Applied Research Advances Volume 00, Issue 00 (2026) 1-11

CORE
CENTER FOR OPEN RESEARCH AND EDUCATION

Applied Research Advances

Journal homepage: www.ara-journal.org
ISSN: 3104-2643

Targeted Intersection Safety in Data-Sparse Cities: A Discrete-Time Microsimulation and Decision-Making Framework Applied to a Hazardous Urban Junction in Libya

Ibrahim Badi[1,*], Mouhamed Bayane Bouraima[2], Sam Aberi Okemwa[3]

[1] Libyan Academy, Misrata, Libya
[2] School of Civil Engineering, Southwest Jiao Tong University, Chengdu, Sichuan Province, China
[3] Zalika Greentech, Nairobi County, Kenya

ARTICLE INFO

Article history:
Received 11 March 2026
Received in revised form 19 May 2026
Accepted 4 June 2026
Available online 7 June 2026

Keywords:
Urban Traffic Operations; Intersection Safety Application; Transportation Research; Discrete-Time Microsimulation; Technique for Order Preference by Similarity to the Ideal Solution; Surrogate Safety Measures

ABSTRACT

Urban safety policy choices in low-data contexts frequently face both high uncertainty and pressing timelines. This paper suggests a lightweight and reproducible framework that combines a discrete-time microsimulation of a single, high-risk four-leg intersection with multi-criteria decision-making. In the model, vehicles and pedestrians are generated via Poisson arrival processes, while behavioral variability such as speeding, red-light running, jaywalking, and driver yielding is modeled using probabilistic parameters calibrated to local Libyan traffic conditions. Four low-cost interventions (i.e., speed bumps, a red-light camera, an improved pedestrian crosswalk, and a one-lane roundabout) are evaluated against the baseline. Each strategy is evaluated using four main simulation-based criteria (i.e., reduction in accidents, effect on vehicle delay, cost of implementation, and a pedestrian safety measure) that combine near-miss and waiting-time changes. These outputs are fed into a Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) analysis under safety-first, cost-sensitive, and pedestrian-focused stakeholder perspectives. Outcomes exhibit clear, mechanism-consistent trends. By reporting uncertainty explicitly and providing scenario-dependent rankings, the framework translates limited local data into clear, defensible decision guidance. The contribution is both practical and methodological; i.e., a sparse-data pipeline that urban areas can readily implement to prioritize first-step safety spending at high-risk intersections.

1. Introduction

Urban intersections concentrate exposure, conflict, and uncertainty within a limited physical area, making them a constant source of road traffic injury. The operational complexity of four-legged intersections, characterized by competing traffic cycles, mixed vehicle behaviors, and vulnerable road users operating on different schedules, establishes situations where little behavioral variation can

---

[*] *Corresponding author.*
E-mail address: i.badi@lam.edu.ly

https://doi.org/10.65069/ara21202617

generate severe consequences [1,2]. Meanwhile, urban authorities frequently operate under limited budgets and spotty data, especially in developing or post-conflict contexts, making large-scale investments difficult to justify and rigorous before–and–after assessment nearly impossible. Such realities call for a decision-making framework that balances analytical rigor with manageable data and computational demands [3]. Prioritizing the intersection-level study can handle this by taking the intractable, city-level problem into a tractable, policy-sensitive experiment [4].

Traditionally, methodological research on traffic safety has depended on statistical estimations of historical crashes, as well as safety performance functions and crash modification factors to evaluate treatments. While these methods have been greatly influential, they require extended observation horizons and well-collected exposure data that are not always available. In response, microsimulation and agent-based models have emerged as complementary approaches, enabling analysts to build controlled counterfactuals and account for dynamics leading up to crashes. Since actual accidents are rare events, researchers increasingly use simulation in conjunction with surrogate safety indicators, such as time-to-collision (TTC), post-encroachment time (PET), and conflict counts, that offer more statistically stable measures within manageable simulation horizons. This micro-scale, mechanism-based approach is especially attractive for professionals requiring quick, comparable evidence to assist a large range of low-cost safety interventions [5,6].

Regarding interventions, the literature documents several treatments that can be applied to a signalized four-way intersection. Speed management devices, such as speed cushions or bumps, are consistently shown to lower approach speeds and reduce crash severity, though their effects on delay vary by context. Automated enforcement, especially the use of red-light cameras, improves driver compliance at stop bars and reduces angle collisions. However, it may redistribute risk to other locations or modestly increase start-up delays [7]. Pedestrian-focused upgrades, generally reduce pedestrian delays and conflicts when accompanied by adequate driver yielding. Additionally, converting a stop-controlled or signalized junction into a single-lane roundabout tends to reduce high-energy angle collisions by enforcing lower circulating speeds and simplified conflict geometry. However, such conversions entail higher capital cost and geometric feasibility constraints [8]. Across these options, the evidence highlights heterogeneity in terms of volumes, behavior, and site design, emphasizing that it requires case-specific evaluation.

