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EVALUATING THE COST-BENEFIT OF SAFETY RISK MANAGEMENT MEASURES IN URBAN PUBLIC TRANSPORT SYSTEMS

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ABSTRACT
This study evaluates the cost-benefit performance of safety risk management measures in urban public transport systems. Drawing on a mixed research design, the paper combines expert-based risk scoring with passenger survey data from 367 respondents. The analysis focuses on eight risk groups: safety policy and governance, technical operating procedures, training procedures, employee competency assessment, staff operational errors, passenger unsafe behaviour, external traffic participant behaviour, and infrastructure-management environment. Risk priority numbers, expected annual losses, control costs, residual risk, net benefits and benefit-cost ratios are calculated to identify economically efficient safety interventions. The findings show that external traffic behaviour, technical procedures and passenger unsafe behaviour generate the highest safety-economic burden. Targeted procedural, behavioural and stop-zone interventions produce stronger economic returns than broad infrastructure-heavy measures.
KEYWORDS: *Public Transport Safety; Cost-Benefit Analysis; Safety Risk Management; Human Error; Urban Transport.*

1. INTRODUCTION

Urban public transport is a key element of sustainable mobility because it reduces private vehicle dependence, improves access to jobs and education, supports decarbonisation, and enhances the spatial efficiency of urban transport networks. However, its public value depends strongly on operational safety. Inadequate safety management can generate substantial hidden costs, including accidents, injuries, service disruption, compensation, asset damage, loss of passenger confidence and reputational decline. Road traffic injury remains a major global public health and economic challenge, with approximately 1.19 million deaths reported annually [1]. Although public transport is generally safer than individual motorised travel, buses, BRT, electric buses and urban rail systems operate in environments shaped by staff errors, passenger behaviour, external road users, infrastructure constraints and organisational weaknesses. Therefore, safety management must go beyond technical compliance. SMS frameworks emphasise hazard identification, risk assessment, safety assurance and continuous improvement [4], [5], while ISO 31000 links risk management to decision-making and monitoring [6]. This paper evaluates 40 risk items using 18 expert assessments and 367 passenger responses, applying cost-benefit analysis to identify risk controls with the strongest safety and economic returns [7], [8].

2. LITERATURE REVIEW

Safety in public transport has commonly been examined through engineering, operational and regulatory perspectives. In rail, metro and mass transit systems, the RAMS framework—reliability, availability, maintainability and safety—provides a structured basis for linking technical dependability with operational safety performance [7], [9]. Safety is therefore not only the absence of accidents, but also the ability of a transport system to maintain controlled operation, prevent unacceptable risk and recover from disruptions. When vehicles, infrastructure, control systems or operating procedures are unreliable, staff workload increases and the probability of procedural violations may also rise.

From a broader risk management perspective, ISO 31000 defines risk as the effect of uncertainty on objectives and promotes a systematic process of risk identification, analysis, evaluation, treatment, monitoring and communication [6]. This logic is highly applicable to public transport agencies, where safety risks involve operators, passengers, external road users, infrastructure managers and regulators. Safety policy, technical operating procedures, training systems and competency assessment should therefore be treated as central elements of safety governance, rather than administrative requirements. Similarly, the Federal Transit Administration requires public transport agencies to implement Safety Management System processes, including safety risk management and safety assurance [4], [5].

Human error theory provides an important foundation for public transport safety analysis. Reason argues that front-line unsafe acts frequently originate from latent organisational weaknesses, such as inadequate supervision, poor resource allocation, weak training, unclear procedures and unsuitable workplace design [11], [12]. In public transport, unsafe stop alignment, delayed incident response or door-operation mistakes may appear to be individual errors, but they may also reflect fatigue, insufficient recurrent training or poor interface design. Rasmussen further shows that safety boundaries may gradually erode when organisations operate under economic and workload pressures [13],[14]. Therefore, cost reduction and operational efficiency may increase safety risk if governance mechanisms are weak.

