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Contextualising Pedestrian Countermeasure Effectiveness in Developing Countries: A Variant iRAP Model with Weighted Risk Adjustment

Joel Mubiru * and Harry Evdorides

Department of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom

* Correspondence: jxm1471@student.bham.ac.uk/mubirudalt@yahoo.com

Abstract

Pedestrian crashes are disproportionately concentrated in developing countries (DCs), where scarce and unreliable crash data limit the calibration of global road safety assessment tools. The International Road Assessment Programme (iRAP) provides a globally recognised framework for evaluating pedestrian facilities; however, its countermeasure effectiveness (CME) values are derived largely from data from high-income countries. This study develops and tests a variant countermeasure effectiveness model that integrates locally relevant contextual factors not considered in iRAP. Building on a systematic review (which identified 33 contextual factors) and statistical modelling with artificial datasets (which profiled 16 absent factors), the study introduced two novel contributions: the Adjusted Effectiveness Formula (Eqn 1) and the Adjusted Pedestrian Star Rating Score (PSRS) Formula (Eqn 7). Eleven contextual factors were retained for integration based on a threshold criterion (Fi < 0.9 or Fi > 1.1). Four weighting methods (correlation, regression, principal component analysis, and budget allocation) were compared; the Budget Allocation Method was selected for its suitability in data-poor contexts. Interpolated risk values were generated across performance levels using a log-linear approach (Eqn 6). Application of the adjusted model revealed significant shifts in star rating outcomes. At operating speeds of 40–50 km/h, factors such as overtaking tendency, traffic rule enforcement, countermeasure as an afterthought, human capacity of agencies, and employed population caused several road segments to shift from Star 2 to Star 1, classifying them as unsafe at speeds above 45 km/h. This outcome, not captured by the current iRAP model, underscores the need for localised recalibration. The adjusted model, embedded directly into iRAP's PSRS framework, improves realism and predictive accuracy, offering a practical tool for context-sensitive prioritisation of pedestrian safety countermeasures in DCs.

Keywords: pedestrian safety; countermeasure effectiveness; international road assessment programme (iRAP); developing countries (DCs); contextual risk factors; star rating score (SRS); road safety modelling; sustainability

1. Introduction

Pedestrian crashes remain a critical global public health and development challenge, disproportionately affecting low- and middle-income countries (LMICs)/ developing countries (DCs). According to the WHO Global Status Report on Road Safety 2023, an estimated 1.19 million people die annually in road traffic crashes, with a further 50 million sustaining non-fatal injuries [1]. Vulnerable road users (pedestrians, cyclists, and motorcyclists) account for over half of these deaths. The burden falls heaviest on LMICs, which account for more than 90% of road traffic fatalities despite owning only 60% of the world's vehicles [2]. Regionally, Africa has the highest road traffic fatality rate globally (26.6 deaths per 100,000 population), followed closely by Southeast Asia (17.0 per 100,000), with pedestrians comprising a disproportionately large share of victims [3,4]. Beyond the human cost, road crashes impose severe economic impacts, estimated at up to 5% of GDP in many LMICs [5,6], straining already fragile health systems and undermining sustainable development goals.

Pedestrian safety is shaped by a complex interplay of factors, including poor infrastructure, excessive speeds, weak enforcement, and behavioural patterns [7,8]. To address these challenges, the International Road Assessment Programme (iRAP), first introduced by the World Bank, has become a *de facto* global framework for road safety assessment and investment prioritisation [9–11]. The iRAP methodology systematically evaluates the safety of road infrastructure for different user groups and assigns Star Ratings based on infrastructure risk and predicted countermeasure effectiveness [12]. The tool has been applied in over 100 countries, and is widely endorsed by governments, development agencies, and funding institutions as a standard for benchmarking and improving road safety [13,14].

However, a growing body of evidence highlights critical limitations in applying iRAP's globally standardised effectiveness values directly in DC contexts [15]. The countermeasure effectiveness (CME) values and crash modification factors (CMFs) used in iRAP are primarily calibrated from high-income country (HIC) datasets [16,17]. This reliance risks overestimating countermeasure benefits in settings where contextual realities such as poor infrastructure maintenance, weak enforcement, infrastructure encroachment, and socio-behavioural norms undermine safety outcomes [18,19].

A recent systematic review conducted by the authors, following PRISMA 2020 guidelines [20,21], screened 1,911 records and identified 33 contextual factors influencing the performance of pedestrian countermeasures in DCs. Among these, factors such as weak institutional capacity [13], poor enforcement [22,23], and inadequate maintenance [24] were repeatedly shown to diminish the real-world effectiveness of measures assumed to be highly effective in global models. A subsequent performance gap analysis of five before-and-after case studies revealed a mean discrepancy of 30.89% (SD = 29.89%) between iRAP-predicted and observed effectiveness, underscoring the magnitude of systematic overestimation in DC settings.

Building on this, statistical modelling with artificial datasets (2,000 random samples per variable) was conducted to approximate the influence of contextual factors on pedestrian crash frequency in data-scarce environments [25]. Using pairwise correlation, stepwise regression, and Negative Binomial (NB) modelling [26], 16 contextual factors absent from iRAP's framework were identified as critical. These included "overtaking tendency"[26], "countermeasure as an afterthought"[22], "human capacity of agencies"[12], and "traffic rule enforcement"[27], which strongly shaped safety outcomes in DC contexts. Although coefficients from NB modelling did not reach conventional statistical significance, reflecting the limitations of artificial data rather than the irrelevance of the factors, the exercise demonstrated a replicable approach for systematically ranking and integrating locally relevant variables.

Together, these findings underscore a fundamental research gap where iRAP's global countermeasure effectiveness values do not adequately reflect the localised realities of DC road environments, leading to inflated safety benefit predictions and suboptimal investment decisions.

The aim of this paper is therefore to present a contextualised countermeasure effectiveness model for pedestrian safety in DCs. This variant model recalibrates iRAP's baseline effectiveness values by incorporating weighted contextual risk modifiers and introduces an adjusted Pedestrian Star Rating Score (PSRS) formula. By embedding socio-behavioural, infrastructural, and institutional realities into the assessment framework, the model enhances predictive accuracy and provides a more reliable basis for prioritising countermeasures in resource-constrained settings.

2. Materials and Methods

2.1. Data Sources and Factor Selection

The development of the contextualised countermeasure effectiveness model was based on evidence from two complementary research stages. A systematic literature review, following

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PRISMA 2020 guidelines [20,28,29], identified 33 contextual factors influencing pedestrian countermeasure performance in developing countries. These included socio-behavioural, infrastructural, and institutional variables such as poor maintenance, weak enforcement, pedestrian demographics, and road encroachment. A subsequent modelling exercise using artificial datasets (2,000 random samples per variable) applied pairwise correlation, stepwise regression, and Negative Binomial (NB) modelling to quantify the influence of 20 variables. From this stage, 16 factors were found to be absent from the iRAP framework.

For integration into the adjusted model, a threshold criterion for factor inclusion was applied following the Highway Safety Mannual [30]. Factors with risk values (Fi) between 0.9 and 1.1 were considered to have trivial influence and were excluded. This resulted in the retention of **11 factors**. Of these:

- Some coefficients were derived from the NB modelling (expressed as Incident Rate Ratios, IRRs).
- Others were sourced from published models in external literature (expressed as Odds Ratios or IRRS).

Although combining IRRs and ORs introduces methodological consistency challenges, this was mitigated through the application of the rare-event assumption [31], which allows conversion across effect measures when events are infrequent. The approach prioritised inclusivity of influential contextual factors, recognising that empirical crash data in developing countries are limited.

The final set of 11 factors is presented in Table 1, alongside their coefficients, risk values (Fi), and data sources.

Table 1. Factors to be considered in the variant Model.

Variable / factor	Coefficient (β)	Risk factor (F_i) = e^{β}	In NB Model	iRAP Covered	Include in Model? (Fi , 0.9 or > 1.1)	Type of model and source
Pedestrian/Vehicle Volume Ratio	0.004	1.004	✓	✗	✗	
Vehicle Age / Technology (%)	0.150	1.162	✓	✗	✓	
Overtaking Tendency (1/0)	0.502	1.652	✗	✗	✓	NB [26]
Traffic Rule Enforcement (1/0)	-0.980	0.375	✗	✗	✓	Logistic [36]
Public Safety Awareness (%)	0.113	1.120	✗	✗	✓	Logistic [37]
Driver Safety Awareness (%)	0.127	1.135	✗	✗	✓	Logistic [38]
Countermeasure as Afterthought (%)	-0.460	0.631	✓	✗	✓	
Footpath Encroachment (%)	0.000	1.000	✓	✗	✗	
Human Capacity of Agencies (1/0)	-0.248	0.780	✗	✗	✓	Logistic [11,12,39,40]
Age 18–49 (%)	0.140	1.150	✓	✗	✓	
Age 50+ (%)	-0.080	0.923	✓	✗	✗	
Male Pedestrians (%)	0.110	1.116	✓	✗	✓	
Female Pedestrians (%)	-0.150	0.861	✓	✗	✓	
Employed Population (%)	0.200	1.221	✓	✗	✓	
Street Furniture Vandalism (0/0.5/1)	-0.030	0.970	✓	✗	✗	
Age of Countermeasure (years)	-0.010	0.990	✓	✗	✗	

2.2. Adjusted Effectiveness Model

The first novel contribution of this study is the Adjusted Effectiveness Formula, which recalibrates iRAP's baseline Countermeasure Effectiveness (CME) by integrating the contribution of locally relevant contextual risk factors. Unlike the iRAP framework, which applies globally standardised values, this model embeds both factor influence values (Fi) and weights (Wi):

$$CME_{adj} = CME_{iRAP} \times \left(1 - \sum_{i=1}^{n} w_i * F_i\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eqn\ 1)$$

where:

- CME_{iRAP} = baseline countermeasure effectiveness from iRAP,
- F_i = influence (risk factor value) of contextual factor i,
- w_i = normalised weight of each contextual factor i,

- $(\sum_{i=1}^{n} w_i * F_i) \approx \delta$, with $\delta \approx 0.3089$ (the average observed discrepancy between iRAP-predicted and actual effectiveness in DC settings).

