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Intersection Control Evaluation for Highway Safety Analysis

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Abstract

Road traffic accidents take more lives than a combination of other accidents and natural disasters. An article published on September 9, 2023, in the Nepali Times reported that between April 2022 and April 2023, a total of 2,320 individuals lost their lives, with 28,856 sustaining injuries, many resulting in lifelong impairment. Traffic studies have revealed that Intersection Control Evaluation (ICE) facilitates strategic decision-making through the use of factual information, data, and metrics. The primary objective of this research on intersection control evaluation is to explore how the screening process and the selection of alternative intersections in ICE contribute to the reduction of accidents at intersections.

A focused examination of the literature assessing the methodology's effectiveness in maintaining intersection safety suggests that intersection control evaluation aids in strategy selection during expansion and signal usage at major intersections. Subsequent discussions utilized various spreadsheet tools and online forums. The findings indicate that ICE serves as an effective framework for screening intersection alternatives and identifying optimal solutions.

Results show that tools such as 'Capacity Analysis for Planning of Junctions' (CAP-X) effectively evaluate intersection types. Additionally, 'Safety Performance of Intersection Control Evaluations' (SPICE) is employed for safety analysis at grade intersections. Cost analysis demonstrated the cost-effectiveness of this approach based on results obtained from the Life Cycle Cost Estimation Tool (LCCET) spreadsheet.

In light of the results and discussions, it is recommended that intersection control evaluation play a crucial role in implementing safer, more balanced, and cost-effective solutions at road intersections.

1. Introduction

Intersection control evaluation is the process of assessing the effectiveness, efficiency, safety, and overall performance of intersection control measures. Intersections are critical points in road networks where two or more roadways intersect or meet, serving as key junctures for traffic movement. The efficient and safe operation of intersections is essential for maintaining smooth traffic flow, minimizing congestion, and ensuring the safety of motorists, pedestrians, and cyclists. Intersection control evaluation plays a crucial role in assessing the effectiveness, efficiency, and safety of various control measures implemented at intersections.

With advancements in technology and innovative approaches to transportation management, intersection control evaluation is evolving to incorporate intelligent transportation systems (ITS), connected vehicle technologies, and data-driven analytics. These advancements offer opportunities to enhance intersection operations in real-time, optimize signal timings, and improve overall transportation efficiency.

2. Review of literature

In this review of literature, we delve into the various methodologies, findings, and challenges related to the evaluation of intersection control. Our focus includes examining how different control measures, such as signalized intersections, roundabouts, and stop-controlled intersections, impact traffic flow and safety.

Furthermore, we explore current trends, technological advancements, and potential future research directions in the field of intersection control evaluation. Through synthesizing existing research and identifying gaps in knowledge, the goal of this literature review is to contribute to a deeper understanding of intersection control

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evaluation. Additionally, it aims to offer insights for enhancing both the operations and safety of intersections within transportation systems. In summary, this literature review aims to provide valuable insights for policymakers, transportation professionals, and researchers to improve intersection operations and safety in transportation systems by fostering a better understanding of intersection control evaluation.

3. Proposed strategies and methods

The methodologies adopted for intersection control evaluation are:

1. Before-After Studies: Conducting studies that collect data on intersection performance before and after implementing specific interventions, such as new traffic signals or roundabouts. This comparison helps researchers assess the effectiveness of the intervention in improving traffic flow, safety, or other performance measures.

2. Simulation Studies: Utilizing computer models to replicate real-world traffic conditions and assess the effects of different intersection control strategies. Researchers can adjust parameters like traffic volumes, signal timings, and geometric features to analyze impacts on traffic flow, queuing, and safety under various scenarios.

3. Field Observation Studies: Directly observing and recording traffic behavior and intersection operations in real-world settings. Researchers may use video cameras, manual counts, or automated sensors to collect data on traffic volumes, vehicle movements, and queuing behavior to assess intersection performance.

4. Surrogate Safety Analysis: Using proxy measures, such as traffic conflicts or near-miss events, to assess intersection safety. Analyzing the frequency and severity of surrogate safety indicators helps identify potential safety hazards and evaluate the effectiveness of intersection control measures in reducing crash risk.

