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Cost-Effective and User-Oriented Sizing of Rural Roads

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ABSTRACT

Analyzed in this paper are two important aspects of road sizing: the common approach to selecting the 30th highest hourly volume for design hourly volume (DHV) for all types of road uses; and the development of a cost-effective annual average daily traffic (AADT) criterion for upgrading two-lane rural highways. The study's most important feature is that the road type variable is used in a more detailed and objective manner than in past studies. The highway system for Alberta, Ontario, Canada is investigated and the roads are classified into six types according to trip characteristics (e.g., trip purpose and trip length distribution). Based on other road design and traffic data, and economic cost statistics from Alberta Transportation, a detailed economic analysis is carried out. The main conclusions of this study are that: (a) the type of road use is a significant variable that must be considered for appropriate sizing of roads from the economist's and user's perspectives; (b) to provide a more uniform service to the users of various road facilities, it is more appropriate to use a range of highest volume hours for the design of different types of roads; (c) the total highway cost is minimized typically at a volume-to-capacity ratio of 0.35 regardless of the type of road use; and (d) the typical AADT values at which two-lane rural roads would need upgrading vary from a range of 1,750 to 2,500 for highly recreational routes to 6,500 to 8,500 for commuter routes.

During the recent years of budgetary constraints, highway authorities have attempted to achieve the greatest use from the dollar spent. There is an increasing concern about many of the past approaches to highway design and improvement programming that have typically been subjective in nature and generally lacking in economic rationalization (1,2). The sizing of roads, for example, has not been definitive under Alberta Transportation policy to date. The major parameters considered in the past have been (a) the traditional 30th highest hourly volume for designing a new facility, (b) the average annual daily traffic (AADT) volume and safety considerations for upgrading an existing facility, and (c) the use of level of service B for all applications including the urban and suburban areas that fall in the Alberta Transportation jurisdiction.

Another point of concern regarding the current practice in Alberta and other Canadian provinces is that, in general, the basis for road-sizing criteria has been dependent mainly on U.S. research during the 1940s and has seldom involved detailed economic analysis of Canadian primary highways. Also, the current practice focuses on facility utilization rather than being roadway-user oriented. The purpose of this paper is to emphasize the need for economic and road-user considerations in designing and upgrading rural highways.

In particular, this study is concerned with two aspects of road sizing: a cost-effective AADT criterion for upgrading two-lane rural roads, and the reexamination of design hourly volume (DHV) from the road user's perspective. The road use type, or road user's perspective, is characterized in this paper by such variables as trip purpose and trip length distribution. More specifically, the objectives of the analysis presented in this paper are to

1. Investigate the effect of road use type on DHV and prioritization of highway improvements;
2. Suggest a range of highest hourly volumes suitable for design purpose from the user's perspective, rather than the commonly used 30th highest hourly volume, which focuses on facility utilization;
3. Investigate a cost-effective volume-to-capacity (V/C) ratio for the design of roads; and
4. Carry out economic analysis for determining the most appropriate levels of AADT values at which roads of given geometric design standard and traffic conditions should be considered for improvements.

However, it should be emphasized that the work in this paper is based on a cost-effectiveness methodology that is not, in any sense, intended to replace a benefit-cost analysis.

Presented first in this paper is a brief description of the variables considered in the analysis. Then methodologies for reexamination of DHV and derivation of highway cost relationships in terms of the V/C ratio and AADT are explained. Next the results and discussion are provided, followed by a summary and conclusions.

STUDY VARIABLES AND ANALYSIS PROCEDURE

On the basis of a review of literature and Alberta Transportation experience, the major critical elements that need to be considered in road sizing are (a) traffic variables such as road use characteristics, AADT, vehicle classification, and speed-volume relationship; (b) geometric design variables such as road standard type, passing sight distance (PSD), and average highway speed (AHS); and (c) economic factors such as cost of highway construction, maintenance, travel time, and accidents; vehicle running costs; and discount rate.

All of the previously mentioned factors are considered in this analysis with Alberta Transportation statistics as the data base. The economic analysis methodology and the DHV evaluation included here are based mainly on concepts previously developed by Haritos (3), Cameron (4), and Winfrey and Zellner (5). The classification of the road system under investigation is based on a recent paper by Sharma (6).

Classification of Alberta Highways According to Road Use Type

From past Alberta experience, it became evident that one of the most important variables affecting the design and upgrading of two-lane highways was the user/driver consideration reflected by the purpose and length of trips that involved use of a given facility. This user/driver variable was included in the present analysis by grouping the roads into different categories by using an improved method of road classification based on temporal volume variations and road use characteristics (e.g., trip purpose and trip length distribution). The improved method, as proposed by Sharma (6), was believed to be more objective, comprehensive, and statistically more credible than the existing methods. It involved the application of such standard computational and statistical techniques as (a) hierarchical grouping and (b) Scheffe's S-method of multiple group comparisons. The road system under investigation was classified into six main types that were found to be significantly different from each other with respect to variables such as monthly, daily, and hourly variations in traffic volume; trip purpose; and trip length distributions. These types are as follows:

1. Suburban commuter, [e.g., the Permanent Traffic Counter (PTC) site C9 located on Highway 3 east of Lethbridge];
2. Regional commuter/recreational (e.g., the PTC site C39 located on Highway 1 west of Secondary Road 791);
3. Rural long distance (e.g., the PTC site C18 located on the Trans-Canada Highway west of Redcliff);
4. Rural nonrecreational (e.g., the PTC site C144 located on Highway 2 north of Nampa);
5. Long distance/recreational (e.g., the PTC site C114 located on Highway 16 east of Jasper National Park); and
6. Highly recreational (e.g., the PTC site C165 located on Highway 11 near Nordegg).