This adjustment corrects for the 30.89% performance gap identified in earlier analyses, representing the aggregate influence of local contextual factors on countermeasure performance.

2.3. Weighting Methods

To allocate relative importance among the 11 contextual factors, four weighting techniques were compared. These methods were selected because they represent both statistical approaches (objective, data-driven) and participatory approaches (judgement- or impact-based), ensuring methodological balance [32,33].

2.3.1. Factor Correlation Weighting (Spearman ϱ)

$$W_i^{(corr)} = \frac{|\rho_i|}{\sum_{j=1}^{n}|\rho_j|} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eqn\ 2)$$

where: ρ_i is the Spearman rank correlation between variable *i* and pedestrian crash frequency

This method captures monotonic relationships without assuming linearity. It is particularly relevant for DCs where crash variables interact in complex, non-linear ways [32]. Microsoft Excel software was used to compute the correlation weights.

2.3.2. Regression-Based Weights

$$W_i^{(reg)} = \frac{|\beta_i|}{\sum_{j=1}^{n}|\beta_j|} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eqn\ 3)$$

where β_i is the standardised regression coefficient from the NB model.

This method derives weights directly from multivariate regression contributions, reflecting the relative influence of each variable [33]. Microsoft Excel software was used to calculate the regression weights.

2.3.3. Principal Component Analysis (PCA)

$$w_i^{(PCA)} = \frac{loading_i}{\sum_{j=1}^{n} loading_j} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eqn\ 4)$$

where *loading* refers to the factor loading or eigenvalue associated with each variable on the first principal component.

PCA reduces dimensionality, extracting latent patterns of interrelationships. Factor loadings from the first component form the basis of weights [33,34]. Python script was used to compute PCA weights.

2.3.4. Budget Allocation (BA)

$$W_i^{(budget)} = \frac{|Fi_i - 1.0|}{\sum_{j=1}^{n}|Fi_j - 1.0|} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eqn\ 5)$$

where $F_i = e^{\beta_i}$ is the risk factor impact score. The further Fi is from 1.0, the stronger its influence (impact distortion).

This method distributes a hypothetical "budget" (e.g., 100 points) across variables based on their relative influence, reflecting performance loss theory. While it introduces subjectivity, it allows inclusion of both NB-derived and literature-derived coefficients.

Each method produced normalised weights, which were then compared against factored weights (Table 2). The factored weights account for both magnitude and variability, providing a more robust criterion for method selection. The Budget Allocation Method achieved a value of 0.991 (closest to 1.0 among the methods tested) and was therefore selected as the final weighting technique.

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Table 2. Comparison of normalised and factored weights using different methods.

Factor/Variable	Data			Normalised Weights				Factored Weights (Fi*Wi)			
	Spearman correlation coefficient (ϱ)	**Regression Coefficient(β)**	**Relative risk factor (F_i) = e^{β}**	**Spearman Correlation Weights**	**Regression weights**	**Principle Component Analysis Weights**	**Budget allocation weights**	**Spearman Correlation Weights**	**Regression weights**	**Principle Component Analysis Weights**	**Budget allocation weights**
Vehicle age /technology	0.003	0.150	1.162	0.011	0.047	0.097	0.056	0.013	0.055	0.113	0.065
Public Safety Awareness	-0.026	0.113	1.120	0.105	0.036	0.012	0.041	0.118	0.040	0.013	0.046
Driver Safety Awareness	0.017	0.127	1.135	0.068	0.040	0.031	0.047	0.078	0.045	0.035	0.053
Overtaking Tendency	-0.037	0.502	1.652	0.151	0.158	0.086	0.224	0.249	0.261	0.141	0.370
Traffic Rule Enforcement	0.009	-0.980	0.375	0.035	0.308	0.233	0.215	0.013	0.116	0.087	0.081
Countermeasure as Afterthought	-0.032	-0.460	0.631	0.128	0.145	0.184	0.127	0.081	0.091	0.116	0.080
Human Capacity of Agencies	0.013	-0.248	0.780	0.053	0.078	0.009	0.075	0.041	0.061	0.007	0.059
Age 18-49	0.031	0.140	1.150	0.124	0.044	0.157	0.052	0.143	0.051	0.180	0.059
Female Pedestrians	-0.023	-0.150	0.861	0.092	0.047	0.082	0.048	0.079	0.041	0.070	0.041
Male Pedestrians	0.036	0.110	1.116	0.146	0.035	0.110	0.040	0.163	0.039	0.123	0.045
Employed Population	0.021	0.200	1.221	0.086	0.063	0.000	0.076	0.105	0.077	0.000	0.093
TOTAL				**1.000**	**1.000**	**1.000**	**1.000**	**1.083**	**0.875**	**0.887**	**0.991**

This multi-step approach ensured that the choice of weighting method was not arbitrary but grounded in comparative performance, addressing concerns of subjectivity in model construction.

- Figure 1 presents the schematic flowchart of the modelling process, showing the sequential steps of normalisation, factoring, and method selection.
- Figure 2 shows the Python script used to compute PCA weights.

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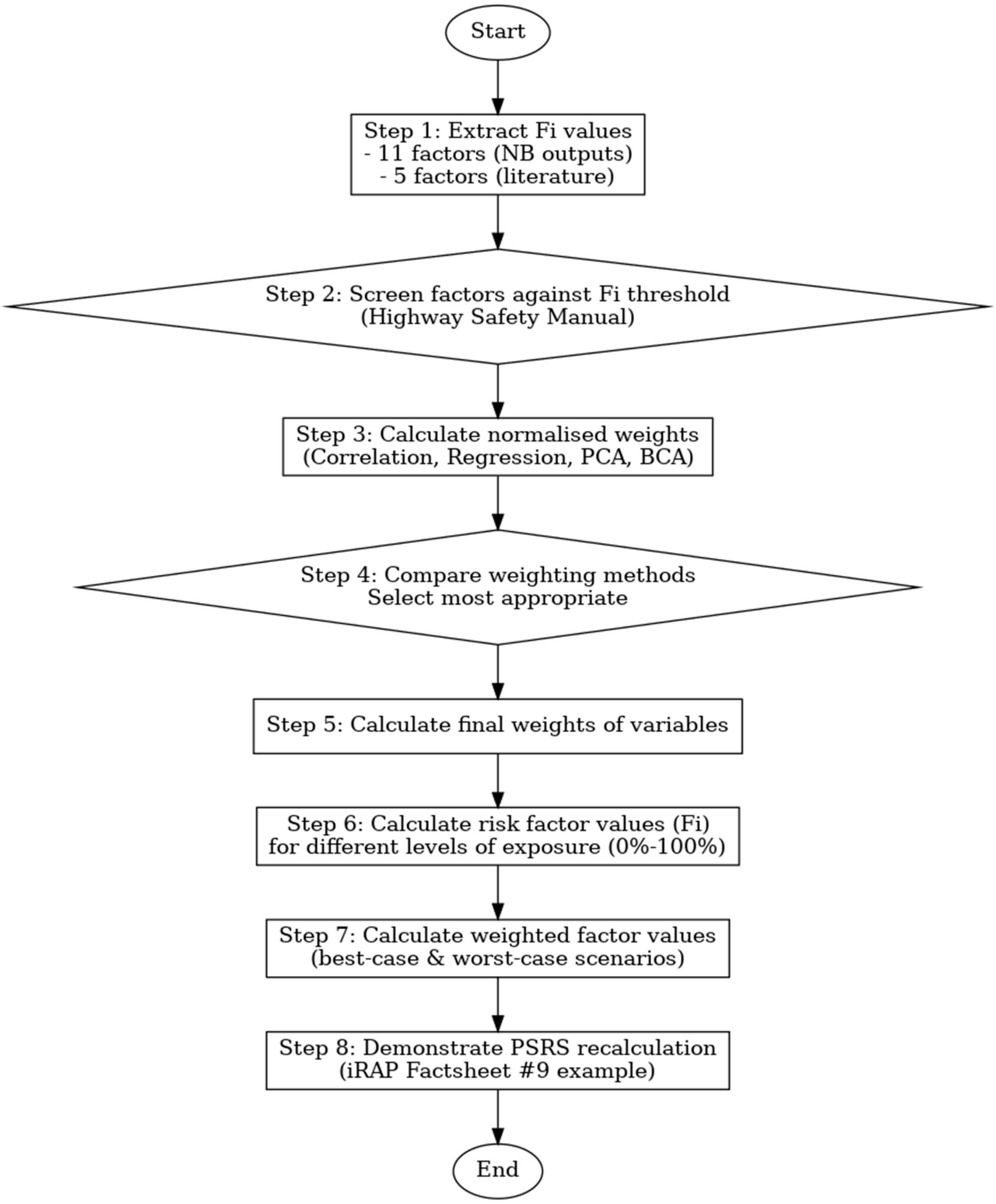

Figure 1. Flowchart illustrating the process for developing and applying the contextualised variant effectiveness model.

