PROCEEDING OF 2nd INTERNATIONAL CONFERENCE

February 3-4, 2023
Kathmandu, Nepal

Integrated Transport Sustainable Mobility

Ministry of Physical Infrastructure and Transport (MOPIT)

Society of Transport Engineers Nepal (SOTEN)

Ministry of Physical Infrastructure and Transport (MoPIT)

Society of Transport Engineers Nepal (SOTEN)

2nd International Conference On Integrated Transport for Sustainable Mobility

3-4 February 2023
Kathmandu, Nepal

Conference Supported By

- Department of Roads
- Department of Railways
- Department of Local Infrastructure
- Department of Urban Development and Building Construction
- Construction Business Development Council
- Department of Transport Management

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Society of Transport Engineers Nepal

Society of Transport Engineers Nepal (SOTEN) is a professional organization, established in 2009 by a team of enthusiastic engineers working in transport sector in Nepal. Its membership includes transport engineers working in government agencies, private firms and business, and academic institutions. Society is dedicated for professional development by generating and disseminating knowledge and sharing professional experiences.

The Society of Transport Engineers Nepal (SOTEN) has taken various initiatives to bring the stakeholders into a common forum for a seamless interface and a better understanding of the approaches, research, developments, and other efforts on planning and implementation of transportation systems.

Ministry of Physical Infrastructure and Transport

The Ministry of Physical Infrastructure and Transport (MoPIT) is the central authority of Government of Nepal charged with the responsibilities to enhance the economic and social development of country by linking various geographical and economic regions through the national strategic transport network. MoPIT is responsible for linking rural areas of country with markets to support various economic activities and projects related with tourism, agricultural, electrical, industrial, and other sectors of Nepal.

The key role of the Ministry lies with preparing plans, policies and programs regarding development of physical infrastructures such as roadways, railways, waterways, subways, flyovers and ropeways; Transport (except Air Transport) and transit management and its operation related plans, policies and programs; its implementation; monitoring and evaluation; inspection.

2nd International Conference

The conference was organized to disseminate the state-of-the-art approaches, proven best practices, and scientific know-how for addressing the integration issues for sustainable mobility. It aims to provide an opportunity for professionals to understand the research and development outcomes on the prevalent issue. The conference brought together national and international researchers, professionals and institutions to discuss on the sustainable mobility and its various dimensions.

Integrated Transport for Sustainable Mobility

The theme of this conference "**Integrated Transport for Sustainable Mobility**" builds on the discussions and needs outlined by the National Seminar on "Integrated Transport Infrastructure Development: Issues and Way Forward" organized by SOTEN in December 2021.

Conference Proceeding

The proceedings of the conference were prepared by the publishing committee with support from the rapporteurs. It has been outlined to the way the conference was conducted.

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Preface

The international conference on "Integrated Transport for Sustainable Mobility" is 2nd iteration of the international conference organized by the Society of Transport Engineers Nepal (SOTEN) in collaboration with the Ministry of Physical Infrastructure and Transport. The event capitalized on the summary of the National Seminar on a similar topic organized in December 2021 which highlighted the need for an integrated transport for sustainability.

SOTEN and MoPIT jointly formed a organizing committee coordinated by the Joint Secretary of MoPIT. The committee further formed different thematic committees required to organize the conference. The selected papers were categorized to be presented into six different sessions as follows:

1. International Best Practices in Transport Sector
2. Papers from KST-SOTEN Collaboration
3. Sustainable Transport Infrastructure
4. Integration of Transport for Sustainable Mobility
5. Road Safety and Traffic Engineering
6. Efficient Public Transportation

The papers were presented in subsequent sessions that ran for two days. Each session had a session chair and a session moderator to facilitate paper presentation and discussions on the papers presented.

This proceeding follows the conference format with the opening session, six technical sessions and a closing session in chronological order. Each session had two to four papers. The conference attracted 200 participants from various related government agencies (ministries, departments, units and projects), development partners, private sector, universities and educational institutions, and international delegates.

This report was prepared by the conference rapporteurs and the reporting committee as a factual summary of what occurred at the conference.

Opening Session

Conference Welcome

The President of Society of Transport Engineers Nepal (SOTEN) Prof. Dr. Padma Bahadur Shahi chaired the Inaugural session. Honorable Deputy Prime Minister and Minister for Ministry of Physical Infrastructure and Transport Mr. Narayan Kaji Shrestha joined the dais as Chief Guest of the session. Similarly, Honorable Dr. Dinesh Chandra Devkota, Member, Bagmati Province Parliament joined the dais as Keynote speaker of the conference. Mr. Keshab Kumar Sharma, Secretary, MoPIT; Mr. Gopal Prasad Sigdel, Secretary MoEWRI and Mr. Sushil Bhatta, CEO, Office of Investment Board Nepal also joined the dais as special guest of the event.

The opening ceremony was also joined by Immediate Past President of SOTEN, Dean of Institute of Engineering, Director General of Department of Roads, Department of Railways, Department of Transport Management, Department of Local Infrastructure, Civil Aviation Authority Nepal, Department of Urban Development And Building Construction; Executive Directors of Roads Board Nepal And Town Development Fund; President of Nepal Engineers Association And Society For Consulting Architect And Engineering Firms; Representative From UNESCAP; And Conference Coordinator.

The conference was inaugurated officially by the Chief Guest of the Conference Honorable Deputy Prime Minister and Minister for Ministry of Physical Infrastructure and Transport Mr. Narayan Kaji Shrestha digitally. It was followed by the National Anthem.

Mr. Prabhat Kuamr Jha, Joint Secretary of MoPIT and coordinator of the conference gave his welcome speech. He extended his warmest welcome to all the participants on behalf of the organizers, MoPIT and himself. He laid out the foundation to proceed with the conference highlighting the need for integration of transport sector for sustainable mobility as the need of the hour. It emphasized that Nepal needs to tackle the issue of integration promptly and that the conference would bring out brilliant ideas and a good resolution would be prepared that would guide all the stakeholders.

Remarks by Mr. Jha was followed by inaugural message by **Prog. Dr.-Ing. Seonha Lee, Kongju National University** online. He presented on digital traffic platform using PTV SW. His presentation highlighted various flow and simulation models for signal optimization. He also added on traffic actuated signal simulation for priority signal and coordination in network and need of traffic impact analysis. The coordinated and interconnected signaling supports demand flow management. He emphasized that these models and approaches can help Kathmandu reach its SDGs.

