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Accident Experience of Flashing Traffic Signal Operation in Portland, Oregon

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ABSTRACT

Traffic signals affect the safety and efficiency of traffic operations. Flashing-signal operation reduces delays during low-volume periods and may conserve energy. However, flashing operation has been found to affect the safety of the intersection adversely. The relative accident impacts of flashing-signal operation versus regular signal operation in the city of Portland are evaluated. Analyses were conducted to determine whether an increase in accidents occurred at the intersections when the control devices were operated in the flashing mode during low-volume nighttime hours. For the intersections studied, the accident levels, volume levels, intersection geometry, and speed and parking data were collected. A statistical analysis was made to determine the safety of flashing operation for intersections with various volume ratios, street classifications, types of approaches, approach speed limits, and parking conditions. Intersections at which the major-street volumes were more than twice the minor-street volumes experienced a significant increase in accidents when flashing operation was used. Significant increases in accidents were also found when flashing signals were installed at intersections with major-street approach speeds in excess of 30 mph. Accidents also increased with flashing operation when both streets were two-way and where parking was allowed on both streets. Accident severity increased for many situations, often because there was an increase in right-angle accidents.

Traffic signals affect the efficiency and safety of traffic operations. When traffic volumes are high, signals eliminate traffic conflicts by alternating the assignment of right-of-way. However, when traffic volumes drop substantially below the stated volume warrants for two or more consecutive hours, it may be desirable to replace the conventional signal for that period with a flashing signal (1). Flashing-signal operation reduces delays during low-volume periods and may conserve energy. The major argument for retaining 24-hr "full-color" operation may be that flashing operation may adversely affect the safety of the intersection.

This paper contains the summary of a research effort begun at Oregon State University in 1984 to analyze statistically the accidents experienced at 30 intersections in Portland, Oregon, at which the installation of flashing traffic signals was carried out in accordance with accepted guidelines. The specific objective of this study was to investigate the safety of use of flashing versus full-color

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operation at signalized intersections during low-volume hours.

Statistical tests were used to compare intersection safety performance with differing

* Volume ratios,
* Street classifications,
* Types of approaches,
* Approach speed limits, and
* Parking conditions.

The intersections were grouped on the basis of these variables. Before-and-after accident rates per million entering vehicles (MEV) for each group were calculated for the test of significance.

Experience has shown that the use of yellow or red flashing traffic signals at night has often resulted in an increase in accidents over that experienced under normal full-color operation. Both the Manual on Uniform Traffic Control Devices (MUTCD) (2) and the Traffic Control Devices Handbook (TCDH) (3) give criteria and guidelines for the safe operation of the flashing control signals. The MUTCD indicates that the major street should receive the yellow indication, and the flashing rate should be not less than 50 nor more than 60 times per minute. The TCDH gives criteria for flashing signal operation. These include

1. Unrestricted sight distance and low traffic volumes,
2. Monitored accident patterns and severity, and
3. Signal malfunctions, repairs, or maintenance.

In earlier editions of the MUTCD, a volume warrant of a 50 percent drop in volume for two or more consecutive hours justified the use of flashing operation (1).

In Oregon, the Department of Transportation has specified warrants for flashing-signal operation during low-volume periods based on volume, type of signal indication, and sight distance.

The most comprehensive review of the relative safety impacts of flashing versus regular signals is provided by an FHWA study (4) in which the results of several studies of the conversion of signal operations to flashing nighttime operation were evaluated. A primary result of the FHWA study was that the number of right-angle accidents was significantly higher at intersections when flashing signals were used than when regular signals were used. The two variables that had the most effect on accidents were two-way main-street volume in the first flashing hour and the ratio of main-street to side-street volume. This study recommended that flashing operation not be used if the main-street volume was more than 200 vehicles per hour (vph) unless the volume ratio was greater than 3.

Studies done by the Florida section of the Institute of Traffic Engineers (ITE) (5) and by Radelate (6) have also shown a significant increase in accidents with flashing-signal operation. However, operation in the flashing mode was found to conserve energy and reduce delay. Quan (7) found that if flashing operation were completely implemented in the city and county of San Francisco, there would be 514,000 vehicle-hr per year less delay, a saving of 450,000 gal of gasoline per year, and 10 percent conservation of electrical energy to power the signal operation.

