Highway and Railway Design 1 **EXERCISES 4.** (for Lecture 7. of **Dr. A. Timár)**

1. Example

In a given calendar year the motor vehicle fuel consumption in a city is 5 082 million liters. In that year there were 3114 motor vehicle fatalities, 355 799 motor vehicle personal injuries, 6 721 049 motor vehicle registrations and an estimated population of 18 190 238. Average length of motor vehicle travel per liter of fuel consumed is 12.42 km/liter. Calculate registration death rate, population death rate and personal injury accident rate per vehicle km traveled.

Solution

Approximate vehicle kilometers of travel = Total consumption of fuel * kilometers of travel per liter of fuel = $5.08*10^9*12.42 = 63.1*10^9$ km.

1. *Registration death rate* can be obtained from the equation

$$\mathbf{R} = (B*10\ 000) / M$$

here,

R is the death rate per 10 000 vehicles registered,
B (Motor vehicle fatalities) is 3 114,
M (Motor vehicle registered) is $6.72*10^6$

thus

$\mathbf{R} = (3114*10000) / (6.72*10^6) = \mathbf{4.63}$

2. *Population Death Rate* can be obtained from the equation:

$$\mathbf{R} = (B*100,\ 000) / P$$

here,

R is the death rate per 100,000 population,
B (motor vehicle fatalities) is 3114,
P (estimated population) is = $18.2*10^6$.

thus

$\mathbf{R} = (3\ 114*100\ 000) / (18.2*10^6) = \mathbf{17.1}$

3. *Personal injury accident rate per vehicle kilometers of travel* can be obtained from the equation below:

$$\mathbf{R} = (C*100\ 000\ 000) / L$$

here,

R is the accident rate per 100 million vehicle kilometers of travel,
C (number of total injury accidents) is 3 114 + 355 799 = 358 913,
L (vehicle kilometers of travel) is $63.1*10^9$.

thus

$\mathbf{R} = (358\ 91.3*10^9) / (63.1*10^9) = \mathbf{568.8}$

2. Example

Considering their safety ranking based on *accident severity indices* and *accident rates*, select the worst and the best intersection. Accident data related to the four intersections of similar type and traffic load (collected during three consecutive calendar years), are summarized in the following table:

Intersection	**Number of**			**Annual Average Daily Traffic (AADT; vehicle/day) entering the intersection**
	F -fatal (severity weight: 120)	**I -personal injury (severity weight: 30)**	**PDO- property damage only (severity weight: 1)**	
	accidents			
A	3	1	2	13000
B	3	2	0	14000
C	1	1	3	12000
D	2	3	1	13500

Solution

Accident frequency (**N**) is defined as the total number of accidents occurring at each intersection:

$$N_A = 6; N_B = 5; N_C = 5; N_D = 6$$

Accident severity index (**SI**) gives an indication of the accident severity at each intersection:

$$\mathbf{SI} = (120*F + 30*I + 1*PDO) / N$$

thus

$SI_A = [(120*3) + (30*1) + (1*2)] / 6 = 391/6 =$ **65.2** (rank: **3.**)
$SI_B = [(120*3) + (30*2) + (1*0)] / 5 = 421/5 =$ **84.2** (rank. **4. –** worst)
$SI_C = [(120*1) + (30*1) + (1*3)] / 5 = 151/5 =$ **30.2** (rank: **1.** best)
$SI_D = [(120*2) + (30*3) + (1*1)] / 6 = 271/6 =$ 4**5.2** (rank: **2.**)

Accident rate (**AR** per million entering vehicles) takes into account the total number of accidents compared to the average traffic volume entering the intersection:

$$\mathbf{AR} = N / (AADT\ veh/day * 365days * 3years * 10^{-6})$$

thus

$\mathbf{AR}_A = 6 / (13\,000*365*3*10^{-6}) =$ **0.4215** (rank: **3**.)
$\mathbf{AR}_B = 5 / (14\,000*365*3*10^{-6}) =$ **0.3262** (rank: **1.** best)
$\mathbf{AR}_C = 5 / (10\,000*365*3*10^{-6}) =$ **0.4566** (rank: **4.** worst)
$\mathbf{AR}_D = 6 / (13\,500*365*3*10^{-6}) =$ **0.4060** (rank: **2**.)

3. Example

The *critical values* of road safety indicators for a two-way main road (pavement width 7.5 m), determined by the relevant authorities for a 5 year long period, are the following:

Accident rate: $AR_{critical}$ = *5.0* accident/km-year
Accident frequency: $AF_{critical}$ = *0.003* accident / veh-km
Accident severity: $AS_{critical} = (150*A_{fatal} + 50*A_{injury} + 1*A_{pdo})$ = *100* accidents/km-year

During the last 3 years the following accidents were observed on two similar sections of a main collector road:

Road section	A (L= 1.9 km; ADT = 1380 PCU/year)				B (L= 2.4 km) ADT = 1430 PCU/year)			
Accident type	A_{fatal}	A_{injury}	A_{pdo}	Σ	A_{fatal}	A_{injury}	A_{pdo}	Σ
1st year	2	5	7	14	0	3	5	8
2nd year	0	4	5	9	3	5	10	10
3rd year	1	5	6	12	0	4	6	15
yearly average	3/3=1	14/3=4. 7	18/3=6	11.7	3/3=1	12/3=4	21/3=7	12

Calculate the safety indicators for both sections and select the "black spot".