The Keynote speech was presented by **Dr. Dinesh Chandra Devkota, Member, Bagmati Province Parliament**. He began by outlining that the Honorable Deputy Prime Minister could use the knowledge about the various contemporary issues to spark a growth in the transport sector as current focus is only on engineering aspect and the social and governance issues are often neglected. He highlighted that there is need for accessible modern infrastructure and intensive connectivity. He highlighted that there is 2% to 3% loss in GDP in Nepal within 50 years due to climate related issue and the project economics is not considering this fact. He argued that traditional thinking is the biggest barrier to sustainable mobility, and we need to look beyond environmental and social aspects only, urban areas should have people centric design, due diligence required for electric mobility, safety needs to be prioritized, need to integrate modes, better and quality of road should be prioritized over quantity of roads developed. He also emphasized that there is a need to evolve on research and learning, that current level of infrastructure and service is a bare minimum and there is a need for huge upgradation through increased investment and integration for better monitoring and project management, and to reach the targets of sustainable development and Paris Agreement.

Chief Executive Officer of Investment Board Nepal, Mr. Sushil Bhatta congratulated the organizers and wished for successful event drawing upon a resolution that will serve as key guidelines for the future of transport related issues in Nepal. He highlighted the need for collaborated work in integrated approach with commitment from each of the parties, and need of a clear roadmap of implementing framework that utilizes life cycle costing, resource mobilizing and funding the gap. He also stressed on learning from models that have worked in Nepal and developing models for transport sectors as well. Pertaining to large number of barriers in implementation of mass transit solutions he recommended on clear demarcation of roles and responsibilities, uniformity in understanding and clarity (not in isolation) and focusing on electric vehicle ecosystem (not just procuring EVs).

Mr. Keshab Kumar Sharma, Secretary, MoPIT concurred with the contextual relevance of the conference topic and its need for infrastructure development for national integration, socio-economic development, and peace.

Honorable Minister Narayan Kaji Shrestha, Ministry of Physical Infrastructure and Transport outlined that sustainable mobility goes far beyond emissions as broadly prescribed in the Sustainable Development Goals.

Presentation of Papers

Technical Session 1: International Best Practices in Transport Sector

Session Chair: **Mr. Birendra Bahadur Deoja, Former Secretary, Government of Nepal**

Session Moderator: **Dr. Surya Raj Acharya, Executive Committee Member, SOTEN**

Five papers were presented by presenters from India, China, Korea, Japan and Thailand on public transport, high-speed rail service, hydrogen mobility, user behavior change and motorcycle safety.

Upon presentation of all the papers, the session chair noted that the session gave a clear message that the transport sector in Nepal has a long way to go and there is a need for research-based feedback and improvements. He thanked the presenters and suggested that the papers would be beneficial for the revision of the national transport policy.

The moderator of the session, Dr. Acharya pointed out that the papers must have provided a valuable context for the young researchers and thanked online speakers for their input in the conference.

Technical Session 2: Papers of KST-SOTEN Collaboration

Session Chair: **Prof. KIM Hyun, Korea National University of Transportation**

Session Moderator: **Mr. Hemant Tiwari, General Secretary, SOTEN.**

Three papers were presented by presenters on impacts of COVID-19 on activity-travel behavior, analysis of crash barriers and road safety.

Upon presentation of all the papers, the session chair shared his message that shifting the prompt from “Transport” to “Mobility” is very important in transportation field and the issue of integrating transport is something that has eluded and engaged the professionals and researchers around the world.

Technical Session 3: Sustainable Transport Infrastructure

Session Chair: Dr. Chandra Bahadur Shrestha, Director, NTDRC

Session Moderator: Dr. Rojee Pradhananaga, Executive Member, SOTEN

Five papers were presented that covered research and learnings from different countries. The papers included research on regaining the economic sustainability for Sri Lanka, defect-free concrete, role of financing institutions in road infrastructure construction, pavement deterioration forecasting and redefining public transport in the USA.

The Session Chair, after listening to all the research presentations, expressed his gratitude to all the delegates, presenters, and participants of the conference. According to him, the key take aways were that superficial solutions may not be effective unless the underlying constraining factors are identified and something fundamental for people's adherence to car-oriented transport needs to be talked out; rigid pavement and flexible pavement do not present a clear distinct regime for their use; the presentation on redefining public transport in the USA was thought provoking.

Technical Session 4: Integration of Transport for Sustainable Mobility

Session Chair: Mr. Sushil Bhatta, CEO, IBN

Session Moderator: Mr. Kamal Pandey, Infrastructure Specialist

The session on Integration of Transport for Sustainable Mobility was dedicated to organizational papers by major governmental and non-governmental bodies in transport sector in Nepal. Organizational papers were presented by Ministry of Physical Infrastructure and Transport (MoPIT), Civil Aviation Authority of Nepal (CAAN), Roads Board Nepal (RBN), Department of Local Infrastructure (DoLI), and Society of Consulting Architecture and Engineering Firms (SCAEF).

The summary of the departmental papers are as follows:

Ministry of Physical Infrastructure and Transport

Mr. Prabhat Kumar Jha, Joint Secretary, MoPIT presented the paper on behalf of the Ministry of Physical Infrastructure and Transport. He shared that the vision of the ministry is infrastructure development for national integration, socio-economic development, and vision. The main aim of the ministry is to harmonize the policies and bring efficiency and effectiveness in the provision of infrastructural services. It is the central authority of government responsible for enhancing economic and social development of country by linking various geographical and economic regions through the national transport network.

He also shared the Vison 2100 of the 15th Plan by NPC to upgrade all the highways to Asian Highway Standard, development of multimodal transport system and federal capital – province capital and province capital – province capital high speed transport linkage. He elaborated on the scenario of climate change in Nepal and its impact on transport sector and public transport sector. He also pointed that Nepal is not off the track on road safety but on a slow pace. He also shared that the ministry has drafted the road safety action plan for 2030. The ministry is working on ratifying old conventions that will pave way for standardizing road safety, licensing, traffic lights and to attract fundings.

Civil Aviation Authority Nepal (CAAN)

On behalf of the Civil Aviation Authority of Nepal, Er. Babu Ram Paudel, Director, CAAN presented the paper. He shared that CAAN has two major function- Regulatory functions and Service providing functions. He shared the major achievements of CAAN as the Effective Implementation rating by ICAO USOAP CMAP audit has been improving and has reached above global and Asia Pacific average. In terms of service provisions, he shared that there are 53 airports that CAAN is managing where 33 are regular operating, 3 are recently paved and other 3 are under construction.

He summarized that CAAN is committed to achieve ICAO's strategic objectives of Safety, Capacity and Efficiency, Security and Facilitation, Economic Development and Environmental Protection to contribute to the Global Aviation System; focused on ensuring safe aircraft operation; and enhancing efficiency in airport operation in Nepal.

