

DECISION AID FOR ALLOCATION OF TRANSPORTATION FUNDS TO ROADSIDE SAFETY ENHANCEMENT*

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Abstract– Each year, due to the uncontrolled exit of vehicles from the roadway and hitting roadside obstacles -especially rollovers on embankments-huge costs are imposed on communities. For the reduction of such costs, different safety improvement programs may be implemented; for example guard installations, embankment slope reduction and/or the roadside clear zone enhancement. But the real problem always is the scarcity of available resources and how to allocate such scarce resources among the proposed alternatives and programs. In this research-work, by developing a specific approach, the optimized technique for the allocation of financial resources for safety improvement of roadside embankments is presented. Additionally, by developing special graphs, such facility is provided for planners and designers in different sections of road construction and maintenance to make optimum decisions either to install protective guards or to flatten roadside slopes. The results might also be beneficial for the correction and/or completion of the present related code of standards.

Keywords– Encroachment, optimization, roadside safety, embankment, guardrail

1. INTRODUCTION

Driving at the time of drowsiness, tiredness, drinking, drugs intoxication, unsuitable magnitudes and/or arrangements of slopes and curvatures, slippery surface, deteriorated tires, defective brakes, rain, snow, thick fog, insufficient light, and similar hazardous situations may cause a vehicle to leave the roadway. Consequently, the vehicle may hit roadside obstacles, being overturned and/or being prolapsed into the side valley or precipice. All these events lead to potentially huge damages and costs. To reduce losses and economic damage, different countermeasures including roadside guardrail installation, embankment slope reduction, and/or the roadside clear zone width increase might be implemented. Previous studies show that the existence of safety guards in high and steep embankments, positively enhance the safety situation and reduce the severity of developed losses. Such a positive effect, however, does not exist in short and mild slope embankments. The guardrails themselves are potential factors of danger beside the roads, and their existence might provide a relative degree of safety. Therefore, even when the installation of guards considering the values of embankment height and slope is estimated to be acceptable; before taking the final decision, the solution(s) of reducing height and/or slope based on an economical analysis must be considered, and the option of guard elimination be taken. On the other hand, in spite of the severity of the issue, the available resources for tackling the problem are seriously lacking and it is absolutely necessary that these resources be spent efficiently and cost effectively. In this paper, a method which has been developed for solving this problem is presented.

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The abovementioned method provides such facility as to select the optimum solution amongst the competing alternatives of guard installation, slope flattening or the combined solution of simultaneous roadside clear zones enhancement and slope flattening. In this approach, at the first stage the frequency of the encroaching vehicles as a function of traffic volume and road geometry is estimated. Then, considering the distance between the potential obstacle and the pavement edge, the probable number of errant vehicles which will hit the obstacle is predicted. At the final stage, considering the type of obstacle (guardrail, slope, and/or embankment height), the accident severity and then the accident cost will be estimated. Eventually through economical analysis, the best optimized solution for the safety improvement of the embankment is selected.

Reviewing the literature- Glennon presents a cost-effectiveness approach based on a hazard model for guardrail installation [1]. AASHTO suggests a ranking factor for comparing sites for guardrail installation [2]. Mak provides an overview of methods applying cost-effectiveness procedures to the evaluation of roadside safety improvements, i.e. guardrails [3].

AASHTO presents a cost-effectiveness procedure. The technique calculates the present worth of accident costs and highway department costs incurred over the life of the project [4]. Wolford and Sicking developed simplified charts for determining when guardrails are warranted [5].

Flatter roadside slopes have been found to have a significant effect on accidents, especially single-vehicle accidents [6].

2. AN ESTIMATION OF THE COST OF ROADSIDE ACCIDENTS

An estimation of the exact cost of road accidents caused by vehicles going out of control and leaving the roadway, using data collected by police is not feasible in some countries, including Iran. Since in police data collection forms the types of obstacles hit by vehicles are not specified; and additionally, many single-vehicle accidents are not reported to the police. In this study, such costs are estimated by utilizing predictive models.