5. Traffic Signal Optimization: Adjusting signal timings and coordination to improve traffic flow and reduce delays at intersections. Researchers use traffic signal optimization software or algorithms to optimize signal phasing, cycle lengths, and offsets based on traffic demand and operational objectives.

6. Queuing Theory Analysis: Applying mathematical models to analyze waiting lines and congestion at intersections. By modeling factors like arrival rates, service times, and queue lengths, researchers can predict queuing behavior, estimate delay times, and optimize intersection control strategies to minimize congestion.

7. Cost-Benefit Analysis: Evaluating the economic feasibility and effectiveness of intersection control measures by comparing their costs to expected benefits. Researchers assess factors such as construction costs, maintenance expenses, travel time savings, and safety improvements to determine the overall value and return on investment of different control strategies.

4. Data analysis

The following data are required to accurately analyze and model traffic behavior at intersection:

1. Traffic Volume Data: Traffic volume data provides information on the number of vehicles passing through an intersection within a specific time frame. It helps in understanding the demand for roadway capacity and identifying peak traffic periods.

2. Vehicle Classification Data: Vehicle classification data categorizes vehicles based on characteristics such as size, weight, and purpose. This data is essential for assessing the composition of traffic, understanding traffic flow dynamics, and evaluating the impact of different vehicle types on intersection operations.

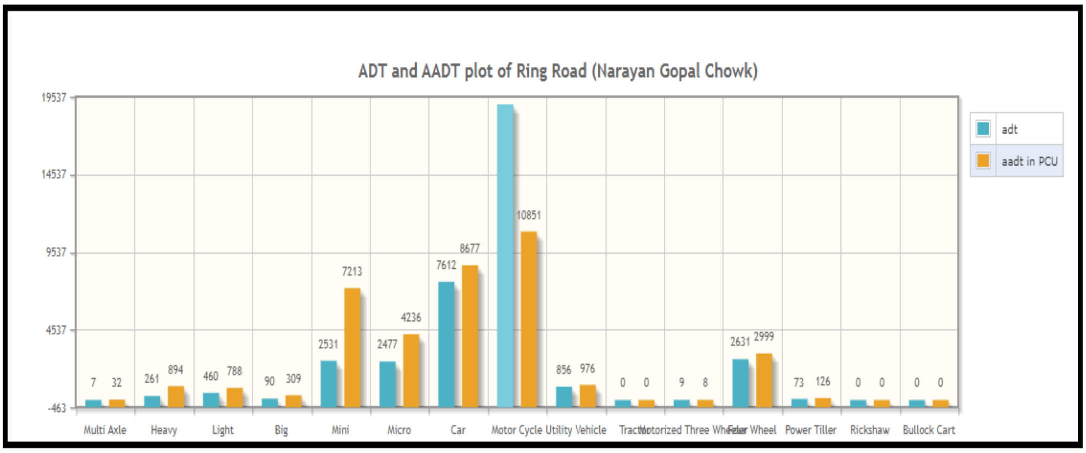


Figure 1. Traffic Volume and Vehicle Classification

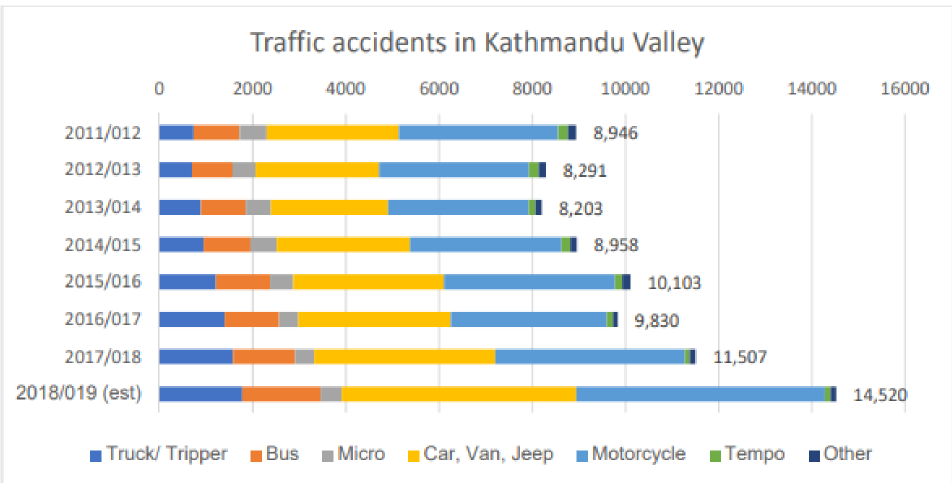
1. Speed Data: Speed data measures the velocities of vehicles traveling through an intersection. It helps in assessing compliance with speed limits, identifying areas with speeding issues, and evaluating the impact of speed on safety and traffic flow.

