EVALUATING HAZARDS AT RAILROAD GRADE CROSSINGS

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SYNOPSIS

Rather negative results are reported for the attempt to find a formula by which the highway-railway grade crossings in Mississippi could be rated with respect to highway hazards.

The formula, presented in *Public Roads* August 1941 by Peabody and Dimmick was applied to the record of accidents at all railroad grade crossings in Mississippi, but no significant correlation was found.

A method of rating grade crossings in terms of sight distance hazard was developed by the Division of Planning. This sight distance rating was combined with the P.R.A. formula in a "Special Rating" which gave slightly more significant results when applied to the crossing accident record. Although not satisfactory the list of crossings has been rated thereby, for aid in planning a program of crossing protection and elimination. Lacking is any information on the type of protective installation that could be considered most effective for the different ratings.

No significant correlation was found between accident records and number of train movements, volume of highway traffic, number of railroad tracks or clear view distance.

The railroad grade crossing study in the State of Mississippi was initiated for the primary purpose of planning a program of railroad-highway grade crossing elimination and protection for the highway system of the State. In order to plan a sound program some method had to be devised whereby the crossings could be evaluated on the basis of their relative hazard to highway traffic. An attempt was made to develop a formula that would produce numerical ratings indicative of the relative hazards of the crossings. It would then be possible to list all the crossings in the State in the order of their relative hazard as a basis for a program of railroad-highway grade crossing improvements that would result in the greatest amount of protection for the money expended.

It is an accepted fact that the only positive method of preventing collisions at railroad-highway grade crossings, intersections at grade, is by separation of these grades. The cost of grade separation is high and the amount of funds available for this type of construction is limited. It was felt that in some instances other types of installations, much more economical that grade separations, would provide adequate protection. Just when such action could be justified was one of the questions to be answered through information collected and analyzed in the grade crossing study.

APPROACH TO THE PROBLEM

After studying the available information on other investigations of the problem of evaluating hazards at railroad grade crossings, it was decided first to rate all of the grade crossings in the State by the formula proposed by L. E. Peabody and T. B. Dimmick in *Public Roads*, August 1941. This formula was intended to predict the probable number of accidents in five years at a given crossing by combining three factors: (1) number of trains per 24 hours; (2) number of cars crossing on the highway in 24 hours; (3) type of protection.

This work although started in 1941 was interrupted by the war and not completed until 1946. When the number of accidents predicted by the formula was compared with the accidents that had occurred, the results were found to be so erratic, it was concluded that this method is not satisfactory. The formula was applied to 1254 crossings, of which 784 were municipal and 470 were rural.

After this comparison was made it was thought that perhaps if a factor of sight distance were included in the formula better results might be produced.

SIGHT DISTANCE HAZARD FORMULA

Through the "Road Inventory" and "Municipal Grade Crossing Study", conducted in the early part of the Statewide Highway Planning Survey, information had been collected regarding the sight distance at all railroad-highway grade crossings in the State both rural and, municipal. Using this information a "*Sight Distance Hazard Formula*" was developed.

The formula developed for municipal crossings will be discussed as the ratings for both rural and municipal crossings were obtained in the same manner. The only difference is that more information was taken on municipal crossings than on rural crossings.

Sixteen clear sight distances were recorded at each municipal crossing. These distances were obtained from eight points in the road; 300, 200, 100 and less than 100 feet from the crossing on each side of the railroad. The distances recorded are the maximum distances that a train would be from the crossing when it could be first seen by a motorist from the designated point of observation.

The three principal contributions to danger at a grade crossing are the number and speeds of cars, the number and speeds of trains and the visibility at the crossing. Sight distances are assumed to contribute to the degree of hazard of a crossing in the same ratio that the blinded travel distance bears to the total necessary clear travel distance.

Based on the limiting distances used in our survey, a motorist is considered safe, at a distance of 300 ft. from the crossing, when he can see a train that is 2000 ft. from the crossing. This distance is assumed to be composed of a travel ratio of six to one, for the train over the car, plus 200 ft. of train travel during the reaction time of the motorist.

