AT-GRADE INTERSECTIONS VERSUS GRADE-SEPARATED INTERCHANGES
(AN ECONOMIC ANALYSIS OF SEVERAL BYPASSES)

by

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INTRODUCTION

In an effort to reduce traffic in central business districts, bypasses have been built to provide through traffic a circumferential route and also to ease the burden of traffic in downtown areas. In many cases, though, bypasses have created a serious accident potential because they were built with at-grade intersections and no access control. This has led to commercial developments along the bypass and congestion at major intersections. When congestion increases at an intersection, traffic signals must be installed; this increases vehicle operating and time costs and creates a rear-end collision potential. In some cases, the bypass circumvents a relatively small town where congestion is not an immediate problem, but there is still an accident problem at the at-grade intersections. Bypasses have been built in this manner because of the high initial cost of grade-separated interchanges and access control. Retrospective analyses of several bypasses were undertaken to determine if accident cost savings along with time and operating cost savings would have justified higher initial costs of interchanges. Such analyses may serve to justify needed improvements and to guide design decisions on future facilities.

The high initial cost of an interchange limits its use to those locations where the required expenditure can be justified. The conditions to be considered in reaching a rational decision are the applicable warrants *(1)*:

1. a freeway development,
2. elimination of bottlenecks or spot congestion,
3. elimination of hazards,
4. site topography,
5. road-user benefits, and
6. traffic volume warrant.

On urban bypasses, Warrants 2, 3, 5, and 6 could be considered applicable in most cases. This study will be concerned only with Warrants 3 and 5.

When considering highway improvements, it is essential to view the investment as a business enterprise in which the economic costs of highways are matched by future economic benefits to the state, community, and individual user. Since the motor vehicle itself accounts for about 88 percent of the total cost of highway transportation, with highway construction accounting for the remaining 12 percent, the highway designer must consider the effects of highway design on the running cost of motor vehicles *(2)*. The principal benefits of highway improvements accrue to those who travel the highway. These benefits reach the road user primarily through the operating cost of motor vehicles, reduction in highway accidents, and reduction in travel time. Such market factors are those on which a dollar value can be placed. There are also the nonmarket consequences of comfort and convenience.

PROCEDURE

Accident Analysis

Accident reports were obtained from city, county, and state police for a period of 18 months (January 1, 1970 -- June 30, 1971). Collision diagrams for the subject locations were drawn on aerial photographs to give an overall view of the most serious accident locations. A separate collision diagram was drawn for each intersection which had a significant number of accidents. A determination was made as to whether each accident could have been prevented if the bypass provided interchanges or access control. If the accident could have been prevented with the above-mentioned controls, the accident was classified as "correctable". If not, the accident was classified as "not correctable".

Cost Analysis

Calculation of costs resulting from the lack of interchanges can be divided into two parts. First, the total cost of the accidents, and conversely the benefits gained by preventing the "correctable" traffic accidents, were calculated using National Safety Council figures *(3)*. Accident cost figures used herein were as follows:

Fatality	$45,000
Non-fatal injury	2,700
Property damage accident	400

Accident costs for the 18-month study period were converted to a 12-month period to simplify analysis. The second part of the cost analysis was the calculation of time and operating costs incurred by the motoring public as a result of stopping and returning to initial speed at the at-grade intersections, and conversely the benefits gained by building interchanges. This was done by using cost data in Table 1 and Table 2 *(4)*. With the cost data, traffic volumes, and assumed speeds at the locations, calculations were made for a one-year period.

Finally, using a study period of 20 years and a uniform-percentage-gradient-series present-worth factor, the present worth of accident saving, and time and operating cost savings were calculated. The present-worth factor *(5)* is calculated from

$$P_{ijN} = ((1 + i)^N - (1 + j)^N)/((i - j)(1 + i)^N)$$

in which N $=$ number of years under consideration,

        i $=$ interest rate, and

        j $=$ percent traffic volume increase from year to year.

The interest rate used was seven percent. The annual percentage increase in traffic volume (j) chosen was 3.5 percent. Traffic volumes over the past years had tended to increase geometrically (exponentially) more so than linearly (straight line). Traffic data indicates that 3.5 percent is an accurate estimate of

the average annual increase for the state of Kentucky. The increase in traffic volume has been affected recently by the energy crises, but there is no evidence to change the figure used for the long period considered in an urban or suburban area. Likewise, a constant percentage increase in volume is applicable to the accident costs and the time and operating costs. Also, since cost values in Tables 1 and 2 are given in dollars per 1000 stops, it is clear that volume is directly related to time and operating costs.