The detailed information on temporal volume variations, trip purpose, and trip length characteristics of these different types of roads are included in the paper by Sharma (6).

Road Type and Highest Hourly Volume Characteristics

The highest hourly volume patterns are conventionally represented by plotting the percent of AADT volume versus highest volume hours of the year. From past experience, it is conceptually known that the road use characteristics of a given route generally affect such highest hourly volume patterns. This generalization was found to be true for the highest hourly volume patterns of various road types observed in the present study. In fact, a statistical analysis indicated that the type of road use has a much more significant effect on the highest hourly volumes compared with other variables such as volume of traffic or AADT value. The high demand for travel on predominantly recreational road sites during only a few periods of the year accounts for a large proportion of the total annual traffic, but on commuter road sites, the total annual volumes are more evenly distributed throughout the hours of the year.

The distribution of hourly volumes associated with a particular type of road is used as one of the main variables in this study. All of the 8,760 hourly volumes in a year are considered in the analysis. The probability that a user will experience a traffic volume exceeding the nth highest hourly volume is defined by the relationship

$$P(CON)_n = [100/365(AADT)] \sum_{i=1}^{n} \cdot V_i \quad (1)$$

where $P(CON)_n$ is the percent probability that a user will experience a traffic volume exceeding the

TABLE 1 Vehicle Classification at Typical Road Sites

Road Site and Type	Vehicle Classification (%) PC	RV	SU[a]	HT	Remark
C9 - Suburban commuter	84.0	5.0	6.0	5.0	Average of 6 samples
C39 - Regional commuter/recreational	75.0	9.0	6.0	10.0	Average of 3 samples
C18 - Rural long distance	72.0	11.0	7.0	10.0	Average of 15 samples
C144 - Rural nonrecreational	80.0	6.0	7.3	6.7	Average of 5 samples
C114 - Long distance/recreational	71.0	20.0	4.0	5.0	Average of 4 samples
C165 - Highly recreational	78.0	20.0	2.0	0.0	Guessed

Note: PC = passenger cars; RV = recreational vehicles; SU = Single-unit trucks; HT = heavy trucks.
[a]Buses are included in SU class.

nth highest hourly volume, and V_i is the volume during the ith highest hour. The probability value calculated from Equation 1 is also referred to in this paper as the probability of user congestion. The hourly volumes, when ranked in decreasing order of their percentages of AADT, are referred to as "highest hourly patterns", or "hourly volume signatures."

Road Type and Vehicle Classification

Another important variable in this study is vehicle classification. Although the proportion of various types of vehicles will vary within the different road classes to a certain extent, there will usually be a significant variation between the classes. For example, the recreational road sites would be expected to have a larger proportion of recreational vehicles, and the rural long distance road sites would generally be expected to have a larger proportion of trucks than would the commuter sites.

The vehicle classification in this study is used as a variable that is associated with a particular type of road. Table 1 shows the vehicle classification at the typical road sites. (These data are based on past Alberta Transportation studies.)

Alberta Highways Cost Data

In any attempt to define the costs attributable to providing a highway link, the costs for right-of-way, construction, maintenance, environmental disruption, motor-vehicle running costs, accidents, and travel time might be included. In the analysis presented here for Alberta, the following cost factors are used: construction, maintenance, motor-vehicle running cost, and travel time.

Quantifiable costs related to environmental disruption (e.g., costs of erosion control, noise attenuation, and other measures to protect the environment) can be included in construction costs. However, unquantifiable costs, (e.g., those for wildlife disruption) are not included. Accident costs have not been included here because no Alberta data were readily available and accident costs can be considered part of the safety analysis that some agencies prefer to handle separately.

The highways cost data and the road design data that follow are based on past Alberta Transportation studies (7,8) and can be updated to 1982 dollars by using appropriate inflation factors. RAU-209, RAU-211, and RAU-213 are road design class codes used in Alberta and refer to rural arterial, undivided, two-lane facilities with total pavement widths of 9, 11, and 13 m, respectively. A right-of-way cost of $4,942/hectare ($2,000/acre) is included in the cost figures. (Also, these costs apply for the region east of Red Deer and may vary considerably from area to area.)