Solution

Average number of accidents for section A: (14+9+12) / 3 = **11.67** accident/year
B: (8+10+15) / 3 = **11.00** accident/year

(i) Average accident rate for section AR_A: [(14/1.9)+(9/1.9)+(12/1.9)]/3=**6.14**/km-year
AR_B: [(8/2.4)+(10/2.4)+(15/2.4)]/3=**4.58**/km-year

(ii) Accident frequency for section AF_A: 11.67/1380*1.9 = **0.00445** accident/veh-km
AF_B: 11.00/1430*2.4 = **0.00321** accident/veh-km

(iii)Accident severity AS_A: (1*150+4.7*50+6*1)/1.9 = **205.80**/km-year
AS_B: (1*150+4.0*50+7*1)/2.4 = **146.25**/km-year

If a certain road section shows higher values than the critical ones for *all three parameters*, the section is considered to be a *black spot*, thus section A is to be considered a „black spot", but section B isn't.

4. Example

Due to the recent sudden increase of traffic load at a rural T intersection, the total number of personal injury accidents is increased substantially, reaching **17/year**. A review of the relevant literature revealed that

(i) channelization of traffic flows by implementing *splitter islands*, *median islands* and purposeful *pavement markings* may lead to the reduction of the total number of accidents by **40%**, **30%**, and **10%**, respectively;
(ii) results of *multiple treatments* may be expressed by the following equation:
$\boldsymbol{ARF_t} = ARF_1 + (1-ARF_1)*ARF_2 + (1-ARF_1)*(1-ARF_2)*ARF_3 + \ldots$

where:

ARF_t = total crash reduction
ARF_x = individual crash reductions

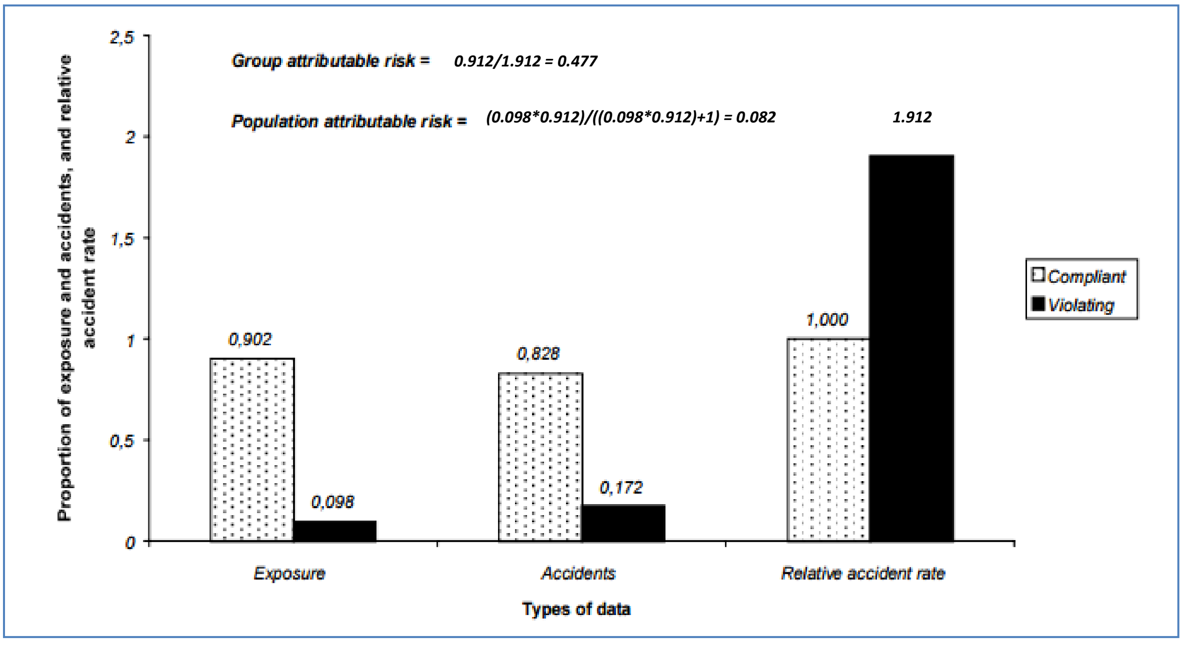
What could be the reduced total number of accidents to be expected following the implementation of splitter islands (on the minor road) and median islands (on the major road) as well as appropriate pavement markings?