ACCIDENT EXPERIENCE

Study Site

The city of Portland was selected for the field studies because of previous experience with night flashing traffic signals in 1981 and in early 1982. As a result of the increase in accidents, flashing operations were terminated in late 1983, and 30 intersections that had been changed from normal to nighttime flashing operation were returned to regular, full-color nighttime operation.

Data Collection

Before-and-after accident data were obtained from the computer records available from the Portland Bureau of Traffic Engineering. The before-and-after periods each encompassed either a 1- or 2-year interval, with an equal number of months in the study periods for all cases. The data were collected immediately before and immediately after the date of implementation of flashing-signal operation. In addition to accident data, information on traffic volumes, street classifications, types of approach, and speed limits was obtained.

Data Analysis

Maximum possible time frames were used in this study. All the intersections under study were grouped on the basis of the following variables:

1. Volume ratio: zero to twice as much volume on the major approach as on the minor (0.0 to 2.0), two to four times the volume on the major street (2.0 to 4.0), and more than four times greater major-street volume (greater than 4.0);
2. Street classification: an arterial intersecting with a collector, arterial with a local, collector with a local, collector with a collector, local with a local, arterial with a local or a collector;
3. Type of approach: two-way/two-way, two-way/one-way, one-way/one-way;
4. Speed limit: less than or equal to 30 mph or greater than 30 mph; and
5. Parking or no parking.

Accident data were split into the following categories for analysis:

1. Accident by type and
2. Accident by severity.

The before-and-after periods in the analysis were determined on the basis of actual date of installation and elimination of the flashing-signal system.

The volumes of the intersection approaches were used to obtain accident rates for both the before and the after periods for accident analyses. Intersection accident rates were calculated by using the following equation:

$$\text{Accident rate} = [(\text{no. of acc.})(1{,}000{,}000)] \div [(\text{volume})(\text{time})]$$

where

rate = accidents per million entering vehicles,
volume = entering volume (vehicles/day),
time = study period (days).

Before-and-after accident rates for each of the 30 intersections were calculated with this relationship. Each accident rate represents the average accidents per million vehicles passing through the intersection.

A measure of the relative severity of accidents was given by a severity index (SI), which is the proportion of total accidents in which an injury or a fatality occurs:

SI = (fatal plus injury accidents)/(total accidents)

Statistical Analysis

The evaluation of the change in safety characteristics at intersections was based on a comparison of their respective means. When two means differed markedly, little problem existed in deciding whether there was a significant change. But, when the difference was small, there was always a question of whether the change was due to chance variation in the data rather than to the improved conditions. The effectiveness of the traffic improvement was judged by a statistical evaluation of the before-and-after data to determine whether the changes were significant.

In this study a statistical analysis was performed for each data group classified on the basis of the stratifying variables mentioned earlier. The differences in the means were tested for statistical significance. The procedure adopted to evaluate the before-and-after rates statistically was Student's t-test. The null hypothesis was that there was a significant difference between the before-and-after accident rates. This was tested against the alternative hypothesis that there was no significant difference between the two means:

Null hypothesis:

$$H_0: t_{\alpha,\nu} > \{(\bar{x}_1 - \bar{x}_2)/[(S_1{}^2/N_1) + (S_2{}^2/N_2)]^{1/2}\}$$

Alternative hypothesis:

$$H_a: t_{\alpha,\nu} \not> \{(\bar{x}_1 - \bar{x}_2)/[(S_1{}^2/N_1) + (S_2{}^2/N_2)]^{1/2}\}$$

where

- α = level of significance;
- ν = degrees of freedom = $N_1 + N_2 - 2$;
- t = statistic of the t-distribution;
- $\bar{x}_1$ = mean of the regular-operation period = x_{1i}/N_1, where x_{1i} is the individual N_1 accident rates under regular operation;
- $\bar{x}_2$ = mean of the flashing-operation period = x_{2i}/N_2, where x_{2i} is the individual N_2 accident rates under flashing operation;
- S_1 = standard deviation of the regular-operation data = $[(x_{1i} - \bar{x}_1)^2/(N_1 - 1)]^{1/2}$
- S_2 = standard deviation of the flashing-operation data $[(x_{2i} - \bar{x}_2)^2/(N_2 - 1)]^{1/2}$;
- N_1 = number of samples during regular operation; and
- N_2 = number of samples during flashing operation.