Roads Board Nepal (RBN)

On behalf of the Roads Board Nepal, Mr. Ganesh Bahadur KC, ED stated that since the Roads Board Nepal deals with maintenance of the infrastructure (road), sustainable mobility is directly linked with the organization referring to the paper title – Road maintenance and sustainable mobility. He shared the information on the existing status of the road network and the need and scope of maintenance works. He also highlighted the road maintenance management cycle and the need of RBN as there are many agencies who are involved in in asset building but very few are involved in asset management and preservation.

He reiterated that RBN aspires for a concrete approach to align the aspirations and capabilities to achieve goals and create public value and enhanced road maintenance policy and its implementation to keep the pace in developing road asset management through performance-based maintenance system.

Department of Local Infrastructure (DOLI)

Er. Shyam Mani Kaphle, SDE, DOLI presented the departmental paper from the department of local infrastructure. Er. Kaphle shared the status of road network and trend in sub-national road network development. He presented the targets of rural road network development targets as envisioned by the 15^{th} plan by NPC which outlined target to reach 94% of households in 2022/23 with access to transport within 30 minutes of walk and an average road density of 0.69 km/sq.km. He also shared the major projects that are currently in implementation to achieve this target.

He also presented the observed issues in ownership of sub-national roads, insufficient budget allocation, lack of proper project selection guidelines and project bank, and lack of innovativeness and research in this area. There are issues in coordination resulting in duplication or omission of projects, and unreliable data records among the various agencies.

His recommendations on way forward included formulation of a National level Transport Policy that addresses the integration of sub-national roads with National Roads, uniformity in design standard, norms and guidelines; defined role of federal institutions for integration and guidance; monitoring and evaluation of the system to harmonize them in totality; focus on research and development, and issues of environment, social and safety. He ended his presentation with the statement that the institutions need to work themselves to integrate the integration efforts and then work towards integration of transportation components.

Society of Consulting Architectural and Engineering Firms (SCAEF), Nepal

The presentation from SCAEF was presented on behalf of Mr. Tuk Lal Adhikari Ms. Mandakini Karki. The presentation discussed on the read classification and division of responsibility with regional context. She also highlighted major issues and challenges in existing transport including pedestrian infrastructure, high rate of vehicle registration and subsequent increase in traffic, low road density, high axle load vehicles in operation, parking issues, congestion, and inconvenient public transport service.

She outlined that we need to move ahead towards more sustainable and mass transit systems. She also recommended that unsuccessful examples in other countries should be considered as experiences and should not discourage decision makers. She pointed out that all possible options of transport system should be studied at feasibility stage with sufficient public and stakeholder consultations, and road safety must be improved through more stringent rules.

Upon presentation of all the papers, the session chair, Mr. Sushil Bhatta, thanked the moderator for managing a very interactive session. He noted that there are a lot of problems that all the stakeholders are facing regarding project development, implementation, timely completion, and sustainability. He further emphasized that the problems also have solutions and the stakeholders, agencies, law makers need to delve into them and design a solution in an integrated way. He further added that there is need for an integrated transport master plan with result-oriented framework that envisions the required policy, framework, and method from project ideation to implementation and operation that facilitates the function and need it was designed for in a must efficient way. The targets could be ambitious ones but a clearly worked out gaps and well-designed and collaborated solution design can resolve them.

Technical Session 5: Road Safety and Traffic Engineering

Session Chair: Prof. Dr. Thusitha Chandani Shahi, Director NEC-cps

Session Moderator: Er. Sushil Babu Dhakal, Project Director, DoR Project Directorate ADB

In this session on road safety and traffic engineering, five papers were presented by researchers from India and Nepal on impact of road geometry on user behavior and road safety, safety evaluation of national highway, modeling delay due to curb-side bus stops, road crash costing and urban intersection modeling for signal coordination and adaptive traffic control.

Session Chair Prof. Dr. Thusitha Chandani Shahi summarized her key take of the presentations as to the fact that over 80% of the crashes are due to driver behavior and emphasis needs for standardized procedures to improve road quality and driver behavior; measures to minimize road crashes on a specific road section by MR. Mohan Dhoj KC; impact of curb-side bus stops on vehicular delay and the need to increase the distance between bus stops and intersections; there is large importance of planning and budget allocation for road interventions to minimize losses.; and pre-time signal coordination can be an effective option to improve the operational performance of closely located intersections.

Technical Session 6: Efficient Public Transportation

Session Chair: Prof. Satish Chandra, IIT Roorkee

Session Moderator: Dr. Hare Ram Shrestha, Executive Member, SOTEN

The session was SOTEN-UN ESCAP- TREN Joint Session titled as efficient public transportation. Five papers were presented by presenters from Korea, and Nepal on railway system development in Korea, low carbon transport policies for Asia, regional cooperation mechanism on low carbon transport, service quality assessment and a presentation by Town Development Fund.

Upon presentation of all the papers, the session chair acknowledged that all the papers were wonderful and enriching focused on sustainability in the transport system. He noted that Prof. Kim's presentation on railways aligns well with the theme of sustainability as railways are considered as one of the most sustainable transport systems. The importance of reducing carbon emissions is clearly presented by three presenters. The indicators for evaluating the public transport system were well presented. Prof. Chandra emphasized that electric vehicles are not the only solution, as alternatives exist. He also highlighted the need for careful planning while implementing BRT to avoid challenges faced in other cities like Delhi.

Closing Session

The closing session was chaired by Mr. Keshab Kumar Sharma, Secretary, MoPIT. Honorable Minister Bikram Pandey, Ministry of Urban Development was the Chief Guest of the session. Prof. Dr. Padma Bahadur Shahi, President, SOTEN was the Special Guest for the session. Mr. lal Krishna KC, IPP, SOTEN; Mr. Arjun Jung Thapa, DG, DoR; Mr. Rohit Kumar Bisural, DG, DORW; Dr. Tokraj Pandey, DG, DoTM and Mr. Shankar Prasad Pandit, Secretary, MoPID, Bagmati Province also seated on the dais as Guests of the session. Similarly, other distinguished guests were seated in the front row.

The official opening of the closing session was followed with the declaration of conference resolution by the Resolution Declaration Committee Chair Mr. Saroj Kumar Pradhan, Executive Member, SOTEN.

Resolution

Second International Conference on Integrated Transport for Sustainable Mobility organized by Ministry of Physical Infrastructure and Society of Transport Engineers Nepal (SOTEN) held on February 2-4 2023 in Kathmandu had extensive discussion on following six technical sessions on the following topics;

1. International best practice in transport sector (5 papers)
2. KST-SOTEN Collaboration (4 papers)
3. Sustainable transport infrastructures (5 papers)
4. Integration of transport for sustainable mobility (6 papers)
5. Road safety and traffic engineering (5 papers)
6. Efficient public transport (SOTEN-UNESCAP-TREND Joint Session) (5 papers)

- Prioritize public transport: Encourage the use of public transport by improving its infrastructure, increasing frequency and reliability, and making it more accessible and affordable.
- Promote active transportation: Encourage cycling and walking as sustainable modes of transportation by building dedicated infrastructure such as bike lanes and pedestrian paths.
- Promote intermodal connections: Ensure smooth connections between different modes of transportation, such as public transport, cycling, and walking, through the provision of transfer hubs, bike-sharing programs, and real-time information systems.
- Recognize the importance of safe transport system and ensure the safe transport by recognizing application and promotion of road safety measures, its adoption and awareness raising.
- Encourage sustainable land use planning: Promote compact, mixed-use development patterns that reduce the need for personal car use and support the integration of various modes of transportation.