Evaluation designs echo this diversity. Before–and–after studies and observational quasi-experiments are most appropriate when long panels are possible and confounders are controllable. In case where such data are lacking, analysts resort to calibrated simulations to test "What-If" questions under controlled assumptions. In simulation contexts, performance is multi-dimensional, necessitating agencies to trade off safety outcomes against mobility (vehicle delay), pedestrian experience (waiting time and near-misses), and affordability (implementation cost) [9]. No single indicator can completely capture these competing goals, and progress in one dimension can negatively affect another [10]. Therefore, the application of multi-criteria decision-making (MCDM) that can accommodate heterogeneous indicators and definite stakeholder preferences without consolidating them into a single, ad hoc index is important.

MCDM methods such as Simple Additive Weighting (SAW), the Analytic Hierarchy Process (AHP), and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) have been applied to transport planning, safety program selection, and infrastructure prioritization [11,12]. These methods are beneficial for their clarity [13]. They normalize, weight, and aggregate criteria in a way that is easy to communicate and interpret to both non-technical and technical stakeholders [14]. Moreover, they permit flexibility by accommodating various weighting sets to reflect different stakeholder priorities, while sensitivity analyses help assess the robustness of rankings [14]. When coupled with simulation models that delivers consistent and comparable outputs across strategies, MCDM can bridge the gap between engineering evidence and policy decisions by making trade-offs clear and explicitly measurable.

Building on this context, this study proposes a compact, data-lean framework tailored to settings with limited historical crash data but urgent safety challenges. The framework models a single hazardous four-leg intersection using a discrete-time microsimulation of vehiclar and pedestrian movements, including simple behavioral factors such as speeding, red-light running, jaywalking, and yielding. The framework evaluates a baseline scenario with four low-cost treatment: speed bumps, a red-light camera, an improved pedestrian crosswalk, and conversion to a single-lane roundabout; each tested across various simulation runs. The simulation yields four decision criteria; i.e., crash reduction relative to the baseline (C_1), vehicle delay improvement (C_2), implementation cost (C_3), and a pedestrian safety score that combines near-miss and waiting-time reductions (C_4). These criteria are evaluated using a TOPSIS method under three stakeholder perspectives: safety-first, cost-conscious, and pedestrian-priority, to generate transparent, scenario-dependent rankings.

The aim of the paper is twofold:

i. to present a rigorous yet practical methodology that urban authorities can applied quickly;
ii. to produce an actionable recommendation for the case setting that prioritizes the most balanced intervention in terms of safety, efficiency, pedestrian experience, and cost under locally relevant preferences.

1.1 Research Questions

- *RQ1* – How effective are low-cost intersection interventions such as speed bumps, red-light cameras, improved crosswalks, and a single-lane roundabout in enhancing safety? Specifically, what is their potential to reduce crashes and near-misses within a lean, calibrated microsimulation context?
- *RQ2* – What trade-offs appear among safety, mobility (vehicle delay), pedestrian experience (waiting time), and cost, and how do various weighting scenarios (safety-first, cost-conscious, pedestrian-first) affect the resulting intervention rankings in the TOPSIS method?
- *RQ3* – How sensitive are the outcomes and intervention rankings to the most critical behavioral parameters, such as speeding share, red-light running, yielding, jaywalking, that reflect the characteristics of the local traffic context?

1.2 Research Novelty

i. *Targeted, data-efficient framework* – A discrete-time microsimulation centered on a single intersection utilizing a calibrated conflict-to-crash conversion and per-driver and per-phase red-run logic integrated with TOPSIS to support decision-making in data-scarce contexts.
ii. *Pedestrian-focused assessment with uncertainty* – A composite pedestrian safety index integrating reduction in near-misses and waiting times, scaled from 1 to 5, with results reported as ±95% confidence intervals across various simulation runs.
iii. *Scenario-driven decisions* – Report rankings are produced from various stakeholder perspectives rather than a single aggregate score, implicating clear behavioral levers that allow rapid retuning to other similar sites.

2. Methodology

Below is a description of the methodology used to evaluate low-cost safety interventions at a single, hazardous four-leg intersection. The approach couples lightweight microsimulation with MCDM so that safety, mobility, pedestrian experience, and cost can be weighed transparently under different stakeholder preferences.

First, a discrete-time microsimulation of one signalized four-way intersection with one lane per approach is presented. The simulation indicates vehicles and pedestrians as agents, generated separately on each approach and crosswalk using the Poisson processes (exponential inter-arrival times). Behavioral heterogeneity is modelled through simple Bernoulli states: drivers may be compliant or speeding, compliant or running a red light, while pedestrians may be compliant or jaywalking; drivers may yield or fail to yield to pedestrians. Traffic control can be either a fixed-time signal (two green phases with yellow clearance) or a simplified single-lane roundabout (yield-at-entry). The simulation advances in small time steps (e.g., 1–5 s), servicing a limited number of movements each second according to right-of-way rules and queue availability. Red-light violations are modeled as a per-driver Bernoulli event, evaluated when a vehicle reaches the stop line during a red phase; only one violation per opposing approach is permitted in each red phase, while compliant drivers stop and join the queue.

