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16. Abstract
This report is a preliminary examination of special aspects of grade crossing protection for operation of high-speed passenger trains in rail corridors for which complete grade separation is not possible. Overall system needs and constraints are indicated, and their implications examined. Application of conventional and improved hardware is considered, with special attention to activation criteria, appropriate motorist-warning devices, stalled-vehicle indicators, and train-mounted components. Non-technical aspects of the problem are also discussed, and areas for which future research efforts may be appropriate are identified.

17. Key Words
Grade crossing protection; High speed passenger trains; Rail corridors; Rail passenger safety

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PREFACE

The work described in this report was performed in the context of an overall program at the Transportation Systems Center to provide a technical basis for the improvement of grade crossing protection. The program is sponsored by the Federal Railroad Administration, Office of Research, Development and Demonstrations, Rail Systems Division. The program is designed to promote greater safety in railroad freight and passenger service.

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1. INTRODUCTION

The possibility of a grade crossing accident is one of the most serious and challenging safety concerns to arise in connection with the establishment of high-speed, high-density rail passenger corridors. Such an occurrence could have consequences comparable to those of a major airplane crash. An example is the oft-mentioned collision of a Buddliner, traveling at moderate speed, with a fuel oil truck, in Everett, Massachusetts.[1] Eleven passengers and two crew members died in the resulting fire. A large vehicle need not be involved. A collision at 33 mph between a freight train and a pick-up truck derailed three locomotives and eleven cars (killing one crew member and injuring two) in Scotland, Illinois.[2] When a large truck struck a passenger train in Collinsville, Oklahoma, two passengers were killed and 27 injured; only seven passengers were unhurt.[3] These cases make clear the potential severity of accidents involving light, high-speed railcars carrying hundreds of passengers.

Referring to the related situation for rail rapid transit systems, the National Transportation Safety Board declared in a recent report that "...grade crossings are not compatible with rail rapid transit operations".[4] It is therefore appropriate to consider this topic in some detail in order to delineate more fully the nature of the problem and of the constraints and guidelines governing protective measures. This paper is intended to provide an introductory examination of the subject and a framework for further discussion in the context of specific applications.

In the recent FRA/FHWA Report to Congress,[5] Section VI deals with this topic and provides a helpful introduction. That discussion has been included here as Appendix A. Its emphasis is almost entirely on minor variations of existing protective systems, and it is also apparently oriented toward basically conventional rail operations in which "high-speed" refers primarily to the higher velocities now found in revenue service. It is the aim of this report to supplement that treatment by considering protection techniques of greater complexity and sophistication which assume passenger rail vehicles operating at speeds in the range of 150 to 120 mph.

The basic case considered here will be that of corridors which -- almost by definition -- pass through regions generally characterized by high population density, with the implication of relatively high traffic counts. If the rail service is to be both socially useful and economically viable, one may anticipate medium to heavy rail traffic as well. In addition, the potential death toll, as noted above, can easily be ten to one hundred times greater than when only motor vehicle occupants are considered. Therefore, conventional cost-benefit calculations, adjusted for the much greater cost of accidents in this case, will virtually always indicate that grade separation (or rail relocation) is warranted, particularly when motorist delay costs are included. However, a detailed cost-benefit analysis is unnecessary: public and political acceptability clearly require that the risk of a crossing accident be reduced to the barest minimum.

Unfortunately, the problem is not that simple. Even if warranted, the expense of relocation or separation -- particularly in the urban regions usually involved -- can be a heavy burden. The national average of one grade crossing per mile of right-of-way is now exceeded in several potential corridors, and construction costs are typically of the order of $500,000 to $1 million per separation. An even more rigid constraint may be the impact upon local land use associated with such structures. Finally, neither relocation nor separation are suitable approaches when a trial is being conducted for a limited time in order to determine the economic viability of a proposed corridor project. Similarly, treatment of the problem through closing of crossings is desirable, and will undoubtedly play an important role. However, considerations of public acceptability and economics suggest that in many cases there will remain a significant number of rail-highway intersections at grade, which will require a class of automatic protection now unknown in this country.

2. ACCIDENT-RATE CALCULATIONS

In order to estimate the level of protective effectiveness now obtained, and compare it to that which is required, it is useful to carry out some simple, though highly approximate, calculations. According to the most comprehensive available examination of accident statistics,[6] the estimated annual number of train-involved accidents at a specifed grade crossing (N_a) may be predicted by the equation

$$N_a = .2 \times 10^{\left(C_0 + C_1 \log\overline{V} + C_2\sqrt{\overline{T}}\right)}$$

where C_0, C_1, and C_2 are constants which depend on the crossing protection (passive or active) and the location (urban or rural). $\overline{T}$ is the average number of trains per day, and $\overline{V}$ is the average daily vehicular traffic. Figures 1 and 2 are reproduced from Reference 6 to indicate the nature of the relationships described by the equation.

Inadequacies of currently-available data limit the applicability of this equation. In particular, there is no discrimination between flashing lights alone and automatic gates, and the results are not reliable for $\overline{T}$ greater than 20 trains per day. However, for the purposes of this inquiry, this approach is adequate.

Consider a hypothetical corridor, characterized by the following parameters:

Length: 200 miles

Traffic Density: 50 Trains per day

Train Capacity: 300 seats

Load Factor: 50%

Such a system will record total traffic of 550 million passenger miles per year; these numbers are in reasonable accord with proposed actual corridors. In recent years, the fatality rate associated with scheduled domestic air carriers, buses, and rail service has been of the order of 0.2 deaths per hundred-million passenger-miles;