- Promote sustainable transport financing: Provide financing for sustainable transport initiatives through various means, such as taxes, public-private partnerships, and user fees.
- Encourage the use of low-carbon vehicles: Encourage the use of low-carbon vehicles, such as electric vehicles, by providing incentives and infrastructure, such as charging stations.
- Encourage cities towards reduction of their carbon footprint, while improving the quality of life of their citizens by promoting sustainable mobility.
- Recognize the importance of integrated transport in creating sustainable mobility system and reducing negative impacts on environment and public health.
- Encourage adaptation of integrated transport planning and policies to collaborate with the private sector and civil society to create sustainable mobility solutions.
- Call for increased research and innovation in the field of integrated transport with a focus on developing sustainable efficient and accessible transport options.
- Call upon putting high emphasis on need for public engagement and education to raise awareness to the benefit of integrated transport and promote behavior change towards sustainable mode of transportation.
- Recognize the role of technology such as intelligent transport systems in enabling the transition to integrated transport and the creation of smart sustainable mobility system.
- Reiterate the importance of international cooperation and exchange of best practices and its adoption in advancing the integration of transportation for sustainable mobility worldwide.

The resolution was applauded by all and was declared passed.

The **Chair of the Technical Committee of the Conference, Dr. Surya Raj Acharya** thanked all the participants for their presence in the two-day event. He stated that with the best collaborative efforts of all the agencies made the event a success with all the distinguished officials and professionals of the sector gathered along with all the international paper presenters sharing their research, experience, and learnings. He admitted that there might have been a few shortcomings which are expected in such international events. He expressed his thanks to the technical team, the organizing committee and advisors, the researchers, and paper presenters. He also appreciated the efforts at top political level, the efforts given to infrastructure and development. He urged keeping the spirit alive and moving forward in the future for collaborative efforts in organizing these kinds of events.

The immediate past president of SOTEN, Mr. Lal Krishna KC introduced **President of Eastern Asia Society of Transport Studies (EASTS) and President of Korea Transport Institute (KOTI) Dr. Jaehak Oh**. Prof. Dr. Sigeon Kim readout the message from Dr. Oh. In his remarks, Dr. Oh expressed his appreciation for the efforts put together by SOTEN to organize the second international conference. The international academic conference with members of EASTS is an encouraging event.

President of SOTEN, Prof. Dr. Padma Bahadur Shahi shared his remarks. He stated that the efforts made and lessons learned in organizing the event would guide future events. He thanked all the supporters, international partners, domestic partners and supporters and institutions, various committee members, volunteers, and participants for their efforts in making the event a success. He also thanked all the members of the Society, Practitioners and Engineers.

Special remarks was delivered by the **Chief Guest Honorable Minister Bikram Pandey, Ministry of Urban Development**. He congratulated the organizers for successfully concluding the event. He stated that transport is an essential component of any society and civilization for basic need to overall development of the country. Transport is the infrastructure of infrastructure. For sustainable transport, road construction is not the defining factor, the roads need to be well maintained along with provision of various modes and means of transport with their integration. For this, necessary policies need to be prepared, and updated. In this regard, this conference has been a very relevant one. The recommendations made through the conference resolution will be very useful to guide the works by the MoUD and other agencies. He further added that sustainability, environmental footprint, inclusion, affordability, and safety are priority of GON. For this GON is working at in policy making and implementation of projects to realize them. On doing so, conference like this has a huge input. He thanked the organizers for inviting him to the conference and sharing the knowledge that was discussed.

The remarks were followed by sharing the Token of Appreciation with the guests and all the supporting institutions of the event.

Mr. Rajendra Raj Sharma, Vice President, SOTEN shared the vote of thanks on behalf of SOTEN organizers to all the participants, presence, contribution in making the program valuable and memorable. He thanked all the chief guests, keynote speaker, special guests, session chair and moderators, paper presenters and all the participants. The program has been vibrant and thought provoking because of the interaction and discussions. He appreciated all the international presenters and participants from foreign countries for their time and effort. He extended special thanks to MoPIT, DOR, DORW, DOTM, DOLI, DUDBC, NRSC, SCAEF, ECBDC, CAAN, IBN, RBN, NEA, TDF, UN ESCF, KST, and EASTS. And also thanked all the committees who have worked tirelessly to make each component of the event organization. He also shared special thanks to the young volunteers who too have work very hard. Lastly, he wished a great stay and safe return home to all the international participants of the conference.

In the closing remarks **Session Chair Mr. Keshab Kumar Sharma, Secretary, MOPIT** expressed his thanks and vote of congratulations to the organizers and all the supporters (national and international) for a very successful and fruitful two-days conference. The various sessions presented and discussed on various pertinent topics. The resolution presented recommendations and they cover important solutions based on international best practices fit for local ground realities. He shared that he was confident that these will be valuable in making and implementing policies. He also thanked all the contributors to the conference.

Full Papers

Modelling Delay due to Curb-Side Bus Stops at Signalized Intersection: A Case Study of New Baneshwor Intersection

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Abstract

This study analysed the patterns of vehicular delays at curb side lanes near intersection due to three bus stop parameters : distance between bus stop and intersection, length of bus loading area and maximum dwell time. The study was conducted at New Baneshwor, one of the busiest intersections in Kathmandu, Nepal. Traffic data were collected for three hours, of each five weekdays by videographic survey and field observations. VISSIM microsimulation model was calibrated to the local traffic conditions. Then, 192 combinations of scenarios were simulated for the variations in the three bus stop parameters and vehicular delays on the curb side lanes were evaluated. The simulation results showed that for higher values of maximum dwell times, downstream positions were found to have lesser vehicular delays than at upstream, while for lower values of maximum dwell times, the vehicular delays for upstream positions were found to be lesser than or near to that of downstream positions. Furthermore, the delay showed a decreasing trend when the distance of bus stop from intersection increased, while increase in the maximum dwell time showed significant increase in the delay. The vehicular delays for the optimum bus stop scenarios for minimum delays were found to reduce significantly by 82.83% and 75.66% from existing scenarios at the two curb side lanes of the study intersection, which shows that curb side bus stops were found to have significant impact on vehicular delays at the curb side lanes.