The cost of accidents caused by a vehicle colliding with a fixed object is a function of [7]:

- the probability of the vehicle leaving the roadway
- the probability of the vehicle hitting a fixed object
- the average of lost capital in a collision of a vehicle with a fixed object

The lost capital caused by the collision of a vehicle with any fixed object may be estimated using the following relationship [7]:

$$E(L) = ADT \cdot P(E) \cdot L \cdot P(A|E_x) \cdot C(SI) \quad (1)$$

E(L): The expected loss on a roadway segment due to a particular type of fixed object accidents,

ADT: Average daily traffic (vehicles/day),

P(E): Probability of leaving the roadway (encroachments/km/yr/vehicle/day),

L: Length of the hazard on the roadway segment (km),

P(A|E_x): Probability of striking a hazard given that a vehicle has encroached on the roadside, and x: the distance between the hazard to the roadway edge in meters,

C(SI): Cost associated with index severity SI,

SI: Severity index of an accident.

a) Estimating vehicle roadside encroachment frequencies

In the following discussion, a "roadside encroachment" is said to occur when an errant vehicle crosses the outside edges of the travel way and encroaches on the shoulder, including both inside and outside

shoulders. The frequency of such encroachments is a function of traffic volume, road geometry characteristics like horizontal and vertical profiles, road width and the number of traffic lanes.

Only three studies have, so far, treated the issue of vehicles encroachment: Hutchinson and Kennedy studied 39.6 Km of freeways in the State of Illinois, with a design speed of 113 Km/h and daily traffic volume of 1,900 to 25,000 vehicles [8]. Also Cooper and his co-researchers (June-October 1976) studied 4,560 Km of undivided two lanes roads and divided four lanes highways in Canada, with speed limits of 80 to 96 Km/h and a traffic volume of 700 to 29,300 vehicles per day [9]. Miao's studies were on the 712 Km of undivided two lane roads in the State of Washington, with a design speed of 90 Km/h and a daily traffic volume of less than 1,200 vehicles per day [10].

The value suggested by AASHTO is 0.00031 encroachments per Km per day per average daily traffic in an undivided two lane (3.6 m/l), even and straight road. This value is to some extent conservative and is compatible with the results of both Cooper's and Hutchinson's studies; provided the following conditions are met [11]:

- compatible with Cooper's findings, at a traffic volume of less than 5,500 veh/day,
- compatible with the slope of the Hutchinson and Kennedy graph, at a traffic volume of 5,500 to 25,000 veh /day,

The existence of horizontal curvatures, longitudinal slopes, and the reduction of lane width increase the frequency of vehicle encroachments from the roadway. The amount of such encroachments might be estimated from the following relationship [11]:

$$P(E) = E_{BASE} \cdot F_{HC} \cdot F_{VG} \cdot F_{LW} \quad (2)$$

E_{BASE} : 0.00031 encroachments /km / year /ADT

F_{HC} : The factor related to the effect of horizontal curvature from Table 1

F_{VG} : The factor related to the effect of longitudinal slope from Table 2

F_{LW} : The factor related to the effect of lane width from Table 3

Table 1. The factor for horizontal curvature effect [9]

Radius (m)	F_{HC} , inside curvature	F_{HC} , outside curvature
95.5	2	4
95.5-191	191/R	(573/R)-2
191	1	1

Table 2. The factor for longitudinal slope effect [9]

G : Longitudinal slope	F_{VG} (Up Grade)	F_{VG} (Down Grade)
40 – 2%	1	1
2% - 6%	1	0.5 + 0.25 G
> 6%	1	2

Table 3. The factor for road width effect [13]

Average daily traffic ADT	The width of each lane (m)			
	3.6	3.3	3.0	2.7
<400	1.00	1.01	1.02	1.05
400-2000	1.00	$1.01 + 2.5 \cdot 10^{-4} (ADT - 400)$	$1.02 + 1.75 \cdot 10^{-4} (ADT - 400)$	$1.05 + 2.81 \cdot 10^{-4} (ADT - 400)$
>2000	1	1.05	1.30	1.50

b) The probability of a collision of an encroaching vehicle with roadside obstacle

Not each encroachment of a vehicle from the roadway ends in a collision. The probability of such a collision actually happening depends on the obstacle distance from the roadway edge, the speed of the

vehicle at the time of leaving the roadway, the path of the encroaching vehicle, and the driver's reaction to the accumulated circumstances [8].

Fig.1 shows the probability of vehicle collision with the obstacle in accordance with the said speed and distance. This figure is the result of AASHTO in both field and statistical studies [8].