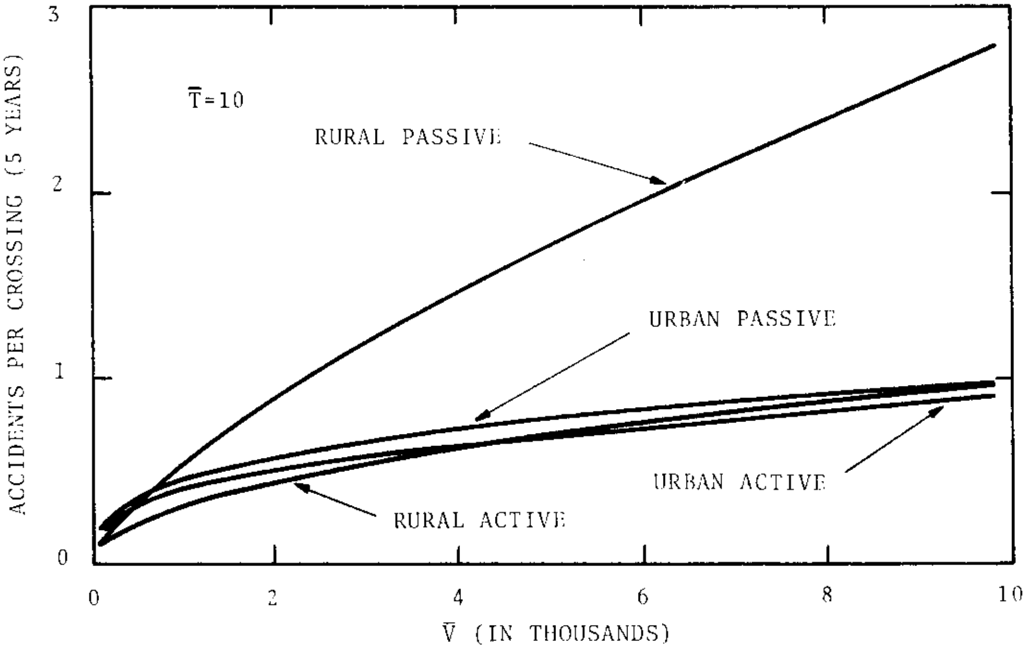

Figure 1. Expected Five Year Accidents per Crossing for $\overline{T}$ = 10 (From Reference 6)

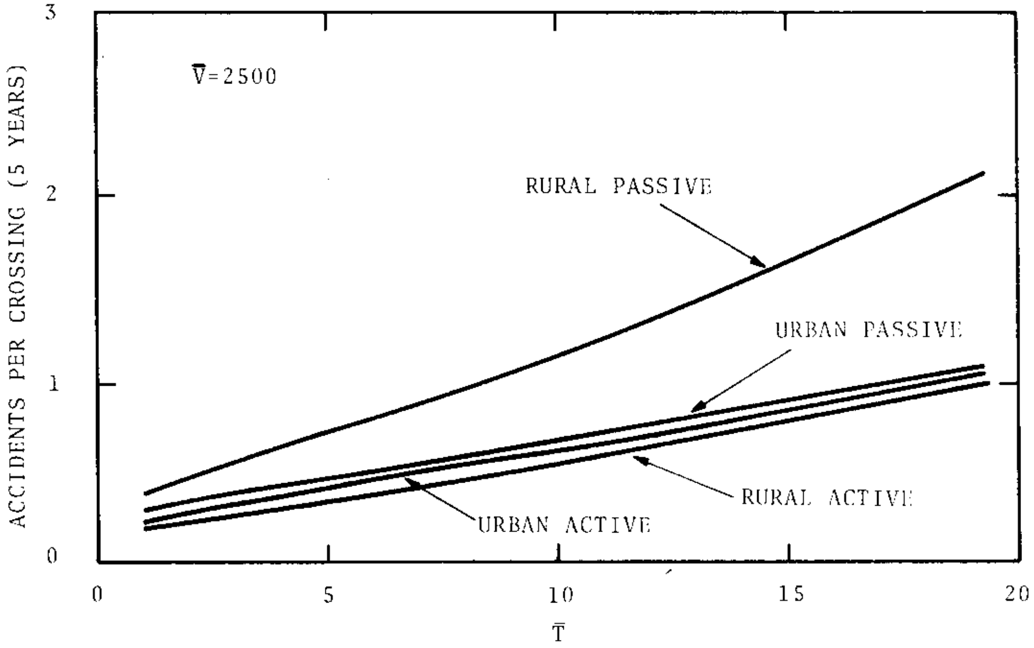

Figure 2. Expected Five Year Accidents per Crossing for $\overline{V}$ = 2500 (From Reference 6)

this is generally received as an acceptable level. Applied to the corridor described above, that value would imply 1.1 fatalities per year.

From Reference 6 one can infer that, for 50 trains per day, moderate traffic (2500 cars per day), and "average" active protection, one would predict 0.6 accidents per year per grade crossing. Numbers given in Appendix A for potential corridors indicate an average of approximately 1 crossing per mile (the same as the national average) so that elimination of 95% of the crossings via closings, separations, and rail relocation would leave 10 on the hypothetical 200-mile corridor, with a prediction of 6 collisions per year for the system. Approximately 20% of the vehicles involved in crossing accidents (and 20% of motor vehicle mileage) is associated with trucks, so if only half of the truck-train collisions initated a serious train accident (and none of the automobile-train accidents), there would be 0.6 such occurrances per year. 30 deaths per accident -- admittedly a very approximate but not unreasonable assumption -- would imply a system fatality rate of 18 deaths per year, approximately twenty times greater than that now found for current public means of inter-city transportation. In addition, this assumes no deaths from any non-crossing derailments or collisions. The calculations of Reference 6 are based on "average" active protection; implementation with the best conventional hardware and system design could achieve a level of protection perhaps three times better. However, the numbers developed above suggest that further improvement by a factor of ten or more is required -- far more if there is a large number of grade crossings.

In Appendix B a more general approach is taken, culminating in an expression for estimation of the factor (R) by which the accident probability for corridor grade crossings must be reduced, compared to the level of protection currently attainable. The final, highly approximate, expression obtained is deceptively simple: $R \sim L_g/100$, where L_g is the average distance between crossings (in miles), and a 20% fatality rate is assumed in the event of a collision leading to derailment. It is further taken that one accident in ten leads to such an occurence. In the above illustrative example, with L_g = 20 miles, this would indicate that accident probability must be reduced to one-fifth that which currently-optimal protection can provide.

3. PROTECTION REQUIREMENTS

The primary cause of almost all grade crossing accidents is an error or series of errors in motorist perception or judgment. Often the situation is made far more hazardous by poor protection or difficult environment. However, even the most well-conceived and effectively-implemented protection can be negated through distraction, willful violations of law, carelessness, or some form of irrational behavior. This is not to criticize conventional protective systems; the hazard associated with a crossing can be reduced by 95% to 98% by such means. However, as indicated earlier, even this excellent performance is not acceptable for corridor applications. Thus, the basic requirement to be met by corridor crossing protection is that it make minimal demands upon the perceptual and judgmental capabilities of motorists -- in short, that it be "foolproof."

System reliability must exceed even current high levels, and credibility -- obtained through constant warning time and freedom from false activations -- must be extremely high. The likelihood that train service will be frequent, and highway traffic at a relatively high level, makes minimum motorist delay a necessity. However, since trains will typically clear the crossings within a few seconds, unlike the case for freight operations, advance warning times somewhat longer than the customary 20 to 30 seconds should be tolerable if required. Advisory warnings before the crossing must necessarily be activated substantially earlier.