The computed values of t were then compared with the critical tabled values of the t-statistic as obtained from the standard t-distribution to determine the significance of the difference between the two sample means. If the computed value of t was greater than the critical value at the selected level of significance, the difference between the two means was considered significant and not just due to chance variation. The difference between the two means was defined as nonsignificant when the calculated t-value was less than the critical value.

Analysis Results

This study was conducted to compare the nighttime accident experience at signalized intersections under regular and flashing operations and to identify those conditions under which flashing-signal operation could be used safely. The study involved the comparative statistical analysis of accidents at 30 intersections controlled with nighttime flashing signals during low-volume periods and the same 30 intersections under regular full-color signal control before flashing signals were installed. For total accidents at all intersections, this investigation determined accident severity and type of accident stratified by volume ratio, street classification, type of approach, approach speed limits, and parking.

Volume Ratio

The summary of the analysis of intersection accident rates under regular full-color and flashing operations with varying volume ratios is given in Table 1. A comparison of total accident rates shows that

TABLE 1 Analysis of Accidents for Intersections with Various Volume Ratios

Classification of Accident	Mean Accident Rate: Full Color	Mean Accident Rate: Flashing	Standard Deviation: Full Color	Standard Deviation: Flashing	t-Statistic
Volume Ratios Between 0.0 and 2.0 (N = 4)					
All	3.29	1.06	6.58	2.12	0.645
PDO	0.00	1.06	0.00	2.12	-1.000
Injury	3.29	0.00	6.58	0.00	0.999
Volume Ratios Between 2.0 and 4.0 (N = 14)					
All	1.20	5.44	2.32	5.39	-2.704[a]
PDO	0.64	0.92	1.34	2.76	-0.340
Injury	0.56	4.52	2.09	4.92	-2.769[a]
Angle	0.00	3.30	0.00	4.03	-3.060[a]
Rear end	0.47	1.60	1.41	3.53	-1.111
Volume Ratios Greater Than 4.0 (N = 12)					
All	1.89	2.76	2.20	3.79	-0.688
PDO	1.02	1.84	1.58	2.41	-0.985
Injury	0.87	0.92	1.49	1.70	-0.076
Angle	0.43	2.21	1.15	2.87	-1.990[b]
Rear end	0.41	0.00	1.09	0.00	1.296

Note: Results are given as accident rate per million entering vehicles. PDO = property damage only.
[a]Significant at 95 percent level of confidence.
[b]Significant at 90 percent level of confidence.

intersections with volume ratios between 2.0 and 4.0 had a significant increase in accident rates during the flashing periods compared with the regular periods of operation, 5.44 accidents/million entering vehicles (MEV) versus 1.20 accidents/MEV, respectively. An increase in angle accidents was seen with the flashing operations (3.30 accidents/MEV) when compared with the regular full-color operations (0.00 accident/MEV). This increase was significant at the 95 percent level of confidence with a sample size of 14 for volume ratios between 2.0 and 4.0 (major-street volume versus minor-street volume). Angle accidents were also found to increase significantly with volume ratios greater than 4.0; 2.21 accidents/MEV was found for flashing operation versus 0.43 accident/MEV for regular operation. The severity of accidents for these volume ratios also increased during the flashing period, as shown by the increase in the severity index from 0.47 to 0.83. Therefore, flashing signals at intersections with volume ratios between 2.0 and 4.0 were found to be very unsafe.

Street Classification

The classification of the intersecting streets also influences the intersection accident potential under flashing operation. Angle accidents were found significantly increased with flashing-signal operation at the intersections between arterials and collectors and between local streets and collector streets or other local streets. The statistical analysis results by street classification are given in Table 2. The severity of accidents also increased noticeably for these types of intersections. It would appear that collector-collector and arterial-local intersections might be operated safely under flashing-signal operation on the basis of the results of this study, which showed a small, though not significant, reduction in accident rates with flashing operation at these intersections. However, the accident severity at collector-collector intersections with flashing operation increased, with a severity index that nearly doubled, 0.49 to 0.89.