Design Speed

Road Specification	Plain	Rolling	Mountainous Grade separation section	Steep	Remarks
Class I	120	100	80	60	It will be Class I based on the future traffic volume by year 2030. However, in consideration of economic efficiency, a design speed of 60 km/hr would be desirable.
Class II	100	80	60	40	

Source: Nepal Road Standard 2070

2. Crash Data: Crash data provides information about traffic accidents and collisions that occur at or near intersections. It includes details such as the type and severity of crashes, contributing factors, and time of occurrence. Analyzing crash data helps identify safety hazards and prioritize intersection improvements.



Source: Metropolitan Traffic Police

Figure 3. Traffic Accident in Kathmandu Valley

3. Pedestrian and Bicycle Data: Pedestrian and bicycle data include information about the volume, movements, and behavior of pedestrians and cyclists at intersections. This data helps in assessing the safety and accessibility of intersections for non-motorized users, informing design decisions to accommodate their needs, and promoting multimodal transportation.
4. Queue Length Data: Queue length data measures the length of vehicle queues formed at intersection approaches, indicating congestion levels and delays. It helps in evaluating the effectiveness of intersection control measures, identifying areas where queuing problems occur, and optimizing traffic signal timings to reduce delays and improve traffic flow.

The steps involved in data analysis are:

4.1 Stage I (Screening):

The CAP-X Tool uses a critical lane volume analysis to determine the volume to capacity ratio for a variety of intersection control strategies and also provides an assessment of the pedestrian and bicycle accommodations for the selected intersection types. Based on the input parameters, the tool is able to generate a list of intersection types, ranked by volume to capacity ratio and given a multimodal score based on pedestrian and bicycle accommodations. Practitioners can choose to directly use turning volumes as input into the spreadsheet or grow the volumes based on a user specified volume growth percentage.The screening is carried out as:

1. Volume to Capacity Screening: This process entails evaluating the volume of traffic in relation to the capacity of the transportation infrastructure.
2. Pedestrian and Bicycle Safety Screening: Analyzing data concerning pedestrian and bicycle safety, including accident statistics and infrastructure design, is essential for this screening.
3. Motor Vehicle Safety Screening: This screening focuses on a thorough analysis of data related to motor vehicle safety, aiming to assess and enhance safety measures.
4. Environment Screening: Environmental factors associated with transportation, such as air quality and noise pollution, are scrutinized in this screening process.
5. Cost Screening: This screening involves the examination of costs linked to transportation projects or systems, providing insights into the financial aspects of these endeavors.

4.2 Stage II (Analysis and Alternative Selection):

The Safety Performance for Intersection Control Evaluation (SPICE) tool serves as a valuable resource for transportation practitioners, offering a comprehensive means of assessing anticipated safety performance of various intersection control strategies. By integrating these factors, SPICE provides practitioners with a holistic view of how different control strategies may impact safety outcomes at intersections.