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```python
# -*- coding: utf-8 -*-
"""
Created on Tue Jun  3 10:04:50 2025

@author: jxm1471
"""

import pandas as pd
import numpy as np
from sklearn.decomposition import PCA
import os

# Define variable names (same order as your correlation matrix)
variables = [
    "Vehicle Age/Technology", "Overtaking Tendency", "Traffic Rule Enforcement", "Public Safety
Awareness", "Driver Safety Awareness", "Countermeasure as an Afterthought",
    "Human Capacity Agencies", "Age 18-49 years", "Male Pedestrians", "Female Pedestrians", "Employed
Population"
]

# Spearman correlation matrix
correlation_matrix = np.array([
    [ 1.000, 0.018, -0.034, -0.039, -0.001, 0.001, 0.019, -0.014, 0.020, 0.009, -0.021],
    [0.018,  1.000, 0.009, 0.063, 0.003, 0.021, -0.011, 0.002, 0.070, -0.002, 0.016],
    [-0.034, 0.009, 1.000, 0.006, -0.025, -0.047, -0.008, 0.029, -0.021, -0.001, -0.020],
    [-0.039, 0.063, 0.006, 1.000, 0.006, 0.011, -0.009, -0.007, 0.019, 0.010, 0.018],
    [-0.001, 0.003, -0.025, 0.006, 1.000, 0.000, 0.004, -0.001, 0.036, 0.043, 0.008],
    [ 0.001, 0.021, -0.047, 0.011, 0.000, 1.000, 0.009, -0.021, 0.026, -0.022, 0.002],
    [ 0.019, -0.011, -0.008, -0.009, 0.004, 0.009, 1.000, 0.017, 0.005, -0.006, -0.005],
    [-0.014, 0.002, 0.029, -0.007, -0.001, -0.021, 0.017, 1.000, 0.025, 0.021, 0.026],
    [ 0.020, 0.070, -0.021, 0.019, 0.036, 0.026, 0.005, 0.025, 1.000, 0.008, 0.013],
    [ 0.009, -0.002, -0.001, 0.010, 0.043, -0.022, -0.006, 0.021, 0.008, 1.000, -0.017],
    [-0.021, 0.016, -0.020, 0.018, 0.008, 0.002, -0.005, 0.026, 0.013, -0.017, 1.000]
])

# Create DataFrame
df_corr = pd.DataFrame(correlation_matrix, columns=variables, index=variables)

# PCA setup
pca = PCA()
pca.fit(df_corr)

# Extract loadings (components) and eigenvalues
loadings = pca.components_.T
eigenvalues = pca.explained_variance_

# Select only components with eigenvalue > 1 (Kaiser criterion)
valid_components = eigenvalues > 1
loadings_selected = loadings[:, valid_components]

# Compute weights as sum of squared loadings per variable
raw_weights = np.sum(loadings_selected**2, axis=1)

# Normalize weights to sum to 1
normalized_weights = raw_weights / np.sum(raw_weights)

# Create DataFrame
weights_df = pd.DataFrame({
    "Variable": variables,
    "PCA Weight": normalized_weights.round(4)
})

# Save to Excel on desktop
desktop_path = os.path.join(os.path.expanduser("~"), "Desktop")
output_file = os.path.join(desktop_path, "PCA_Variable_Weights.xlsx")
weights_df.to_excel(output_file, index=False)