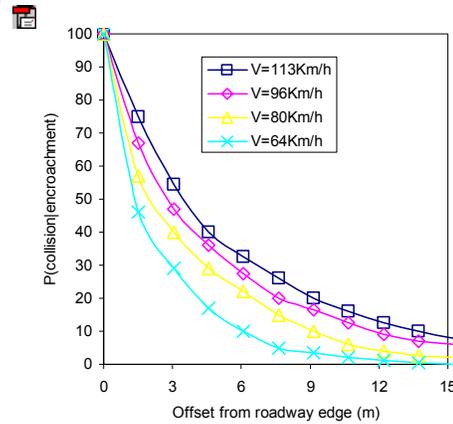


Fig. 1. The probability of vehicle collision with the roadside obstacle [8]

c) The estimation of the severity of vehicle collision with roadside obstacles

At the collision with an obstacle, the severity of the accident depends on the speed of the vehicle at the time of the collision, the geometry of the obstacle (height, width, slope, slenderness, angle configuration), the rigidity and mass of the obstacle, and the size and weight of the vehicle [6]. This severity is defined by an index called Severity Index (SI). This index is a relative scale which starts at zero and terminates at ten. Each SI is an indicator of the possibility of the accident to be fatal, injury or damage only [11] (Table 4). The average cost of rural road accidents in the year 2003 in Iran were estimated to be 810, 67 and 5 million Rials for fatal, injury, and damage only accidents respectively [14]. Thus, for each index, a specific amount of cost is connected, which is, in reality, the weighted average costs of the accidents related to that index. The cost of rural road accidents in Iran for each severity index is estimated and shown in Table 4.

Table 4. Severity and cost of roadside accidents [8]

SI	Percent of damage only accidents	Percent of injury accidents	Percent of fatal accidents	Total percent	Accidents' cost (million Rials)
0	0	0	0	100	0
0.5	100	0	0	100	5
1	90.4	9.6	0	100	12
2	71	29	0	100	23
3	43	56	1	100	47.8
4	30	67	3	100	70.7
5	15	77	8	100	117
6	7	75	18	100	196.4
7	2	68	30	100	243.4
8	0	50	50	100	438.5
9	0	25	75	100	624
10	0	0	100	100	810

Figure 2 shows the severity index of the collisions of vehicles with embankments (having different slopes and heights), at a speed of 95 Km/h. The magnitude of this index is 2.9 for a guardrail. These values are

obtained by the investigation of the antecedent of such collisions and real tests. The severity index is linearly proportional with the speed. These graphs are only valid for cars and light vehicles weighed at 800 to 2000 Kg., and yet comprehensive and exact information for the collisions of heavy vehicles with embankments are not available [5].

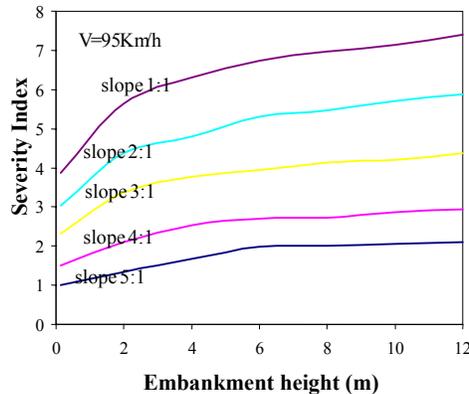


Fig. 2. The severity index for collisions with embankments [3]

3. ECONOMIC ANALYSIS

The present value of the total investment approach is one of the best and most useful ways for the selection of one particular investment program amongst a set of non-compatible alternatives. In this approach, the amount of all costs and benefits are converted to their present value, and eventually the alternative with a maximum present value is selected.

For the conversion of the yearly value of investment to its present value, the conversion factor K may be estimated from either of Eqs. (3) as follow [15]:

$$K = \frac{(1+i)^n - 1}{i(1+i)^n} \quad (3)$$

K: the conversion factor of the yearly values of investment to the present value of the project life investment

n: project life in years

i: the minimum acceptable yearly rate of return, for which in public beneficiary projects, the values of 4% to 6% are suitable[11].

For the promotion of the embankments' safety, either of the two following options may be selected:

- the installation of safety guardrails
- the flattening of embankments

a) The installation of safety guardrails

Previous studies show that the existence of safety guards in high and steep embankments, positively enhance the safety situation and reduce the severity of the incurred losses. Such a positive effect, however, does not exist in short and mild slope embankments [11].

