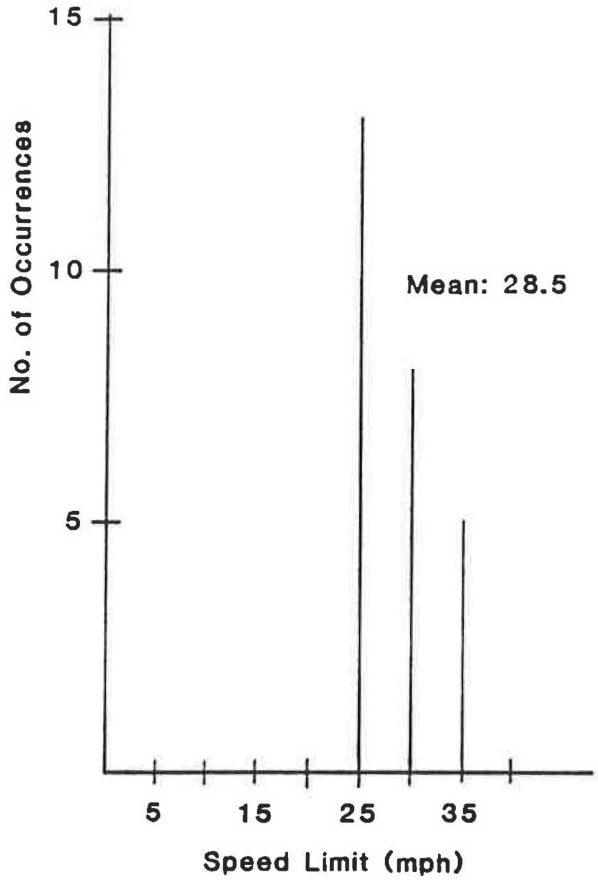
Statistical tests were performed to determine if different values were appropriate for use with different types of RHGCs. As was the case with the diurnal distribution analyses, in city versus not in city and urban versus rural (as defined by the roadway's functional classification in the Inventory) were thought to offer potential means of grouping the RHGCs.

The results of the *t*-tests are shown in Table 3. Examination of Table 3 reveals that the difference in mean speed limit is not significant at the 0.05 level for urban versus rural, but is significant at the 0.001 level for in city versus not in city. Thus, two default speed limits (25 mph for "in city" crossings and 30 mph for "not in city" crossings) were used for all subsequent analyses.

Delay Model

The computation of delay to roadway vehicles was performed by using the simple, deterministic model illustrated in Figure 4. This model was not developed expressly for this research; similar, if not identical, models can be found in texts regarding queuing theory or traffic control signal operation. According to this model, roadway traffic arrives at the RHGC at a rate of q. When a train arrives (A), a queue begins to form. The queue grows in length until the train clears the RHGC (B), and then diminishes as vehicles depart at a saturation flow rate of s (assumed to be 1 vehicle per 2.1 sec). The queue is completely dissipated at C, when the arrival line intersects the departure line. The number of vehicles in the queue at any given time is the vertical distance between AB or BC and the arrival line. The total delay caused by the presence of a train is the area of triangle ABC.

It is recognized that this model is quite simple and does not consider the probabilistic characteristics of traffic flow and site-specific geometrics. However, given the simplifying assumptions required to estimate train length, train speed,



Source: Field Observations of RHGCs in Philadelphia Subdivision and Washington Subdivision

FIGURE 3 Speed limits at RHGCs.

TABLE 3 *t*-TEST RESULTS: SPEED LIMITS

Inventory Parameter	Number of Cases	Mean	t Value	Significant at
In city	11	25.4	4.91[1]	<.001
Not in City	15	30.7		
Urban	20	27.8	-1.75	.09
Rural	6	30.8		

[1] Modified t-test used. F-test showed usual t-test should not be used.

Source: Field observations of RHGCs in Philadelphia Subdivision and Washington Subdivision

and total blockage time, this shortcoming was not thought to be severe. The model is applicable to a single-lane, single-direction approach at an RHGC blocked by a train.