To be safe from 300 ft. on each side of the crossing, the clear sight distance must be 2000 ft. in each quadrant. Thus 8000 ft. of clear sight distances are needed for 100 percent safety from 300 ft. If for example, one-fourth of the necessary clear distance, or 500 ft., were clear in each quadrant, then the crossing would be considered 25 percent clear or 75 percent dangerous as far as the 300 ft. point is concerned.

To obtain the percentage of danger from 300 ft., add the four clear sight distances, subtract the sum from 8000, multiply the remainder by 100, and divide the product by 8000.

Based on the same train-car travel ratio of six to one, plus 200 ft. of train travel during the reaction time, a motorist would need 1400 ft. of clear sight distance to clear a crossing safely from 200 ft.

To obtain the percentage of danger from 200 ft, add the four clear sight distances, subtract the sum from 5600, multiply the remainder by 100, and divide the product by 5600. For 1050 ft. of clear sight distance in each quadrant the crossing would be 75 percent safe in this case.

Likewise to be safe from 100 ft. on each side of the crossing, if it is possible to be safe from that distance, the clear sight distance must be 800 ft. in each quadrant. If, from this distance, 700 ft. were clear in each quadrant, then the crossing would be considered 87.5 percent safe.

The distances of less than 100 ft. and not less than 15 ft. are variable, dependent upon obstructions at the individual crossings. If the maximum view occurs at the 50 ft. point, 500 ft. of train travel time would be necessary to clear the crossing, and if the maximum view occurred close enough to require a stop, 500 ft. of train travel time would be necessary to clear the crossing safely, so on that basis, a 500 ft. minimum was established for distances less than 100 ft.

Extremely short sight distances have no value. If, from 300 ft., a motorist sees a train only 50 ft. from the crossing or even upon the crossing, he has a good travel distance in which to stop, and the short distance has a value. At less than 100 ft. if he sees a train only 100 or 200 ft. from the crossing he probably won't be able to cross or stop without colliding with the train. On this basis, sight distances of less than 250 ft. will be considered blind and distances over 500 ft. will be considered to be unused. The percentage of blind area will be considered to be that percentage blinded between sight distances 250 and 500 ft.

The total *Sight Distance Rating* is obtained by adding the percentage of danger figured for each of the four points just described and dividing the sum by four.

For use in rating any crossing Table 1 has been prepared by tabulating the maximum total usable sight distances from each point (sum of four sight distances) divided into equal brackets, with the corresponding percentage of danger for the summation of sight distances for each bracket divided by four.

To determine the sight distance hazard

rating for any crossing from Table 1 proceed as follows: (1) determine the sums of the clear sight distances in all four directions at points 300, 200, 100 and less than 100 ft. from the crossing, (2) In each column take the rating opposite the bracket in which the sum of the four sight distances falls, (3) Add these four ratings, (5) The sum is the sight distance hazard rating for the crossing.