Keywords: Curb Side; Bus Stop; Vehicular Delay; VISSIM Simulation; Bus Loading Area; Maximum Dwell Time; Bus Blocking Effect

1. Introduction

The exponential increase in the number vehicles has been a major problem on Kathmandu's streets causing congestion and delays. As per 2019 statistics, vehicle registration in Kathmandu has an overall annual growth rate of 14% (DoTM, 2019).

In an urban context, curb side bus stops are usually present near intersections. When a bus arrives at a curb side bus stop, it creates a temporary bottleneck and obstructs the movement of vehicles in the curb lane, causing vehicular. Such delays can be reduced by proper configuration and service time regulation of curb side bus stops.

There have been several studies on where best to locate a bus stop relative to its nearby intersection (Wentao, Guomin, Dongfang, & Dian-hai, 2020; Liu & Jian, 2019; Chen, Xie, & Wang, 2019; Diab & El-Geneidy, 2015; Gu, Gayah, Cassidy, & Saade, 2014; Wong, Yang, Au yeung, & Cheuk, 1998; SanClemente & Furth, 2006). Some studies have found in favour of far-side stops, while others have reached the opposite conclusion. The matter has yet to be further established, because many studies have by necessity focused on relatively small numbers of select cases and traffic conditions. For example, Gu et al. (2014) used Markov chain model and discovered that the downstream bus stop was better when the intersection approaches saturation, or when the bus dwell time was too long. On the other hand, Liu & Jian (2019) used modified optimal velocity model and found that the upstream bus stop outperforms the downstream one, especially when the entering probability is larger and the distance between the bus stop and the intersection is in the range of 50 – 200 m. Only few literatures have examined the combined effect of stopping configuration and dwell time of bus stops on vehicular delays. Furthermore, such studies are fewer in case of heterogenous traffic and non-lane behaviour conditions as generally prevalent in context of cities in developing countries of Asia. This shows an obvious gap in the literature and an opportunity to address them in this research.

So, this study aims to analyse the effects due to curb side bus stops near intersections on vehicular delays at the curb side lanes. As a study intersection, New Baneshwor has been taken, as it is one of the most congested

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intersections in Kathmandu (JICA, 2019). There are existing curb side stops at curb side lanes at East to West (Tinkune to Maitighar) and West to East (Maitighar to Tinkune) directions.

This study would help the traffic planning and management authorities to assess various scenarios for the proper placement of bus stops near the study intersection, which would help in minimizing the vehicular delays arising from the blocking effects of bus stop. It would also help understand the relation between vehicular delays at curb side lane due to variations in bus stop configuration and dwelling times. As the study is in context of heterogenous and non-lane behaviour traffic conditions relevant to developing countries like Nepal, the calibrated data of VISSIM driving behaviour parameters obtained would also help for traffic microsimulation studies in other cities with similar conditions.

2. Methodology

Videographic survey as well as field observations for maximum queue lengths, bus stop dwell times, speed and other traffic data was conducted at the study intersection from 8:30 am to 11:30 am in the morning for five weekdays within 6 to 13th June 2022. Based on this data, VISSIM model has been formed and scenario analysis have been carried out using the calibrated model.

2.1. Microsimulation Model and VISSIM

PTV VISSIM is one of the microscopic multi-modal traffic flow simulation software packages developed by PTV Planung Transport Verkehr AG in Karlsruhe, Germany (Wikipedia, 2022). In VISSIM microscopic simulation software, there are many parameters related to vehicle, driver behaviour, lane changing, trajectory, signal control and so on, which can be changed for modelling the driver behaviour patterns. The parameters have inbuilt default values, but can be adjusted during the calibration process to suit the local conditions (Suthanaya & Upadiana, 2019). The latest version of PTV Vissim 2022 (SP06) (Academic License) with unlimited network size and simulation time has been used.

2.1.1. Base Model Formation

The base model formation included the following steps:

- Geometry coding – The intersection road geometry was formed by the help of Google Earth Imagery. Links and link connectors were then formed over it.
- Vehicle inputs – Traffic demand data was input in the forms of entry volumes and turning movements at intersections at 15-minute interval as per vehicle types and composition to specific links within the VISSIM network. 3D models of each vehicle type prevalent at the study intersection along with their dimensions were input.
- Vehicle Routings: Routing decisions in the form of static vehicle routing decisions were coded on the corresponding links as the vehicle input.
- Speed – Maximum and minimum values of vehicle speed were entered as per the field data.
- Signal control –Phase sequence and Timings were input into the Signal Program and Signal Heads were added at the Stop line of each leg.
- Transit Stops: Transit Stops and their length were input. Similarly, field measured maximum dwell times were input to each stop based on different categories of public transit vehicles.
- Finally, Nodes, Data Collection points and Queue counters were placed to obtain output for calibration, validation and scenario analysis simulations.

Figure 1 shows the formation of links (blue lines) and connectors (pink lines) to depict the geometric configuration of New Baneshwor Intersection (left) and the setup of stops (right).

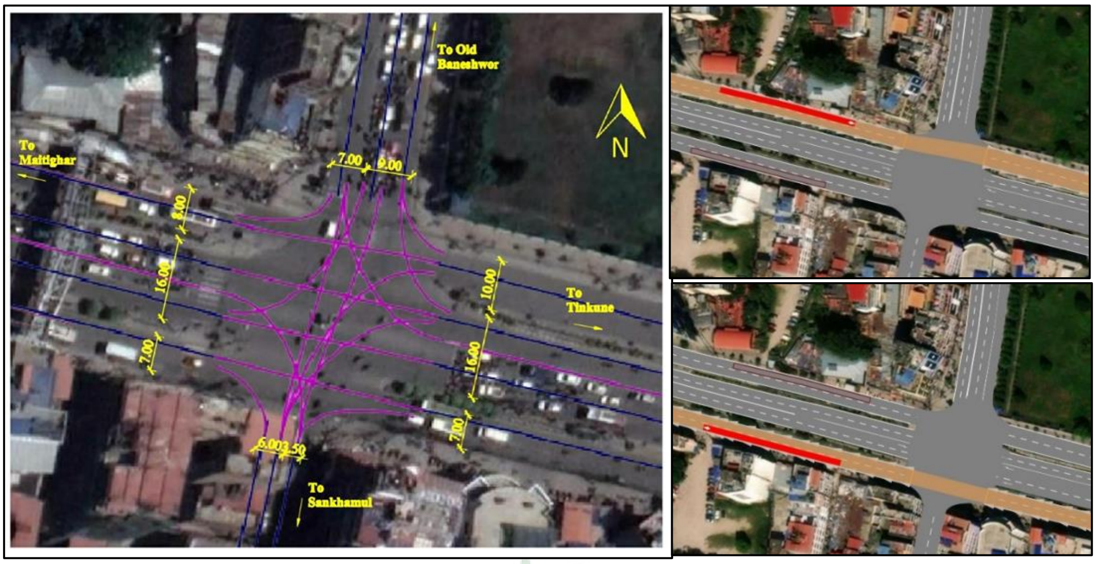

Figure 1. Setup of New Baneshwor Intersection (left) and transit stops (right) (Source: PTV VISSIM)

From review of literatures under heterogeneous and non-lane behaviour traffic conditions, the minimum lateral clearances for all categories of vehicles at stationary (0 km/h) and 50 km/h situations were adopted. The values of minimum lateral clearance for different categories of vehicles as per the corresponding literatures referred and that adopted in this study is shown in Table 1.