The following analysis is carried out in this stage:

1. Vehicle Delay Analysis: Examining data pertaining to the delays experienced by vehicles in the transportation system is the focus of this analysis.
2. Pedestrian and Bicyclist Safety Analysis: A more in-depth examination of safety data for pedestrians and cyclists is undertaken, possibly involving detailed studies or models.
3. Motor Vehicle Safety Analysis: Conducting a comprehensive analysis of motor vehicle safety data, which may encompass factors like crash rates, road design, and other pertinent details.
4. Construction Cost Analysis: Evaluating the costs associated with constructing transportation infrastructure is the main objective of this analysis.
5. Life-Cycle Cost Analysis: Analyzing the costs of a transportation project over its entire lifecycle, inclusive of maintenance and operational costs.
6. Environmental Analysis: Investigating environmental factors related to transportation, potentially involving more detailed studies or models to gain a comprehensive understanding.
7. SPICE incorporates a range of factors essential for evaluating safety performance, including traffic volume, vehicle speeds, geometric design elements, and the effectiveness of intersection control

measures such as traffic signals, stop signs, roundabouts, and signage for various types of intersection (i.e. signalized, non-signalized and roundabout).

The following analysis is performed for different types of intersection:

1. Non-signalized Intersection

1. Safety Evaluation: Evaluating the safety performance of non-signalized intersections involves the analysis of crash data. This process aims to identify potential safety hazards and assess the effectiveness of safety countermeasures implemented at these intersections.
2. Operational Analysis: Operational analysis focuses on assessing traffic flow, capacity, and the level of service at non-signalized intersections. The goal is to identify congestion, delays, and queuing issues, thereby improving the overall efficiency of these intersections.
3. Driver Behavior Studies: Conducting studies on driver behavior helps understand how drivers interact and make decisions at non-signalized intersections. Factors such as gap acceptance, yielding behavior, and compliance with traffic rules are investigated to enhance our understanding of driver interactions in these settings.
4. Infrastructure Design: Evaluating infrastructure design considerations involves assessing geometric design elements, sight distances, signage, and pavement markings at non-signalized intersections. The goal is to ensure that the infrastructure is designed in a way that promotes safe and efficient operation.

2. Signalized Intersection

i. Traffic Signal Optimization: Optimizing traffic signal timings and coordination is aimed at improving traffic flow, reducing delays, and minimizing stops at signalized intersections.
ii. Queue Management: Managing vehicle queues at signalized intersections involves optimizing signal phasing, cycle lengths, and detection systems to minimize queuing and maximize intersection efficiency.
iii. Safety Analysis: Safety analysis examines crash data, intersection geometry, signal operations, and traffic volumes to identify safety deficiencies and implement improvements at signalized intersections, ensuring a safer environment for all road users.
iv. Pedestrian and Cyclist Considerations: Considering pedestrian and cyclist needs involves designing signalized intersections with features such as crosswalks, pedestrian signals, bike lanes, and bicycle signal detection. This approach enhances safety and accessibility for non-motorized users, promoting a more inclusive and secure transportation environment.

3. Roundabouts

i. Capacity and Efficiency Analysis: Analyzing capacity and efficiency at roundabouts involves assessing entry and circulating capacities, queue lengths, and traffic flow characteristics. This analysis aims to optimize roundabout design and operations to ensure smooth traffic flow.
ii. Safety Evaluation: Evaluating safety at roundabouts includes analyzing crash data, observing driver behavior, and assessing geometric features. The goal is to identify safety improvements and enhance overall roundabout safety for all road users.
iii. Pedestrian and Bicycle Accommodations: Providing accommodations for pedestrians and cyclists at roundabouts involves designing crosswalks, refuge islands, and dedicated bicycle lanes. This ensures safe and convenient crossings, promoting the integration of non-motorized users in the roundabout environment.
iv. Public Perception and Acceptance: Understanding public perception and acceptance of roundabouts involves conducting surveys, public outreach, and education campaigns. These efforts address concerns, increase awareness, and promote acceptance of roundabouts as a preferred intersection design option, considering community preferences and expectations.