Second, safety dynamics are represented with two complementary mechanisms:

i. *Conflicts leading to crashes* – A crash is realized when two antagonistic streams attempt to occupy the same conflict zone within the same time step, especially due to a red-light run. The probability of a crash per conflict is small ($\approx 10^{-5}$–10^{-4} p) and calibrated to realistic levels. This probability increases with the mean approach speed of the two vehicles (proxy for kinetic energy), serving as a proxy for kinetic energy, and is later elevated if the conflict is "forced" (i.e., red-run), applying a 5–10× multiplier. A modest speed effect, capped at 2× reflects higher kinetic energy at greater approach speeds.

ii. *Surrogate safety (near-misses)* – For each potential conflict, a coarse TTC proxy is computed from relative speed. Conflicts with TTC below a threshold (e.g., 1.5 s) are counted as near-misses, offering a statistically stable proxy for safety in rare-event scenarios.

Third, we evaluate a baseline alongside four interventions by adjusting parameters to reflect each treatment's causal levers: speed bumps (lower speeding probability and approach speeds), red-light camera (lower red-run probability), improved crosswalk (lower jaywalking and higher driver yielding), and roundabout (change control logic with lower approach speeds). For each strategy s, the simulation returns four metrics; i.e., annualized crashes (A_s), mean vehicle delay (D_s), mean pedestrian wait (PW_s), and near-miss rate (NM_s). The evaluation is structured using a four-criterion MCDM decision matrix (C1–C4), distinguishing benefit and cost criteria as follows: C_1 crash reduction %=$100(1 - A_s/A_{base})$ (benefit), C_2 delay improvement %=$100(1 - D_s/D_{base})$ (benefit), C_3 implementation cost in USD (cost), and C_4 pedestrian safety score (benefit), a normalized composite of near-miss and pedestrian-wait reductions (e.g., $0.7\%\Delta NM + 0.3\%\Delta PW$) scaled to 1–5 across strategies. We then apply TOPSIS under three stakeholder weight sets (i.e., safety-first, cost-conscious, pedestrian-priority) to obtain scenario-dependent rankings, with optional sensitivity around weights and intervention effects.

Finally, to ensure reproducibility and practicality in data-sparse settings, the model uses fixed random seed sets across strategies, simple conflict rules aligned with the control logic, and criteria that are easy to explain to non-technical decision-makers. Figure 1 outlines the methodology workflow, from initialization and time-step simulation to aggregation of outputs and scenario-specific TOPSIS ranking.