The following steps were taken to compute roadway vehicle delay over the course of a year, using the model described above:

1. The average daylight hourly volume on each approach was determined by using the assumed 60 to 40 directional split.
2. The number of lanes on the roadway was obtained from the Inventory, and the approach volume was evenly divided among those lanes.
3. The total blockage time per daylight train was determined as described earlier, and roadway delay per daylight train was computed.
4. The delay obtained during the preceding step was multiplied by the number of daylight trains to obtain total daily daylight delay.
5. Steps 1–4 were repeated for night conditions.
6. The delay obtained in Steps 4 and 5 were summed and the sum was multiplied by 260 (52 weeks per year at 5 days per week) to obtain total yearly delay.

Weekends were not expressly considered in the analyses. On most roadways and rail lines, volumes are substantially lower on weekends than weekdays, resulting in considerably less delay to roadway vehicles. In addition, even less information is available regarding weekend volumes than is available regarding weekday volumes. For these reasons, only weekdays were considered in the analyses. It should be noted that delay at RHGCs is not linear with respect to train length, but rather is proportional to the square of train length. Com-

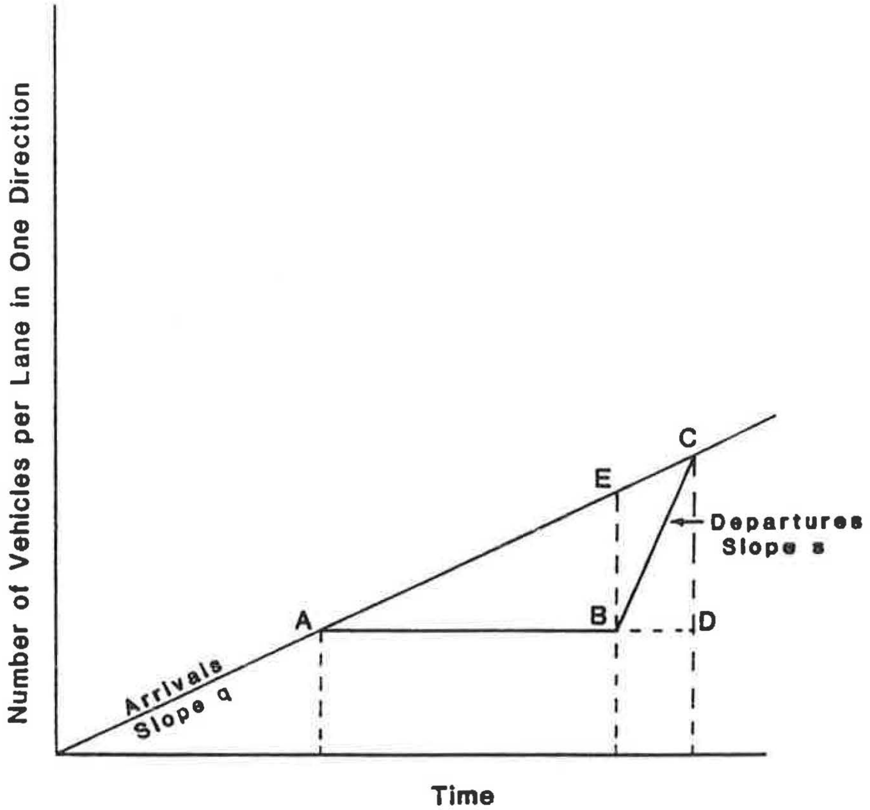


FIGURE 4 Delay model.

putations using the data shown in Figure 1 reveal that the mean delay occurs for a train consisting of 58 cars, rather than for a train consisting of the 35-car mean length. For purposes of the methodology, it was decided that the mean train length would still be used in the delay computations, due to the relatively small sample available for comparison of train lengths and the sensitivity of a "mean-delay train length" to the distribution of train lengths in the sample. (A distribution of train lengths with a standard deviation smaller than that of the distribution shown in Figure 1 could yield the same mean train length but a considerably shorter mean-delay train length.)