1. Capital costs: $306,180/km for RAU-209, $364,500/km for RAU-211, and $422,820/km for RAU-213;
2. Annual maintenance costs: $1,600/km for RAU-209, $1,900/km for RAU-211, and $2,200/km for RAU-213;
3. Discount rate: 8 percent over a 20-year (design) life of facilities;
4. Vehicle running costs: The 1979 running costs given by Ashtakala (7) were updated to 1982 dollars. The running costs for recreational vehicles (RVs), however, were not given by Ashtakala (7); therefore, an average of costs for passenger cars (PCs) and single-unit trucks (SUs) was estimated to be the running cost for RVs; and
5. Value of travel time: $7.00/hr for passenger cars, $7.00/hr for recreational vehicles, $13.30/hr for single-unit trucks, and $15.30/hr for heavy trucks (HTs). These values are also in 1982 dollars and are based on the Alberta Transportation studies (7,8).

Cost-Volume Relationships

It can be observed from these data that the fixed capital costs for roads are high, and annual maintenance costs are also significant. If the road carries little traffic, the unit agency cost of providing the roadway is very high; as volume increases, however, unit cost decreases.

For road user costs (time plus running costs), lower traffic volumes usually provide the least unit cost, and as volume increases, the cost to the user increases because of congestion. Adding the agency cost (construction cost plus the maintenance cost) curve and the road user cost curve should result in a relationship in which, at some volume of traffic, a minimum total cost of travel will occur.

To compute the total cost relationship as a function of the volume of traffic, it is necessary to relate capital and maintenance costs and road user costs to a common base. Because agency costs are a function of volume and road user costs are a function of travel speed, the speed-volume relationships presented in the 1965 Highway Capacity Manual (HCM) (9) were used to determine the user costs as a function of volume and expressed in term of cents per vehicle kilometer.

Two types of cost-volume relationships were computed for the purpose of this study, unit cost (in cents per vehicle kilometer) versus V/C ratio, and unit cost versus AADT.

The agency cost for a particular volume of hourly traffic was calculated by using the relationship

$$AC = [100(CC \times CRF_{i,n} + MC)]/8,760\ Vol \qquad (2)$$

where

AC = agency cost (¢/vehicle-km);
CC = capital cost ($/km);
$CRF_{i,n}$ = capital recovery factor for interest rate i and useful facility life of n years;
MC = annual maintenance cost ($/km); and
Vol = volume of traffic (vehicles/hr).

The first step in determining the vehicle running cost was to calculate the V/C ratio for a particular hourly volume of travel and given road traffic and design conditions. The speed of travel was then estimated from the speed-volume curves presented in the HCM (9). Finally, the vehicle running costs were obtained from the empirically derived tables of running costs at various speeds (7).

The denominator of the V/C ratio, [e.g., the capacity (C) of a road facility] was calculated by using the HCM method for two-lane rural highways. The values of adjustment factor (W) for lane width and lateral clearance at capacity were assumed to be 0.90, 0.95, and 1.0 for RAU-209, RAU-211, and RAU-213, respectively. The passenger-car equivalents (10) of 2 and 1.6 were used for trucks and RVs, respectively.

The travel time cost for a given traffic stream was calculated by using the following relationship:

$$TC = \{[(P_{pc}T_{pc} + P_{rv}T_{rv}) + (P_{su}T_{su} + P_{ht}T_{ht})] \div 100\}[(1/S) - (1/AHS)], \text{ or}$$

$$TC = (TW/100)[(1/S) - (1/AHS)] \qquad (3)$$

where

TC = travel time cost (¢/vehicle-km);
$P_{pc}, P_{rv}, P_{su}, P_{ht}$ = percentages of PCs, RVs, SUs, and HTs, respectively, in the traffic stream;
$T_{pc}, T_{rv}, T_{su}, T_{ht}$ = time values for PCs, RVs, SUs, and HTs, respectively (¢/hr);
TW = weighted mean travel time cost;
AHS = the average highway speed or the desired speed of travel (km/hr); and
S = space-mean speed of travel possible at a given volume of travel (km/hr).

The cost-volume relationship in terms of AAHC (average annual hourly cost in cents per vehicle kilometer) versus AADT was developed to exhibit a measure of economic efficiency that might be used to minimize the total highway cost as a function of AADT, which undoubtedly is the most common measure of traffic volume used by all those who are involved in highway transportation. At a given value of AADT, the traffic volumes for each of the 8,760 hours of the year were computed from the (highest) hourly volume pattern associated with a particular type of road use. The total highway cost for each of the hourly volumes was then calculated in the manner described earlier. The weighted average annual hourly cost was defined as

$$AAHC = [1/365(AADT)] \sum_{i=1}^{8,760} [V_i(AC_i + RUC_i + TC_i)] \qquad (4)$$

where

$AAHC$ = average annual hourly cost (¢/vehicle-km);
AC_i, RUC_i, TC_i = the agency cost, vehicle running cost, and travel time cost, respectively, for the ith hour (¢/vehicle-km); and
V_i = traffic volume for the ith hour.

RESULTS AND DISCUSSION

Reexamination of DHV Concepts from the User's Perspective

The DHV is the volume of traffic during 1 hour that is used as an acceptable operating condition for design purposes. Traditionally, the determination of DHV involves the use of a graph showing the highest hourly volumes of the year according to rank. The 30th highest hourly volume is used by a number of agencies as the DHV for rural highways on the premise that the slope of the curve changes rapidly at that point and it provides the most economical volumes for use in design (1). In a case in which the slope changes rapidly at some point other than the 30th highest hourly volume, the DHV is chosen at the knee of the curve.