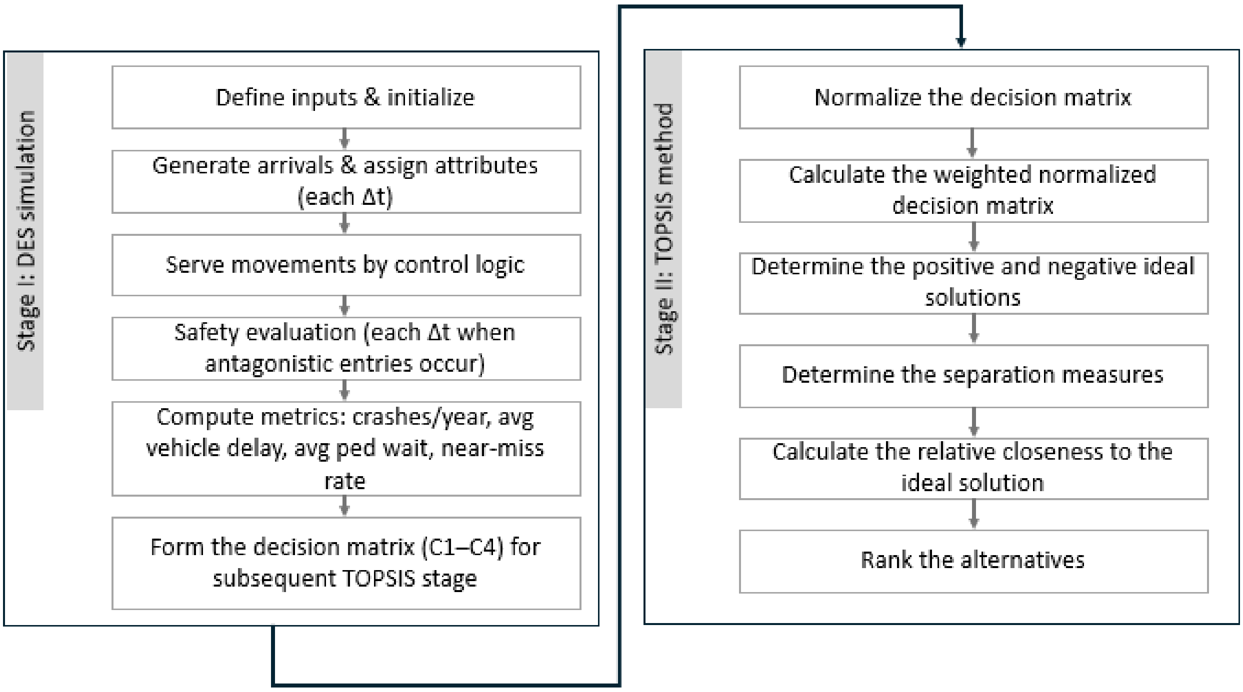

Fig. 1. Methodology workflow

3. Case Study

Libya’s urban mobility landscape has become increasingly car-dependent as population growth and urbanization outpaced investment in public transport and data-driven management. Between 1995 and 2013, the population increased from approximately 4.39 to 6.10 million, while the number of registered vehicles surged by around 122% (from 1.20 to 3.55 million). This shift has been driven by weak transit provision and low fuel prices, compounded by fragmented governance and limited, unsystematic data [16]. The resulting dependency on private cars has caused severe congestion and elevated environmental loads, with the transportation sector accounting for an estimated 18.7 million tons of annual emissions (approximately 30.7% of national pollutants) in 2017, further exacerbated by the import of older, poorly maintained vehicles [17].

The country’s road safety situation mirrors these structural issues [18]. Libya records one of the world’s highest traffic fatality rates (≈26–26.3 deaths per 100,000 inhabitants, roughly 2,500 deaths annually), with risk amplified by deteriorated infrastructure, absent or malfunctioning signals, sparse signage, and limited enforcement at intersections [19]. Field observations also highlight context-specific hazards; blowing sand and animals on the carriageway; alongside the near-absence of urban public transport and pedestrian facilities in usable condition [20]. Deferred maintenance, fading markings and reflectors, sand encroachment on shoulders, and uncontrolled access further compound crash risk and delay.

Recent studies in Libya have considerably employed MCDM methods for both diagnosing risk and ranking solutions. Using IMF-SWARA and CoCoSo, studies concluded that driver-related factors dominate crash causation and ranked driver training/education as the top mitigation measure, followed by intelligent transportation systems (ITS), consistent with other work giving priority to surveillance cameras among potential ITS in Libya [16]. These findings reinforce policy recommendations to strengthen enforcement, improve signs and markings, and restore an elementary public-transit alternative, providing pragmatic measures while larger-scale investments remain delayed [19]. The case study selects a single hazardous four-leg city intersection in Libya to make a decision-ready, locally specific comparison of low-cost countermeasures.

The study has two main goals:

i. to quantify, using microsimulation, how a given subset of feasible remedies (i.e., speed bumps, red-light camera, enhanced pedestrian crosswalk, and conversion to single-lane roundabout) affects safety and operations from the current status;
ii. to translate these effects into stakeholder-specific recommendations by employing TOPSIS across three different stakeholder perspectives (i.e., safety-first, cost-sensitive, and pedestrian-priority).

The modeling approach is designed for contexts with data scarcity and implementation constraints. It uses simple, interpretable behavior rules, includes proxy safety measures alongside simulated crashes, and keep cost inputs categorically to render the analysis remain practical for municipal decision-makers.

The major inputs are based on observed or anticipated local conditions. The case study intersection is a typical, one-lane-per-direction, four-leg intersection served by a fixed-time signal (base and three treatment cases) or a one-lane roundabout (conversion case). Traffic demand is represented with Poisson arrivals differentiated by movement: a relatively busier axis (mean inter-arrival about 20 s) and a lighter cross street (about 45 s), plus pedestrian arrivals (about 120 s) split across crosswalks. Driver and pedestrian behavior is parameterized with simple probability factors: 30 percent of driver speed, with speeding speeds drawn around 80 km/h (σ≈8), compliant speeds centered near 45 km/h (σ≈5), red-light running around 10 percent when opposing traffic has right-of-way, jaywalking around 30 percent, and mid-range driver yielding to pedestrians. Each intervention shifts only the levers it plausibly affects: speed bumps lower approach speeds and the share of speeders; a red-light camera reduces the red-run probability; an improved crosswalk reduces jaywalking and increases yielding; a roundabout replaces signal logic with yield-at-entry and lower approach speeds. Implementation costs are treated as order-of-magnitude categories (Base ≈ 0; Bumps ≈ 10k; Crosswalk ≈ 15k; Camera ≈ 100k; Roundabout ≈ 250k). The simulation outputs annualized crashes, average vehicle delay, average pedestrian waiting time, and a near-miss rate. These are transformed into four decision criteria—crash reduction, delay improvement, cost, and a pedestrian safety score—which are used in the TOPSIS analysis under the three stakeholder weight sets. To improve comparability across strategies, multiple replications with a shared seed set are carried out.