TABLE 2 Analysis of Accidents for Intersections with Various Street Classifications

Classification of Accident	Mean Accident Rate: Full Color	Mean Accident Rate: Flashing	Standard Deviation: Full Color	Standard Deviation: Flashing	t-Statistic
Arterial/Collector (N = 2)					
All	1.02	12.02	1.43	0.26	-10.688[a]
PDO	1.01	9.03	1.43	1.62	-5.243[a]
Injury	0.00	2.99	0.00	1.36	-3.117[b]
Angle	0.00	7.00	0.00	1.26	-7.875[a]
Arterial/Local (N = 4)					
All	4.63	3.78	5.91	4.37	0.231
PDO	0.97	0.73	1.95	1.46	0.197
Injury	3.65	3.05	6.38	3.79	0.161
Angle	4.27	3.78	6.21	4.37	0.128
Collector/Local (N = 11)					
All	0.55	2.14	1.30	3.81	-1.309
PDO	0.19	0.80	0.62	1.19	-1.499
Injury	0.36	1.35	1.20	3.65	-0.852
Angle	0.00	1.35	0.00	2.10	-2.129[a]
Rear end	0.00	0.55	0.00	1.82	-1.001
Collector/Collector (N = 6)					
All	4.34	4.14	2.93	5.56	0.078
PDO	2.21	0.46	1.80	1.13	2.225[b]
Injury	2.14	3.68	3.14	5.10	-0.629
Angle	0.22	3.24	0.53	5.32	-1.383
Rear end	1.93	0.67	2.10	1.10	1,301
Local/Local (N = 7)					
All	0.00	3.71	0.00	4.19	-2.343[a]
PDO	0.00	0.36	0.00	0.96	-0.047
Injury	0.00	3.35	0.00	4.41	-2.010[b]
Angle	0.00	1.95	0.00	1.93	-2.675[a]
Rear end	0.00	1.77	0.00	4.67	-1.001

Note: Results are given as accident rate per million entering vehicles. PDO = property damage only.
[a]Significant at 95 percent level of confidence.
[b]Significant at 90 percent level of confidence.

One-Way or Two-Way Approach

The type of approach also has an effect, as seen from the results summarized in Table 3. With flashing operation the total accident rate was significantly increased at two-way/two-way intersections, which also had a higher incidence of angle and rear-end accidents under flashing operation. These increases were found to be significant at the 95 percent level of confidence. This indicated that use of a flashing signal on a two-way/two-way intersection could significantly reduce safety. The accident severity was comparable under both regular full-color operation and flashing operation. None of the accident classifications showed a significant difference between flashing operation compared with the full-color operation when tested with the two-way/one-way and one-way/one-way intersections.

TABLE 3 Analysis of Accidents for Intersections with Various Types of Approaches

Classification of Accident	Mean Accident Rate: Full Color	Mean Accident Rate: Flashing	Standard Deviation: Full Color	Standard Deviation: Flashing	t-Statistic
Two-Way/Two-Way (N = 15)					
All	1.88	6.18	3.48	5.24	-2.647[a]
PDO	0.74	1.97	1.34	3.19	-1.364
Injury	1.14	4.21	3.48	4.88	-1.982[b]
Angle	0.88	3.92	3.40	3.84	-2.295[a]
Rear end	0.09	1.32	0.36	3.44	-3.956[a]
Two-Way/One-Way (N = 10)					
All	2.45	1.40	3.13	2.52	0.824
PDO	1.02	0.70	1.67	1.51	0.448
Injury	1.43	0.70	2.54	1.45	0.787
Angle	0.52	1.14	1.26	2.52	-0.695
Rear end	1.02	0.26	1.89	0.82	1.165
One-Way/One-Way (N = 5)					
All	0.00	1.36	0.00	1.95	-1.557
PDO	0.00	0.51	0.00	1.14	-1.000
Injury	0.00	0.85	0.00	1.89	-1.003
Angle	0.00	1.36	0.00	1.95	-1.557

Note: Results are given as accident rate per million entering vehicles. PDO = property damage only.
[a]Significant at 95 percent level of confidence.
[b]Significant at 90 percent level of confidence.