Computation of Delay Costs

The user costs caused by delays at RHGCs were computed by using a procedure developed by the Federal Highway Administration (FHWA) in 1980 (*1*). Reduced to its simplest terms, this procedure provides graphs and tables that can be used to estimate, for each light-duty vehicle, user costs for stopped conditions and for each speed-change cycle. This procedure was applied to the methodology through use of the following steps with references made to Figure 4:

- Only vehicles that arrived during the total blockage time (*AB*) were assumed to stop. Vehicles arriving while the queue discharged (*BD*) were assumed to be slowed, but not stopped.
- All vehicles were assumed to approach the RHGC at the posted speed and depart at the posted speed. All vehicles slowed but not stopped were assumed to reach a low speed of half the posted speed.
- Tables and graphs were incorporated into the computer program used to execute the methodology.
- Unit costs were updated, using the procedures outlined by FHWA (*1*).

In addition to the procedure described above, traveltime costs were computed by taking the area of triangle *ABC*, assuming a value of $6 per person-hr of traveltime and an average vehicular occupancy of 1.6 persons. The $6 value was developed by updating value of traveltime data included in the FHWA document (*1*) and making an additional adjustment based on local conditions. The average vehicular occupancy was also based upon observations of local conditions. It may be noted that delay costs are linear with respect to both value of traveltime and average vehicular occupancy. Thus, the effect of varying either or both of these parameters may be readily determined.

APPLICATION

Roadway vehicle delay costs were computed for each public RHGC in Maryland using 1984 Inventory data and the methodology described above. For purposes of these computations, it was assumed that the 1984 Inventory data were fully representative of 1985 conditions. The results of these analyses are shown in Figure 5. Examination of Figure 5 reveals:

- Annual delay costs cover a wide range, from a minimum of $0 to a maximum of $407,441, with a mean value of $4,180.
- Eighty-three crossings had annual delay costs in excess of $10,000.
- Annual delay costs below $500 were found at 814 RHGCs.

In order to assess the relative importance of these costs, additional analyses were conducted involving the costs of accidents at the same RHGCs in 1985. Anticipated accident costs were developed through the use of an accident-prediction formula produced by the Transportation Systems Center (unpublished data provided to Kidde Consultants Inc. by the Maryland Department of Transportation, State Highway Administration), a severity index that is part of the Rail-Highway Crossing Resource Allocation Procedure (*2*), and NHTSA cost estimates for various types of accidents (adjusted by the Consumer Price Index to reflect 1985 conditions). Each fatal accident was computed to have a cost of $1,286,029.60. Each injury accident was computed to have a cost of $315,298.57. Each property damage only accident was computed to have a cost of $23,350.58.

The data thus developed are shown in Figure 6. Comparison of Figure 5 and Figure 6 reveals that accident costs generally are greater than roadway vehicle delay costs, with the mean