TABLE 1
SIGHT DISTANCE RATING TABLE FOR MUNICIPAL GRADE CROSSINGS

Vehicle is 300 ft. From Crossing		Vehicle is 200 ft. From Crossing		Vehicle is 100 ft. From Crossing		Vehicle is Less Than 100 ft. From Crossing	
Total Distances Along Railroad in All Four Quadrants		Total Distances Along Railroad in All Four Quadrants With 1400 ft. & over Being Considered as 1400 ft.		Total Distances Along Railroad in All Four Quadrants With 800 ft. & over Being Considered as 800 ft.		Total Distances Along Railroad in All Four Quadrants With 500 ft. & over Being Considered as 500 ft.	
Distance	Rating	Distance	Rating	Distance	Rating	Distance	Rating
7681–8000	1	5376–5600	1	3071–3200	1	1961–2000	1
7361–7680	2	5151–5375	2	2941–3070	2	1921–1960	2
7041–7360	3	4926–5150	3	2811–2940	3	1881–1920	3
6721–7040	4	4701–4925	4	2681–2810	4	1841–1880	4
6401–6720	5	4476–4700	5	2561–2680	5	1801–1840	5
6081–6400	6	4251–4475	6	2431–2560	6	1761–1800	6
5761–6080	7	4026–4250	7	2301–2430	7	1721–1760	7
5441–5760	8	3801–4025	8	2171–2300	8	1681–1720	8
5121–5440	9	3576–3800	9	2041–2170	9	1641–1680	9
4801–5120	10	3351–3575	10	1921–2040	10	1601–1640	10
4481–4800	11	3126–3350	11	1791–1920	11	1561–1600	11
4161–4480	12	2901–3125	12	1661–1790	12	1521–1560	12
3841–4160	13	2676–2900	13	1531–1660	13	1481–1520	13
3521–3840	14	2451–2675	14	1401–1530	14	1441–1480	14
3201–3520	15	2226–2450	15	1281–1400	15	1401–1440	15
2881–3200	16	2001–2225	16	1151–1280	16	1361–1400	16
2561–2880	17	1776–2000	17	1021–1150	17	1321–1360	17
2241–2560	18	1551–1775	18	891–1020	18	1281–1320	18
1921–2240	19	1326–1550	19	761–890	19	1241–1280	19
1601–1920	20	1101–1325	20	641–760	20	1201–1240	20
1281–1600	21	876–1100	21	511–640	21	1161–1200	21
961–1280	22	651–875	22	381–510	22	1121–1160	22
641–960	23	426–650	23	251–380	23	1081–1120	23
321–640	24	201–425	24	121–250	24	1041–1080	24
00–320	25	00–200	25	00–120	25	00–1040	25

COMBINATION OF SIGHT DISTANCE RATING WITH THE PUBLIC ROADS ADMINISTRATION FORMULA

It was assumed that the sight distance rating is equally as significant as the accident hazard rating of the P.R.A. formula. This being the case, it was decided to reduce the sight distance rating to the same basis as the P.R.A. rating, add the two ratings and divide the sum by two; thus obtaining a combination of the two ratings.

The sight distance hazard ratings were calculated on the basis of the percentage of clear sight distance restricted at each crossing. That is, a crossing that is completely blind would have a rating of 100. The P.R.A. Hazard ratings were calculated on the basis of the number of accidents that were likely to occur at a crossing in a five year period. Therefore to reduce the sight distance hazard ratings to the same basis as the P.R.A. hazard ratings, it was necessary to divide the sight distance ratings by a constant. The highest rating obtained from the P.R.A. formula was approximately 12.5. The highest sight distance rating was 100. The latter ratings were divided by a constant of eight, thus reducing them to the same basis as those obtained from the P.R.A. formula.

After reducing the sight distance hazard rating to the same basis as the P.R.A. hazard rating, the two could be added and the sum divided by two to obtain the third rating. This is called a "Special Rating".

For example, if a crossing had a sight distance hazard rating of 84, and accident hazard rating of 5.94 the combined rating (Special Rating) would be:

$$\frac{(84 \div 8) + 5.94}{2} = 8.22$$

"Special Ratings" were calculated for all the grade crossings in the State and compared with their accident records. The crossings with the highest accident records compared more favorably with the crossings with high ratings as obtained by the Special rating, than when based only on the P.R.A. ratings; but the results were still erratic and were not considered altogether satisfactory.

The fact that accidents occur at a railroad-highway grade crossing is not sufficient proof that it is more dangerous than some other crossing where no accidents have occurred. This is perhaps true because there are too many human elements involved to base the degree of hazard on occurrence of accidents alone. It is believed, however, that accident records at crossings should be used to test the reliability of any method of rating crossings on the basis of their relative hazards. With this as a criterion, investigations were made to discover, if possible, some other method of rating the crossings that might prove more satisfactory.

CORRELATION OF ACCIDENTS WITH VARIOUS FACTORS

In a further attempt to find a formula for rating crossings, the accident records of all of the crossings were compared with an exposure factor consisting of the product of the number of trains per 24 hours times the average daily traffic. Again no conclusive results were produced.