Approach Speed

The approach speed for intersections affects the driver's ability to avoid a possible conflict and also influences the selection of a safe gap for minor-street traffic to cross the major street. The speed limit of the intersection approach was used as a surrogate variable to reflect operating speed. The major-street speed was the variable used in this analysis because it logically would have the greatest effect on the accident potential. The approach speed categories are

1. Intersections with major-street approach speed less than or equal to 30 mph and
2. Intersections with major-street approach speed greater than 30 mph.

As seen in Table 4, the total accident rate nearly doubled for intersections under both approach-speed categories. Angle accidents were found to increase significantly regardless of approach speed. However, the accident severity, as shown by a severity index, increases from 0.63 to 0.86 when the approach speed of the major street is less than 30 mph.

TABLE 4 Analysis of Accidents for Intersections Grouped by Approach Speed

Classification of Accident	Mean Accident Rate: Full Color	Mean Accident Rate: Flashing	Standard Deviation: Full Color	Standard Deviation: Flashing	t-Statistic
Major-Approach Speed Limit < 30 mph (N = 22)					
All	1.61	3.36	3.27	4.15	-1.554
PDO	0.59	0.47	1.33	1.03	0.336
Injury	1.02	2.89	3.19	3.99	-1.716[a]
Angle	0.77	2.56	2.89	3.55	-1.834[a]
Rear end	0.30	0.74	1.14	1.85	-0.952
Major-Approach Speed Limit > 30 mph (N = 8)					
All	2.16	4.18	2.73	5.27	-0.962
PDO	1.04	3.09	1.50	4.00	-1.356
Injury	1.12	1.09	1.74	1.59	0.036
Angle	0.16	2.59	0.46	3.15	-2.161[b]
Rear end	0.62	0.00	1.32	0.00	1.329

Note: Results are given as accident rate per million entering vehicles. PDO = property damage only.

[a]Significant at 90 percent level of confidence.
[b]Significant at 95 percent level of confidence.

Presence of Parking

The effect of the presence of parking at the intersections was also evaluated. The records on the parking conditions at the time that the accident data were collected were incomplete, and were supplemented from other sources. Both the incompleteness of parking data and the lack of certainty that vehicles are parked at the intersection to restrict visibility temper the reliability of the results of this analysis. The analysis results considering the presence of parking are given in Table 5. When parking is present on all approaches, the accident rate under flashing operation increases significantly over full-color operations from 2.24 accidents/MEV to 5.07 accidents/MEV.

INTERPRETATION OF RESULTS

Approach Volumes

The level of volume on the major-street approach had an impact on the safety under flashing operations. When the intersecting streets were of about the same volume level, the accident rates decreased. The relatively low volume on the major street provided relatively fewer conflicts. At intersections with major-street volumes between two and four times the minor-street volume, significant increases in accident rates occurred with flashing-signal operation compared with normal full-color signal operation. It is suggested that drivers at these intersections expect drivers on the major approach to also receive a flashing red because, under full-color operations, both streets are treated equally.

Street Classification

The classification of intersecting streets also had an effect. The intersections between an arterial and a collector, a collector and a local, and a local and a local indicated a significant increase in accidents for flashing operation when compared with regular signal operation. The mean accident rates for regular operation were considerably lower than those for flashing-signal operation. Intersections of arterials with collectors also experienced increased accident severity, with severity indices of 0.0 and 0.25 for regular and flashing operations, respectively. Intersections of local streets with other local streets experienced the greatest increase in accident severity; the severity index increased from 0.0 to 0.90 from regular to flashing operation. A severity index of 0.90 for this intersection condition means that 90 percent of the accidents at this intersection involved an injury or a fatality.

TABLE 5 Analysis of Accidents for Intersections Depending on Presence of Parking

Classification of Accident	Mean Accident Rate: Full Color	Mean Accident Rate: Flashing	Standard Deviation: Full Color	Standard Deviation: Flashing	t-Statistic
Parking Allowed on Both Streets (N = 16)					
All	2.24	5.07	3.75	5.16	-1.773[a]
PDO	0.68	1.08	1.48	2.23	-0.598
Injury	1.56	3.98	3.76	4.82	-1.583
Angle	1.06	3.16	3.37	3.96	-1.615
Rear end	0.41	1.40	1.33	3.34	-1.102
Parking Allowed on One Street (N = 8)					
All	1.85	2.44	2.64	4.70	-0.309
PDO	1.04	1.64	1.51	3.60	-0.434
Injury	0.81	0.80	1.32	1.61	0.013
Angle	0.16	1.68	0.46	3.12	-1.363
Rear end	0.62	0.00	1.32	0.00	1.329
No Parking Allowed on Either Street (N = 6)					
All	0.34	2.16	0.84	1.88	-1.162
PDO	0.34	0.77	0.84	1.20	-0.716
Injury	0.00	1.39	0.00	2.16	-1.575
Angle	0.00	2.16	0.00	1.88	-2.812

Note: Results are given as accident rate per million entering vehicles. PDO = property damage only.