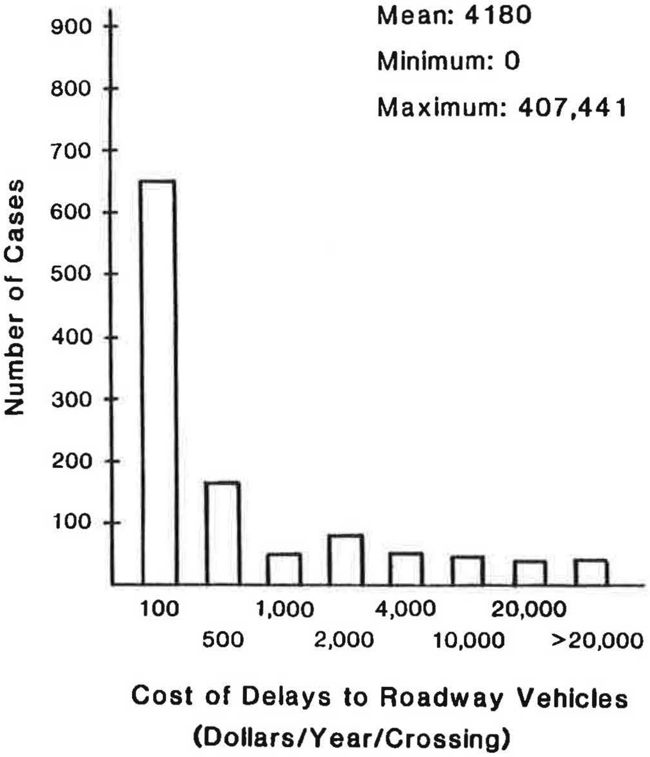


FIGURE 5 Delay costs, 1985 conditions.

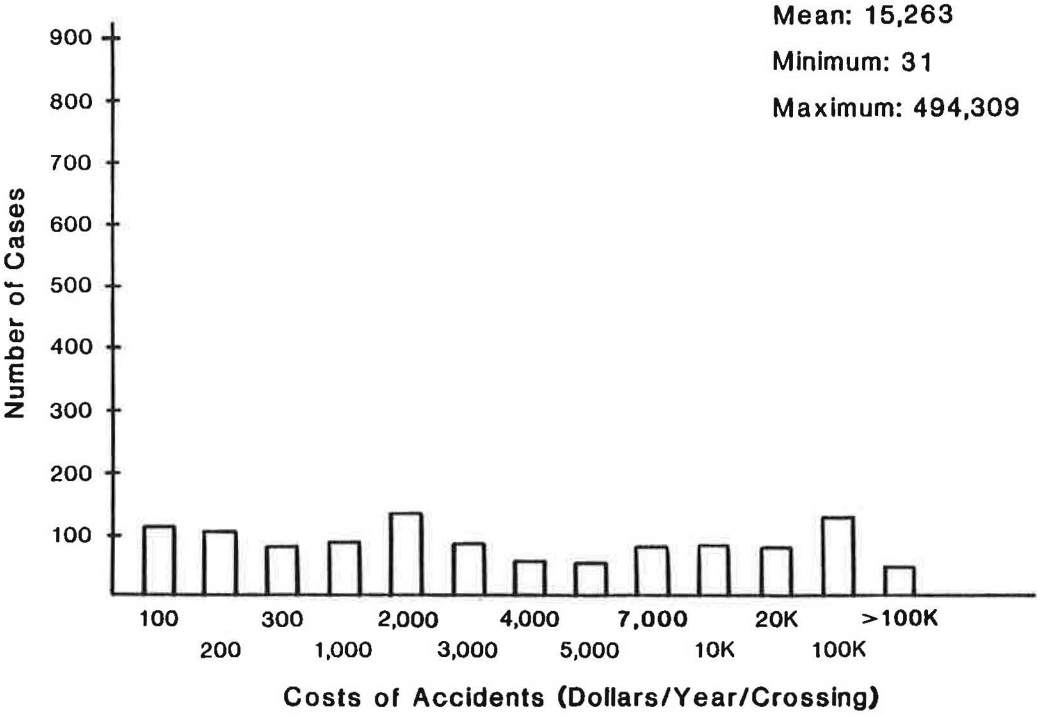


FIGURE 6 Accident costs, 1985 conditions.

value being almost four times greater. Thus, it would appear that delay costs for roadway vehicles, though potentially substantial, are not as large as accident costs.

It should be noted that the large number of simplifying assumptions made in this project undoubtedly bias the results provided by the methodology. The exclusion of weekend data, the use of average train length and average train speed, and the use of a single diurnal distribution for all roadways certainly diminish the accuracy of the numerical results. Without more accurate data, it is difficult to estimate the size of the bias introduced by these assumptions.

SUMMARY

The purpose of this research was to develop a practical methodology for computing lengths of delays and costs of delays to roadway vehicles at RHGCs. The methodology developed here accomplishes this objective, subject to the limitations of available data. Application of the methodology indicates that roadway vehicle delay costs may be substantial, but are generally lower than accident costs.

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