Using the present worth of the combined benefits and the initial cost of construction, a benefit-cost ratio was calculated. A one-year value for the accident, time, and operating costs was calculated. Ten percent of the total volume was assumed to be commercial vehicles. Volume data were obtained from the Division of Planning. Some intersecting streets did not have recent traffic counts, so a few volumes were assumed. When a volume had to be assumed, it was kept low so it would not improperly affect the benefit-cost ratio. Also, the percentage of the total volume which was stopped at the traffic signals had to be assumed, using other references (6). This percentage was also kept low but realistic. In summary, an effort was made to keep all assumed volumes low but realistic so as to not overestimate the time and operating benefits and unduly affect the benefit-cost ratio.

The accident, time, and operating costs were summed and multiplied by a uniform-percentage-gradient-series present-worth factor of 13.88 to obtain the present worth of these values over the study period of 20 years.

Benefit-cost ratios were then calculated for each of the major intersections. This was done by comparing the present worth of benefits over the study period of 20 years with the cost of building an interchange. The approximate cost of a simple diamond interchange was found to be $800,000. This cost was calculated by approximating the cost of the structure at $200,000, the cost of the four ramps at $500,000, and the cost of reconstructing the crossroad at $100,000.

It should be noted that the calculated benefit-cost ratios are not precise values because certain assumptions had to be made. Speeds were assumed using field observations of the traffic stream and the speed limits. Certain volumes had to be assumed, but assumed values were kept low so as to not unduly affect the benefit-cost ratio. Volumes stopped at traffic signals also had to be assumed. Since the time and operating costs of waiting for the signal to change was not considered, time and operating costs should not be unrealistically high. Only the time and operating costs of stopping and returning to initial speed were considered. The construction cost of an interchange was only an average cost and would actually vary from location to location. Finally, the values used for calculating benefits and costs do not reflect the inflation which has taken place in the past few years. It can be assumed, however, that inflation would have affected both the benefits and costs so there would be no significant change in the benefit-cost ratios.

RESULTS

There was a total of 518 accidents on the subject bypasses during the study period. Of these 518 accidents, 373 were property damage, and the remaining 145 were personal injury accidents which resulted in a total of 271 injuries, including 14 fatalities.

A total of 397 of the accidents (76.6 percent) were classified as "correctable". Further study of the accidents showed that 278 (74.5 percent) of the property damage accidents were classified as correctable, and 119 (82.1 percent) of the personal injury accidents were classified as correctable. Of the total of 271 injuries, 234 (86.3 percent) were the result of correctable accidents; of the 14 fatalities, 12 (85.7) percent were the result of correctable accidents.

The same types of accidents were predominant on all the bypasses. The most prominent type of accident was the right-angle collision, followed closely by the rear-end and the oblique or sideswipe types. The right-angle collision would logically be the type most affected by changes which are under study; and since it is also the most predominant type of accident, this explains why such a large percentage of the accidents was classified as correctable. There was also a large number of correctable rear-end accidents, particularly those resulting from traffic signals as well as from left-turning vehicles. There were also many correctable oblique or sideswipe accidents which resulted from the same circumstances, as well as from vehicles turning from the wrong lane. A summary of the types of accidents is given in Table 3.

It was found that the percentage of correctable injuries was greater than the percentage of correctable accidents, indicating the "correctable" accidents were more severe than the "not correctable" accidents. An explanation is that the right-angle collision had the highest severity of any type of accident and was also the most correctable.

Most accidents occurred at major at-grade intersections. Excluding the accidents on one bypass, which were obtained at only one intersection, 348 of 498 accidents (70 percent) occurred at the at-grade intersections. Several bypasses were in rural areas, but even on a bypass in an urbanized area, a majority of the accidents occurred at the at-grade intersections. On some of the bypasses, virtually all correctable accidents occurred at the major at-grade intersections. Of the 348 accidents which occurred at an intersection, 299 (88 percent) were classified as correctable; of the 150 accidents which did not occur at a major intersection, only 80 (53 percent) were classified as correctable (with the addition of access control). Most accidents occurred at major intersections; an even greater percentage of correctable accidents occurred at these intersections. Thus, intersections provide the best potential for improvement.

There were 35 major intersections for which sufficient data were available to calculate a benefit-cost ratio. Of these 35 intersections, 16 had benefit-cost ratios greater than one. Of the 19 which had a

benefit-cost ratio less than one, three had ratios which were relatively high in that they were above 0.80. Also, nine intersections with a benefit-cost ratio less than one were classified as hazardous locations due to their accident experience. It should also be noted that, of eleven signalized intersections investigated, nine had benefit-cost ratios greater than one; the remaining two had ratios of 0.81 and 0.83.

A total of 121 accidents (23.4 percent) were classified as "not correctable." These accidents were primarily the result of the driver losing control of his vehicle because of such causes as inattention, inclement weather conditions, or speeding. There were also several accidents involving the driver's ability being impaired because of drinking. Other causes of these accidents were improper passing, improper turning, etc.