For the estimation of accident costs, first the frequency of the accidents from relationship 2 and Fig.1, the severity index from Fig. 2, and the specific SI related cost from Table 4 would be computed: Eventually, by using relationship 1, the total yearly cost of vehicle collisions with embankments, guardrails and other fixed objects might be estimated.

For a better understanding of this approach, consider the following figure:

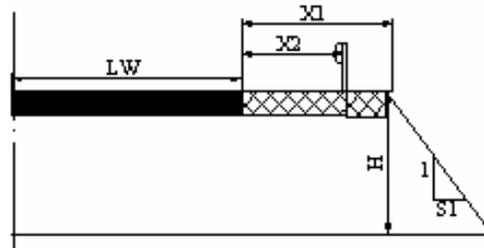


Fig. 3. Installation of guardrail on the embankment

The net present value of the guard installation benefits is equal to

$$NPV = (AC1 - AC2) \cdot K - CI - CM \cdot K - ARC \cdot K \quad (4)$$

NPV: Net Present Value

AC1: the yearly accident costs for alternative 1 (without guardrail)

AC2: the yearly accident costs for alternative 2 (with guardrail)

CI : the initial cost of guard installation (in this example guardrail with weak poles), approximately 150000 Rials per meter in 2003 in Iran

CM: the yearly maintenance cost of the guardrail, which is estimated to be approximately 4% of the initial cost [11]

ARC: the yearly repair cost of the guardrail.

For the estimation of ARC, first the frequency of these types of accidents would be extracted, and then multiplied by the average cost of the guardrail damage in each accident. The amount of this average cost in accordance with the information directly obtained by the authors from the road and transport general office of the province of Fars in Iran, was 900000 Rials per accident in 2003. Thus, the yearly cost of guardrail repair could be estimated as follows:

$$ARC = 0 \cdot 5 ADT_d \cdot P(E) \cdot L \cdot P(A|E_{X_2}) \cdot C_{R/Ac} \quad (5)$$

$C_{R/Ac}$: the average cost of guard repair per accident (Rials)

X_2 : the distance between guardrail to roadway edge in meters

By substituting of the magnitude of every variable in relationship (5), the following relationship will be concluded:

$$NPV = 0 \cdot 5 ADT_d \cdot P(E) \cdot L \cdot [P(A|E_{X_1}) \cdot C(SI_1) - P(A|E_{X_2}) \cdot C(SI_G)] \cdot K - CI \cdot L - [CM \cdot L + 0 \cdot 5 ADT_d \cdot P(E) \cdot L \cdot P(A|E_{X_2}) \cdot C_{R/Ac}] \cdot K \quad (6)$$

H: embankment height

X_1 : the distance of the embankment frontline to the edge of roadway (m) which is taken to be $(X_2 + 0.8m)$. Its minimum value is 0.8 meter, which is the minimum distance to keep the guard poles securely fixed in the soil

$C(SI_G)$: the cost of the collision with guardrail

$C(SI_1)$: the cost of collision with embankment

S_1 : 1 embankment slope (S_1 horizontal: 1 vertical)

If in relationship 6 the estimated value of NPV would come up to be zero; then it means that the benefits gained from the reduction of accident costs is equal to the total cost of guard installation and utilization (fixed cost, repair cost and maintenance and rehabilitation cost). In this study, Fig. 4 is developed based on this concept. Actually, each curve in Fig. 4 might be interpreted to be the border of the

optimized allocation of financial resources for the payment of the full cost of guard installation, repair, and maintenance on one hand, and the benefits gained due to the reduction of accident costs on the other hand. It must be noted that this analysis is based on the following assumptions:

- road type: major rural with two lanes
- average speed: 95 Km/h
- traffic volume: similar in both lanes
- slope: for the sake of better safety $i=4\%$
- traffic mix: mainly light vehicles and cars
- prices: valid for the year 2003
- project useful life: 30 years

For utilizing graphs in Fig. 4, considering the embankment height and design average daily traffic, one single point is distinguished on the figure. Now, if this point is situated above the curve related to the slope of the considered embankment, then guardrail installation will be economical and cost effective.