Finally, the hazard factors used in the combined or Special formula, were each compared with the number of accidents occurring in a 5-year period at a sample composed of 65 crossings at which accidents had occurred, chosen at random from the entire list of crossings. These factors are number of train movements, volume of highway traffic, number of railroad tracks and clear view along the railroad from various points along the highway. There was no significant correlation of any of these factors with accidents, however a few notes are of interest. The sample was small because there are few crossings in the State with high accident records in the 5-year period studied.

When train movements exceed 10 or more per day the occurrence of accidents was more prevalent but there was no definite relationship, between the number of train movements and the occurrence of accidents. In other words, 20 train movements per day over a crossing are not necessarily related to a certain number of accidents in a 5 year period.

The majority of the accidents occurred at crossings where the motor vehicular traffic was less than 1000 vehicles per day. No definite relationship was found between the occurrence of accidents and the number of vehicles over the crossings. One would expect more accidents as the volume of traffic increased, but this was not the case.

Approximately equal numbers of accidents occurred at crossings with 1, 2, 3 and 4 tracks, with a slightly higher occurrence of accidents at those crossings with 3 tracks.

In every case accidents occurred at crossings where the sight distance was much less than that required when calculated by the sight distance hazard formula. This fact afforded some encouragement, and tended to substantiate the belief that sight distance should be included in any group of factors when attempting to evaluate crossings on the basis of their relative hazard.

WARRANTS SET FORTH IN THE "MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES FOR STREETS AND HIGHWAYS"

Since evaluation of crossings on the basis of relative hazard had proved unfruitful, a study was made of the "Manual on Uniform Traffic Control Devices for Streets and Highways" for the year of 1947. Previous editions of this manual had set forth definite warrants for traffic signals at street intersections based on the number of vehicles through the intersection, right and left turns, pedestrian volumes, accidents, etc. It was thought that the revised edition of the manual might contain some similar warrants for railroad-highway grade crossings. If so, then it would at least be known what grade crossings were not adequately protected, and this would provide a start on a program of improving grade crossing protection.

This inquiry proved to be of little or no value as warrants for "Train Approach Signals and Gates" at railroad-highway crossings were listed as follows:

Train Approach Signals:

Train approach signals shall be installed at railroad-highway grade crossings to warn highway traffic of any approaching train where the volume of traffic of both the railroad and the highway warrants, or where physical obstructions to clear vision exist on highway approaches. Such signals shall be used for no other purpose.

Automatic Gates:

Automatic gates and signals of the type described herein shall be installed at railroad-highway grade crossings to warn highway traffic of any approaching train where the volume of traffic of both the railroad and highway warrants, or where physical obstructions to clear vision exist on highway approaches. These devices shall be used for no other purpose.

If it were possible to rate grade crossings accurately on the basis of their relative hazards would much be accomplished without warrants as a guide in providing the various types of protection that could be afforded? Without warrants over protection might be provided at some crossings and under protection at others. This would put the Department on the same hit or miss basis on which it is operating today.

It has probably been concluded by this time that we are not completely satisfied with the results of our grade crossing study, because none of the methods of evaluating hazards at crossings have been satisfactory.

The formula that was finally used to rate the crossings was the combination of the Public Roads Administration Formula and the Sight Distance Hazard Formula developed by the Planning Division. It is thought that this gives the best basis for rating because the factors that make a crossing hazardous number of trains, number of cars, present type of protection and sight distance are included.

Now that we have the crossings evaluated or rated we are up against the proposition of what to do. Although we know the most hazardous crossings in the State, according to our evaluation, we are still in the dark as to what should be done about the type of protection they require.

As a result of this study we were able to reach only one fairly definite conclusion. That is; until we are able to anticipate what the behavior of the human being is going to be, it will be a tough matter to rate and protect railroad-highway grade crossings as they should be rated and protected; and the only positive method of preventing accidents, as stated in the beginning, is *grade separation.*

DISCUSSION

Burton W. Marsh, *American Automobile Association*—Among the most effective types of railroad-highway grade crossing protective devices are the flashing lights, wig-wags, and automatic protective gate arms with lights (preferably flashing) on them. In general such devices begin to operate when approaching trains cross a track circuit a rather considerable distance away from the grade crossing. This track circuit must be placed a sufficient distance away so that the warning or protective devices will be in effect a number of seconds before a train reaches the crossing. Obviously, the track circuit must be placed so that there will be sufficient time in the case of the fastest train which is using that track.