Safety culture literature stresses management commitment, reporting confidence, near-miss learning and employee participation. TCRP Report 174 emphasises that public transport agencies should assess safety attitudes and embed safety into daily operations [15]. This supports the use of leading indicators, such as training completion, procedural compliance, near-miss reporting and driver behaviour monitoring, rather than relying on accident counts.

Public transport safety is also shaped by external traffic conditions. ITF/OECD research highlights the vulnerability of pedestrians, cyclists and powered two-wheelers in dense urban environments [2]. In mixed-traffic contexts, buses and BRT vehicles interact with motorcycles, private cars and pedestrians at stops, intersections and curbside areas. Stop-zone design, enforcement, lane protection, signal priority and pedestrian management therefore become part of safety risk management.

Cost-benefit analysis provides a practical method for translating risk reduction into economic evidence. European Commission guidance defines appraisal as a comparison between incremental costs and benefits over time [8]. In safety evaluation, benefits include avoided fatalities, injuries, property damage, delays, emergency response costs and service disruption. Elvik similarly argues that safety interventions should be assessed by both technical effectiveness and economic efficiency [10]. The Safe System approach reinforces this view by recognising that humans make mistakes and that transport systems should prevent such mistakes from producing severe harm [3].

Passenger perception is another important dimension. UITP notes that safe and secure public transport strengthens trust and supports ridership [16]. Although safety studies increasingly use vehicle location data, speed indicators, incident records, camera systems and passenger surveys [17,[18], many developing urban systems still lack integrated risk databases. Three research gaps remain: technical safety, human error and economic appraisal are often examined separately; organisational risks are rarely linked to expected loss and benefit-cost ratios; and passenger perception is usually treated as service quality rather than safety-economic evidence. This study addresses these gaps by combining expert risk scoring, passenger survey data and cost-benefit modelling across 40 operational safety risks.

3. METHODOLOGY

This study adopts a mixed-method quantitative design to evaluate safety risk management measures in urban public transport systems, utilizing a dataset of 40 risk items, 18 expert evaluations, and 367 passenger responses. The methodology consists of five integrated stages:

Stage 1: Expert-Based Risk ScoringExperts evaluated 40 risk items across four dimensions (probability **P**, severity **S**, exposure **E**, and detectability difficulty **D**) using a five-point scale. The Risk Priority Number (**RPN**) for each item i and the average RPN for a group g is calculated as in the following:

$$RPN_i = P_i \times S_i \times E_i \times D_i$$

$$Average\ RPN_g = \frac{\sum RPN_i}{n_g}$$

Stage 2 & 3: Economic Loss and Safety Benefit Estimation

The baseline expected annual loss $EL_{before,i}$ for each risk combines annual probability Pr_i, severity weight SW_i , exposure units EU_i and average cost per event CL_i. After applying safety measures with a specific control effectiveness CE_i, the residual loss $EL_{after,i}$ and the resulting economic benefit B_i and the total benefit (**TB**) are determined by:

$$EL_{after,i} = EL_{before,i} \times (1 - CE_i)$$

$$B_i = EL_{before,i} - EL_{after,i}$$

$$TB = \sum B_i$$

Stage 4: Cost-Benefit Analysis (CBA)

To evaluate economic efficiency, the net benefit (NB_i) and benefit-cost ratio (BCR_i) for each intervention are calculated against its control cost (CC_i):

$$NB_i = B_i - CC_i$$

$$BCR_i = \frac{B_i}{CC_i}$$

Stage 5: Passenger Survey & Integration

Data from 367 passenger responses (5-point Likert scale) were analyzed to capture perceived risks and public trust, calculating mean scores and composite construct scores. This passenger perspective complements the technical expert assessment. Mean scores are calculated for perceived external traffic risk, passenger behaviour risk, staff-related risk, infrastructure risk, overall safety perception, trust and willingness to support safety investment. The purpose is to compare expert-prioritised risks with passenger-

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experienced risks. This is consistent with SMS and risk-management principles, which require both technical assessment and stakeholder communication [4], [6].