Highway designers have raised some serious questions in the past about the validity of the conventional DHV approach (1). One is that the identification of the knee of the curve of the hourly volume distribution can be a difficult matter requiring excessive judgment (4). Another criticism of the traditional approach is that it focuses on facility utilization rather than being roadway-user oriented. The problem of selecting a design hourly volume is addressed in the HCM, which contains the statement, "This frequent reference to the 30th highest hour should not be misconstrued as a recommendation for rigid adoption, but rather as an example of typical highest hour relationship and trends."

Figure 1 shows a plot of the percent probability $[P(CON)_n]$ that a user will experience a heavier traffic congestion than design hourly volume. The plots are calculated by using Equation 1. It should be noted here that detailed analyses were carried out for a total of 25 road sites in Alberta, but for the sake of simplicity, only the results for the

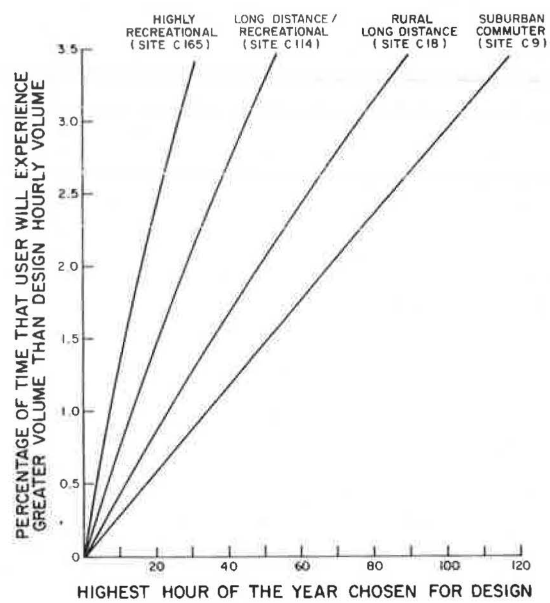

FIGURE 1 Percent user congestion as a function of the highest hour chosen for design.

typical sites of C9, C18, C114, and C165 are included in Figure 1 and the rest of this section. The analysis results for the sample site C144 (rural nonrecreational route) were very similar to the results of site C9, the example of a suburban commuter route. Also for the sake of simplicity, the other sample site, C39 (a regional commuter/recreational route), was excluded from presentations because it appeared to represent conditions between the suburban commuter site, C9, and the rural long distance site, C18.

If the traditional approach of selecting the 30th highest hour as the design hour is taken for all types of road facilities, it can clearly be seen from Figure 1 that even though each facility will experience hours equalling or exceeding the 30th highest hour volume of only 30 hours per year (0.34 percent of all hours), the percent of the time that a typical user will experience a volume exceeding that of the 30th highest hour will vary significantly with respect to the type of road under consideration. For example, of all the travelers using the commuter site, C9, only 0.92 percent will experience user congestion as compared with 1.25 percent for the rural long distance site, C18; 2.2 percent for the long distance recreational site, C114; and 3.35 percent for the highly recreational site, C165. It is therefore obvious that the traditional approach of facility utilization (e.g., 0.34 percent facility congestion at the 30th highest hour) does not provide an equitable transportation service from the user's perspective.

The user congestion plots such as those given in Figure 1 would be helpful to the highway authorities in developing road design policies that consider the user's perspective. One obvious alternative approach is to provide a more uniform service to the user by selecting different design hours for different types of road uses. For example, to provide a service that permits a 1.5 percent user congestion, the highway agency can select a design approximately corresponding to the 50th highest hour for a commuter route, whereas the rural long distance, long distance/recreational, and highly recreational routes could be designed to the 35th, 20th, and 10th highest hours, respectively. (The use of the 10th highest hour in designing a highly recreational route may seem to be an overdesign but the tourism business is so important in some provinces that this has become necessary.)

Cost-Effective Volume-to-Capacity (V/C) Ratio

Figure 2 exhibits cost-volume relationships for the typical road sites. For the highway cost data as used in this study, it is evident that the total (agency plus user) unit cost (CT) for all the sites is at a minimum level corresponding to a V/C value of about 0.35. The magnitude of the minimum cost varies because of the values of travel time and the vehicle mix associated with a particular type of road site. The rural long distance site, C18, operates at a most expensive level because it carries the highest average percentage (17 percent) of trucks for which the value of travel time is considered to be higher than that of passenger cars or recreational vehicles.

Although the location of the minimum cost point shown in Figure 2 lends some credibility to providing level of service B as a design criterion, there are several factors that will affect the analysis and cause a shift of the minimum cost point. These factors include increased construction and maintenance costs in difficult terrain and the perception of travel time value.