As it was explained earlier in this paper, the existence of horizontal curvatures, longitudinal slopes, and also the reduction of lane width increase encroachment frequencies. For the purpose of Fig. 4 graphs utilization in such roads, the adjusted ADT must be used:

$$ADT_{D_{Adj}} = ADT_D \cdot F_{HC} \cdot F_{VG} \cdot F_{LW} \quad (7)$$

As an example, if $F_{HC} = 2$, $F_{VG} = 1$, $F_{LW} = 1$ and $ADT_D = 6000$, then the adjusted traffic volume will be 12000 vehicles per day. Now, it can be realized that in such hazardous roads with reduced quality and safety, in comparison with the roads with straight and even paths and sufficient width, the installation of a guard would be necessary in a comparatively shorter height and milder slope embankment.

In Fig.4, three values are assumed for X_2 (1, 2 and 3 meters). As this figure shows, at constant magnitudes of embankment slope and height, when increasing the distance between the guardrail and the roadway edge, the guard installation would be necessary only at higher values of traffic volume. It is easily concluded that it is necessary to try to install the guards at the maximum possible distance from the roadway edge. It is further concluded that the installation of guards on the embankments with a slope of 3:1, only with a high traffic volume and a height of more than three meters seems to be reasonable and acceptable.

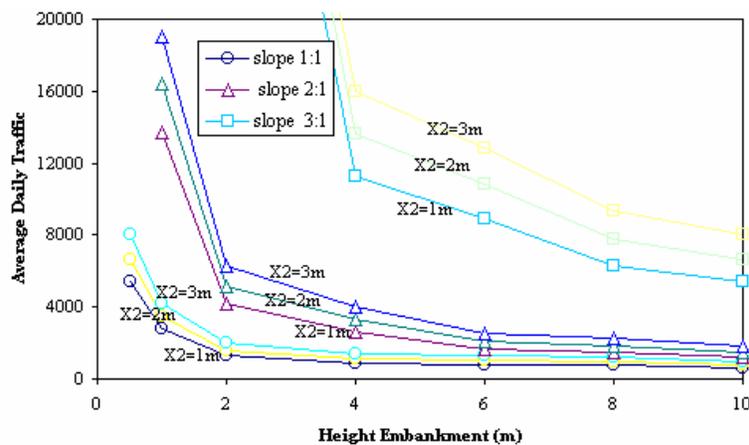


Fig. 4. Guardrail need for embankments

a) Embankment slope reduction

The guardrails themselves are potentially factors of danger beside the roads, and their existence might provide a relative degree of safety. Therefore, even when the installation of guards, considering the values

of embankment height and slope are estimated to be acceptable; before the final decision the solution(s) of reducing height and/or slope based on an economical analysis must be considered and the option of guard elimination taken. At this stage we analyze the two possible options.

1. The option of slope reduction: Considering Fig. 5, the present value of slope reduction is:

$$NPV = 0 \cdot 5ADT_b \cdot P(E) \cdot L \cdot P(A|E_{x1}) [C(SI_1) - C(SI_2)] \cdot K - 1000 \times 0 \cdot 5CH^2(S_2 - S_1)L \quad (8)$$

C: Average cost of 1m³ slope flattening (Rials)

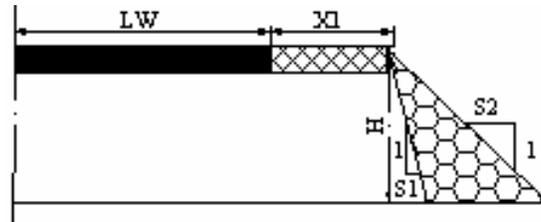


Fig. 5. Embankment characteristics for the option of slope reduction

Since the cost of embankment slope reduction is variable and is a function of location, soil type, and the cost of soil transportation, in this study the value for ADT /C has been selected in such a way that the benefit gained due to accident cost reduction, which is attainable by slope reduction, becomes equal to the cost of slope reduction operation:(NPV=0)

$$\frac{ADT_b}{C} = \frac{1000[0 \cdot 5H^2(S_2 - S_1)]}{0 \cdot 5P(E) \cdot P(A|E_{x1})[C(SI_1) - C(SI_2)] \cdot K} \quad (9)$$

It is recommended that the embankment slope after the shoulder be 4:1 or even less [11]. Thus, our analysis is based on reducing the slopes of 1:1 and 2:1 to 4:1 and 5:1 respectively. The results are shown in Figs. 6 and 7. Three usual values of 2, 4.5 and 7 meters are taken for x1. These graphs show that in an embankment with constant values of slope and height, by increasing x1, the value of ADT /C will also be increased. In embankments of short height and especially with small values of x1, considerable benefit is gained by reducing the slope, because as the graphs show the leveling operation is necessary at low values of ADT /C.