4. ADVANCE WARNINGS

Advance warnings far more elaborate than the conventional passive sign will be necessary. Details will depend upon the characteristics of the highway -- speed limit, number of lanes, intersections, curvature, etc. Standard highway signing principles should be applied to ensure that the location and nature of the potential hazard (the grade crossing) is made known to the motorist with maximum clarity and sufficiently in advance to permit full perception of the situation. Such warnings should include active components to indicate either that the crossing protection is at that time activated, or will be by the time the motorist arrives there. If the corridor involves trains operating at dramatically higher speeds than all other rail traffic in the area, it might be appropriate to develop a special identification symbol for affected crossings. (A 120 mph train might not be visible from the crossing until a few seconds prior to arrival, inspiring doubt in the mind of the uninformed motorist.)

Nearby traffic signals which could affect vehicle movements at the crossing must be interconnected with the crossing protection, with pre-emption of the highway signals when necessary to avoid giving a green light near the crossing, or -- by means of a red light -- backing up traffic so that a vehicle might be trapped upon the crossing. In addition, signing should specifically warn motorists never to enter the crossing area until sure of uninterrupted passage. (These standard crossing protection principles are included here for completeness.)

5. WARNING AND PROTECTIVE DEVICES

5.1 CROSSING-LOCATED DEVICES

The great effectiveness of conventional automatic gates makes them a natural starting point in any discussion of improved protective systems. However, certain modifications are necessary. It is possible, and indeed not unusual, for vehicles to go around the conventional half-gate. For the situations under consideration, this possibility is not acceptable: the highway must be completely blocked. Under these circumstances it is necessary that there be no way in which a vehicle can be "trapped" on the crossing between the gates. Thus, staggered timing is necessary. In Figure 3, gates 1 and 2 would be dropped, then 3 and 4 after an appropriate interval. (Although any vehicle can readily drive through a gate, many motorists fail to realize this, particularly when threatened by an approaching train.) This approach is followed in France, for example, for crossings in the category under consideration.

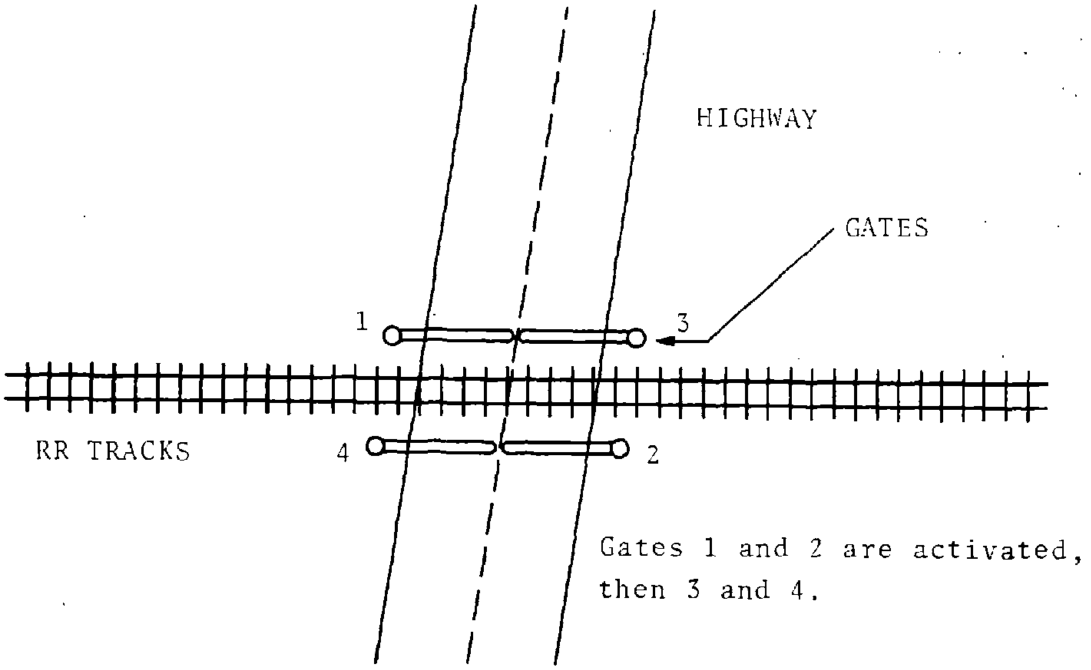

Figure 3. Full-Gate Arrangement

Accurate estimation of the adequacy of the use of full gates requires a detailed examination of accidents now occurring at gate-protected crossings to determine the most common patterns. It appears that such collisions are generally associated with vehicles which attempt, for a variety of reasons, to go around the gates. Thus, a full-gate configuration, with highly credible actuation and effective advance warnings, should achieve the required substantial improvement over existing systems.

Conventional or improved red flashing lights, mounted on a cantilever structure to bring the lights over each traffic lane, should be an inherent part of the installation. The use of standard highway traffic signal lights is a perennial subject of debate in grade crossing circles. Their use might well be preferable in the problem under discussion, where the motorist is to stop until allowed to cross, rather than the more common "stop and proceed when safe" instruction of flashing red lights. The higher power consumption might well be acceptable in this application, and the amber aspect could appropriately be actuated at the same time as the advance warnings. There are some legal questions which arise in this area, but none should be insurmountable.

Special consideration must be given to heavy trucks, particularly those subject to mandatory-stop laws. A number of problems are associated with this class of traffic, even for "conventional" crossings. The likelihood of a stalled engine is increased in such maneuvers, and the crossing exposure time can be quite lengthy for a long, heavily-laden or underpowered truck starting from a full stop. Similar considerations apply to buses. For the train speeds assumed here, the limited value of direct surveillance by drivers of such vehicles substantially reduces the justification for such stops. In addition, the sophistication of the signals and actuation systems will make these warnings especially reliable. Thus, this appears to be a case in which a waiving of the mandatory-stop laws is warranted. If such a specific waiver is achieved, it must be made very clear to the operators of affected vehicles. If, for legal or other reasons, these laws are not waived, the potential hazard of the situation should be recognized through an appropriately longer advance warning time and the use of stalled-vehicle indicators. This topic deserves further study.

5.2 BARRIER-TYPE PROTECTION

It is natural to consider the use of true barriers, that is, structures which can physically prevent a vehicle from crossing. A variety of such devices have been proposed from time to time, often based upon aircraft arresting-cable principles. While it is not possible to rule out such devices unequivocally, a number of difficulties should be noted. One major problem is the hazardous nature of large roadside and median structures. FHWA and numerous states now have quite firm requirements as to the distance such devices must be from the highway, and/or the kind of protection which must be placed around them. Expense is another difficulty. The necessity of rapid, all-weather operation, very high reliability, and sufficient capacity to restrain a large, fully-loaded truck, can lead to capital costs which may approach that of a separation, with a maintenance expense also far greater than is found for conventional systems. Moreover, fail-safe operation is required -- that is, activation in the event of any system failure. Such a malfunction, however, would completely block the highway. Note also that four separate assemblies would be required in the same configuration as seen in Figure 1 for the case of automatic gates.