Figure 2 presents the annualized crash frequency estimated by the discrete-time microsimulation for each strategy, with 95% confidence intervals across replications to reflect stochastic uncertainty. Interventions that curb antagonistic movements or reduce approach speeds show materially lower crash means than the baseline, and the confidence bars help distinguish signal from noise (e.g., whether differences are practically or statistically meaningful). This plot is the main safety result of the analysis.

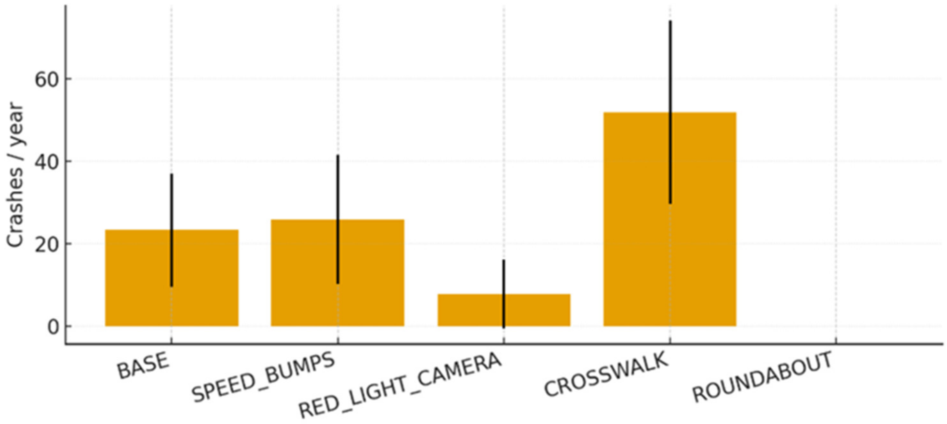

Fig. 2. Crashes per year (mean ±95% confidence intervals)

Figure 3 reports the mean time pedestrians wait before initiating a crossing, including 95% confidence intervals across simulation replications. Interventions that increase yielding or create more predictable crossing opportunities show the largest reductions versus the baseline. These results, indicated with 95% confidence intervals, reported improvement in level of service for vulnerable road users, while the intervals indicate the stability of the estimated effects.

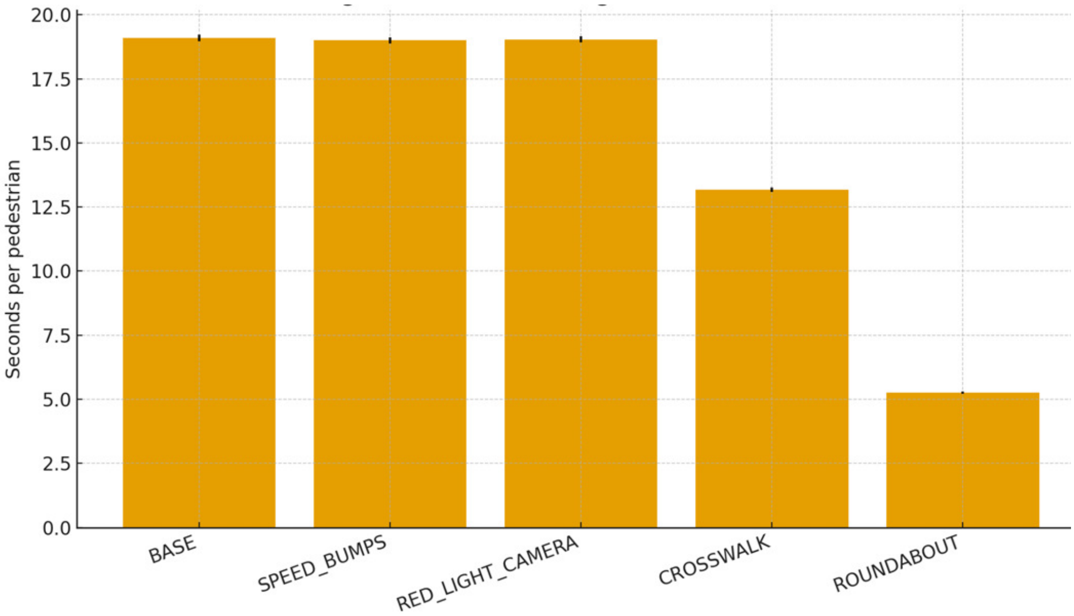

Fig. 3. Average pedestrian waiting time (mean ±95% confidence intervals)

Figure 4 synthesizes the main policy dilemma: the x-axis represents one-time implementation cost (categorical order-of-magnitude estimates), while the y-axis shows the percent reduction in crashes relative to baseline. Interventions appeared higher and further to the left represent more attractive interventions (greater safety benefit for lower cost). Each point is labelled by strategy, allowing quick comparison and providing an intuitive bridge to the subsequent formal multi-criteria analysis.