4. RESULTS

Female respondents account for 194 cases, male respondents for 165 cases and other/prefer-not-to-say responses for 8 cases. The sample is relatively young: 131 respondents are aged 18–24, 104 are aged 25–34, 65 are aged 35–44, 41 are aged 45–54 and 26 are aged 55 or above. Regarding public transport usage, 97 respondents use public transport daily, 120 use it three to five times per week, 78 use it one to two times per week and 72 use it occasionally. Main mode use is concentrated in bus services, with 174 respondents, followed by urban rail/metro with 68, electric bus with 61, BRT with 33 and multimodal trips with 31.

Table 1 summarises the risk profile by group. External traffic participant behaviour records the highest average RPN at 217.8, with one critical and three high-risk items. This indicates that unsafe behaviour by motorcycles, private vehicles and pedestrians around public transport vehicles and stops is a dominant safety-economic concern. Technical operating procedures rank second, with an average RPN of 212.0 and three critical risks. Training procedure ranks third at 198.4, followed by staff operational errors at 187.2. These results show that organisational and procedural risks are nearly as important as visible front-line errors.

Table 1. Risk profile by group

Risk group	No. of risks	Average RPN	Max. RPN	Critical risks	High risks
External traffic participant behaviour	5	217.8	375	1	3
Technical operating procedures	5	212.0	300	3	1
Training procedure	5	198.4	300	2	1
Staff operational errors	5	187.2	240	1	3
Safety policy and governance	5	168.0	192	0	3
Employee competency assessment	5	165.6	240	1	1
Passenger unsafe behaviour	5	137.6	240	1	1
Infrastructure and management	5	85.0	108	0	0

The highest individual risk is motorcycle encroachment into bus stop areas, with an RPN of 375. This finding is consistent with urban mixed-traffic conditions, where the stop zone is not a protected safety envelope but a conflict space shared by buses, motorcycles, private cars and pedestrians. The next two highest risks are poor interface procedures at stops/stations and overly theoretical initial safety training, each with an RPN of 300. These two results are important because they show that safety risks arise at the interface between operating rules and real passenger movement. If door procedures, stop alignment, passenger guidance and degraded-mode instructions are unclear, both staff and passengers face higher exposure.

Table 2. Highest-priority individual risks

Risk ID	Risk group	Risk item	RPN	Level
TG31	External traffic participant behaviour	Motorcycles encroach bus stop area	375	Critical
TP10	Technical operating procedures	Poor interface procedure at stops/stations	300	Critical
TR11	Training procedure	Initial safety training is too theoretical	300	Critical
TP06	Technical operating procedures	Unclear door operation procedure	240	Critical
TP09	Technical operating procedures	Weak incident escalation procedure	240	Critical
PB26	Passenger unsafe behaviour	Boarding/alighting before full stop	240	Critical
EC18	Employee competency assessment	No simulator-based assessment	240	Critical
SE23	Staff operational errors	Unsafe stop alignment	240	Critical

The cost-loss model provides a more explicitly economic interpretation. Across all 40 risks, expected loss before control is USD 6.086 million. Total estimated control cost is USD 3.536 million. Expected loss after control falls to USD 2.945 million, implying risk reduction value of USD 3.142 million. The total net benefit is negative at approximately USD -0.395 million, and the aggregate BCR is 0.89. At first sight, this suggests that not all safety measures are economically justified if implemented as a single undifferentiated portfolio. However, disaggregated results reveal a more useful managerial conclusion: some groups deliver strong economic returns, while others require either redesign, phasing or justification on regulatory and ethical grounds rather than immediate financial payback.