print(f"✅ PCA Weights saved to: {output_file}")
```

Figure 2. Python Code for Computing Principal Component Analysis Weights.

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2.4. Interpolation of Relative Risk Values

To represent how contextual risk factors behave across different performance levels, a log-linear interpolation function was applied. This technique allows dynamic risk modelling by generating interpolated relative risk values across defined performance intervals (from 0% to 100%).

$$Fi(P) = exp\left[\ln(Fi_L) + \frac{P}{100} \cdot (\ln(Fi_H) - \ln(Fi_L)\right] \ldots\ldots\ldots\ldots\ldots\ldots.(eqn\ 6)$$

where:

- *Fi(P)* is interpolated relative risk at performance level P,
- Fi_L is the lower relative risk value,
- Fi_H is the higher relative risk value,
- ln denotes the natural logarithm,
- exp denotes the exponential function,
- *P* is the performance level (expressed as a percentage), measured with reference from the level at which Fi_L occurs.

This function accounts for diminishing or increasing marginal effects**.** For example, the exponential decline in risk associated with increasing public awareness (illustrated in Figure 4). Interpolated values for each factor are shown in Table 5.

2.5. Integration into the Pedestrian Star Rating Score (PSRS) Framework

The contextualised model was embedded into iRAP's Pedestrian Star Rating Score (PSRS) framework by introducing a novel adjusted star rating equation (Eqn 7), derived directly from Eqn 1. This replaces iRAP's baseline star rating equation (Eqn 8), ensuring compatibility while incorporating contextual risk factors:

$$PSRS_{adj} = PSRS_{iRAP} \times \left(1 + \sum_{i=1}^{n} w_i * F_i\right) \ldots\ldots\ldots\ldots.(eqn\ 7)$$

where:

- SRS_{DC} refers to the adjusted star rating scores for developing countries
- SRS_{iRAP} denotes the baseline iRAP pedestrian star score, calculated according to the iRAP Methodology Fact Sheet #6 [35].

$$PSRS_{iRAP} = \sum(likelihood \times Severity \times Operating\ speed \times External\ flow\ influence) \ldots\ldots(eqn\ 8)$$

This modification enables direct comparison between contextualised and conventional star ratings, highlighting how factor integration alters countermeasure prioritisation. Figure 5 presents the adjusted PSRS framework.

2.6. Model Application Using an iRAP Worked Example

To demonstrate practical application, a worked example was conducted comparing PSRS outcomes with and without contextual factor integration. Using interpolated risk values from Table 4, and weighting adjustments (Table 5), star ratings were recalculated for different operating speeds and contrasted with baseline iRAP outcomes.

Results show that when contextual factors such as enforcement, overtaking tendency, or institutional capacity are considered, star rating scores decline significantly compared to iRAP's baseline predictions. This confirms the model's ability to capture the real-world constraints of developing country environments. Full calculation steps are provided in the Appendix A.

3. Results

3.1. Selection of Contextual Factors for the Adjusted Model

Table 1 presents the 16 contextual factors not currently considered in iRAP that were initially identified from the modelling and literature review process. Of these, five factors (pedestrian/vehicle

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volume ratio, footpath encroachment, Age 50+, street furniture vandalism, and age of countermeasure) were excluded because their risk factor values (Fi) fell within the trivial threshold of 0.9–1.1 [30]. The remaining 11 factors were retained for incorporation into the adjusted model.

3.2. Comparison of Weighting Methods

Four weighting techniques were applied (Spearman correlation, regression-based, PCA, and Budget Allocation) and the results compared.

- Table 2 shows the normalised weights computed for each contextual factor.
- These weights were subsequently adjusted into factored normalised weights (Table 2) to facilitate selection of the most appropriate method.

Comparative analysis revealed that the Budget Allocation Method (BA) produced a factored normalised weight of 0.991, closest to the ideal value of 1.0, confirming it as the most suitable weighting approach for the adjusted model.

This finding is further illustrated in Figure 3, which compares the factored weights across the four methods.

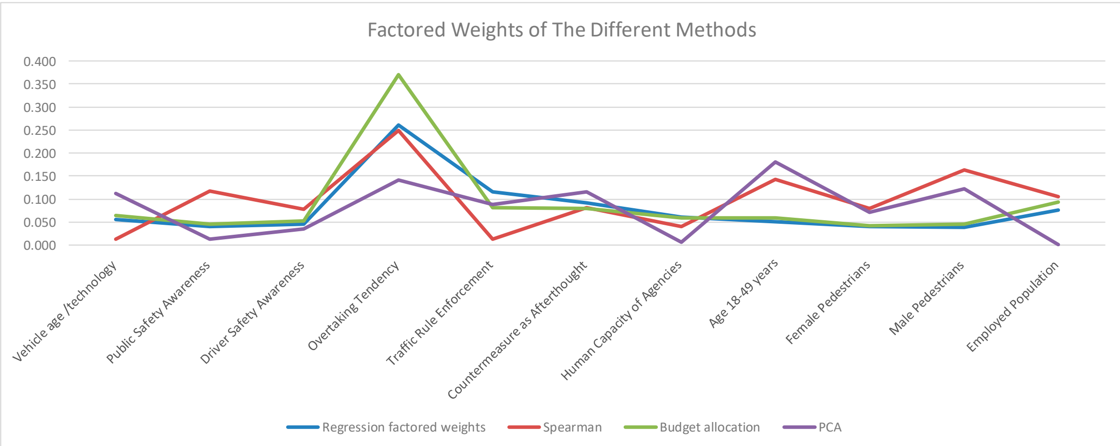

Figure 3. Graph showing factored weight using different methods (Regression, Spearman, BA, & PCA).

3.3. Final Weights per Factor

Table 3 summarises the final weights assigned to each factor under the selected Budget Allocation Method. These weights directly informed the adjusted effectiveness model (Eqn 1) and subsequent risk interpolations.

Table 3. Final weights of each factor, based on the BCA method.

Variable / factor	Coefficient (β)	Factor Number (F_i)	Risk factor (F_i) = e^β	Weight Number (W_i)	Normalised Weight ($W_i^{normalised}$)	Final Weights (W_i^{final})
Vehicle Age / Technology (%)	0.150	F_1	1.162	W_1	0.056	0.017
Public Safety Awareness (%)	0.113	F_2	1.120	W_2	0.041	0.012
Driver Safety Awareness (%)	0.127	F_3	1.135	W_3	0.047	0.014
Overtaking Tendency (1/0)	0.502	F_4	1.652	W_4	0.224	0.067
Traffic Rule Enforcement (1/0)	-0.980	F_5	0.375	W_5	0.215	0.064
Countermeasure as Afterthought (%)	-0.460	F_6	0.631	W_6	0.127	0.038

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Human Capacity of Agencies (1/0)	-0.248	F_7	0.780	W_7	0.075	0.023
Age 18–49 (%)	0.140	F_8	1.150	W_8	0.052	0.015
Female Pedestrians (%)	-0.150	F_9	0.861	W_9	0.048	0.014
Male Pedestrians (%)	0.110	F_{10}	1.116	W_{10}	0.040	0.012
Employed Population (%)	0.200	F_{11}	1.221	W_{11}	0.076	0.023
	Total Weight				**1.000**	**0.300**

3.4. Interpolated Relative Risk Values

The dynamic effect of contextual factors across varying performance levels was captured using the log-linear interpolation formula (Eqn 6). The interpolated risk values for each retained factor are shown in Table 4, enabling incorporation of both baseline and extreme scenarios.

For example, public awareness demonstrates an exponential decline in risk with increasing awareness, although the marginal effect diminishes at higher levels of saturation (Figure 4).

Table 4. Interpolated Relative risk values for each Factor.

Performance level (%)	**Vehicle age /technology**	**Public Safety Awareness**	**Driver Safety Awareness**	**Overtaking Tendency**	**Traffic Rule Enforcement**	**Countermeasure as Afterthought**	**Human Capacity of Agencies**	**Age 18-49 years**	**Female Pedestrians**	**Male Pedestrians**	**Employed Population**
0	1.000	1.120	1.135	1.000	1.625	1.000	1.220	1.000	1.139	1.000	1.000
5	1.008	1.114	1.128	1.025	1.586	1.016	1.208	1.007	1.132	1.006	1.010
10	1.015	1.107	1.121	1.051	1.548	1.032	1.196	1.014	1.124	1.011	1.020
15	1.023	1.101	1.114	1.078	1.511	1.048	1.184	1.021	1.117	1.017	1.030
20	1.030	1.095	1.107	1.106	1.475	1.065	1.172	1.028	1.110	1.022	1.041
25	1.038	1.089	1.100	1.134	1.439	1.082	1.161	1.036	1.103	1.028	1.051
30	1.046	1.083	1.093	1.163	1.405	1.099	1.149	1.043	1.095	1.033	1.062
35	1.054	1.076	1.086	1.192	1.371	1.116	1.138	1.050	1.088	1.039	1.072
40	1.062	1.070	1.079	1.222	1.338	1.134	1.127	1.057	1.081	1.045	1.083
45	1.070	1.064	1.072	1.253	1.306	1.152	1.116	1.065	1.074	1.051	1.094
50	1.078	1.058	1.065	1.285	1.275	1.170	1.105	1.072	1.067	1.056	1.105
55	1.086	1.052	1.059	1.318	1.244	1.189	1.094	1.080	1.060	1.062	1.116
60	1.094	1.046	1.052	1.351	1.214	1.207	1.083	1.087	1.053	1.068	1.127
65	1.103	1.040	1.045	1.386	1.185	1.226	1.072	1.095	1.047	1.074	1.139
70	1.111	1.035	1.039	1.421	1.157	1.246	1.061	1.103	1.040	1.080	1.150
75	1.119	1.029	1.032	1.457	1.129	1.266	1.051	1.111	1.033	1.086	1.162
80	1.128	1.023	1.026	1.494	1.102	1.286	1.041	1.118	1.026	1.092	1.173
85	1.136	1.017	1.019	1.532	1.076	1.306	1.030	1.126	1.020	1.098	1.185

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90	1.145	1.011	1.013	1.571	1.050	1.327	1.020	1.134	1.013	1.104	1.197
95	1.153	1.006	1.006	1.611	1.025	1.348	1.010	1.142	1.007	1.110	1.209
100	1.162	1.000	1.000	1.652	1.000	1.369	1.000	1.150	1.000	1.116	1.221

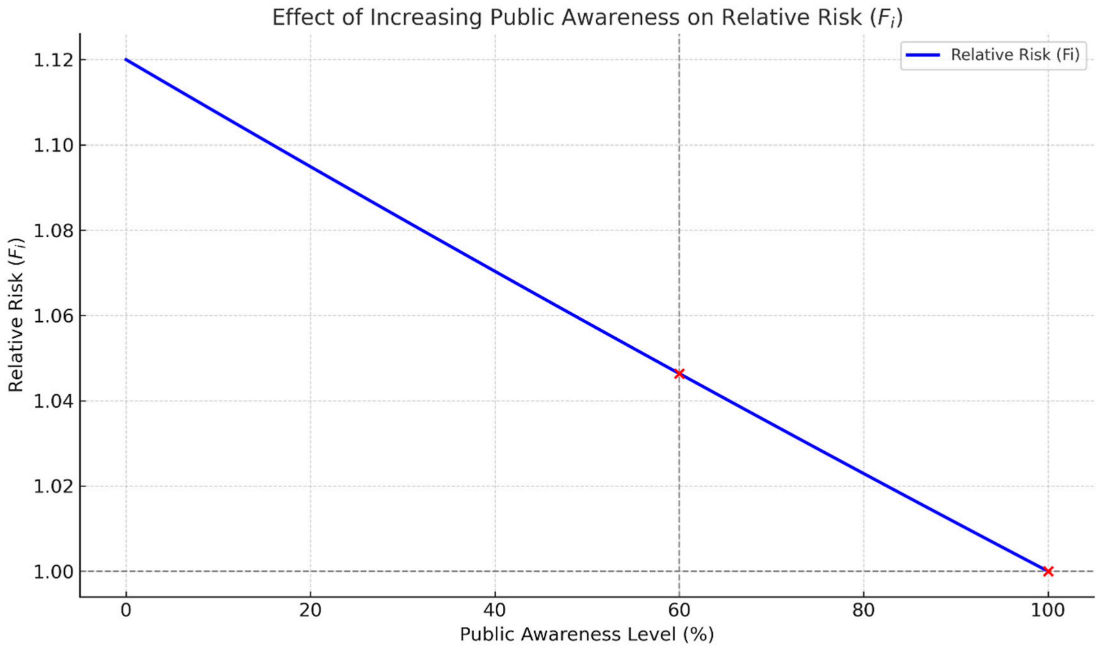
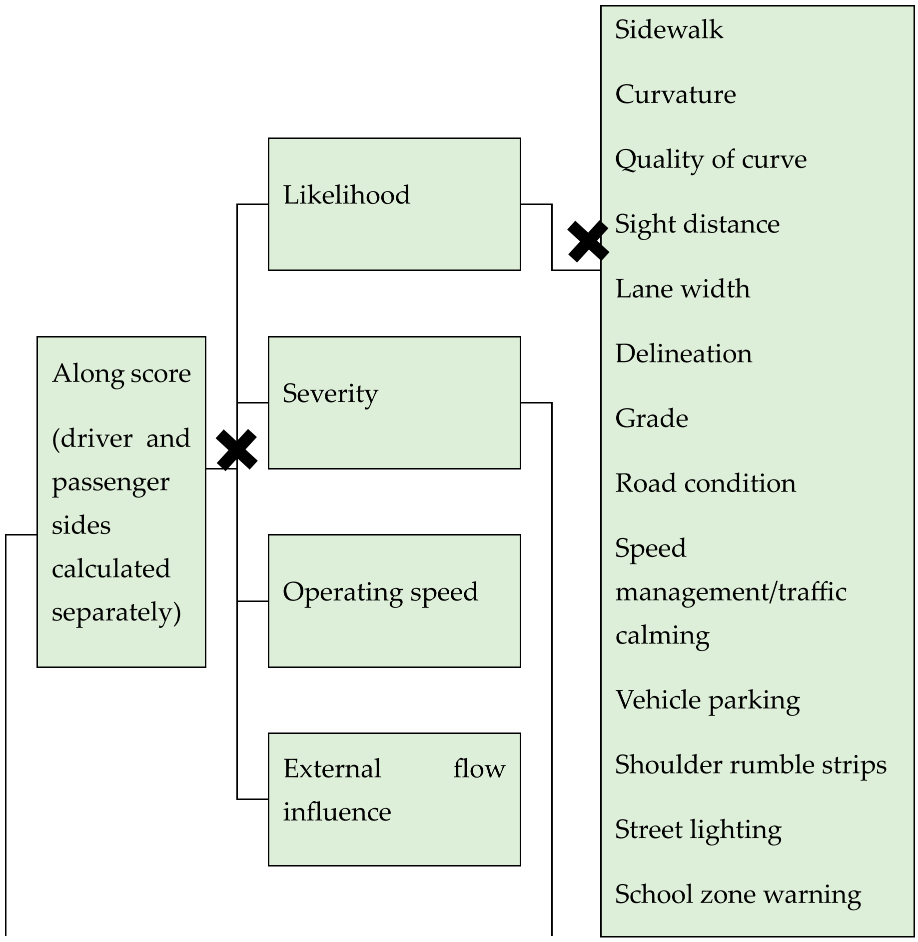


Figure 4. Exponential decline of relative risk as public awareness increases.



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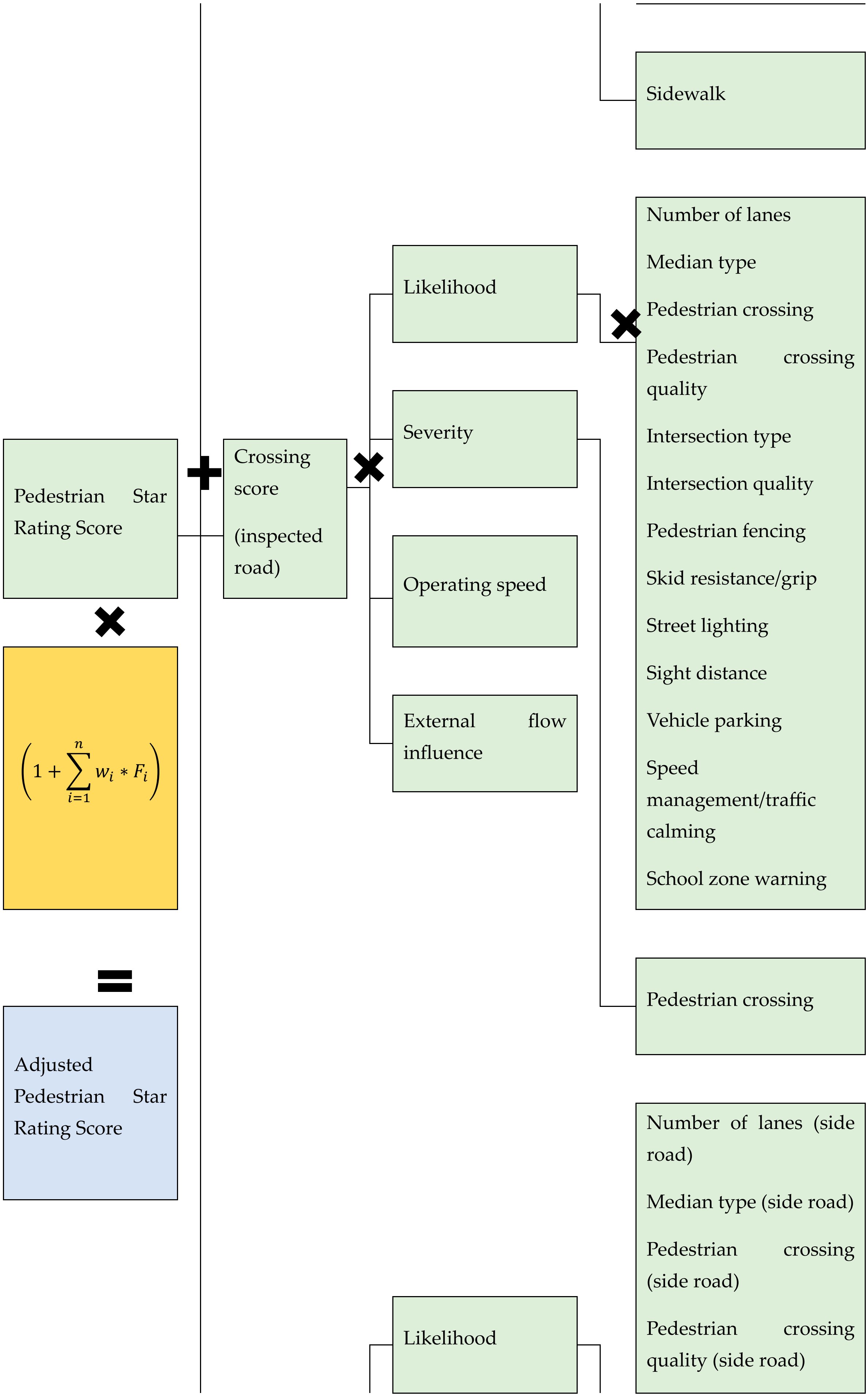

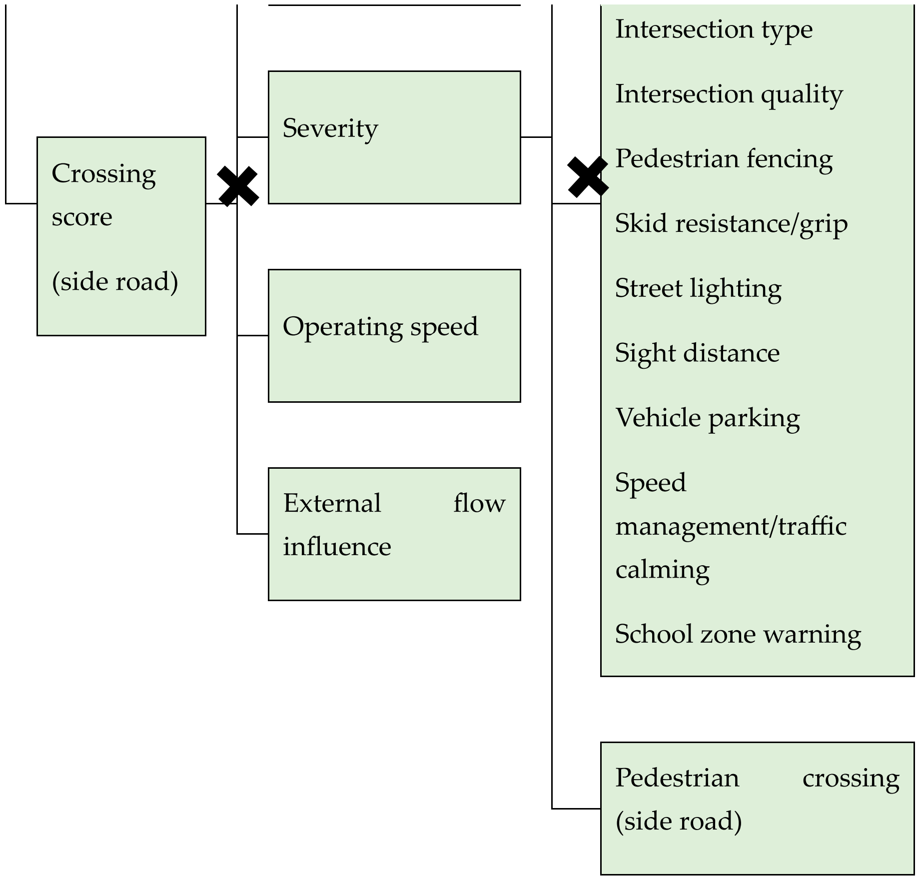