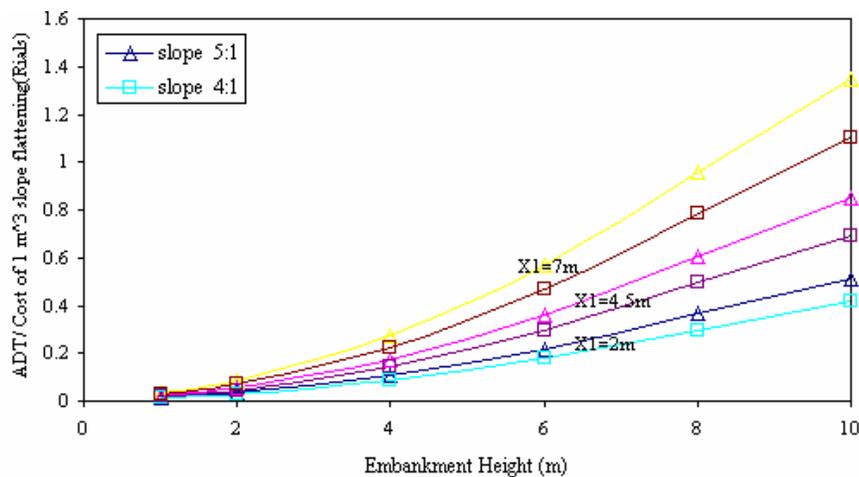


Fig. 6. Graphs for optimized safety promotion of embankment (Slope 1:1)

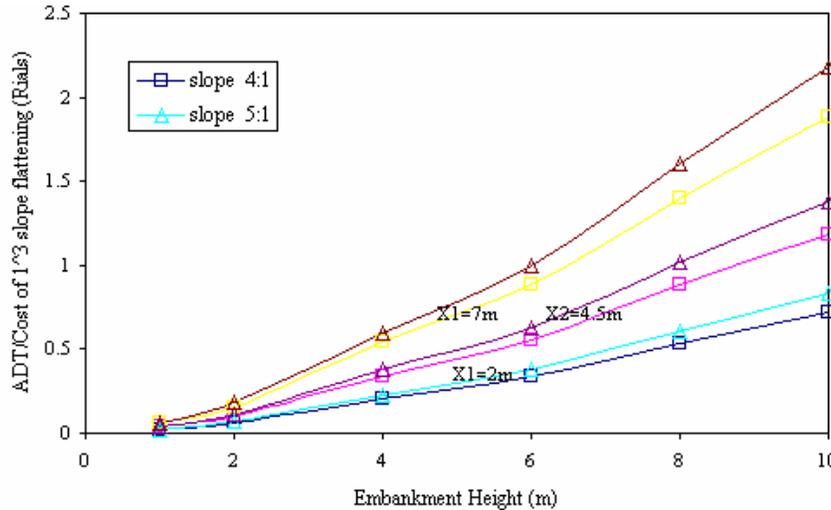


Fig. 7. Graphs for optimized safety promotion of embankment (Slope 2:1)

2. Roadside clear zone width extension in conjunction with slope reduction: The existence of sufficient Roadside clear zone width provide the most needed opportunity for drivers to stop the out of control and deviated vehicle or to lead it back to the roadway. Considering the variables of Fig.8, the value of ADT/C is required to be set in order that the benefit gained from the accidents' cost reduction due to clear zone width extension plus slope reduction come up to be equal to the safety promotion operation (NPV=0):

For x1 two values of 2.0 and 4.5 meters and for x2 (the new developed clear zone width) three values of 4.0, 6.5 and 8.5 meters are considered. At the same time, the roadside clear zone enhancement, the embankment slope, will also be flattened (the slopes of 2:1 and 1:1 are converted to 4:1 or to 5:1).

$$NPV = 0.5ADT_b \cdot P(E) \cdot LK \times [P(A|E_{x1}) \cdot C(SI_1) - P(A|E_{x2}) \cdot C(SI_2)] - 1000C [0.5H^2(S_2 - S_1) + H(X_2 - X_1)]L \quad (10)$$