In summary, this approach appears to be unpromising. If further consideration is deemed appropriate, it should begin with a survey of accident records, particularly for collisions involving trucks, to permit estimation of the need for protection which goes beyond that already described. Further research, if warranted, should then follow the pattern used for locomotive crash attenuation structures: a feasibility and preliminary design study to provide information on criteria for installation, potential effectiveness, possible means, estimated costs, and the preferred realization.

5.3 APPLICABILITY OF CONVENTIONAL ACTUATION HARDWARE

5.3.1 Track Circuit Systems

If one assumes that the only rail traffic involved will be high-speed passenger trains, all traveling at the same velocity, a very simple block track circuit would in principle be completely adequate. Relatively long blocks would be required -- as much as three miles -- to provide timely actuation of advance warning signals for trains at speeds of 150 mph and above. Thus, special hardware would be required to deal with such a distance, which is now unknown for grade crossing protection. However, existing basic designs, suitably modified, should be adequate.

To treat the more realistic situation of variable train movements and speeds, more sophisticated means of train detection will be required to avoid unnecessary motorist delay and false activations. For conventional crossings, this is now accomplished with the Grade Crossing Predictor,[7] which determines train distance and speed through measurement of the impedance seen across the rails at the crossing. Again, the conventional concept is satisfactory, but operation over the extreme range involved would be likely to require a significant engineering effort. Such circuits are commonly used with a "wrap-around" block circuit which provides completely fail-safe protection; this back-up should be retained.

Several difficulties can arise in the use of these techniques. The long blocks involved will require that relatively low-frequency modulation be used. This will limit the number of frequencies available and interference problems could be encountered if track circuits for several crossings overlap. If the rail line is electrified, very thorough precautions will be required to prevent other types of interference. Such systems are also readily susceptible to malicious unnecessary activation or disablement by simple shunting of the rails. Although such failures can be confined to safe modes, the resulting excessive motorist delay can lead to loss of motorist credibility and public complaint.

A similar problem can arise during winter in areas where salt is used to remove ice from the highway; a brine solution can short circuit the tracks bringing both highway and rail traffic to a halt through restrictive signal activations. Use of track circuits could also require attention to problems of poor shunting due to rust build-up on the rails, a non-safe failure mode. This is not normally a problem when rail traffic is high, but operation of lightweight rolling stock, with trains consisting of only a few cars, could alter the situation, particularly for low-frequency track circuits. Two factors favorable to track circuits are likely to be present: continuous welded rail (eliminating bond problems), and good maintenance of way. Also, it is assumed that effective prevention of serious vandalism can be achieved.

In summary, conventional actuation methods are satisfactory in principle, but a substantial and comprehensive engineering effort will be required to realize hardware suitable for the intended application. The cost will be high compared to present hardware, and cases of adjacent crossings will require particularly careful system design. These subjects warrant further detailed study, best carried out by an experienced supplier of rail signal equipment.

5.3.2 Other Techniques

The compelling need for proper performance of the warning actuation system suggests the desirability of additional redundant train detection. As a first step, information from the block signal system can presumably be made available at the crossing. Given the existence of a hard-wired signal/communication capability along the right-of-way, other information can be derived, preferably from sensors not associated with the rails or track circuits. Magnetometers or inductive loops appear appropriate to this application, although seismic detectors and very short-range track circuits might also be useful. Either microwave or infra-red radar are natural means to consider, and appear promising. A down-track radar could convey useful information via either cable or a simple microwave communication link. Its use at the crossing is less attractive, due to the relatively long range involved and the requirement for line-of-sight operation.

Cooperative systems, involving either active or passive equipment on the train, are not useful in general rail operations because of the requirement that all head-end units be properly equipped. Further, obtaining information sufficiently precise and detailed to operate crossing protection is rather costly, and fail-safe operation is difficult to achieve. However, the corridor situation may in some cases be sufficiently constrained to warrant consideration of this approach. Two examples of implementation means can be cited. Radar can be made far more effective if the train has a reflecting antenna which in some way modulates the received signal prior to reflection. This technology has been developed for other applications.[8] Another existing system utilizes active transponders in such a way as to provide accurate range (hence, velocity) information.[9] The cost of this approach is not trivial; a reasonable estimate is several thousand dollars per vehicle, and of the order of $10,000 per crossing.

5.3.3 Train-Mounted Protective Means

In addition to possible use of cooperative signal actuation systems, there are several other ways in which the train could be equipped with devices to enhance safety.

FRA has devoted considerable effort to studying means of enhancing the conspicuity of trains, by way of strobe lights, for example, and this should be considered. However, as stated earlier, the effectiveness of protection should be as nearly as possible independent of the perceptual abilities and judgments of motorists. In addition, the speed of the train (150 mph = 220 ft/sec, or 1 mile in 24 seconds) renders direct observation almost useless as a protective element. Fatal errors in estimating both distance and velocity are likely to be common, even when sight distances of the order of 1 mile are possible. Thus, conspicuity-enhancement devices would be utilized only for purposes of completeness, credibility, and final redundancy.

Audibility enhancement has also been studied by FRA.[10] It was found that train horns can provide no meaningful protection for grade crossings. The great range involved, the sound-proofing and internal sound sources of modern automobiles and trucks, and the limitations imposed on train horns in connection with community noise abatement programs all combine to render this approach ineffective.

More relevant, but of uncertain value at present, is the use of a crash-impact-attenuation and vehicle-deflection structure on the train. The present feasibility study is focused upon conventional railroad operations, in which the principal goal is the reduction of accident severity for the motorist, and the assumed rail vehicle is a locomotive. The applicability of this work to the protection of a lightweight passenger unit is not known at present, but this could be the subject of a special study effort, in which the primary objective would be derailment prevention. In both situations, the desirability of deflection of the motor vehicle is unquestioned.