SUMMARY

After a study of the present traffic control used on the subject bypasses, it was found that there is not much that has not already been done in an effort to reduce the accident potential. Existing signs, signals, and markings are performing their intended purposes well.

It is apparent that even with the best possible controls on these bypasses, numerous accidents will continue to occur. The only solution to a majority of the accidents is interchanges. Slightly over three quarters of the accidents could be prevented with the addition of interchanges and access control. Since a majority of the accidents occurred at the at-grade intersections, these intersections have created the most serious accident potential. Some accidents, of course, would take place by other means when interchanges were built. However, the total number of accidents and their severity would be greatly reduced.

It was shown that injury accidents would be reduced more than property damage accidents because the right-angle accident had the greatest accident severity as well as being the type of accident that would be the most "correctable". With at-grade intersections, the only solution to the right-angle accident problem is the addition of traffic signals. While the traffic signal will reduce the number of right-angle collisions, the number of rear-end accidents and possibly the total number of accidents will increase, and time and operating costs will greatly increase.

It can be concluded from the preceding discussion that, with the addition of interchanges and access control, the accident rate of the subject bypasses would be reduced significantly. This was not a surprising result since previous studies have shown that access control has a powerful accident reduction effect (7, 8). It can also be concluded that accidents most frequently occurred at intersections; this agrees with findings by others (8).

The critical question is whether the reduction in accident costs, along with the reduction in time and operating costs, justifies the higher initial expense involved in building bypasses with interchanges. From the study results, it can be seen that slightly under one half of the major intersections studied had benefit-cost ratios greater than one. While accident costs clearly had an effect on the benefit-cost ratios, it was apparent that time and operating costs were the more significant factors in a majority of cases. Generally, signalized intersections had the highest benefit-cost ratios; this was primarily due to the larger volume of traffic required to stop, which is logical since volume warrants must be met to justify a traffic signal. At very high volume locations, signalization would be required at a diamond interchange, but the number of stops would still be far below that required for an at-grade intersection.

When the benefit-cost ratio is coupled with the realization that a serious hazard could be eliminated, a strong argument can be made in favor of constructing interchanges at a majority of the major intersections on the bypasses studied. In planning a new facility, both future traffic volumes and the accident potential should be considered. If the traffic volume at an intersection is anticipated to be high, the argument for an interchange is strong. If the predicted future volume is high enough to indicate that the intersection will require signals, the argument in favor of an interchange is very strong. Also, if the intersection is going to create a safety hazard, the argument is strong in favor of an interchange. Examples of a created safety hazard would be building an intersection having restricted sight distance, or constructing an at-grade intersection of a crossroad, which has a relatively high volume of traffic, with a high volume and high speed mainline facility. An illustrative example is the installation of an intersection control beacon at an intersection when a new facility is first opened. This indicates that the intersection has the potential of becoming a high accident location and the beacon was installed as an accident deterrent. There have been a number of bypasses built with partial control of access and at-grade intersections, but this study shows that this does not solve the major problem -- the at-grade intersection.

In conclusion, it was shown that in almost all cases it would be warranted and economically justifiable to build an interchange at an intersection where a relatively high volume of traffic would be required to stop or where it would be possible to eliminate a hazardous location.

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TABLE 1

ADDITIONAL TIME COST OF STOPPING
AND RETURNING TO INITIAL SPEED

INITIAL SPEED (MPH)	COST (DOLLARS PER 1000 STOPS)	
	PASSENGER CARS	COMMERCIAL VEHICLES
15	4.76	9.50
20	5.71	12.60
25	6.69	15.86
30	7.74	19.27
35	8.86	22.94
40	10.05	26.97
45	11.41	31.50
50	13.13	36.87
55	15.44	43.78
60	18.73	53.64

TABLE 2

ADDITIONAL OPERATING COST OF STOPPING
AND RETURNING TO INITIAL SPEED

INITIAL SPEED (MPH)	COST (DOLLARS PER 1000 STOPS)	
	PASSENGER CARS	COMMERCIAL VEHICLES
15	3.26	9.30
20	4.95	14.15
25	6.96	20.11
30	9.36	27.39
35	12.24	36.26
40	15.76	47.12
45	19.99	60.12
50	25.15	76.06
55	31.43	94.91
60	39.09	117.44

TABLE 3

SUMMARY OF THE TYPES OF ACCIDENTS

TYPE OF ACCIDENT	NUMBER
Right Angle	176
Oblique or Sideswipe	131
Rear End	129
Single Vehicle	39
Fixed Object	17
Multiple Rear End	11
Head On	10
Other	5