Figure 5. Graphical representation of Adjusted Star Rating Score.

3.5. Weighted Factor Scenarios

Table 5 shows the calculated weighted factors for best- and worst-case scenarios, illustrating how countermeasure effectiveness varies when contextual conditions are favourable versus adverse. These weighted risk values were computed using Eqn 6 and serve as direct inputs into the adjusted effectiveness calculations.

Table 5. Calculation of the weighted factors for best- and worst-case scenarios.

Factor/Variable	**Weights W_i**	**Relative risk value (F_i) - Best case**	**Relative risk value (F_i) - Worst case**	**W_i*F_i Best Case**	**W_i*F_i Worst Case**
Vehicle age /technology	0.017	1.000	1.162	0.017	0.019
Public Safety Awareness	0.012	1.000	1.120	0.012	0.014
Driver Safety Awareness	0.014	1.000	1.135	0.014	0.016
Overtaking Tendency	0.067	1.000	1.652	0.067	0.111
Traffic Rule Enforcement	0.064	1.000	1.625	0.064	0.105
Countermeasure as Afterthought	0.038	1.000	1.369	0.038	0.052
Human Capacity of Agencies	0.023	1.000	1.220	0.023	0.028
Age 18-49 Years	0.015	1.000	1.150	0.015	0.018
Female Pedestrians	0.014	1.000	1.139	0.014	0.016
Male Pedestrians	0.012	1.000	1.116	0.012	0.013
Employed Population	0.023	1.000	1.221	0.023	0.028
		Sum		**0.300**	**0.420**

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3.6. Star Rating Inputs

To ensure comparability with the iRAP methodology, two additional standard reference tables were applied. Table 7 provides relative risk values for different operating speeds, while Table 8 specifies the colour-coded classification bands for Pedestrian Star Rating Scores (PSRS), ranging from 1-star (least safe) to 5-star (safest).

Table 6. Weighted risk values for each factor at various performance levels.

Performance level (%)	Vehicle age /technology	Public Safety Awareness	Driver Safety Awareness	Overtaking Tendency	Traffic Rule Enforcement	Countermeasure as Afterthought	Human Capacity of Agencies	Age 18-49 years	Female Pedestrians	Male Pedestrians	Employed Population
0	0.017	0.014	0.016	0.067	0.105	0.038	0.028	0.015	0.016	0.012	0.023
5	0.017	0.014	0.016	0.069	0.102	0.039	0.027	0.016	0.016	0.012	0.023
10	0.017	0.014	0.016	0.071	0.100	0.039	0.027	0.016	0.016	0.012	0.023
15	0.017	0.014	0.016	0.072	0.097	0.040	0.027	0.016	0.016	0.012	0.024
20	0.017	0.014	0.015	0.074	0.095	0.040	0.027	0.016	0.016	0.012	0.024
25	0.017	0.013	0.015	0.076	0.093	0.041	0.026	0.016	0.016	0.012	0.024
30	0.017	0.013	0.015	0.078	0.091	0.042	0.026	0.016	0.016	0.012	0.024
35	0.018	0.013	0.015	0.080	0.088	0.042	0.026	0.016	0.016	0.012	0.024
40	0.018	0.013	0.015	0.082	0.086	0.043	0.026	0.016	0.016	0.013	0.025
45	0.018	0.013	0.015	0.084	0.084	0.044	0.025	0.017	0.015	0.013	0.025
50	0.018	0.013	0.015	0.086	0.082	0.044	0.025	0.017	0.015	0.013	0.025
55	0.018	0.013	0.015	0.089	0.080	0.045	0.025	0.017	0.015	0.013	0.025
60	0.018	0.013	0.015	0.091	0.078	0.046	0.025	0.017	0.015	0.013	0.026
65	0.018	0.013	0.015	0.093	0.076	0.047	0.024	0.017	0.015	0.013	0.026
70	0.019	0.013	0.015	0.096	0.075	0.047	0.024	0.017	0.015	0.013	0.026
75	0.019	0.013	0.014	0.098	0.073	0.048	0.024	0.017	0.015	0.013	0.027
80	0.019	0.013	0.014	0.100	0.071	0.049	0.024	0.017	0.015	0.013	0.027
85	0.019	0.013	0.014	0.103	0.069	0.050	0.023	0.017	0.015	0.013	0.027
90	0.019	0.012	0.014	0.106	0.068	0.050	0.023	0.018	0.015	0.013	0.027
95	0.019	0.012	0.014	0.108	0.066	0.051	0.023	0.018	0.014	0.013	0.028
100	0.019	0.012	0.014	0.111	0.064	0.052	0.023	0.018	0.014	0.013	0.028

Table 7. Relative risk values for different operating speeds by iRAP.

Operating Speed (Km/h)	30	35	40	45	50	55	60
Relative risk	0.011	0.027	0.050	0.080	0.119	0.168	0.228

Table 8. Star Rating Score Colour Codes by iRAP.

Star Rating	**Pedestrian Star Rating score**		
	Total	**Along**	**Crossing**
5	0 to < 5	0 to < 0.2	0 to < 4.8
4	5 to < 15	0.2 to < 1	4.8 to < 14
3	15 to < 40	1 to < 7.5	14 to < 32.5
2	40 to < 90	7.5 to < 15	32.5 to < 75
1	90 +	15 +	75 +

3.7. Application of the Variant Model in a Worked Example from iRAP Factsheet #9

A practical demonstration of the model was conducted using the iRAP Methodology Factsheet #9 Pedestrian Star Rating Score worked example [41] is presented in Appendix A.1.

- Step 1: Baseline PSRS values were computed using the unadjusted iRAP model (Appendix A.2.

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- Step 2: Adjusted effectiveness values were calculated by substituting the weighted factors (Fi × Wi) from Table 9 into the Adjusted Effectiveness Formula (Eqn 1).
- Step 3: These adjusted effectiveness values were applied to the same formulas embedded in the Factsheet framework, ensuring full methodological consistency.
- Step 4: Operating speed values were drawn from Table 7, while final PSRS classifications were assigned using Table 8.

The recalculated PSRS outcomes are presented in Appendix A.3, allowing direct comparison with the baseline results in Appendix A.2.

The recalculated PSRS, presented in Appendix A.3, revealed that all contextual factors incorporated into the variant effectiveness model had a measurable influence on star rating outcomes. In particular, five factors registered significant changes in star rating bands: overtaking tendency, traffic rule enforcement, countermeasure as an afterthought, human capacity of agencies, and employed population.

These changes were most pronounced at operating speeds between 40 km/h and 50 km/h, where some road segments that previously registered as Star 2 under the baseline iRAP model shifted to Star 1 after contextual adjustment. This recalibration implies that certain road environments, previously judged as meeting a minimum safety standard, are in fact very unsafe at speeds beyond 45 km/h once local realities are considered. The current iRAP model does not capture this heightened risk, underscoring its limitations when applied unadjusted in DC settings.

- By integrating the weighted contextual factors (Table 9) directly into the adjusted effectiveness equation (Eqn 1), the recalculated PSRS values provide a more conservative but realistic assessment of pedestrian safety. Importantly, the adjusted variant effectiveness model can be fully embedded within the iRAP PSRS framework, as the computed weighted values can be directly substituted into the PSRS formula (Eqn 7). This ensures methodological compatibility while improving sensitivity to localised risk exposures.

4. Discussion

4.1. Addressing the Overestimation in iRAP's Framework

The recalculated Pedestrian Star Rating Scores (PSRS) presented in this study provide clear evidence that iRAP's global framework systematically overestimates countermeasure effectiveness in developing country (DC) contexts. This overestimation stems from the framework's reliance on countermeasure effectiveness (CME) values and crash modification factors (CMFs) derived predominantly from high-income country datasets. By incorporating contextual factors, the adjusted model reveals a more conservative but realistic picture of countermeasure performance, underscoring the need for locally calibrated tools.

These findings are consistent with earlier analyses. A recently concluded systematic literature review identified 33 contextual factors influencing countermeasure performance in DCs, with a subsequent gap analysis showing an average discrepancy of 30.89% (SD = 29.89%) between predicted and observed effectiveness. This study's recalculation of star rating scores using weighted contextual factors confirms that this discrepancy materially alters countermeasure prioritisation.

4.2. Justification of the Weighting Approach

A key contribution of this study is its rigorous comparison of weighting techniques for factor prioritisation. Statistical methods (Spearman correlation, regression coefficients, PCA) provide robust mathematical bases but were limited in their ability to incorporate coefficients derived from literature (i.e., ORs and IRRS). By contrast, the Budget Allocation Method (BA) allowed both empirically modelled and literature-derived factors to be integrated into a unified framework.

The factored weight comparison (Table 2) revealed BA as the most suitable approach, with an aggregate normalised value of 0.991, closest to unity. This selection was not arbitrary; it was