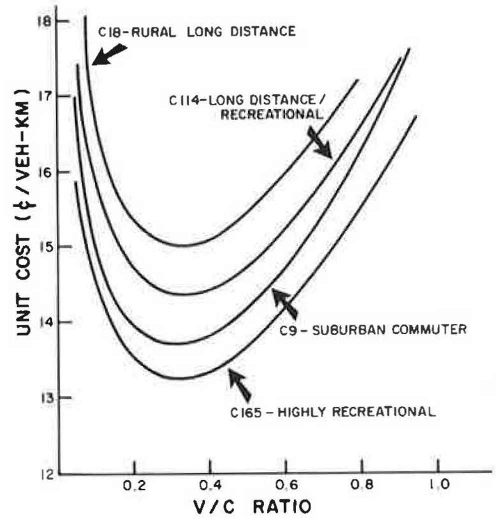

FIGURE 2 Cost versus volume-to-capacity ratio (RAU-211; AHS = 100 km/hr; PSD = 80 percent).

The literature on travel time value (11) suggests that the long distance travellers attach more importance to the amount of travel time saved and its dollar value than do the short distance travellers. Comfort and convenience are also considered to be more important for long distance trips. If these factors were considered in the analysis and different travel time values were assigned to the different road sites depending on the trip length distribution, then the suburban and regional commuter roads would have the cost minimization at the higher V/C ratio than the long distance or provincial and interprovincial roads.

AADT as a Criterion for Upgrading of Roads

Figures 3-6 show certain cost relationships in which the unit costs are plotted against AADT values. Each of these figures is drawn for a different sample site and contains three types of curves: (a) the annual average hourly cost as calculated from Equa-

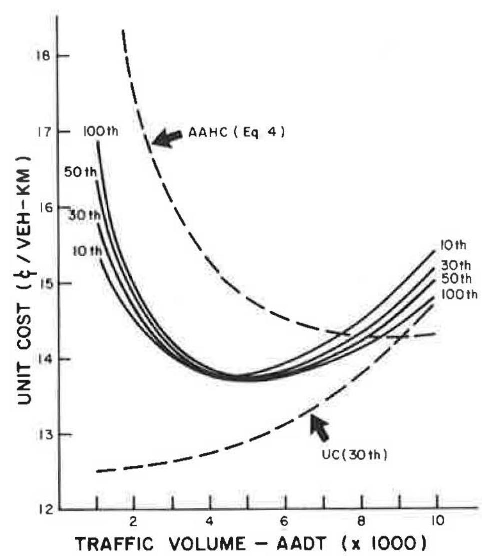

FIGURE 3 Cost versus AADT curves for site C9 (RAU-211; AHS = 100 km/hr; PSD = 80 percent).

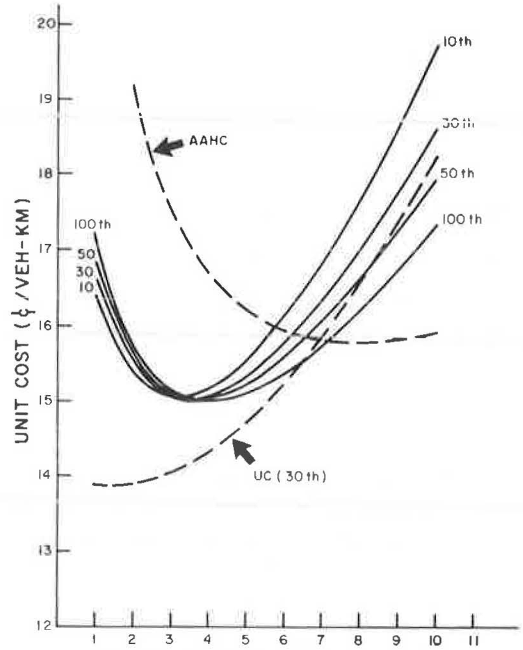

FIGURE 4 Cost versus AADT curves for site C18 (RAU-211; AHS = 100 km/hr; PSD = 80 percent).

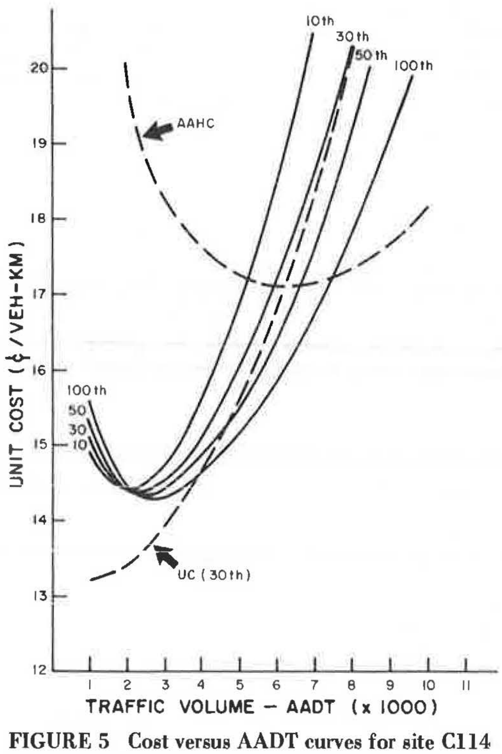

FIGURE 5 Cost versus AADT curves for site C114 (RAU-211; AHS = 100 km/hr; PSD = 80 percent).

tion 4 versus AADT; (b) the total unit cost (CT) curves for the 10th, 30th, 50th, and 100th highest hours; and (c) the road user cost during the 30th highest hour [UC(30th)] as a function of AADT.