5.4 INDICATION OF STALLED VEHICLES OR SYSTEM FAILURE

The proposed use of full gates, completely closing the crossing, makes it appropriate to consider the possibility of stalled or otherwise "trapped" vehicles on the crossing. In conventional rail operations, any situation which permits stopping of the train also allows time for vehicle occupants to vacate the scene. However, when the primary issue is protection of the train, this topic becomes more meaningful. Thus, it is appropriate to consider means of realizing surveillance of the crossing immediately following activation of the gates to ensure that the crossing is clear. The French (SNCF) are aware of this hazard and are currently considering a microwave beam-interruption approach.[11] Other means -- magnetic, inductive, etc. -- are also possible. If a problem is found, the information can be conveyed to the train in the form of an emergency brake-application command via the existing signal system and/or (as in France) via flares, etc. Clearly, utilization of such a system is possible only if malicious activation can be virtually precluded.

Similarly, the signal system can be used to notify the train of any failure of the protective devices, or conversely, to validate their operation, although the use to be made of such information requires careful consideration. Emergency brake applications are not undertaken without peril, and realistic choice of an operating strategy depends strongly upon one's estimate of the likelihood of false alarms. Further, certain laws of physics impose limitations on the range of such actions. Failure of the crossing protection to operate properly, or presence of a vehicle within the gates, can be detected only after crossing activation, which implies that the train has reached some miminum distance from the crossing. For a given train velocity and braking capability, it may not be possible to stop the train within that distance. For a specified advance warning time t_a (the required time interval between complete crossing actuation and train arrival) and velocity v_0, actuation will occur when the train is at a range s_a, given by $s_a = v_0 t_a$. The train stopping distance s_s, for a deceleration α, is $s_s = v_0^2/(2\alpha)$. The train can be stopped only if s_s is less than s_a, and braking must be initiated while the train progresses from distance s_a to s_s. Δt, the time available for detection of a hazardous condition, communication with the train, and initiation of braking, is given by $\Delta t = (s_a - s_s)/v_0 = t_a - v_0/(2\alpha)$. Figure 4 shows Δt as a function of v_0 for various α (.1, .15, and .2 G) and t_a (20 sec, 40

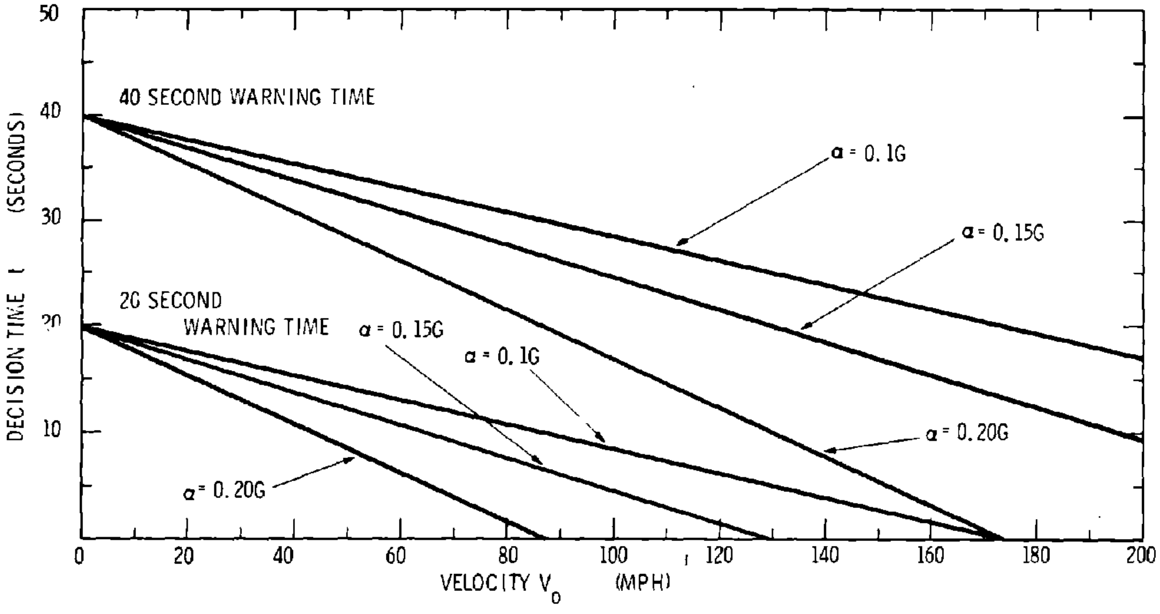

Figure 4. Decision Time vs. Velocity for α = 0.10, 0.15, 0.20 G and Working Times of 20 and 40 Seconds

sec). It will be noted that the train can be stopped in most cases, but the decision-time is generally very short.

System failure which can be identified prior to actuation could be conveyed to the train by the signal system. However, in addition to the hoped-for rarity of such occurrences, the use of such information raises questions similar to those suggested above. To what degree should the train reduce its velocity? What impact would such a system have upon liability considerations? Preliminary examination suggests that non-safe failure modes for which this approach would be applicable are unlikely to be sufficiently frequent to warrant implementation.

Related to all types of failures is the importance of immediate and precise reporting of any damage or malfunction. Those notified should include railroad maintenance and operations personnel, local police and, in some cases, the highway authorities. Implementation of such communication is not, in a technical sense, a difficult problem, but a substantial effort may be warranted in instrumenting the crossing to detect failed lights, broken or frozen gates, transfer to reserve power supplies, etc.

6. SPECIAL CONSIDERATIONS

There are a number of special circumstances which may arise in particular situations. Typically these will relate to characteristics of either rail or highway traffic. These cannot be discussed here in detail, but comments on certain general cases are appropriate.

6.1 RAIL TRAFFIC

The underlying assumption of the previous discussion is the use of a dedicated right-of-way, carrying only high-speed passenger trains at relatively frequent intervals. However, it is quite possible that the right-of-way, or even the tracks, could be shared with conventional passenger and/or freight trains. This may significantly complicate the attainment of uniform warning time, particularly if station stops or switching moves occur in the vicinity of the crossing. More important, such a situation makes even more likely the misinterpretation of continued warning activation following passage of a train. A motorist or pedestrian may well assume that the system is malfunctioning and ignore the warning, only to collide with a second train on another track. Worse, someone might assume crossing activation to be due to a nearby switching move, presenting no discernible hazard, when in fact a high-speed train is approaching. Consideration should be given to use of special displays which indicate the track and direction of approach for all trains in the vicinity. Finally, if conventional rail traffic predominates, it will be particularly important to inform the motorist of the special hazard associated with occasional very high speed operations, in which he will not see the train until it is within a few seconds of the crossing.

6.2 HIGHWAY TRAFFIC

Highway traffic can vary in both composition and density. The most important aspect in this instance is the number of large and/or hazardous-material vehicles using the crossing. A requirement that all vehicles above a certain gross weight use an alternative route is logical, but it may prove to be neither practical nor politically acceptable. Such measures become of even greater concern when buses (particularly school buses) are involved. Aside from restricting crossing use, no special measures appear feasible other than emphasis on certain techniques mentioned elsewhere in this study.