5. Results and Discussion

5.1. Stage I (Screening):

1. Volume to Capacity Screening: Examining the volume of traffic in relation to transportation infrastructure capacity has revealed congested areas and potential bottlenecks. Identifying locations where traffic exceeds capacity is crucial for prioritizing infrastructure enhancements and optimizing traffic flow.
2. Pedestrian and Bicycle Safety Screening: Analyzing safety data for pedestrians and cyclists has pinpointed areas with high accident rates and identified infrastructure design shortcomings. Improving pedestrian and bicycle safety involves addressing these deficiencies and implementing measures to enhance visibility and separation from vehicular traffic.
3. Motor Vehicle Safety Screening: Thoroughly analyzing motor vehicle safety data has identified factors contributing to crashes and highlighted areas with high accident rates. Enhancing motor vehicle safety requires addressing road design issues, improving signage and markings, and implementing targeted enforcement measures.
4. Environment Screening: Environmental analysis has identified transportation-related factors like air quality and noise pollution. Mitigating environmental impacts involves considering transportation planning strategies that promote sustainability and reduce emissions and noise.
5. Cost Screening: Conducting cost analysis has provided insights into the financial implications of transportation projects or systems. Evaluating costs helps prioritize investments and ensures the efficient allocation of resources to maximize benefits.

5.2. Stage II (Analysis and Alternative Selection):

1. Vehicle Delay Analysis: Quantifying delays experienced by vehicles within the transportation system, vehicle delay analysis is instrumental. Addressing these delays involves optimizing signal timings, improving intersection design, and implementing traffic management strategies to minimize congestion.
2. Pedestrian and Bicyclist Safety Analysis: Conducting a detailed analysis of safety data for pedestrians and cyclists is crucial for identifying risks and opportunities for improvement. Enhancing pedestrian and cyclist safety requires designing intersections with dedicated facilities, improving visibility, and educating road users.
3. Motor Vehicle Safety Analysis: Motor vehicle safety analysis delves into crash data and road design factors influencing safety. To enhance motor vehicle safety, addressing road design deficiencies, enforcing traffic laws, and promoting safe driving behaviors are essential.
4. Construction Cost Analysis: Assessing the costs associated with building transportation infrastructure, construction cost analysis is a key consideration. Evaluating these costs helps prioritize projects and ensures cost-effective implementation while meeting transportation needs.
5. Life-Cycle Cost Analysis: Considering the long-term costs of transportation projects, including maintenance and operation, life-cycle cost analysis plays a vital role. Analyzing life-cycle costs guides decision-making to minimize overall costs and maximize the lifespan and performance of transportation infrastructure.
6. Environmental Analysis: Environmental analysis goes beyond to examine transportation-related impacts on air quality, noise pollution, and other factors. Integrating environmental considerations into transportation planning helps minimize adverse impacts and promotes sustainable transportation solutions.

In a similar manner, the study encompassed non-signalized intersections, signalized intersections, and roundabouts, shedding light on critical elements like safety evaluation, operational analysis, infrastructure design, traffic signal optimization, pedestrian and cyclist considerations, capacity analysis, safety evaluation, and public perception. Through a systematic examination of data across different intersection types, transportation planners and engineers can formulate effective strategies to enhance safety, streamline traffic flow, and optimize overall transportation system performance. These findings offer valuable insights for making informed decisions and prioritizing investments in transportation infrastructure and management.

6. Conclusion

In conclusion, the extensive screening and analysis conducted in Stages I and II provide crucial insights and practical recommendations to enhance transportation systems. By adopting a comprehensive approach that includes volume to capacity screening, safety assessments for pedestrians, cyclists, and motor vehicles, cost evaluations, and environmental considerations, transportation planners and engineers develop a holistic understanding of the transportation network's strengths and weaknesses.

The identification of congestion hotspots, safety deficiencies, and environmental impacts lays the groundwork for targeted interventions to improve traffic flow, enhance safety for all road users, and mitigate negative environmental effects. Furthermore, the thorough analysis of construction and life-cycle costs ensures that investments in transportation infrastructure are economically viable and sustainable in the long term.

Moreover, the specific focus on different intersection types emphasizes the need for tailored solutions to address unique challenges and optimize performance. By integrating safety evaluations, operational analyses, infrastructure design improvements, and public perceptions, transportation stakeholders can develop strategies that prioritize safety, efficiency, and user experience.

Overall, the findings from these screening and analysis stages offer valuable guidance for informed decision-making and resource allocation in transportation planning and management. By systematically addressing identified issues and leveraging opportunities for improvement, transportation systems can evolve to better meet the needs of communities while promoting sustainability and resilience in the face of future challenges.

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