The minimization of AAHC cannot be taken as an appropriate criterion for upgrading (or designing) two-lane roads because, before the AAHC reaches a minimum value, hundreds of highest hours would experience user congestion--an unacceptable situation

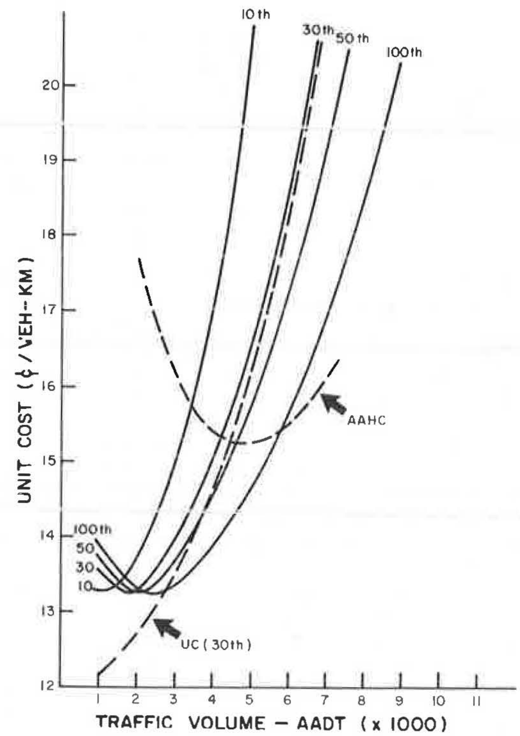

FIGURE 6 Cost versus AADT curves for site C165 (RAU-211; AHS = 100 km/hr; PSD = 80 percent).

from the user's point of view. But the AAHC curves along with the other cost curves in Figures 3-6 appear to help in establishing the appropriate values of AADT at which the roads of different types should be upgraded.

By taking the example of rural long distance site C18 and carefully examining the various cost curves of Figure 4, a number of interesting points can be made. One is that the AAHC, which includes both the agency cost and the user cost, is very high at low AADT values and the rate of increase of AAHC is particularly high for AADT values less than 4,000. Another observation is that, when the total agency and user costs during the 10th, 30th, 50th, or 100th highest hour are considered, the highway cost is minimized at an AADT value between 3,000 and 4,000. Finally, the plot of user cost during the 30th highest hour appears to indicate that the user cost starts increasing rapidly beyond the 3,000-4,000 AADT range. The plots of user costs during other sample hours, (i.e., the 10th, 50th, and 100th) were excluded to avoid overcrowding the figures. Moreover, the results would not be affected by including the user costs during those hours.

The AADT ranges at which the highway costs for other examples are minimized during the selected design hours are 4,500-5,500 for the commuter site, C9; 2,000-3,000 for the long distance/recreational site, C114; and 1,000-2,500 for the highly recreational site, C165. These are also the AADT ranges at which the user costs start increasing rapidly.

Figures 3-6 may also be used to compare the AADT values resulting in the minimum highway cost if a user congestion of 1.5 percent is permitted for all types of roads. As mentioned previously, a 1.5 percent user congestion corresponds to the 50th highest hour for site C9, the 35th highest hour for site C18, the 20th highest hour for site C114, and the 10th highest hour for cite C165. The values of AADT at which minima occur are 4,500, 3,500, 2,300, and

1,250 for sites C9, C18, C114, and C165, respectively.

Another interesting observation that can be made from these figures concerns the user cost increase rate with respect to AADT beyond the range where the total cost minimization occurs. It is evident that this rate is lowest in the case of the commuter site, C9, and highest in the case of the highly recreational site, C165. The user cost increase rate is higher for the long distance/recreational site, C114, as compared with the rural long distance site, C18.

The plots of Figures 3-6 correspond to the road standard RAU-211 with an average highway speed (AHS) of 100 km/hr and a passing sight distance (PSD) of 80 percent. The costs were also computed for other road standards (e.g., RAU-209 and RAU-213) and PSDs (e.g., 0 and 100 percent). Other variables being constant, it was generally found that the higher the road standard, the higher will be the value of AADT at the point of cost minimization. For example, if site C18 is considered with 1.5 percent user congestion, the AADTs for the minimum costs will be approximately (a) 3,250 for RAU-209 with 80 percent PSD and (b) 3,750 for RAU-213 with 80 percent PSD, as compared with a value of 3,500 for RAU-211 with 80 percent PSD.

Importance of the Road Use Variable

The analysis carried out for this study clearly indicates that the consideration of the road use type is one of the most important variables affecting the sizing of rural highways. It may even be stated that for a project such as this the road use variable is more important than the vehicle classification (or percent trucks) variable that is widely used in traffic engineering studies.

Figure 7 shows the importance of the road classification (RC) variable as compared with the vehicle classification (VC) variable. It may be recalled that the RC variable has been characterized in this paper by the highest hourly pattern or hourly volume signature exhibited by the road under consideration. In Figure 7(a), the road classification (RC) is varied while the vehicle classification (VC) is kept constant at a PC of 72 percent, an RV of 11 percent, an SU of 7 percent, and an HT of 10 percent--the same vehicle classification as that of site C18 (i.e., VC18).