Three stakeholder weight sets are applied in the TOPSIS approach: safety-first [0.5, 0.1, 0.2, 0.2], cost-conscious [0.3, 0.2, 0.4, 0.1], and pedestrian-priority [0.3, 0.1, 0.2, 0.4]. The criteria C_1 (crash reduction), C_2 (delay improvement), and C_4 (pedestrian safety) are benefit criteria, while C_3 (cost) is a cost criterion. The decision matrix is normalized using the vector approach, and distances to both ideal best/worst are computed accordingly.

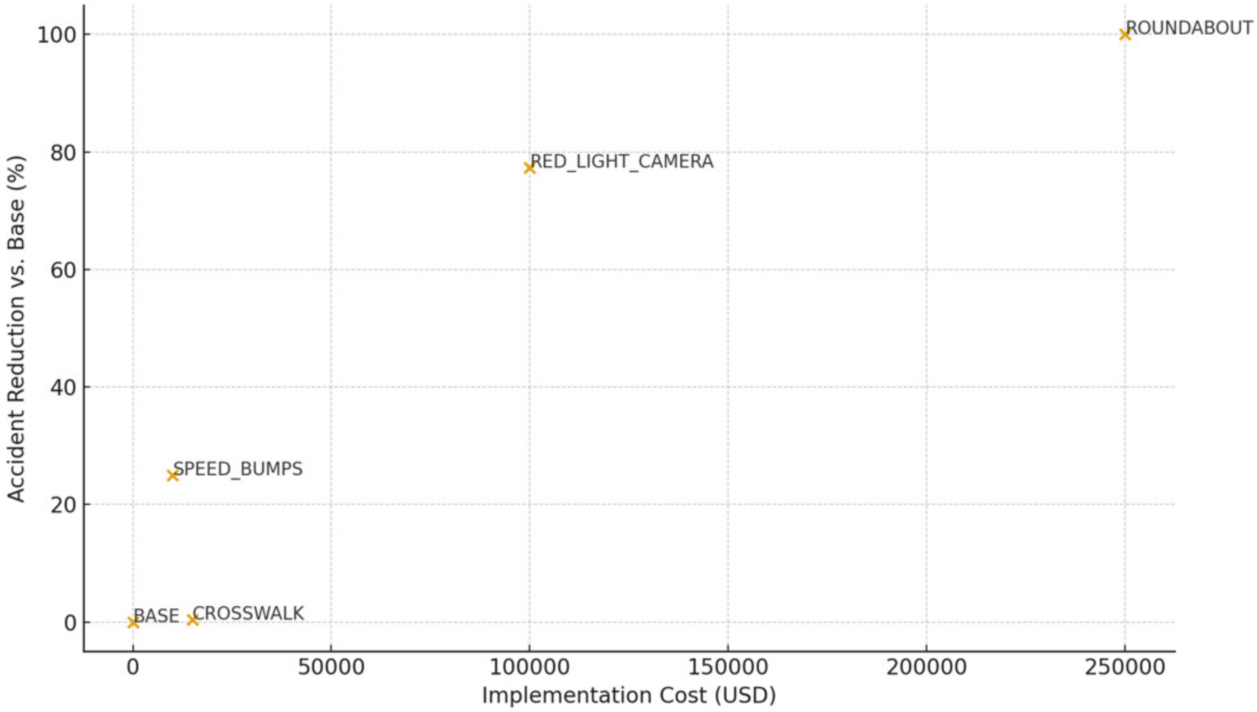

Fig. 4. Accident reduction vs. cost

Table 1 summarizes the results of the TOPSIS analysis, indicating the rankings of strategies under each scenario (i.e., safety-first, cost-conscious, and pedestrian-priority), along with their respective closeness score to the ideal solution. The first-ranked strategy within each scenario represents the scenario-specific recommendation, while lower-ranked options illustrate trade-offs across criteria (e.g., pedestrian benefits versus cost). Since the TOPSIS approach is applied to crash reduction, delay improvement, cost, and a pedestrian safety score derived from near-miss and waiting-time changes, the resulting rankings offer a clear, evidence-based link between simulation outputs and decision-making guidance.