Solution

ARF_t = 0.4 + (1-0.4)*0.3 + (1-0.4)*(1-0.3)*0.1 = 0.4 + 0.6*0.3 + 0.6*0.7*0.1 = 0.4 + 0.18 + 0.042 = 0.622, or a **62.2%** reduction of the number of accidents per year could be achieved, which is expected to remain below **11** accidents/year.

5. Example

According to the collected data related to a given road network, traffic violators made up 9.8% of all kilometers driven (as a car driver). They were, however, involved in 17.2% of personal injury accidents. Assuming the accident rate for drivers complying with the law is equal to 1.0, what could be the size of the reduction of the number of personal injury accidents if traffic violations were eliminated?



Solution

If the accident rate (accidents/vehicle-km) for drivers complying with the law is set equal to 1.0, the relative accident rate for the violators becomes: (0.172/0.098) / (0.828/0.902) = **1.912**
If this excessive risk were eliminated, the accident rate of the violators would drop by 0.912/1.912 = 47.7% (0.477 as a proportion). This is the group attributable risk for the group of traffic violators. Traffic violators make up 9.8% of all drivers. Hence, their contribution to the total number of accidents, referred to as population attributable risk, is:

(0.098*0.912) / [(0.098*0.912) + 1] = **0.082**; i. e. **8.2%**

This can be interpreted as the size (percentage) of the reduction of the number of personal injury accidents that could be accomplished if traffic violations were eliminated, but traffic violators continued to drive the same number of kilometers as before, while complying with the law.

6. Example

A road segment is 1.8 km long, it has an average daily traffic (ADT) of 4 000 vehicles/day and recorded 12 accidents in the last calendar year. The Safety Performance Function (SPF) for similar roads is:

$$0.0224*ADT^{0.564} \text{ accidents/(km-year)}$$

with an overdispersion parameter ν= 2.05/km. Estimate the safety (accident frequency) of this road segment and its standard deviation.

Solution

Step 1: Calculate a*verage* for entities of this kind.

Roads such as this have $0.0224*4000^{0.564}$ = **2.41** accidents/(km-year), on average. Therefore segments that are 1.8 km long are expected to have 1.8*2.41 = **4.34** accidents/km in one calendar year.

Step 2: Calculate w*eight*.

We need a „weight" for joining the 12 accidents recorded on this road and the 4.34 accidents/(km-year) for an average road of this kind. For weight the following equation is to be used:

$$\textbf{weight} = \mathbf{1 / 1 + (\mu*Y) / \nu}$$

where
Y is the number of years of accident counts used (here 1).
ν is the estimated overdispersion parameter (here 2.05/km)
μ is the average accident rate on that kind of road (here 2.41 accidents/km-year)

therefore:
weight = 1 / [1+(2.41*1) / 2.05] = **0.460**. Note that both μ and ν are 'per unit length'.

Step 3: *Estimate* expected accident frequency

The estimate of the expected accident frequency for the specific road segment at hand is calculated using the following equation:

Estimate of the Expected Accidents for an entity = Weight * Accidents expected on similar entities + (1 - Weight) * Count of accidents on this entity

thus: 0.460*4.34 + (1-0.460)*12 = **8.48** in one year is the estimated number of accidents for the road segment under scrutiny. Note that 8.48 is between the average for similar sites (4.34) and the accident count for this site (12). The estimator pulls the accident count towards the mean and thereby accounts for the regression to mean bias. The standard deviation (δ) of the estimate of the expected accident frequency is given by:

$$\boldsymbol{\delta}\textbf{(estimate)} = \sqrt{\textbf{(1- weight)*estimate}}$$

Here:

$$\delta = \pm\sqrt{(0.54\times 8.48)} = \pm\mathbf{2.14} \text{ accidents in one calendar year.}$$

7. Example

For the same 1.8 km long road segment studied in the Example 6, we have three years of accident counts: 12, 7, 8, and the average daily traffic (ADT) in each of those three years was around 4000 vehicles/day. Calculate the estimated level of safety attributed to that road segment.

Solution

Step 1: Calculate a*verage* entities of that kind

As before, segments of this kind are expected to have 2.41 accidents/km-year. On 1.8 km in three years 1.8*3*2.41= **13.01** accidents are expected.

Step 2: Calculate *weight*

The weight is 1/[1+(2.41*3) / 2.05] = **0.220** Note that with one year of accident data used, the weight was 0.460. As more years of accident data are used, the weight (given to the number of accidents expected on similar entities) diminishes.

Step 3: *Estimate* expected accident frequency

Expected accidents = 0.220*13.01 + (1-0.220)*(12+7+8) = 23.92 accidents in three years, while the yearly accident frequency is:

23.92 / (3*1.8)±4.43 / 3*1.8 = **4.43±0.82** accidents/km-year