Table 1. Minimum Lateral Clearance of Vehicles adopted with reference from Literatures

Literatures referred	**At Speed 0 km/h**					**At Speed 50 km/h**				
	Two-wheeler	**Three-Wheeler**	**Four-Wheeler**	**Bus**	**Truck**	**Two-wheeler**	**Three-Wheeler**	**Four-Wheeler**	**Bus**	**Truck**
(Khan, et al., 2022)	0.25	0.25	0.3	0.4	0.4	0.3	0.3	0.5	0.5	0.7
(Maheshwary, et al., 2019)	0.4		0.6	0.8		0.4		0.6	0.8	
(Mistrya, et al., 2022)	0.25	0.25	0.3	0.4	0.4	0.3	0.5	0.5	0.7	0.7
(Dey, et al., 2018)			0.6					0.8		
(Mondal & Gupta, 2021)	0.1	0.1	0.2	0.5	0.5	0.5	0.6	0.8	0.8	0.9
(Raju, et al., 2020)	0.25	0.25	0.3	0.4	0.4	0.3	0.3	0.5	0.7	0.7
(Jayasooriya & Bandara, 2018)			0.5					0.75		
Adopted for this study	**0.25**	**0.25**	**0.3**	**0.4**	**0.4**	**0.3**	**0.5**	**0.5**	**0.75**	**0.75**

2.1.2. Calibration

This study used the trial-and-error method by adjusting parameters iteratively to obtain the best match possible between the model outputs and field measurements. The calibration of model has been done using the three day's data. An effective calibration should include one system performance measure and localized performance measure (Karl Wunderlich; Meenakshy Vasudevan; and Peiwei Wang, 2019). For calibration, traffic volume has been selected as a key performance measure, while maximum queue length was selected as an additional calibration measure. The model calibration procedure used in this study is presented in Figure 2.

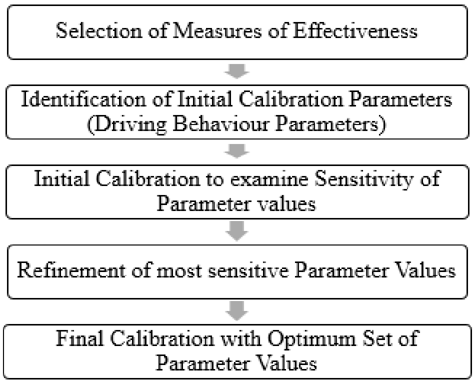

Figure 2: Steps in the Calibration Process

A comprehensive review of literatures related to VISSIM calibration under heterogenous and non-lane-based traffic was carried out. Based on the review, nine set of driving behaviour parameters were found to be suitable for calibration for these traffic condition. The range of these driving behaviour parameter values were adopted as per findings of the studies. Three values of each parameter within these ranges were taken, so that sensitivity of these parameters could be examined. The parameters taken for initial calibration have been presented in Table 2.

Table 2. Parameter value ranges taken for Initial Calibration with reference from Literatures

S.N.	Initial Parameters		VISSIM Default Values	Value Ranges with reference from Literatures	Values adopted for Initial Calibration		
	Following						
1	Look ahead distance	Min (m)	0	10 - 30	10	20	30
2		Max (m)	250	100 - 140	100	120	140
3	Look back distance	Min (m)	0	6 - 24	6	12	18
4		Max (m)	150	80 - 120	80	100	120
	Wiedemann 74						
5	Average standstill distance (m)		2	0.40 - 1.20	0.6	0.8	1.2
6	Additive part of safety distance		2	0.10 - 1.00	0.20	0.6	1
7	Multiplicative part of safety distance		3	0.60 - 1.20	0.6	0.8	1.2
	Lane Change						
8	Min. clearance (front/rear) (m)		0.5	0.25 - 0.80	0.25	0.4	0.8
9	Safety distance reduction factor		0.6	0.20 - 0.60	0.25	0.4	0.6

Note:
Literatures Referred are (Khan, et al., 2022; Paul, et al., 2019; Bandi & George, 2021; Hussain, et al., 2017; R., et al., 2020; P.a, et al., 2019; Mistrya, et al., 2022; Dey, et al., 2018; Mondal & Gupta, 2021; Raju, et al., 2020; Acharya & Marsani, 2020; Sharma, 2016)

2.1.3. Statistical Methods used for Calibration and Validation

To check the accuracy of output, GEH (Geoffrey E. Havers) statistic will be used. Root Mean Squared Normalized Error (RMSNE) have been used, to measure the percentage deviation of the simulated data from field data. The equations for GEH and RMSNE are shown by equations (1) and (2) respectively.

$$GEH = \sqrt{\frac{2(M-C)^2}{(M+C)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here, M = Modelled Value, C = Counted Value

$$\text{RMSNE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\text{yi,sim}-\text{yi,obs}}{\text{yi,obs}}\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Here, n= total number of traffic measurement observations, yi, sim and yi, obs = simulated and observed data

As per FDOT (2014), the acceptance threshold for GEH is less than 5%, for RMSNE is less than 0.15 and for % difference is less than 20%, for traffic volumes and queue lengths.

2.1.4. Scenario Analysis using Validated Model

There are various factors affecting vehicular travel time, delay and reliability. However, there are some basic factors that are widely agreed to have effects. Intersection control, traffic volumes, configuration of bus stops and bus passenger loadings are some of them which are mentioned in several literatures (Abdy, 2010; Alshnawa, 2017; B. Vinayaka, 2016; Buck, 2017; Chen, et al., 2019; Huo, et al., 2018; Dogan, et al., 2020; Wong, et al., 1998; Shi-dong, et al., 2016; Gu, et al., 2014). For this study, the scenario analysis was carried out by varying the following combination of bus stop parameters:

1. Distance between Bus Stop and Intersection Stop line
2. Length of Bus loading area (Bus Stop)
3. Maximum Dwell Time

Forty-eight combinations each due to variation of these bus stop parameter values were formed, for upstream and downstream positions at both the Maitighar-Tinkune and Tinkune-Maitighar directions. The distance between bus stop and intersection was varied from 40 m to 140 m at an interval of 20 m, 40 m and 60 m length of loading area were taken, while maximum dwell times were taken as 60 sec, 90 sec, 105 sec and 120 sec. A total of 192 scenarios were simulated including both the curb side bus stops as well as upstream and downstream positions.