Table 1
TOPSIS rankings

Scenario	Strategy	Score	Rank
Safety-first	One-lane roundabout	0.6981	1
	Red-light camera	0.5993	2
	Speed bumps	0.4230	3
	Base	0.3147	4
	Improved pedestrian crosswalk	0.3054	5
Cost-conscious	Speed bumps	0.6003	1
	Base	0.5613	2
	Improved pedestrian crosswalk	0.5479	3
	One-lane roundabout	0.4940	4
	Red-light camera	0.4733	5
Pedestrian-priority	One-lane roundabout	0.6615	1
	Speed bumps	0.5519	2
	Red-light camera	0.4227	3
	Improved pedestrian crosswalk	0.3564	4
	Base	0.3549	5

4. Managerial implications

The findings support applying a staged implementation approach that prioritizes low-cost, high-impact interventions in the short term. Strategies such as speed management (speed bumps) and crosswalk improvements provide stable improvements in pedestrian waiting times and considerable reductions in simulated crashes, providing strong returns on the safety investment for restricted budgets. Automated enforcement (e.g., red-light cameras), on the other hand, can bring down high-risk angle conflicts more effectively where a safety-only objective is paramount. Automated enforcement with immediate communication directed towards specific enforcement can work together to help sustain compliance.

Project selection should be scenario-driven, aligning with specific stakeholder priorities rather than depending on aggregate assessment scores. In using MCDM ranking, the recommended scenario-specific alternative (safety-only, cost-conscious, pedestrian-priority) will explicitly classify trade-offs for decision-makers. Designs convert a specific roundabout site only when the site geometry has sufficient capacity and capital funding to initialize the project design, given that redesign may simplify conflict structure and overall impact speed, but still requires someone to afford the upfront investment. Programmer uncertainty by conveying our reported 95% confidence intervals, with emphasis that the relevant measure or any reported numbers is about relative gain (or loss) in programming rather than exact count.

Execution and scaling should rely on light, fast monitoring. Within 4–6 weeks of installation, track approach speeds, red-run frequency, driver yielding, and pedestrian waiting should be collected as early performance indicators. These observations can be used to recalibrate the model and update the site's ranking if needed. The same analytical pipeline can then be applied to other high-risk intersections, implementing one low-cost treatment per quarter, while reserving higher-cost projects (e.g., roundabouts) for external funding windows or multi-year programs.

5. Conclusion

This study shows that a focused, intersection-scale approach can deliver decision-ready safety guidance even in places lacking long crash histories and rich traffic datasets. By combining a lean microsimulation, built on transparent behavioral levers, with the TOPSIS approach, heterogeneous outcomes (crashes, delay, pedestrian experience, and cost) are translated into clear, stakeholder-specific rankings. In the Libyan case, the findings align with practical expectations and policy needs. Automated enforcement and speed management consistently reduce simulated crashes and close calls, strengthening their value as immediate safety measures. Pedestrian-oriented upgrades materially reduce waiting without compromising operations. Conversely, roundabout conversion, while promising for conflict severity, remains a high-cost option suited to sites with adequate space and strong implementation capacity. Presenting uncertainty through replication-based confidence intervals further strengthens interpretability and guards against overconfidence in point estimates.

Two limitations deserve attention. First, the model purposely simplifies conflict geometry and roundabout gap-acceptance. Future work should incorporate calibrated critical gaps, follow-up times, and richer movement pairs, as well as motorcycles and heavy vehicles that are common locally. Second, since absolute crash counts in any finite simulation are uncertain, the analysis complements rare-event outcomes with surrogate safety (near-misses) and recommends before–and–after monitoring if treatments are installed. Despite these limitations, the proposed framework remains actionable and ready for deployment. Using a concise set of factors and a shared codebase, city engineers can re-run the analysis in hours, align assumptions to local observations, and advance a transparent, defensible recommendation for near-term intersection safety investment.

Building on these results, the framework can be extended beyond a single intersection to support corridor- or network-level safety screening. Using basic, site-specific inputs, such as approach volumes and key behaviors, batch simulations can produce comparable metrics (C_1–C_4) across many intersections. These outputs can then be integrated into a common MCDM scheme to rank investments under shared scenario weights. A minimal monitoring program, focusing on approach speeds, red-run frequency, driver yielding, and pedestrian waiting, could enable periodic recalibration and re-ranking. Additionally, targeted external validation through empirical-Bayes or matched before–after assessments at pilot sites would help confirm the model's robustness and enhance its implementation across various urban contexts.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

The authors received no external funding for this research.

References

[1] Coll, B., Moutari, S., & Marshall, A. H. (2013). Hotspots identification and ranking for road safety improvement: An alternative approach. *Accident Analysis & Prevention, 59*, 604-617. https://doi.org/10.1016/j.aap.2013.07.012.

[2] Polders, E., Daniels, S., Hermans, E., Brijs, T., & Wets, G. (2015). Crash patterns at signalized intersections. *Transportation Research Record, 2514*(1), 105-116. https://doi.org/10.3141/2514-12.

[3] Schneider, R. J., Proulx, F. R., Sanders, R. L., & Moayyed, H. (2021). United States fatal pedestrian crash hot spot locations and characteristics. *Journal of Transport Land Use, 14*(1), 1-23. https://doi.org/10.5198/jtlu.2021.1825.