However, in Figure 7(b) , all the plots use the same RC or hourly volume signatures as that of site C18 whereas the variable VC is assigned the values VC9, VC18, VC114, and VC165, which are the vehicle classifications for C9, C18, C114, and C165, respectively. (Note that the notations such as RC18, etc. represent the road classes or hourly volume signatures of the various sample sites such as C18, etc.)

It is obvious from these figures that road use type greatly influences cost minimization in relation to AADT. A two-lane recreational route would require upgrading at a much lower AADT value than a two-lane commuter route from the perspectives of total highway cost and user cost. The overall highway cost levels are higher for roads carrying a higher percentage of trucks because of the higher value of time allocated to these vehicles.

Testing of Results and Further Comments

The study results pertaining to the minimization of highway costs as a function of AADT were tested by comparing them with the actual practice by Alberta Transportation of upgrading two-lane roads.

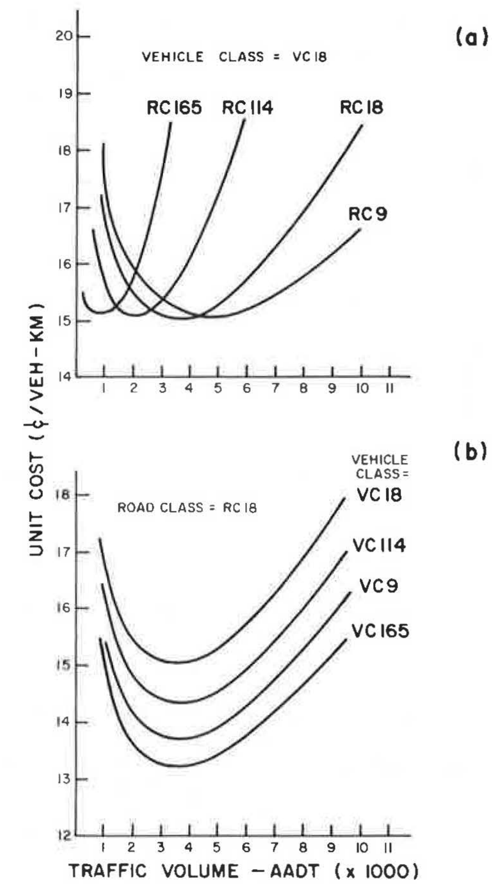

FIGURE 7 Effect of road type and vehicle mix on cost curves at 1.5 percent user congestion (RAU-211; AHS = 100 km/hr; PSD = 80 percent).

As mentioned earlier, upgrading two-lane roads to three- or four-lane facilities has not been definitive under Alberta Transportation policy to date. In the past, facilities have been reconstructed on the basis of need, as dictated by traffic demand and safety. In one of its reports (12), Alberta Transportation indicated that "expansion to four-lanes will not be undertaken until volumes reach the 6,000 to 8,000 AADT range." However, since the time of that report, the province has received a large number of user complaints about the poor level of service provided by some of the two-lane roads carrying volume ranges of 2,000 to 4,000 AADT. In many such cases, requests were made to upgrade these roads to four-lane standard.

Table 2 includes a list of two-lane roads typically of RAU-211 standard with AHS equal to 100 km/hr and PSD equal to 80 percent that were expanded to four-lane standard during the last several years. The upgrading of some sections of Highway 1 (Trans-Canada Highway) at a range of 3,000 to 5,000 AADT might have been perceived by some as political or a result of public pressure at the time. But the results of this study indicate that there is good justification from both the economic and user considerations to upgrade rural long distance roads at AADT values in the range of 3,000 to 5,000.

As shown in Table 2, the recent cases of road upgrading in Alberta have been for three types of roads: (a) suburban commuter, (b) regional commuter/recreational, and (c) rural long distance. A careful examination of the actual practice and the results of this study, such as those shown in Figures 3 and

TABLE 2 Some Recent Alberta Examples of Two-Lane Roads Upgraded to Four-Lane Standard

Road Section	Year of Upgrading	Estimated AADT Before Upgrading
Rural long distance sites		
Highway 1 west of Highway 36	1981	4,490
Highway 1 east of Secondary Road 550	1982	4,250
Highway 1 east of Secondary Road 873	1983	3,110
Highway 1 east of Redcliff	1981	4,500
Highway 1 west of Highway 41	1983	3,120
Regional commuter/recreational sites		
Highway 1 east of Medicine Hat	1983	5,650
Highway 1 east of Highway 21	1981	5,100
Highway 2 south of Morinville	1984	5,430
Highway 16 east of Highway 22	1983	5,160
Highway 16 east of Elk Island Park	1982	5,500
Suburban commuter sites		
Highway 1 west of Highway 3 in Medicine Hat	1981	8,000
Highway 2 north of St. Albert	1984	9,180

Note: Two-lane roads were typically of RAU-211 standard with AHS = 100 km/hr and PSD = 80 percent.

4, appears to indicate that an appropriate range of AADT for upgrading is past the minimum cost point when the total highway cost starts to increase rapidly.