If NPV=0, then:

$$\frac{ADT_b}{C} = \frac{1000[0.5H^2(S_2 - S_1) + H(X_2 - X_1)]}{0.5P(E)[P(A|E_{x1}) \cdot C(SI_1) - P(A|E_{x2}) \cdot C(SI_2)] \cdot K} \quad (11)$$

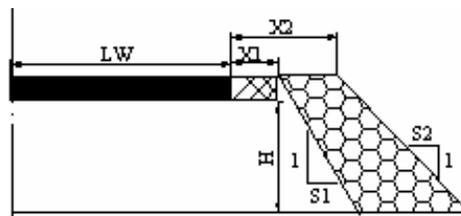


Fig. 8. The embankment characteristics for clear zone width extension in conjunction with slope reduction

The outcomes of the analysis are summarised in Figs. 9 and 10. In accordance with these figures, at short embankments – and especially with small amounts of x1 – and even in low volume roads, the simultaneous increase of roadside clear zone width and flattening of the embankment slope entails substantial economical benefit. The comparison of these figures with Figs. 6 and 7 show that in short embankments – especially with small amounts of x1 – the efficiencies of both safety improvement methods (slope flattening only or the combination of slope flattening and roadside clear zone

enhancement) are almost equal. But it seems that in high embankments, the solution of only flattening is more economical.

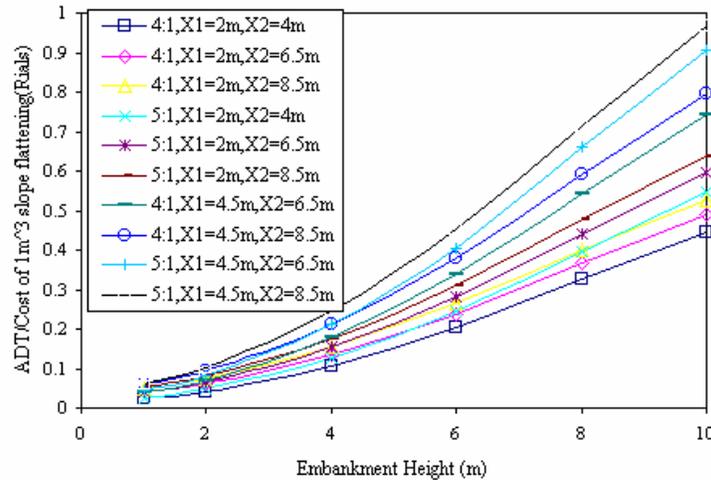


Fig. 9. Graphs for optimized embankment safety promotion (slope 1:1)

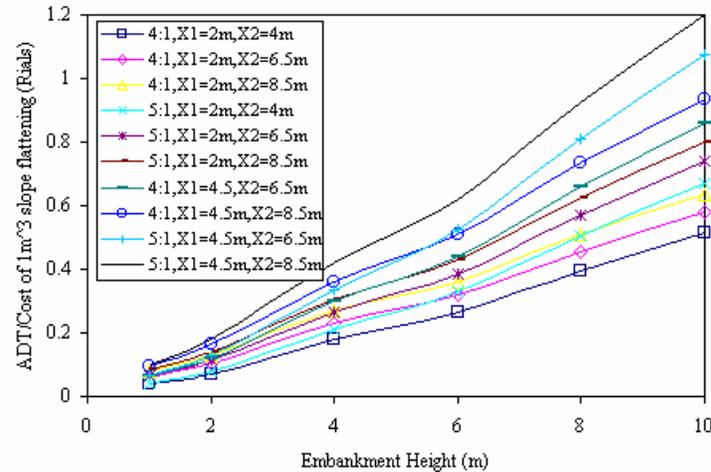


Fig. 10. Graphs for optimized embankment safety promotion (slope 2:1)

3. The best alternative selection: In previous analyses, the object was to select either of the two nominated alternatives (to act for guard installation or not to act, to act for slope reduction or not to act), but at this stage the intention is to select the optimized solution amongst all feasible alternatives.

As previously discussed, in short embankments the efficiencies of two solutions, slope flattening by itself or a combination of slope flattening and roadside clear zone enhancement are almost equal. But in high embankments, the solution of only slope flattening is more effective. Therefore, the comparison is limited to two alternatives of guard installation or slope flattening (changing the embankment slope to 4:1). The distance between the guard and the embankment edge is taken equal to 0.8 meter – x1-0.8 – and for the value of x1 (the distance between embankment and pavement edge) two values of 2.0 and 4.0 meters are considered. Now, the intention is to calculate the maximum price of slope flattening of a one cubic meter embankment in such a way that the cost-benefit ratios related to both alternatives of guard installation and embankment slope flattening become equal to one.