At the present time there is a very large differential in the speed of trains, from the express streamliner to the heavily loaded, relatively slow freight. The result of this considerable differential in speed is that the warning or protective devices operate for a long time before the slow train reaches the crossing. In the case of the flashing or wig-wag devices, there is a danger that motorists will take a chance and go on across, having found that they had to wait so long at the same crossing some other time, or at other crossings. If the motorists wait, as they must with the protective gate arms, they are forced to wait an unreasonable length of time for a slow train.

Is it not time that there should be designed and installed equipment which would take account of the approach speed of trains and relate the beginning of the operation of the warning or protective devices to that approach speed? This idea can be applied through the use of two track circuits, spaced at a proper distance, and with proper equipment to take account of the time interval between the wheels of the engine cross the first and second track circuits. Such equipment, which would relate the starting of the warning or protective equipment to the speed of the approaching train, would obviously be most appropriately first used in the more important locations where the speed differential is considerable.

It is, of course, true that sometimes the speed of trains changes and such two-track circuit equipment would not provide a perfect answer. However, it would seem unlikely that trains could increase their speed sufficiently in the distance involved, to cause hazard from the two-track circuit plan since a reasonable factor of safety would always exist anyway in the time when the grade crossing devices start to work. If the train slowed down, there would be some unnecessary delay, but in the over-all this would prove much less that with the one-track circuit equipment.

Some discussions have been held on this matter and while there would be technical problems involved, it is believed that there is no insurmountable obstacle to institution of this idea. True, it would cost some more, but at least for the most important crossings, it is believed that the increased cost would be more than warranted.

JOHN W. MCDONALD, *Public Roads Administration*—In evaluating those crossings at which some form of warning device or automatic barrier has already been installed, should not the sight distance to such a device or barrier be considered as well as the sight distance to the approaching train itself? It seems that ample sight distance to a warning signal at a particular crossing would compensate for the fact that an approaching train might be obscured from view and probably this fact was one of the reasons for the original installation.

MR. CRECINK, *Closure*—The factor discussed by Mr. McDonald certainly warrants serious consideration, and there are probably other factors of equal significance that should be considered in a study of this kind. It is believed that a thorough and detailed investigation of the topography at each individual crossing included in the scope of the study will be necessary, if a satisfactory method of evaluating hazards at railroad highway grade crossings is to be attained. Even then the human element will play a great part in the accident toll, and will make the task of developing a mathematical formula by which the relative hazard of crossings can be evaluated a difficult one.

DEPARTMENT OF MATERIALS AND CONSTRUCTION

C. H. SHOLER, *Chairman*

REPORT OF COMMITTEE ON WATER IN HARDENED CONCRETE

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PHYSICAL CONSTITUTION OF HARDENED PORTLAND CEMENT PASTE (AS REVEALED BY STUDIES OF ITS WATER CONTENT) AND ITS RELATION TO THE PROPERTIES OF HARDENED CONCRETE

SYNOPSIS

The discussions presented at an open meeting of the Committee on Water in Hardened Concrete are reported. After a review of the empirical relationships pertaining to the constitution of portland cement paste, including classification of water in hardened paste, and paste porosity, the following topics were discussed: volume changes that accompany changes in moisture content and temperature, freezing of water in hardened paste considered in relation to the durability of concrete. An annotated bibliography pertaining to water in paste or concrete is appended.

The discussion was opened with the following review by Chairman Powers of empirical relationships pertaining to the constitution of hardened portland cement paste, as set forth in the paper by Powers and Brownyard in the Proceedings of the American Concrete Institute.[1]

[1] Ref. B-1-16 to 18, in the bibliography at the end of the report.

Many of the important properties of concrete can be understood in terms of the peculiarities of the hydration products of portland cement. These hydration products form a solid mass called the hardened paste. The hardened paste is not a homogeneous solid; it may be considered to be composed of a large number of primary units bound together to form a porous solid. The chemical con-