In cases for which traffic density or composition is a sharp function of time, as in the vicinity of schools or factories, it might in some circumstances be feasible to arrange train schedules to avoid the traffic peaks. This could reduce the collision probability substantially. However, it assumes tightly scheduled operations, and could not be applied to many crossings without a high probability of mutual inconsistencies. This strategy would also present benefits in terms of reduced motorist delay time. However, special caution -- possibly reduced speed -- might be necessary if schedule slippage caused a train to arrive unexpectedly at a peak time.

7. NON-TECHNICAL COUNTERMEASURES

There are a number of actions which are appropriate to undertake in any corridor grade crossing activity which have no connection with the technology involved. These are generally elaborations on steps which are always desirable, but often omitted due to inadequate resources or low priority.

7.1 EDUCATION/PUBLICITY

In most cases, the major portion of crossing traffic is basically local. Thus, it is advisable to accompany installation of protection (and impending presence of high-speed trains) with a substantial educational campaign. The existence of the corridor is likely to generate local interest, and an attempt should be made to see that all publicity draws attention to the elaborate and sophisticated level of grade crossing protection provided, and the respect which must be given to high-speed trains. Particular emphasis should be placed on informing those who work at, or otherwise frequent, factories, schools, shopping centers, etc., in the vicinity of an affected crossing, as well as professional drivers who use the crossing often.

7.2 LAW ENFORCEMENT

Special attempts should be made to gain the cooperation of local traffic control authorities, particularly with respect to rigorous enforcement of speed laws in the vicinity of the crossing, and to periodic attention to motorists who attempt to cross just after signal activation. If some types of vehicles are prohibited from the crossing, compliance with prohibition must be insured. Prevention of vandalism of protective devices is also partially a function of police presence. Such efforts are likely to be carried out with more vigor if those responsible for enforcement of the law are fully informed as to the nature of the hazard, the operational characteristics of the protective system, and the value of their taking an active role. In addition, their advice concerning local traffic and driving characteristics can be beneficial in both planning and implementing the overall protective system. Finally, malfunction or damage to the crossing protection should automatically and immediately be made known to permit rapid dispatch of traffic controllers to the crossing. Such personnel must have full knowledge of crossing operations so that they may act effectively, without inadvertently creating hazardous circumstances.

7.3 SITE CHARACTERISTICS

Installation of full protection will often require major improvements and restructuring of the road for a substantial distance from the crossing. This could include straightening, leveling, removal of obstructions to a clear view of signals, etc. Special area illumination may be warranted in some cases, either during train passage or at all times. Adequate space should be provided at the side of the road to permit evasive maneuvers by motorists, parking for maintenance personnel, etc. In general, distractions of all types should be minimized insofar as possible. The road surface must be of good quality and well maintained to allow minimal likelihood of skidding or sliding under adverse weather conditions. Cooperation of the local road-maintenance authority should be sought to ensure that the vicinity of the crossing will receive early and complete attention in the event of poor driving conditions.

7.4 CORRIDOR ROUTE SELECTION

Effective implementation of grade crossing protection will require substantial effort and money. It is therefore appropriate that such factors be included at the early planning stages of all projects. Special attention should be given to impact upon the signal, communication, and control systems, to route selection and to overall system safety. It should be noted that grade crossing concerns are likely to arise very soon after a community is informed that it will be part of a corridor project. The FRA grade crossing inventory program now under way should be quite useful in obtaining a first approximation to the grade crossing costs associated with any particular routing, but any case which has several realistic options will require a full diagnostic team analysis of each crossing to assess overall impact of this factor.

7.5 DISASTER FACILITIES

A serious accident involving a high-speed passenger vehicle will make heavy demands upon the emergency facilities of the community in which it occurs. This is true regardless of whether the accident occurs at a grade crossing, and the topic is mentioned here only for completeness. All local authorities and institutions which might be expected to take part in rescue operations must be made aware of the possibility of such events, of the special characteristics of train accidents, and of the need for coordinated planning.

7.6 PRIVATE CROSSINGS

Private crossings are common in this country (approximately half as numerous as public crossings) and a substantial number may occur on any planned corridor. As suggested earlier, the conventional treatment (passive protection) becomes completely unacceptable when one is concerned with the lives of the passengers, and when visual observation may provide only a few seconds' warning at best. The character and location of the roads involved may permit relatively low cost "culvert-type" separations; in other cases closing will be required.

8. CONCLUSION

This study concentrates on implementing maximally-effective active crossing protection. It is understood that those concerns become relevant only when all possibilities for separation, closing, and rail relocation have been exhausted. The degree to which any or all of the protective measures described here are warranted in a particular case must remain a matter of policy and economic reality. This is especially true for the marginal cases such as private crossings and low traffic-density roads, for which "complete" protection is felt to be too expensive. Experience, further studies, and careful analysis of each situation will be required for final decisions. An examination of the experiences of other countries, particularly in Europe, should be of value.

The basic conclusions and constraints identified in this brief examination may be stated as follows:

(1) Improved protection is required in virtually all cases to equal the safety record now achieved in public inter-city transportation.

(2) The necessary degree of improvement appears feasible for average grade crossing spacing as low as 10 miles.

(3) Protection must depend very little upon driver perception and judgment; motorists will rarely see trains more than a few seconds prior to arrival.

(4) The major engineering developments required entail extension of the range of constant-warning-time track-circuit train detection systems to several miles.

(5) A study of accidents at gate-protected crossings is necessary to refine estimation of the effectiveness of the suggested modifications of current practice.

(6) In view of the ineffectiveness of visual observation and the anticipated high reliability of the automatic protection, mandatory-stop laws should be waived.

(7) Comprehensive site-specific studies will be required.

More information concerning characteristics of motorist behavior would be useful, particularly with respect to the design of effective advance warnings, although the existing body of traffic signing knowledge and principles is adequate to meet foreseeable needs. Means of derailment prevention in general and the development of vehicle designs exhibiting improved crashworthiness are highly appropriate topics for both research and engineering design programs; however, they are topics that require study regardless of grade crossing considerations. As indicated, improved train conspicuity is of little value for the speeds involved; even if the train can be seen at an adequate distance, judgment of closing rate and range is likely to be highly inaccurate.

As for non-technical factors, the most important activities to be considered depend upon strong interaction among the involved parties: system designers, rail operating personnel, local authorities, highway authorities, police, etc. Only in this manner can special local data be included in the decision-making process, and such cooperation will be crucial to dealing with the ultimate local impact of corridor operations.