For this purpose, the cost-benefit analysis approach will be used. The cost-benefit ratio is defined as follow: $B/C = [\text{benefits utilized for public}]/[\text{direct costs}]$

The benefits include reduction gained in both frequency and severity of roadside accidents. The direct costs include the costs of installation, maintenance and repair of safety equipment.

Based on the abovementioned definition, this ratio might be written in the form of relationship 12. The independent variables of the said relationship have been defined in previous sections of this study. The outcomes of the analysis are summarised in Fig. 11. The method for utilising this figure is such that by knowing the height of the backfill and the maximum price of slope flattening of a one cubic meter embankment, one specific point on the figure is distinguished. If the said point is situated above the curve, then the guard installation is more economical; but if it is beneath the curve, then slope flattening is more economical. As these curves show, in embankments with a height above 3 to 4 meters, guard installation is more economical than slope flattening. This crucial height is increased by the traffic volume increase and the distance between the pavement edge and the embankment decrease.

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{0.5 \text{ADT}_D \cdot P(E) \left[P(A|E_{(X_1 - 0.8)}) \cdot C(SI_G) - P(A|E_{X_1}) \cdot C(SI_2) \right] \cdot K}{500CH^2(S_2 - S_1) - \left[CI - K(CM - 0.5 \text{ADT}_D \cdot P(E) \cdot P(A|E_{(X_1 - 0.8)}) \cdot C_{R/AC}) \right]} = 1 \quad (12)$$

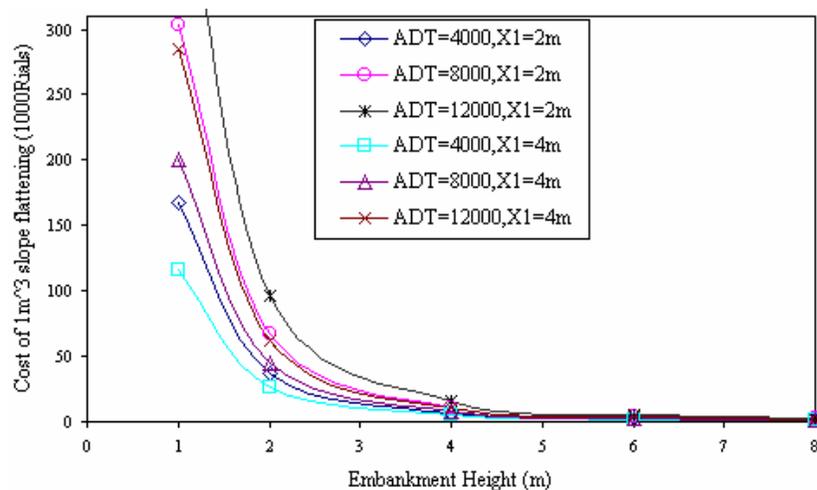


Fig. 11. Graphs for the best alternative selection of slope 1:1

4. DISCUSSION AND CONCLUSION

In this study, the economical and optimized safety promotion of road embankments in two-lane undivided roads in Iran was investigated. The results are summarized as follow:

- The installation of guardrails on the embankments with slopes of 3:1, only with high traffic volume and a height of more than three meters seems to be reasonable and acceptable.
- With increasing the distance between the guardrail and the roadway edge, the guardrail installation would be necessary only at higher values of traffic volume. It is easily concluded that guards must be installed at the maximum possible distance from the roadway edge.
- The need for guard installation in steep and curved (especially the outside curve with a radius of less than 195 meters) tracks is much greater than straight and level tracks. The existence of the outer curve accompanied by an excessive longitudinal slope can increase the probability of encroachment up to eight times in comparison with the situation in which the road is in a straight and level condition.
- Flattening short embankment slopes, especially where the distance between the embankment and the pavement edge is small, is more beneficial than guard installation. But at embankments higher than 3 to 4 meters, guard installation is more economical than slope flattening. This magnitude of height is

increased by increasing traffic volume and decreasing the distance between the pavement edge and the embankment itself.

In high embankments, the solution of only slope flattening in comparison with the combination of roadside clear zone width and slope flattening is more economical.

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