To obtain the average vehicular delays for these scenarios, travel time for each simulation were collected with Travel Time Collection (TTC) segments. TTC segments were coded with a starting point and stopping point, at a distance 250 m upstream from the intersection and 250 m downstream from the intersection to allow for sufficient provision of distance for deceleration or acceleration distance on approaching and departing from the stop.

Prior to scenario analysis, the simulation was first run to get the average travel time of all vehicles was determined under no bus stop condition, so that it could be used as a basis to calculate delay due to the effect of bus stops only. Then the delay due to bus stops under several scenarios were calculated by subtracting it with the travel time under no bus stop condition.

3. Results & Discussion

The results from VISSIM calibration and the Scenario analysis from the validated model thereafter have been discussed in the subsequent subheadings.

3.1. Model Calibration

Model calibration was done in steps as described under previous heading and the results have been presented subsequently.

3.1.1. Initial Calibration

The initial calibration was carried out using the above values for the nine set of parameters. Each set contains three variations in values. During each run, only one parameter value was changes while keeping the other parameters unchanged from the VISSIM default values. Simulation output of Traffic volume showed very low percentage differences, from 0.86% to 21.76% in each of the intersection approaches, most of them bring close to 10%. The intersection approach wise percentage difference between field data and simulation output of maximum queue length has been presented in Table 3.

Table 3. Percentage Difference between Field Data and Simulation Output for Maximum Queue Length at each approach

Set	Parameter Values	Variation in Parameter Values	% Difference of Field Data and Simulation Output for Maximum Queue Length						Cumulative % Difference
			MG SL	MG ML	TK SL	TK ML	OB	SM	
1	Look ahead distance (Min)	10.00	94.32%	22.29%	5.04%	135.51%	3.61%	111.19%	371.95%
		20.00	**73.95%**	**22.99%**	**21.23%**	**87.08%**	**9.68%**	**87.61%**	**302.54%**
		30.00	77.13%	24.88%	17.09%	116.20%	6.44%	90.85%	332.60%

Set	Parameter Values	Variation in Parameter Values	% Difference of Field Data and Simulation Output for Maximum Queue Length						Cumulative % Difference
			MG SL	MG ML	TK SL	TK ML	OB	SM	
2	Look ahead distance (Max)	**100.00**	85.60%	23.57%	16.23%	67.09%	2.61%	95.67%	290.77%
		120.00	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		140.00	94.52%	29.28%	10.39%	129.51%	7.06%	90.06%	360.82%
3	Look back distance (Min)	6.00	68.91%	25.45%	7.06%	122.99%	6.84%	107.34%	338.58%
		12.00	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		18.00	75.51%	27.42%	11.39%	119.16%	3.84%	128.64%	365.96%
4	Look back distance (Max)	80.00	73.95%	24.25%	21.23%	87.08%	9.68%	87.61%	303.80%
		100.00	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		120.00	73.95%	24.25%	21.23%	87.08%	9.68%	87.61%	303.80%
5	**Average standstill distance (m)**	**0.60**	77.76%	10.72%	0.30%	59.71%	3.04%	70.23%	221.76%
		0.80	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		1.20	77.28%	41.06%	29.37%	158.34%	32.26%	155.22%	493.53%
6	**Additive part of safety distance**	**0.20**	87.06%	19.78%	0.12%	55.41%	0.21%	89.90%	252.48%
		0.60	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		1.00	65.67%	29.39%	25.60%	133.82%	7.85%	120.93%	383.25%
7	Multiplicative part of safety distance	0.60	81.98%	20.12%	9.98%	101.11%	7.20%	113.02%	333.41%
		0.80	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		1.20	49.83%	26.21%	10.59%	136.49%	9.21%	100.05%	332.38%
8	Minimum clearance (front/rear) (m)	0.25	92.69%	24.35%	5.38%	83.59%	5.60%	99.05%	310.66%
		0.40	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		0.80	58.99%	29.33%	21.84%	152.75%	4.47%	119.29%	386.67%
9	Safety distance reduction factor	0.25	75.12%	23.29%	36.46%	66.69%	8.76%	100.69%	311.01%
		0.40	73.95%	22.99%	21.23%	87.08%	9.68%	87.61%	302.54%
		0.60	78.31%	27.77%	8.93%	117.47%	6.17%	104.77%	343.42%

Note: MG – Maitighar, TK- Tinkune, OB – Old Baneshwor, SM – Sankhamul, ML – Main Lane, SL – Side Lane

The cumulative percentage difference gives a measure of sensitivity among the three parameter values to traffic volume and maximum queue length. The bold highlighted values showed, in general least percentage difference or better convergence from field maximum queue lengths, as compared to two other values of same parameter. From the simulation results, it is seen that simulation output of maximum queue length showed significant percentage difference from field values as high as 135.51%. Since, the percentage difference of the maximum queue length and traffic volumes have surpassed the acceptance threshold of 20%, it was felt necessary to further calibrate the parameter values for maximum queue length.

3.1.2. Refinement of Sensitive Parameters

On the basis of cumulative percentage differences, two parameters were then selected for further refinement as they showed significant sensitivity or variations in cumulative percentage differences for maximum queue length. The selected parameters are shown in Table 4, which were varied one at a time.

Table 4. Parameters selected for further refinement

Set	Parameter	Value taken for Final Calibration
Set 5	Average standstill distance (m)	0.40
Set 6	Additive part of safety distance	0.10

As before, simulated traffic volume showed better convergence to field values, with percentage difference for most of them less than or near to 10%. The simulation results for maximum queue length is shown in Table 5.

Table 5. Percentage differences of field data and simulation output for maximum queue length at each approach

Set	Parameter Values	Variations in Parameter Values	% Difference of Field Data and Simulation Output for Maximum Queue Length						Cumulative % Difference
			MG SL	MG ML	TK SL	TK ML	OB	SM	
5	Average standstill distance (m)	**0.40**	53.17%	3.49%	9.04%	28.27%	10.91%	4.48%	109.37%
		0.60	77.76%	10.72%	6.17%	59.71%	3.04%	44.65%	202.05%
6	Additive part of safety distance	**0.10**	70.34%	11.68%	1.15%	31.45%	1.26%	37.99%	153.85%
		0.20	87.06%	19.78%	6.35%	55.41%	0.21%	61.36	230.17%

Note: MG – Maitighar, TK- Tinkune, OB – Old Baneshwor, SM – Sankhamul, ML – Main Lane, SL – Side Lane

The percentage difference results obtained during refinement of both parameters indicates better convergence for both maximum queue lengths and traffic volumes. The bold highlighted values showed, in general less percentage difference or better convergence from field maximum queue lengths, as compared to the other value of same parameter. However, the percentage difference for maximum queue length at Maitighar Side Lane, Tinkune Main Lane and Sankhamul is still as high. This is because the simulation results are due to change in only one of the parameter values at a time, while keeping the values of another parameter constant. The combination of all optimum parameter values will be taken in the final calibration.