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grounded in the need for methodological inclusivity in data-scarce environments. While BA introduces subjectivity, it also reflects the "performance loss" concept, whereby the influence of contextual factors is proportional to observed deviations from baseline effectiveness. This balance of statistical and practical considerations strengthens the model's applicability in real-world DC settings.

4.3. Limitations in Coefficient Estimation

A methodological limitation lies in the mixing of coefficients derived from different sources, i.e., Incident Rate Ratios (IRRs) from NB models of artificial datasets, and Odds Ratios (ORs) or Incident Rate Ratios (IRRS) from external literature. While such mixing is not ideal, the rare-event assumption [31] was invoked to justify comparability. This compromise reflects the reality of DC research environments, where high-quality, disaggregated crash data are often unavailable.

Furthermore, not all contextual factors could be retained. Of the 16 factors identified, five were excluded because their risk factor values (Fi) fell within the 0.9–1.1 threshold, indicating trivial associations [30]. These exclusions, such as pedestrian/vehicle volume ratio and footpath encroachment highlight the model's methodological discipline, ensuring that only substantively meaningful factors were included.

4.4. Capturing Non-Linear Risk Dynamics

Another advancement is the use of log-linear interpolation (Eqn 6) to model contextual factors across performance levels. This approach moves beyond static coefficient estimates by recognising that risk effects are non-linear. For example, increases in public awareness initially yield steep declines in risk but eventually taper, as illustrated in Figure 4. This feature introduces much-needed flexibility into pedestrian safety modelling and aligns with real-world dynamics observed in awareness, enforcement, and infrastructure conditions.

4.5. Practical Implications of the Worked Example

The worked example based on iRAP Factsheet #9 demonstrates the practical implications of the adjusted model. The inclusion of contextual risk factors not only recalibrated PSRS values but also shifted star rating bands for critical factors such as overtaking tendency and enforcement levels. At operating speeds between 40 km/h and 50 km/h, these contextual adjustments caused several segments to fall from Star 2 to Star 1, indicating that such environments are highly unsafe at speeds above 45 km/h.

For engineers, this is a critical insight. Road segments previously classified as marginally acceptable under the baseline model are reclassified as severely unsafe once DC-specific risks are accounted for. This has direct implications for speed management policies, prioritisation of enforcement, and the allocation of investment toward countermeasures with proven resilience in weak-institution contexts.

4.6. Contribution to the Field

The variant effectiveness model introduced here represents two novel contributions:

1. Adjusted Effectiveness Formula (Eqn 1), explicitly incorporating contextual weighting (Fi × Wi) and recalibrating CME values by the empirically observed 30% performance gap.
2. Adjusted PSRS Formula (Eqn 7), embedding contextualised effectiveness directly into iRAP's star rating framework, enabling seamless integration with existing global methodologies.

Together, these innovations extend iRAP from a globally standardised framework to a flexible, context-sensitive tool better suited to the needs of low- and middle-income countries.

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5. Conclusions

This study introduced and validated a Contextualised Countermeasure Effectiveness Model that recalibrates iRAP's baseline countermeasure effectiveness estimates by incorporating weighted contextual risk factors. Two novel contributions were advanced i.e., the Adjusted Effectiveness Formula (Eqn 1) and the Adjusted PSRS Formula (Eqn 7), both of which embed contextual weighting directly into iRAP's existing star rating framework.

The results confirm that contextual factors materially alter pedestrian star rating outcomes. Factors such as overtaking tendency, enforcement, and institutional capacity drove significant shifts in star rating bands, particularly at 40–50 km/h, where road segments moved from Star 2 to Star 1 once local risk modifiers were considered. This outcome reveals that the current iRAP model underestimates pedestrian risk in DC settings, potentially leading to misplaced confidence in the safety of certain countermeasures.

By allowing the direct substitution of weighted contextual values into the PSRS formula, the adjusted model enhances realism, local relevance, and predictive accuracy [42]. It offers policymakers and engineers in DCs a tool better suited to their realities, enabling more context-sensitive prioritisation of pedestrian safety investments.

Future work should focus on:

- calibrating the model with real crash data from DCs,
- testing sensitivity to non-linear interactions among contextual factors,
- and expanding participatory methods (e.g., expert elicitation) to strengthen the validity of weighting assignments.

In sum, this study demonstrates that global tools like iRAP can [and must] be adapted for local contexts. Incorporating socio-behavioural, institutional, and infrastructural risk modifiers into predictive frameworks represents a crucial step toward more equitable and effective pedestrian safety planning in developing countries.

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Abbreviations

The following abbreviations are used in this manuscript:

BA	Budget Allocation
CME	Countermeasure Effectiveness
CMF	Crash Modification Factor
DC	Developing Country
HIC	High-Income Country
iRAP	International Road Assessment Programme
LMIC	Low- and Middle-Income Countries
NB	Negative Binomial
PCA	Principal Component Analysis

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PSRS Pedestrian Star Rating Scores
SLR Systematic Literature Review
SRS Star Rating Scores

Appendix A

Appendix A.1. Extract of the iRAP Methodology Fact Sheet #9 Pedestrian Star Rating Score Worked Example

Supporting data

Attribute	Data / category
Vehicle flow (AADT)	15,000
Motocycle %	21% - 40%
Pedestrian peak hour flow across the road	26 to 50
Pedestrian peak hour flow along the road driver-side	101 to 200
Pedestrian peak hour flow along the road passenger-side	101 to 200
Bicycle peak hour flow	51 to 100
Speed - 85th percentile	50km/h

Pedestrian Star Rating Scores

Along (driver side)

Type of risk factor	Category	Risk factor	Score
Road attribute (likelihood)			
Sidewalk - driver-side	None	20.00	
Curvature	Straight or gently curving	1.00	
Quality of curve	Not applicable	1.00	
Sight distance	Adequate	1.00	
Lane width	Narrow (≥ 0m to < 2.75m)	1.10	
Delineation	Poor	1.20	
Grade	0% to < 7.5%	1.00	
Road condition	Good	1.00	
Speed management / traffic calming	Not present	1.25	
Vehicle parking	One side	1.20	
Shoulder rumble strips	Not present	1.25	
Skid resistance / grip	Sealed - medium	1.40	
Street lighting	Not present	1.25	
Product of road attribute (likelihood) risk factors			86.625
Road attribute (severity)			
Sidewalk - driver-side	None	90.00	
Product of road attribute (severity) risk factors			90.000
External flow influence	15000 vehicles per day		0.030
Operating speed	50km/h		0.228
Along (driver side) Star Rating Score			**53.326**

Along (passenger side)

Type of risk factor	Category	Risk factor	Score
Road attribute (likelihood)			
Sidewalk - passenger-side	Informal path 0m to <1.0m	6.00	
Curvature	Straight or gently curving	1.00	
Quality of curve	Not applicable	1.00	
Sight distance	Adequate	1.00	
Lane width	Narrow (≥0m to < 2.75m)	1.10	
Delineation	Poor	1.20	
Grade	0% to < 7.5%	1.00	
Road condition	Good	1.00	
Speed management / traffic calming	Not present	1.25	
Vehicle parking	One side	1.20	
Shoulder rumble strips	Not present	1.25	
Skid resistance / grip	Sealed - medium	1.40	
Street lighting	Not present	1.25	
Product of road attribute (likelihood) risk factors			25.9875
Road attribute (severity)			
Sidewalk - passenger-side	Informal path 0m to <1.0m	90.00	
Product of road attribute (severity) risk factors			90.000
External flow influence	15000 vehicles per day		0.030
Operating speed	50km/h		0.228
Along (passenger side) Star Rating Score			**15.998**

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Crossing (inspected road)

Type of risk factor	Category	Risk factor	Score
Road attribute (likelihood)			
Number of lanes	Two	2.80	