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Table 3. Cost-loss and benefit-cost results by risk group

Risk group	Expected loss before (USD)	Control cost (USD)	Risk reduction value (USD)	Expected loss after (USD)	Net benefit (USD)	Group BCR
External traffic participant behaviour	1,570,177	803,375	991,362	578,814	187,987	1.23
Technical operating procedures	692,447	132,375	347,049	345,398	214,674	2.62
Training procedure	532,920	323,788	316,066	216,854	-7,722	0.98
Staff operational errors	917,265	475,975	387,742	529,522	-88,233	0.81
Safety policy and governance	336,384	232,663	129,534	206,850	-103,129	0.56
Employee competency assessment	300,062	452,579	149,783	150,279	-302,796	0.33
Passenger unsafe behaviour	1,638,266	298,979	759,411	878,855	460,432	2.54
Infrastructure and management environment	98,956	816,493	60,564	38,392	-755,929	0.07

The most economically efficient group is technical operating procedures, with a BCR of 2.62. This indicates that relatively modest investments in clear door procedures, safe stop procedures, interface management at stops, incident escalation and degraded-mode rules can generate large avoided losses. The second strongest group is passenger unsafe behaviour, with a BCR of 2.54 and net benefit of USD 460,432. This suggests that behavioural interventions—boarding discipline, anti-crowding management, handrail-use campaigns, door-area control and passenger guidance—can be economically powerful because they target frequent, visible and relatively controllable incidents.

External traffic participant behaviour has the largest expected loss before control among high-risk external categories and a positive BCR of 1.23. Its total risk reduction value is USD 991,362, exceeding control cost by USD 187,987. This supports investment in stop-zone protection, enforcement, junction redesign and separation of public transport vehicles from risky mixed-traffic interactions. The result is economically significant because external road-user behaviour is often treated as outside the operator's responsibility. The data suggest that public transport safety economics should not stop at the vehicle door; it must include the curbside, pedestrian approach space, intersection and bus lane environment.

Training procedure has a BCR of 0.98, slightly below the conventional threshold of 1.0. This does not mean that training is unimportant. Rather, it suggests that training design should be made more targeted and performance-based. The high RPN for theoretical initial safety training indicates that training expenditure may be inefficient if it is not linked to realistic scenarios, passenger interaction, emergency response and recurrent competency verification. Similarly, employee competency assessment shows a low group BCR of 0.33, mainly due to high control costs. Simulator-based assessment, fitness checks and formal certification can be expensive. Yet these measures may still be justified for high-severity risks, especially in urban rail or high-capacity BRT systems where a single failure can affect many passengers.

Infrastructure and management environment shows the weakest economic result, with a BCR of 0.07. This reflects high investment cost relative to the modelled expected loss reduction. The interpretation should be cautious. Infrastructure investments often generate wider benefits not fully captured in the dataset, including accessibility, passenger comfort, universal design, climate resilience and network efficiency. However, from a narrow safety-cost perspective, infrastructure-heavy interventions should be prioritised at locations with demonstrably high incident frequency or high exposure.

Passenger perception results provide a complementary view. The highest perceived risk is external vehicle conflict, with a mean score of 3.64 out of 5, followed by pedestrian conflict at 3.63. Passenger crowding risk scores 3.49, handrail non-use 3.46 and door behaviour risk 3.41. These findings are consistent with the expert-based RPN results: passengers experience the greatest concern at the interface between the public transport vehicle, crowded passenger movement and the surrounding traffic environment. Overall safety perception is moderate at 3.22, while trust in public transport is lower at 2.98. Willingness to support safety investment is relatively high at 3.74, suggesting that passengers may accept safety-related expenditure when risks are visible and understandable.

Table 4. Selected passenger perception indicators

Indicator	Mean score
External vehicle risk	3.64
Pedestrian conflict risk	3.63
Crowding risk	3.49
Handrail non-use risk	3.46
Door behaviour risk	3.41
Overall safety perception	3.22
Trust in public transport	2.98
Willingness to support safety investment	3.74

The combined expert-passenger evidence yields three main results. First, the dominant risks are not purely technical failures but interaction risks at the boundary between policy, procedure, staff action, passenger behaviour and external road users. Second, measures with the highest economic returns are those that target frequent interface risks: technical procedures, passenger behaviour and traffic-participant conflicts. Third, safety policy, training and competency systems should not be dismissed when their immediate BCR is low, because they create latent capacity for risk detection, learning and long-term safety culture.