[4] Mitra, S., Neki, K., Mbugua, L. W., Gutierrez, H., Bakdash, L., Winer, M., Balasubramaniyan, R., Roberts, J., Vos, T., Hamilton, E., Naghavi, M., Harrison, J. E., Soames Job, R. F., & Bhalla, K. (2021). Availability of population-level data sources for tracking the incidence of deaths and injuries from road traffic crashes in low-income and middle-income countries. *BMJ Global Health, 6*(11), e007296. https://doi.org/10.1136/bmjgh-2021-007296.

[5] Arun, A., Haque, M. M., Bhaskar, A., Washington, S., & Sayed, T. (2021). A systematic mapping review of surrogate safety assessment using traffic conflict techniques. *Accident Analysis & Prevention, 153*, 106016. https://doi.org/10.1016/j.aap.2021.106016.

[6] Strauss, J., Zangenehpour, S., Miranda-Moreno, L. F., & Saunier, N. (2017). Cyclist deceleration rate as surrogate safety measure in Montreal using smartphone GPS data. *Accident Analysis & Prevention, 99*, 287-296. https://doi.org/10.1016/j.aap.2016.11.019.

[7] Goldenbeld, C., Daniels, S., & Schermers, G. (2019). Red light cameras revisited. Recent evidence on red light camera safety effects. *Accident Analysis & Prevention, 128*, 139-147. https://doi.org/10.1016/j.aap.2019.04.007.

[8] Gross, F., Lyon, C., Persaud, B., & Srinivasan, R. (2013). Safety effectiveness of converting signalized intersections to roundabouts. *Accident Analysis & Prevention, 50*, 234-241. https://doi.org/10.1016/j.aap.2012.04.012.

[9] Yannis, G., Kopsacheili, A., Dragomanovits, A., & Petraki, V. (2020). State-of-the-art review on multi-criteria decision-making in the transport sector. *Journal of Traffic Transportation Engineering, 7*(4), 413-431.

[10] Martins, M. A., & Garcez, T. V. (2021). A multidimensional and multi-period analysis of safety on roads. *Accident Analysis & Prevention, 162*, 106401. https://doi.org/10.1016/j.aap.2021.106401.

[11] Fancello, G., Carta, M., & Fadda, P. (2019). Road intersections ranking for road safety improvement: Comparative analysis of multi-criteria decision making methods. *Transport Policy, 80*, 188-196. https://doi.org/10.1016/j.tranpol.2018.04.007.

[12] Trivedi, P., & Shah, J. (2022). Identification of road crash severity ranking by integrating the multi-criteria decision-making approach. *Journal of Road Safety, 33*(2), 33-44. https://doi.org/10.33492/JRS-D-21-00055.

[13] Ciardiello, F., & Genovese, A. (2023). A comparison between TOPSIS and SAW methods. *Annals of Operations Research, 325*(2), 967-994. https://doi.org/10.1007/s10479-023-05339-w.

[14] Özekenci, E. K., Topcuoglu Onat, K., & Pamucar, D. (2026). A Comprehensive Bibliometric Analysis of Objective Weighting Methods in Multi-Criterion Decision-Making. *Management Science Advances, 3*(1), 246-265. https://doi.org/10.31181/msa31202645.

[15] Kumar, R. (2025). A comprehensive review of MCDM methods, applications, and emerging trends. *Decision Making Advances, 3*(1), 185-199. https://doi.org/10.31181/dma31202569.

[16] Badi, I., & Bouraima, M. B. (2023). Development of MCDM-based frameworks for proactively managing the most critical risk factors for transport accidents: a case study in Libya. *Spectrum of Engineering Management Sciences, 1*(1), 38-47. https://doi.org/10.31181/sems1120231b.

[17] Elmansouri, O., Almhroog, A., & Badi, I. (2020). Urban transportation in Libya: An overview. *Transportation Research Interdisciplinary Perspectives, 8*, 100161. https://doi.org/10.1016/j.trip.2020.100161.

[18] Mostafa, S., & Bakar, M. (2025). Two Decades of Road Traffic Injuries in Libya: Trends in Trauma Severity and Clinical Outcomes. *Tobruk University Journal of Medical Sciences, 9*(2), 15-20.

[19] Song, M., Stević, Ž., Badi, I., Marinković, D., Lv, Y., & Zhong, K. (2025). Assessing public acceptance of autonomous vehicles using a novel IRN PIPRECIA-IRN AROMAN model. *Facta Universitatis, Series: Mechanical Engineering, 23*(1), 127-145. https://doi.org/10.22190/FUME240729040S.

[20] Badi, I., Stević, Ž., Radović, D., Ristić, B., Cakić, A., & Sremac, S. (2023). A new methodology for treating problems in the field of traffic safety: case study of Libyan cities. *Transport, 38*(4), 190-203. https://doi.org/10.3846/transport.2023.20609.