Median type	Physical median width ≥0m to < 1.0m	1.60	
Pedestrian crossing facilities - inspected road	No facility	6.70	
Pedestrian crossing quality	Not applicable	1.00	
Intersection type	3-leg unsignalised with no protected turn lane	1.10	
Intersection quality	Poor	1.20	
Pedestrian fencing	Not present	1.25	
Skid resistence / grip	Sealed - medium	1.40	
Street lighting	Not present	1.25	
Sight distance	Adequate	1.00	
Vehicle parking	One side	1.20	
Speed management / traffic calming	Not present	1.25	
Product of road attribute (likelihood) risk factors			130.007
Road attribute (severity)			
Pedestrian crossing facilities - inspected road	No facility	90.00	
Product of road attribute (severity) risk factors			90.000
External flow influence	External flow influence - through vehicle flow per lane		0.030
Operating speed	50km/h		0.228
Crossing (inspected road) Star Rating Score			**80.032**

Crossing (side road)

Type of risk factor	Category	Risk factor	Score
Road attribute (likelihood)			
Number of lanes	One	1.00	
Median type	Physical median width ≥0m to < 1.0m	3.00	
Pedestrian crossing facilities - side road	No facility	6.70	
Pedestrian crossing quality	Not applicable	1.00	
Intersection type	3-leg unsignalised with no protected turn lane	1.10	
Intersection quality	Poor	1.20	
Pedestrian fencing	Not present	1.25	
Skid resistence / grip	Sealed - medium	1.40	
Street lighting	Not present	1.25	
Sight distance	Adequate	1.00	
Vehicle parking	One side	1.20	
Speed management / traffic calming	Not present	1.25	
Product of road attribute (likelihood) risk factors			87.058
Road attribute (severity)			
Pedestrian crossing facilities - side road	No facility	90.00	
Product of road attribute (severity) risk factors			90.000
External flow influence	External flow influence - through vehicle flow per lane		0.020
Operating speed	50km/h		0.228
Crossing (side road) Star Rating Score			**35.729**

Pedestrian Star Rating Score and Star Rating

Crash type	Star Rating Score	Star Rating
Along (driver side)	53.326	1
Along (passenger side)	15.998	1
Along (average of driver and passenger sides)	34.662	1
Crossing (inspected road)	80.032	1
Crossing (side road)	35.729	2
Total Score / Star Rating	**150.423**	**1**

Appendix A.2. Pedestrian Star Rating Scores of the Current iRAP Model Based on Data of Fact Sheet #9

Current Star Rating Scores withought Contextual factors							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
10%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
15%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
20%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
25%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
30%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
35%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
40%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
45%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
50%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
55%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
60%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
65%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
70%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
75%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
80%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
85%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
90%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
95%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
100%	7.257	17.813	32.987	52.780	78.510	110.838	150.423

Appendix A.3. Effect of Contextual Factors on Pedestrian Star Rating Scores in the Current iRAP Model Based on Data of Fact Sheet #9

Vehicle Age / Technology							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.315	17.956	33.251	53.202	79.138	111.725	151.626
10%	7.366	18.080	33.482	53.572	79.688	112.501	152.679
15%	7.424	18.223	33.746	53.994	80.316	113.387	153.883
20%	7.475	18.348	33.977	54.363	80.866	114.163	154.936
25%	7.533	18.490	34.241	54.786	81.494	115.050	156.139
30%	7.591	18.633	34.505	55.208	82.122	115.937	157.342
35%	7.649	18.775	34.769	55.630	82.750	116.823	158.546
40%	7.707	18.918	35.033	56.052	83.378	117.710	159.749
45%	7.765	19.060	35.297	56.475	84.006	118.597	160.953
50%	7.823	19.203	35.561	56.897	84.634	119.483	162.156
55%	7.881	19.345	35.824	57.319	85.262	120.370	163.359
60%	7.939	19.488	36.088	57.741	85.890	121.257	164.563
65%	8.005	19.648	36.385	58.216	86.597	122.254	165.917
70%	8.063	19.791	36.649	58.639	87.225	123.141	167.120
75%	8.121	19.933	36.913	59.061	87.853	124.028	168.323
80%	8.186	20.093	37.210	59.536	88.560	125.025	169.677
85%	8.244	20.236	37.474	59.958	89.188	125.912	170.880
90%	8.310	20.396	37.771	60.433	89.894	126.909	172.234
95%	8.368	20.539	38.035	60.855	90.522	127.796	173.438
100%	8.433	20.699	38.331	61.330	91.229	128.794	174.791

Public Safety Awareness							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	8.128	19.951	36.946	59.114	87.931	124.139	168.474
5%	8.085	19.844	36.748	58.797	87.460	123.474	167.571
10%	8.034	19.719	36.517	58.427	86.911	122.698	166.518
15%	7.990	19.612	36.319	58.111	86.440	122.033	165.616
20%	7.947	19.506	36.121	57.794	85.969	121.368	164.713
25%	7.903	19.399	35.923	57.477	85.498	120.703	163.811
30%	7.860	19.292	35.725	57.161	85.027	120.038	162.908
35%	7.809	19.167	35.495	56.791	84.477	119.262	161.855
40%	7.765	19.060	35.297	56.475	84.006	118.597	160.953
45%	7.722	18.953	35.099	56.158	83.535	117.932	160.050
50%	7.678	18.846	34.901	55.841	83.064	117.267	159.148
55%	7.635	18.740	34.703	55.525	82.593	116.602	158.245
60%	7.591	18.633	34.505	55.208	82.122	115.937	157.342
65%	7.548	18.526	34.307	54.891	81.651	115.271	156.440
70%	7.511	18.437	34.142	54.627	81.258	114.717	155.688
75%	7.468	18.330	33.944	54.311	80.787	114.052	154.785
80%	7.424	18.223	33.746	53.994	80.316	113.387	153.883
85%	7.381	18.116	33.548	53.677	79.845	112.722	152.980
90%	7.337	18.009	33.350	53.361	79.374	112.057	152.078
95%	7.301	17.920	33.185	53.097	78.981	111.503	151.326
100%	7.257	17.813	32.987	52.780	78.510	110.838	150.423

Driver Safety Awareness							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	8.237	20.218	37.441	59.905	89.109	125.801	170.730
5%	8.186	20.093	37.210	59.536	88.560	125.025	169.677
10%	8.135	19.969	36.979	59.166	88.010	124.249	168.624
15%	8.085	19.844	36.748	58.797	87.460	123.474	167.571
20%	8.034	19.719	36.517	58.427	86.911	122.698	166.518
25%	7.983	19.595	36.286	58.058	86.361	121.922	165.465
30%	7.932	19.470	36.055	57.689	85.812	121.146	164.412
35%	7.881	19.345	35.824	57.319	85.262	120.370	163.359
40%	7.831	19.220	35.594	56.950	84.713	119.594	162.306
45%	7.780	19.096	35.363	56.580	84.163	118.818	161.253
50%	7.729	18.971	35.132	56.211	83.613	118.042	160.200
55%	7.685	18.864	34.934	55.894	83.142	117.377	159.298
60%	7.635	18.740	34.703	55.525	82.593	116.602	158.245
65%	7.584	18.615	34.472	55.155	82.043	115.826	157.192
70%	7.540	18.508	34.274	54.838	81.572	115.161	156.289
75%	7.489	18.383	34.043	54.469	81.023	114.385	155.237
80%	7.446	18.276	33.845	54.152	80.551	113.720	154.334
85%	7.395	18.152	33.614	53.783	80.002	112.944	153.281
90%	7.352	18.045	33.416	53.466	79.531	112.279	152.378
95%	7.301	17.920	33.185	53.097	78.981	111.503	151.326
100%	7.257	17.813	32.987	52.780	78.510	110.838	150.423

Overtaking Tendency							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.439	18.259	33.812	54.099	80.473	113.609	154.184
10%	7.627	18.722	34.670	55.472	82.514	116.491	158.095
15%	7.823	19.203	35.561	56.897	84.634	119.483	162.156
20%	8.027	19.701	36.484	58.375	86.832	122.587	166.368
25%	8.230	20.200	37.408	59.853	89.031	125.690	170.580
30%	8.440	20.717	38.364	61.383	91.307	128.905	174.942
35%	8.651	21.233	39.321	62.914	93.584	132.119	179.304
40%	8.868	21.768	40.311	64.497	95.940	135.444	183.817
45%	9.093	22.320	41.333	66.133	98.373	138.880	188.480
50%	9.326	22.890	42.389	67.822	100.886	142.427	193.294
55%	9.565	23.478	43.478	69.564	103.476	146.084	198.257
60%	9.805	24.066	44.566	71.306	106.067	149.742	203.221
65%	10.059	24.689	45.721	73.153	108.815	153.621	208.486
70%	10.313	25.313	46.875	75.000	111.563	157.501	213.751
75%	10.574	25.954	48.063	76.900	114.389	161.491	219.166
80%	10.842	26.613	49.283	78.853	117.294	165.592	224.732
85%	11.118	27.290	50.537	80.859	120.278	169.804	230.448
90%	11.401	27.985	51.823	82.917	123.340	174.126	236.314
95%	11.691	28.697	53.143	85.029	126.480	178.560	242.331
100%	11.989	29.427	54.495	87.193	129.699	183.104	248.499

Traffic Rule Enforcement							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	11.793	28.947	53.605	85.767	127.579	180.112	244.437