[a]Significant at 90 percent level of confidence.

Type of Approach

The next variable tested was the type of approach, which showed that intersections between two two-way streets had significantly lower accident rates with regular signal operation. The higher level of conflicts present with intersecting two-way streets could make it difficult for the driver to keep track of all conflicts and react safely.

Approach Speed

The analysis of the effect of major-approach speed on accident rate showed a significantly higher accident rate for angle and injury accidents with a considerable increase in mean accident rate for the flashing-signal operation. The increase in right-angle accidents was highly significant, at the 95 percent level of confidence, for approach speeds of more than 30 mph. This is not an unexpected result. With full-color operation there is more positive control of the assignment of right-of-way. The lack of such control with flashing operations would be expected to generate more right-angle collisions. With higher approach speeds, the driver does not have as much time to react, and the potential for accidents increases. Higher impact speeds and right-angle collisions would be expected to increase the rate of injury accidents.

Parking

Consideration of the effect of parking must be tempered by the lack of reliable information on the nature of parking at the time that the data were collected. However, from the data available, the results indicate that, when there is parking on both sides of the major and minor streets, signals at intersections should not be operated in the flashing mode. It is likely that the presence of parking at these locations reduces the visibility to below acceptable sight distances for safe operation.

SUMMARY AND CONCLUSIONS

The results of the accident analysis presented in this study have shown that flashing yellow or red signal operation, in general, significantly increased the hazard of driving at night. There were few situations in which the accident rates were reduced or unchanged because of flashing operation.

The overall results indicated that these intersections, when under flashing operation, had some effect on the severity of accidents. Injury accidents as well as angle accidents increased significantly. The increase in angle-accident frequency has also been observed in other studies (6). When a signal is switched to flashing operation at night, conflicting movements are no longer positively separated, and the potential for an angle-type collision increases.

The increase in accidents in the flashing period may be due to the difficulty in judging when it is safe to proceed. However, drivers might also be confused by the night flashing operation because they do not anticipate that the right-of-way has been given to the other street and that only the minor-street traffic is required to stop. An attempt to improve driver understanding with a public awareness campaign or special signing should be made. Flashing operations should be allowed to continue only if accident experience improves.

Intersections should be planned and located to provide as much sight distance as possible. To eliminate the possibility that sight restrictions at intersections might become a problem, these locations should be investigated with regard to sight distance (day or night) before final approval is given to place the intersection on flashing-signal operation.

RECOMMENDATIONS

In view of the results of this study, the following recommendations are made for placing traffic signals in the flashing mode and for future study:

1. Flashing-signal operation may be used with low-volume conditions when the major-street to minor-street volume ratio has a value less than or equal to 2.0.
2. Flashing-signal operation should be used where approach speeds exceed 30 mph only after careful study and with monitoring of operations and accident experience.
3. Traffic signals in the flashing mode should not be used at intersections of two-way streets without a careful study of the visibility at the location and a monitoring of its operation.
4. A study regarding impaired visibility due to the presence of parking should be made to gain better understanding of this influence on flashing-mode operation and performance.

The cause of higher accident rates with flashing operation is a fruitful topic for future research. A particularly important factor that was not treated in this research is driver expectancy at intersections operating in the flashing mode. Other research has found that accident rates are lower at red/red flashing locations than at yellow/red locations, which implies that drivers expect traffic from both directions to stop (4). Many drivers have stated in accident reports that they thought that traffic in both directions was required to stop. Other behavioral factors may be of similar importance.

Further, it should be restated that there are other significant benefits of using flashing operation during low-volume periods rather than full-color operation, including reduced delays and reduced energy consumption. Decisions regarding the use of flashing operation should consider both the benefits and disbenefits to the traveling public.

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