There is another example regarding the planned upgrading of the Yellowhead Highway (Highway 16) during the next few years. This highway west of Wabamun Lake to Jasper National Park is a two-lane facility with provisions for climbing lanes in some places. It represents a rural long distance/recreational function except in the vicinities of towns (e.g., Edson) where the function changes partly to commuter or regional trips. The estimated AADT on the long distance/recreational portions that now varies between 2,300 to 3,750 is expected to increase to between 2,500 and 4,000 at the time of upgrading. This range of AADT for upgrading a long distance/recreational route is also suggested by the results of this study.

According to these results, a two-lane highly recreational route such as the one represented by site C165 would require upgrading at an AADT value in the range of 1,500 to 2,500. It may be rare, however, to have a route with a high volume such as 2,000 (note that the present AADT at C165 is 700). A similar comment about the nonrecreational rural routes can also be made here. As mentioned earlier, the cost-volume characteristics of nonrecreational routes are similar to those of the local or suburban commuter; therefore, a nonrecreational rural route with a RAU-211 standard classification and a PSD of 80 percent should require upgrading at an AADT above 6,000; however, these roads carry only a low volume of traffic that generally varies between 1,000 and 3,000 in Alberta.

It should be noted that the term "upgrading" does not necessarily refer to a four-lane option only--other options, such as shoulder widening or three-laning, may be appropriate in a number of situations. Also, even though the analysis, such as that presented here, includes many variables (e.g., road type, vehicle classification, AADT, geometric design variables, and various highway costs), other investigations (e.g., the conventional benefit/cost study involving various matters as safety considerations and possible changes in flow patterns because of upgrading) should also be carried out before a final decision is made. In other words, the AADT criterion as proposed in this research should be used to establish a preliminary prioritization of highway improvements.

SUMMARY AND CONCLUSIONS

This paper analyzes two important aspects of road sizing. First, it reexamines the common approach of selecting the 30th highest hour for design hourly volume (DHV) for all types of road uses. Second, it develops a cost-effective AADT criterion for upgrading two-lane rural highways.

The most important feature of this study is that it uses the road type variable in a more detailed and objective manner than in previous studies. Alberta's highway system is investigated and the roads are classified into six types according to trip characteristics such as trip purpose and trip length distribution. These characteristics are

- suburban commuter,
- regional commuter/recreational,
- rural long distance,
- rural nonrecreational,
- long distance/recreational, and
- highly recreational.

Based on other road design and traffic data, and economic cost statistics from Alberta Transportation, a detailed analysis is carried out that attempts to make the DHV approach more user-oriented and minimize the total cost of highway transportation for upgrading two-lane roads. The main conclusions of this study are as follows:

1. Road use type is a significant factor that must be considered for appropriate sizing of roads from the economist's and user's perspectives.

2. If the traditional approach of selecting the 30th highest hour as the design hour is taken for all types of road uses, it is clear that, even though each facility will experience hours equalling or exceeding the 30th highest hourly volume during only 30 hours per year (0.34 percent of all hours), the percent of the time that a typical user will experience a volume exceeding that of the 30th highest hour will vary significantly with respect to the type of road under consideration. For example, of all the travelers using the commuter site, C9, only 0.92 percent will experience user congestion as compared with 3.35 percent for the highly recreational site C165.

3. An obvious alternative DHV approach will be to provide a more uniform service to the users by selecting different design hours for different types of road uses. For example, to provide a service that permits a 1.5-percent user congestion, the highway agency can select a design corresponding to approximately

a. The 50th highest hour for suburban and rural nonrecreational routes;

b. The 40th highest hour for regional commuter/recreational sites;

c. The 30th to 35th highest hour for rural long distance sites;

d. The 20th highest hour for long distance/recreational sites; and

e. The 10th to 15th highest hour for highly recreational routes.

4. The total unit cost versus volume-to-capacity curves indicates that the total highway cost is minimized typically at a V/C ratio of 0.35 regardless of the type of road use. However, there are several other factors that may cause a shift of the minimum cost V/C point (e.g., the perception of the value of travel time).

5. The cost versus AADT curves developed in this study and the actual practice followed by Alberta

Transportation indicate that the AADT can be used as a good criterion for cost-effective and user-oriented upgrading of two-lane roads. The AADT values at which the total highway costs are minimized during certain selected highest hours (i.e., 10th, 30th, 50th, and 100th) vary significantly from one road type to another. The geometric design variables, such as the road (RAU) standard, average highway speed, and PSD also affect the value of AADT at which cost minimization occurs. The analysis also indicates that for the purpose of upgrading two-lane roads, road use type is a more significant variable than vehicle classification.

6. On the basis of results and the experience gained from this study, the suggested typical ranges of AADT for the purpose of prioritizing the upgrading of two-lane roads are

a. 6,500 to 8,500 for suburban commuter and rural nonrecreational routes;

b. 5,000 to 6,500 for regional commuter/recreational routes;

c. 3,750 to 5,000 for rural long distance routes;

d. 2,500 to 3,750 for long distance/recreational routes; and

e. 1,750 to 2,500 for highly recreational routes.

It is believed that the analysis presented in this paper contributes toward the clarification and further understanding of the DHV considerations and cost-effective criteria for upgrading two-lane rural highways. It is hoped that this will lead highway agencies to invest more wisely not only from the economist's viewpoint, but from the user's viewpoint as well.

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