5%	11.510	28.252	52.318	83.709	124.517	175.789	238.571
10%	11.234	27.575	51.065	81.703	121.534	171.577	232.855
15%	10.966	26.916	49.844	79.751	118.629	167.476	227.289
20%	10.704	26.275	48.657	77.850	115.803	163.486	221.874
25%	10.443	25.633	47.469	75.950	112.976	159.496	216.459
30%	10.196	25.028	46.347	74.156	110.307	155.727	211.344
35%	9.950	24.422	45.226	72.361	107.638	151.959	206.230
40%	9.710	23.834	44.137	70.620	105.047	148.301	201.266
45%	9.478	23.264	43.082	68.931	102.534	144.754	196.452
50%	9.253	22.712	42.059	67.294	100.101	141.318	191.789
55%	9.028	22.160	41.036	65.658	97.667	137.882	187.126
60%	8.810	21.625	40.047	64.075	95.311	134.557	182.613
65%	8.600	21.109	39.090	62.544	93.035	131.343	178.251
70%	8.397	20.610	38.167	61.066	90.836	128.240	174.039
75%	8.193	20.111	37.243	59.589	88.638	125.136	169.828
80%	7.997	19.630	36.352	58.164	86.518	122.143	165.766
85%	7.809	19.167	35.495	56.791	84.477	119.262	161.855
90%	7.620	18.704	34.637	55.419	82.436	116.380	157.944
95%	7.439	18.259	33.812	54.099	80.473	113.609	154.184
100%	7.257	17.813	32.987	52.780	78.510	110.838	150.423

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Countermeasure as Afterthought							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.373	18.098	33.515	53.624	79.766	112.611	152.830
10%	7.489	18.383	34.043	54.469	81.023	114.385	155.237
15%	7.606	18.668	34.571	55.313	82.279	116.158	157.643
20%	7.729	18.971	35.132	56.211	83.613	118.042	160.200
25%	7.852	19.274	35.692	57.108	84.948	119.927	162.758
30%	7.976	19.577	36.253	58.005	86.283	121.811	165.315
35%	8.099	19.880	36.814	58.902	87.617	123.695	167.872
40%	8.230	20.200	37.408	59.853	89.031	125.690	170.580
45%	8.360	20.521	38.002	60.803	90.444	127.685	173.287
50%	8.491	20.841	38.595	61.753	91.857	129.680	175.995
55%	8.629	21.180	39.222	62.755	93.349	131.786	178.853
60%	8.759	21.501	39.816	63.705	94.762	133.781	181.561
65%	8.897	21.839	40.443	64.708	96.254	135.887	184.419
70%	9.043	22.195	41.102	65.764	97.824	138.104	187.427
75%	9.188	22.552	41.762	66.819	99.394	140.321	190.435
80%	9.333	22.908	42.422	67.875	100.964	142.538	193.444
85%	9.478	23.264	43.082	68.931	102.534	144.754	196.452
90%	9.630	23.638	43.774	70.039	104.183	147.082	199.611
95%	9.783	24.012	44.467	71.147	105.832	149.410	202.770
100%	9.935	24.386	45.160	72.256	107.481	151.737	205.929

Human Capacity of Agencies							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	8.854	21.732	40.245	64.392	95.782	135.222	183.516
5%	8.767	21.518	39.849	63.758	94.840	133.892	181.711
10%	8.680	21.305	39.453	63.125	93.898	132.562	179.906
15%	8.593	21.091	39.057	62.492	92.956	131.232	178.101
20%	8.505	20.877	38.661	61.858	92.014	129.902	176.296
25%	8.426	20.681	38.298	61.278	91.150	128.683	174.641
30%	8.339	20.467	37.903	60.644	90.208	127.353	172.836
35%	8.259	20.271	37.540	60.064	89.345	126.134	171.181
40%	8.179	20.076	37.177	59.483	88.481	124.914	169.527
45%	8.099	19.880	36.814	58.902	87.617	123.695	167.872
50%	8.019	19.684	36.451	58.322	86.754	122.476	166.217
55%	7.939	19.488	36.088	57.741	85.890	121.257	164.563
60%	7.860	19.292	35.725	57.161	85.027	120.038	162.908
65%	7.780	19.096	35.363	56.580	84.163	118.818	161.253
70%	7.700	18.900	35.000	56.000	83.299	117.599	159.599
75%	7.627	18.722	34.670	55.472	82.514	116.491	158.095
80%	7.555	18.544	34.340	54.944	81.729	115.382	156.590
85%	7.475	18.348	33.977	54.363	80.866	114.163	154.936
90%	7.402	18.170	33.647	53.836	80.080	113.055	153.431
95%	7.330	17.991	33.317	53.308	79.295	111.946	151.927
100%	7.257	17.813	32.987	52.780	78.510	110.838	150.423

Age 18-49 years							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.308	17.938	33.218	53.149	79.060	111.614	151.476
10%	7.359	18.063	33.449	53.519	79.609	112.390	152.529
15%	7.410	18.187	33.680	53.888	80.159	113.166	153.582
20%	7.460	18.312	33.911	54.258	80.709	113.941	154.635
25%	7.519	18.455	34.175	54.680	81.337	114.828	155.838
30%	7.569	18.579	34.406	55.050	81.886	115.604	156.891
35%	7.620	18.704	34.637	55.419	82.436	116.380	157.944
40%	7.671	18.829	34.868	55.788	82.985	117.156	158.997
45%	7.729	18.971	35.132	56.211	83.613	118.042	160.200
50%	7.780	19.096	35.363	56.580	84.163	118.818	161.253
55%	7.838	19.238	35.626	57.002	84.791	119.705	162.457
60%	7.889	19.363	35.857	57.372	85.341	120.481	163.510
65%	7.947	19.506	36.121	57.794	85.969	121.368	164.713
70%	8.005	19.648	36.385	58.216	86.597	122.254	165.917
75%	8.063	19.791	36.649	58.639	87.225	123.141	167.120
80%	8.114	19.915	36.880	59.008	87.774	123.917	168.173
85%	8.172	20.058	37.144	59.430	88.403	124.804	169.376
90%	8.230	20.200	37.408	59.853	89.031	125.690	170.580
95%	8.288	20.343	37.672	60.275	89.659	126.577	171.783
100%	8.346	20.485	37.936	60.697	90.287	127.464	172.986

Female Pedestrians							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	8.266	20.289	37.573	60.116	89.423	126.244	171.332
5%	8.215	20.165	37.342	59.747	88.874	125.469	170.279
10%	8.157	20.022	37.078	59.325	88.246	124.582	169.075
15%	8.106	19.897	36.847	58.955	87.696	123.806	168.022
20%	8.056	19.773	36.616	58.586	87.146	123.030	166.969
25%	8.005	19.648	36.385	58.216	86.597	122.254	165.917
30%	7.947	19.506	36.121	57.794	85.969	121.368	164.713
35%	7.896	19.381	35.890	57.425	85.419	120.592	163.660
40%	7.845	19.256	35.659	57.055	84.870	119.816	162.607
45%	7.794	19.131	35.429	56.686	84.320	119.040	161.554
50%	7.743	19.007	35.198	56.316	83.770	118.264	160.501
55%	7.693	18.882	34.967	55.947	83.221	117.488	159.448
60%	7.642	18.757	34.736	55.577	82.671	116.712	158.395
65%	7.598	18.650	34.538	55.261	82.200	116.047	157.493
70%	7.548	18.526	34.307	54.891	81.651	115.271	156.440
75%	7.497	18.401	34.076	54.522	81.101	114.496	155.387
80%	7.446	18.276	33.845	54.152	80.551	113.720	154.334
85%	7.402	18.170	33.647	53.836	80.080	113.055	153.431
90%	7.352	18.045	33.416	53.466	79.531	112.279	152.378
95%	7.308	17.938	33.218	53.149	79.060	111.614	151.476
100%	7.257	17.813	32.987	52.780	78.510	110.838	150.423

Male Pedestrians							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.301	17.920	33.185	53.097	78.981	111.503	151.326
10%	7.337	18.009	33.350	53.361	79.374	112.057	152.078
15%	7.381	18.116	33.548	53.677	79.845	112.722	152.980
20%	7.417	18.205	33.713	53.941	80.237	113.276	153.732
25%	7.460	18.312	33.911	54.258	80.709	113.941	154.635
30%	7.497	18.401	34.076	54.522	81.101	114.496	155.387
35%	7.540	18.508	34.274	54.838	81.572	115.161	156.289
40%	7.584	18.615	34.472	55.155	82.043	115.826	157.192
45%	7.627	18.722	34.670	55.472	82.514	116.491	158.095
50%	7.664	18.811	34.835	55.736	82.907	117.045	158.847
55%	7.707	18.918	35.033	56.052	83.378	117.710	159.749
60%	7.751	19.025	35.231	56.369	83.849	118.375	160.652
65%	7.794	19.131	35.429	56.686	84.320	119.040	161.554
70%	7.838	19.238	35.626	57.002	84.791	119.705	162.457
75%	7.881	19.345	35.824	57.319	85.262	120.370	163.359
80%	7.925	19.452	36.022	57.636	85.733	121.035	164.262
85%	7.968	19.559	36.220	57.952	86.204	121.700	165.164
90%	8.012	19.666	36.418	58.269	86.675	122.365	166.067
95%	8.056	19.773	36.616	58.586	87.146	123.030	166.969
100%	8.099	19.880	36.814	58.902	87.617	123.695	167.872

Employed Population							
Operating speed	30 km/h	35 km/h	40 km/h	45 km/h	50 km/h	55 km/h	60 km/h
Risk factor	0.011	0.027	0.05	0.08	0.119	0.168	0.228
0%	7.257	17.813	32.987	52.780	78.510	110.838	150.423
5%	7.330	17.991	33.317	53.308	79.295	111.946	151.927
10%	7.402	18.170	33.647	53.836	80.080	113.055	153.431
15%	7.475	18.348	33.977	54.363	80.866	114.163	154.936
20%	7.555	18.544	34.340	54.944	81.729	115.382	156.590
25%	7.627	18.722	34.670	55.472	82.514	116.491	158.095
30%	7.707	18.918	35.033	56.052	83.378	117.710	159.749
35%	7.780	19.096	35.363	56.580	84.163	118.818	161.253
40%	7.860	19.292	35.725	57.161	85.027	120.038	162.908
45%	7.939	19.488	36.088	57.741	85.890	121.257	164.563
50%	8.019	19.684	36.451	58.322	86.754	122.476	166.217
55%	8.099	19.880	36.814	58.902	87.617	123.695	167.872
60%	8.179	20.076	37.177	59.483	88.481	124.914	169.527
65%	8.266	20.289	37.573	60.116	89.423	126.244	171.332
70%	8.346	20.485	37.936	60.697	90.287	127.464	172.986
75%	8.433	20.699	38.331	61.330	91.229	128.794	174.791
80%	8.513	20.895	38.694	61.911	92.093	130.013	176.446
85%	8.600	21.109	39.090	62.544	93.035	131.343	178.251
90%	8.687	21.322	39.486	63.178	93.977	132.673	180.056
95%	8.774	21.536	39.882	63.811	94.919	134.003	181.861
100%	8.861	21.750	40.278	64.444	95.861	135.333	183.666

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