APPENDIX A

HIGH-SPEED RAIL CORRIDORS

This Appendix consists of Section VI of the FRA-FHWA Report to Congress, Railroad-Highway Safety, Part II: Recommendations for Resolving the Problem. This section deals explicitly with the problem of high-speed corridors. However, emphasis is placed to a large degree on the improvement of existing protection -- including passive techniques -- which is appropriate only to relatively limited changes from present-day passenger service conditions. The body of the present report is intended to complement that approach through delineation of the elements which arise if a more dramatic change is considered, such as an increase in train speed by approximately a factor of two. Nonetheless, the relevance of a number of portions of the Congressional submission makes it appropriate that Section VI be included as an Appendix to this report.

* * *

HIGH-SPEED RAIL CORRIDORS

The Highway Safety Act of 1970 includes a requirement for a "... full and complete investigation of the problem of providing increased highway safety at public and private ground-level, rail-highway crossings ... including specifically high-speed rail operations in all parts of the country,...."

Assessment of the magnitude of the problem requires development of a basis for estimating the cost of eliminating or substantially reducing the hazards of grade crossings along the route of potential high-speed rail corridors. In turn, the estimated costs so developed may be applied to several potential corridor candidates located in representative parts of the Nation. In this context it is important to keep in mind that the following discussion offers no recommendations on the merit and need for initiating high-speed railroad service along the corridors included in this study.

BACKGROUND

The rapid growth of population in and around such areas as the Eastern Seaboard megalopolis has put new demands on the high-speed movement of large numbers of people, along with increasing volumes of freight. Transportation through these densely populated areas is rapidly taxing the present highway and air modes. While many advanced systems have been proposed, high-speed rail transportation has proved to be a viable and practical alternative. The Northeast Corridor high-speed rail demonstration has proved that rail travel can be an important part of the mix of intercity passenger travel.

There are other corridors that have either current or future potential for high-speed rail service. While an optimum physical solution would consist of the construction of entirely new facilities similar to Japan's Tokaido Line, the "real world" approach taken in this country is to mount demonstration projects, utilizing existing rail facilities, to measure the public demand and acceptability of high-speed rail service. These demonstrations present various operating and safety problems, particularly with regard to grade crossings.

THE PROBLEM

An important safety problem along a high-speed railroad line arises from the existence of grade crossings of both public highways and private roadways.

On the average existing line with potential for high-speed operation, these crossings are estimated to occur at the rate of one crossing per mile of line. About 60 percent are estimated to be public and the remaining 40 percent private.

The probability of vehicle-train collisions at grade crossings of a high-speed rail corridor, like other grade crossings, is influenced significantly by the volume of highway and rail traffic using the crossing and the type of protection at the crossing. Furthermore, the inherent hazards at "normal" crossings are compounded with the presence of high-speed trains, particularly when there is a mix of high-speed and low-speed movements.

The types of problems created by introducing high-speed rail service on an existing railroad line vary with the type of crossing and type of protection at the crossing.

At grade crossings that have active protection such as flashing light signals or automatic gates, their actuation is usually determined by the length of the approach circuit in the track. These circuits are arranged to give at least a 20-second warning before the train enters the crossing. If the approach circuits are arranged to give such advance warning at train speeds of 50 mph, it is obvious that a train traveling at twice that speed would provide only half the warning time, and modification of the signal circuits becomes a necessity.

At public crossings protected by static warning signs only, the driver's task of determining whether a train is approaching and whether it is safe to proceed is difficult. Even with good visibility up and down the track, it is difficult to judge the time and distance from the crossing of a train approaching at moderate speed. At high train speeds the problem is critically compounded because of the great distance along the track that must be visible to the driver approaching the crossing.

A third, and perhaps the most potentially dangerous type of crossing is the private crossing. These crossings, providing access to industrial facilities, private residences and farm land, often are on narrow, unimproved or gravel-surfaced roads with narrow crossings of the track, limited visibility along the road to the tracks, and limited visibility of approaching trains.

The introduction of high-speed passenger trains, using existing facilities, is clearly a complex problem that can have severe impact on safety at railroad-highway grade crossings. It should be apparent that introduction of high-speed rail service, regardless of its anticipated duration, should be undertaken only after anticipated grade crossing problems have been fully analyzed and corrective action taken.

PROPOSED SOLUTIONS

A significant factor in developing practical solutions to the grade crossing problem in a specific corridor is the anticipated duration of the high-speed demonstration in that corridor.

Short-Term Projects

Prior to initiating even short-term rail passenger service at moderately high speeds, certain actions should be taken as a minimum, including:

1. A comprehensive field review should be conducted to determine the adequacy of existing signing at and approaching each passively protected crossing. New signs should be installed to replace missing standard signs. Existing signs or pavement markings which are less than fully effective should be replaced or refurbished. Special signing should be installed to alert drivers to the need for special attention to the possible approach of a train.
2. Publicity campaigns should be undertaken to advise the populace in the area of the rail corridor of the inauguration of the high-speed train service.
3. Instructions should be issued that trains approaching actively protected crossings operate at required slower speeds in order to provide the minimum 20 seconds of signal activation prior to arrival of the train. Adoption of this practice, however, will compromise the primary goal of high speed.
4. In lieu of (3) at actively protected crossings, the timing circuits should be extended to provide the minimum 20 seconds activation prior to arrival of high-speed trains, with appropriate speed-detection equipment to prevent excessively long periods of activation for slow-speed trains. Without speed prediction equipment, the credibility of the crossing device will be suspect and there may well be an overall negative effect on crossing safety.

5. At all crossings, but particularly at passively protected crossings, an effort should be made to improve sight visibility along the tracks. This action is desirable with or without high-speed service and, if properly maintained, should be of continuing benefit. It is recognized, however, that in many cases private property is involved.

Projects for Extended Periods

For a corridor with higher rail operating speeds or where the duration of the demonstration is to be for extended periods, automatic gate protection should be provided at crossings and activated advance warning signals on the approaches, together with the necessary additional track circuitry, including speed prediction equipment for all crossings, public and private, which are to remain at grade.

While this action is relatively expensive, it provides the highest level of grade crossing protection available with existing technology short of total elimination of crossings at grade, and will be of continuing benefit.

Permanent High-Speed Corridors

In evaluating the feasibility of permanent high-speed rail service along a given corridor it is most important that the grade crossing problems be fully considered as an integral part of the analysis and included as a part of the total cost of the high-speed rail service.

Complete elimination of grade crossings is the desirable solution for high-speed rail corridors which are being established on a permanent basis. Only crossing elimination will afford complete protection to the vehicle driver and occupants and to the train and its passengers. Elimination of grade crossings is the only means to achieve the full potential of high-speed rail service.