5. DISCUSSION

The findings support a layered interpretation of public transport safety economics. At the first layer, agencies should prioritise high-frequency and high-exposure risks that produce strong economic returns. In this study, passenger unsafe behaviour and technical operating procedures deliver BCRs above 2.5. These are attractive interventions because they require moderate expenditure and directly reduce recurrent operational losses. The result is consistent with CBA principles, which recommend allocating resources to interventions with high incremental benefits relative to costs [8]. It also aligns with road safety research showing that targeted operational measures can be more cost-effective than broad capital-intensive programmes when they address specific high-risk mechanisms [10].

At the second layer, external traffic participant behaviour must be recognised as a core public transport safety issue. Urban public transport operates in a shared space. Motorcycle encroachment, illegal manoeuvres, bus lane obstruction and pedestrian conflicts are not merely general traffic problems; they directly affect passenger boarding, vehicle stopping, driver workload and accident exposure. ITF research on urban road safety emphasises the vulnerability of pedestrians and powered two-wheelers in cities [2]. The present findings extend this argument by showing that external traffic behaviour also imposes a measurable expected-loss burden on public transport operations.

At the third layer, organisational controls such as safety policy, training and competency assessment should be evaluated differently from immediate operational countermeasures. Their direct BCR may be lower because they involve fixed costs and diffuse benefits. However, safety literature warns that organisational accidents often emerge from latent weaknesses accumulated over time [11], [12]. A weak safety KPI system, poor reporting culture or absent competency assessment may not produce immediate incidents every day, but such conditions reduce the system's ability to detect and correct emerging hazards. Therefore, agencies should not use BCR mechanically to reject governance and training investments. Instead, they should combine economic appraisal with minimum safety standards, regulatory duties and risk tolerance thresholds.

The passenger findings also have policy implications. Trust in public transport is below overall safety perception, while willingness to support safety investment is high. This suggests that passengers may recognise safety risks but remain open to improvement if agencies provide visible, credible and targeted interventions. UITP's position that safety and security support trust and ridership is relevant here [16]. In practical terms, passengers are more likely to value interventions they can observe: safer stops, clearer door procedures, less crowding, better staff guidance and protection from external vehicles.

Finally, the study confirms the value of combining expert and passenger evidence. Experts identify latent risks such as technical procedures, degraded-mode rules and competency systems. Passengers identify experienced risks such as crowding, unsafe boarding and traffic conflicts. A robust SMS should integrate both sources rather than relying only on accident statistics, which are often incomplete, lagging and insensitive to near-misses [4], [5].

6. CONCLUSION

This study assessed the cost-benefit performance of safety risk management measures in urban public transport systems using a structured dataset comprising 40 risk items, 18 expert evaluations and 367 passenger survey responses. The results indicate that operational safety risks are mainly concentrated in external traffic participant behaviour, technical operating procedures, training procedures and staff operational errors. The most critical risks include motorcycle encroachment into bus stop areas, weak interface procedures at stops and stations, overly theoretical initial safety training, unclear door operation rules, inadequate incident escalation and unsafe stop alignment.

The economic analysis shows that safety measures do not generate equal returns. Technical operating procedures achieve the highest group-level benefit-cost ratio (BCR = 2.62), followed by passenger unsafe behaviour control (BCR = 2.54) and external traffic participant management (BCR = 1.23). These findings suggest that public transport agencies should prioritise low-to-moderate cost interventions targeting frequent operational interface risks, including clearer stop and door procedures, degraded-mode rules, passenger guidance, boarding control, stop-zone protection and enforcement against vehicle encroachment.

Nevertheless, governance, training and competency assessment remain essential despite lower short-term BCRs. They strengthen hazard reporting, safety learning, competence assurance and organisational resilience. The study contributes an integrated framework combining risk scoring, expected loss estimation, control effectiveness and passenger perception for safety investment decisions.

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