As an example of the integral nature of the high-speed rail service and the grade crossing problem, any program to implement permanent high-speed service over a given corridor should include, in conjuction with treatment of the grade crossings, consideration of relocating the rail line to improve the track alignment and/or eliminate grade crossings. On many existing rail lines curvature is severe enough to limit train speed and/or severely restrict visibility along the track for drivers at crossings. Construction of grade separations either over or under the track tends to fix the track alignment permanently. Thus, this coordination is essential in order to achieve the maximum potential for the high-speed service. In some instances, relocation of fairly long sections of rail lines may prove less expensive than construction of several grade separations.

Because of the high cost of grade separations, the elimination of grade crossings along a high-speed rail line must include a mix of grade separations and crossing closures with or without improvement to the existing road network. For example, several closely spaced crossings could be treated as a unit with all but one of them barricaded and improved access roads built to carry the traffic to the remaining crossing provided with a grade separation. This procedure would eliminate the hazard of vehicle-train collisions, while at the same time retaining reasonable continuity of local highway travel. When a configuration of access roads is developed that allows for free movement of vehicular traffic, then the location, type, and number of grade separations can be determined.

Estimated Costs

[The following table] lists representative potential high-speed rail corridors with miles of rail line and estimated total number of public and private grade crossings in each corridor. These corridors represent varying geographic terrain and a wide divergence in crossings per mile.

The method of estimating the costs associated with crossing elimination in the high-speed corridors is based on costs incurred in constructing the Interstate Highway System, along with analysis of approximately 1,000 miles of potential high-speed rail corridor in a typical urban-rural environment. From this it is estimated that complete crossing elimination in such corridors would consist of 35 percent of the crossings being closed and 65 percent being grade separated.

For purposes of this analysis, and based on data described in previous chapters of this report, it is assumed that the 35 percent of crossing closings would occur in the low highway volume categories. Inventory data on all crossings having the rail traffic characteristics of the remaining 65 percent, provided a reasonable estimate of the location and type of crossings to be grade separated, with percentage distribution as follows:

	Rural	Urban
Two lane	50 percent	35 percent
Four lane	2 percent	13 percent
Total percent	52 percent	48 percent

Preliminary cost estimates for grade crossing elimination were determined using four prototype designs for grade separation and estimated unit construction costs. While these figures can vary widely in any particular instance, they represent typical, average costs and are applicable to representative corridors. The estimated costs are:

	Rural	Urban
Two lane	$380,000	$ 825,00
Four lane	$715,000	$1,350,000

The estimated costs associated with closing a grade crossing are:

1-1/2 miles of connector road per crossing	$165,000
Barricades	5,000
Total cost per crossing	$170,000

[TABLE] ESTIMATED COST OF COMPLETE ELIMINATION OF RAILROAD-HIGHWAY GRADE CROSSINGS ON POTENTIAL HIGH-SPEED RAILROAD CORRIDORS

CORRIDOR	MILES	TOTAL CROSSINGS*	ELIMINATION COST** $Millions
Chicago - St. Louis	284	441	220
Chicago - Milwaukee	85	118	59
Los Angeles - San Diego	126	125	63
Chicago-Toledo-Cleveland	341	350	175
Cleveland - Pittsburgh	131	120	60
New York - Buffalo	439	90	45
Pittsburgh - Philadelphia	349	69	40
Miami - Orlando	370	391	195
Orlando - Tampa	92	200	100
Detroit - Chicago	283	284	142
Chicago - Carbondale	307	410	205
Seattle - Portland	186	157	79
Washington - Richmond	114	114+	57

Notes:
* Railroad industry sources
** Based on average cost of $500,000 per crossing
\+ Estimated from national average

An analysis based upon these estimated requirements yields an average cost amounting to about $500,000 per crossing for a complete elimination program. This average cost has validity only when applied to a substantial length of track. This figure was used to produce the crossing elimination costs indicated in [the preceding table].

RECOMMENDATION

Planning and funding of future high-speed railroad corridors give full consideration to the appropriate treatment of railroad-highway grade crossings in accordance with the proposed solutions set forth above.

APPENDIX B

ACCIDENT-RATE CALCULATIONS

The total annual traffic carried by a rail transportation system, expressed in passenger-miles and indicated by N_{pm}, can be written as:

$$N_{pm} = N_t \times N_p \times L \times 365$$

where N_t = number of trains per day

N_p = average number of passengers per train (load factor times capacity)

and L = system length (miles).

A reasonable approximation to the functional relationship between traffic density and accident probability (given in Reference 6) is the simple linear expression:

$$P_a = \frac{N_t}{100}$$

where P_a = annual number of accidents.

This assumes moderate highway traffic (1000 to 5000 vehicles per day) and is understood to be accurate only to within a factor of 2 at best.

It is further assumed that the best of conventional crossing protection is 3 times better (accident probability one-third as great) than for the average upon which the calculations of Reference 6 are based, and that only 1 collision in 10 leads to an accident with serious consequences, such as a derailment. Under these many simplifications, the fatality rate (deaths per year) F for a system including N_g grade crossings in a route length L, will be given by:

$$F = \left(\frac{\frac{1}{3} \cdot \frac{N_t}{100} \times \frac{1}{10}}{N_{pm}} \right)$$

with N_{pm} as given above

or

$$F = \left(\frac{N_g}{L}\right) P_f \times 10^{-6}$$

with P_f the probability that a passenger will lose his life in one of the 1-in-10 "serious" accidents. (It also may be thought of as the percentage of passengers killed.) Thus, in terms of the average distance between crossings,

$$L_g = \frac{L}{N_g} ,$$

$$F = \left(\frac{P_f}{L_g}\right) \times 10^{-6}$$

If F is to be equal to or less than the "acceptable" fatality rate, 0.2 deaths per 100 million passenger miles,

$$\frac{P_f}{L_g} \leq 0.2 \times 10^{-2}$$

This assumes protection providing an accident probability one-third that for "average" conventional devices. If protection can be provided which further reduces the likelihood of a collision by a factor R, and P_f is taken as 0.2 (20% fatalities),

$$R \times \frac{P_f}{L_g} \leq 0.2 \times 10^{-2}$$

or

$$R = \frac{L_g}{100}$$

This very simple relationship includes numerous assumptions, particularly with respect to values used for victims per accident and train accidents per collision. Modification is a simple matter when better data or grounds for estimation are available. Note that the final equation is independent of N_t, N_p, and L; both passenger-miles and accident probabilities are proportional to these quantities, so they drop out.

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