3.1.3. Final Calibration

The set of optimum parameter values obtained from the previous steps of calibration, was given as input in the final step of calibration . Ten simulation runs were done for peak hour duration for ensuring that different random seed values for these simulation runs showed consistent results. GEH and RMSNE values were calculated from the simulation results and field data. GEH and RMSNE results for Traffic Volume and Maximum Queue Length for all intersection approaches satisfied the threshold criteria with GEH less than 5 and RMSNE less than 0.15, as shown in Table 6 and 7 respectively.

Table 6. GEH and RMSNE values for Traffic Volume during Final Calibration at each approach

Time (AM)	Intersection Leg	Links	Traffic Volume (veh/hr)		GEH	RMSNE
			Field	Simulated		
10:30 - 11:30	Maitighar	MG SL	593	590	0.12	0.04
		MG ML	2,307	2,124	3.89	
	Tinkune	TK SL	1,513	1,524	0.28	
		TK ML	6,140	5,808	4.30	
	Old Baneshwor	OB	1,978	1,892	1.96	
	Sankhamul	SM	1,595	1,559	0.91	

Note: MG – Maitighar, TK- Tinkune, OB – Old Baneshwor, SM – Sankhamul, ML – Main Lane, SL – Side Lane

Table 7. GEH and RMSNE values for Maximum Queue Length during Final Calibration for each approach

Time (AM)	Intersection Leg	Links	Maximum Queue length (m)		GEH	RMSNE
			Field	Simulated		
10:30 - 11:30	Maitighar	MG SL	118.67	117.48	0.11	0.10
		MG ML	118.08	120.08	0.18	
	Tinkune	TK SL	96.42	82.87	1.43	
		TK ML	181.08	210.28	2.09	
	Old Baneshwor	OB	84.25	74.83	1.06	
	Sankhamul	SM	107.58	114.75	0.68	

Note: MG – Maitighar, TK- Tinkune, OB – Old Baneshwor, SM – Sankhamul, ML – Main Lane, SL – Side Lane

As the calibration threshold requirements have been satisfied, the final set of parameter values obtained have been summarized in Table 8.

Table 8. Final Calibrated Parameters Values

Parameters		Final Calibrated Values
Following		
Look ahead distance	Min (m)	20
	Max (m)	100
Look back distance	Min (m)	12
	Max (m)	100
Wiedemann 74		
Average standstill distance (m)		0.40
Additive part of safety distance		0.10
Multiplicative part of safety distance		0.80
Lane Change		
Min. clearance (front/rear) (m)		0.40
Safety distance reduction factor		0.40

The calibrated VISSIM model was also validated using the remaining two days data set, which is different than that used for calibration. Validation results for GEH and RMSNE were also found to be within threshold limits.

3.2. Scenario Analysis

The simulated travel time results for case without bus stops are shown in Table 9, while the average vehicular delay under existing bus stop condition is shown in Table 10.

Table 9. Average vehicular travel time without bus stops

Segments	Travel Time (sec)
Maitighar-Tinkune direction	**127.06**
Tinkune-Maitighar direction	**96.12**

Table 10. Average vehicular Delay under existing bus stop condition

Stop Position	Distance from Intersection (m)	Length of Bus Stop (m)	Maximum Dwell Time (sec)	Travel Time (sec)	Average Vehicular Delay (sec)
Maitighar-Tinkune direction	25	70	180	180.61	53.55
Tinkune-Maitighar direction	30	70	120	160.73	64.61

Table 11 shows the average vehicular delays due to bus stops, from simulation runs for all combinations of scenarios, with reference to the travel time obtained in Table 9.

Table 11. Average vehicular delays from Scenario analysis

Bus Stop Parameters			Average Delay due to Bus Stop (sec)			
Distance of Bus Stop from Intersection Stop line (m)	Length of Bus Loading Area (m)	Maximum Dwell Time (sec)	Maitighar- Tinkune Direction		Tinkune -Maitighar Direction	
			Upstream	Downstream	Upstream	Downstream
40	40	60	14.47	20.80	33.62	29.78
		90	21.93	29.38	62.72	54.04
		105	41.14	38.70	294.64	82.96
		120	52.23	42.63	441.12	93.60
	60	60	15.01	15.41	24.14	35.92
		90	21.68	21.26	49.00	55.18
		105	44.73	27.85	130.48	79.25
		120	46.48	30.43	280.70	90.05
60	40	60	17.06	15.41	24.47	38.81
		90	20.63	21.26	59.72	56.71
		105	45.78	27.85	299.97	89.20
		120	58.90	30.43	406.13	107.49
	60	60	17.06	13.98	19.76	28.33
		90	20.63	19.26	37.52	42.30
		105	39.39	24.81	92.35	59.88
		120	52.41	27.80	87.85	79.76
80	40	60	15.39	13.98	21.23	28.72
		90	23.51	19.26	60.94	41.89
		105	38.73	24.81	105.88	66.71
		120	47.71	27.80	343.14	113.17
	60	60	15.39	17.33	22.15	29.37
		90	23.51	24.57	36.38	48.84
		105	40.20	33.51	73.93	77.93
		120	48.39	36.65	120.96	71.48
100	40	60	12.16	17.33	19.28	31.80
		90	16.21	24.57	75.99	52.00
		105	26.23	33.51	232.64	92.85
		120	38.18	36.65	273.72	100.42
	60	60	12.16	15.40	19.72	28.82
		90	16.21	21.50	36.01	45.91
		105	24.58	28.48	71.58	63.97
		120	41.97	31.29	73.01	88.58
120	40	60	9.19	15.40	20.70	31.62
		90	22.39	21.50	46.34	51.89
		105	30.27	28.48	85.45	127.93
		120	36.14	31.29	241.34	113.25
	60	60	9.20	14.74	19.71	29.69
		90	22.39	20.65	38.77	45.37
		105	29.27	26.39	54.17	74.56
		120	36.01	25.90	69.22	92.48
140	40	60	12.08	14.74	15.72	33.12
		90	16.94	20.65	35.73	50.60
		105	33.16	26.39	182.57	87.11
		120	37.63	25.90	206.38	126.34
	60	60	12.08	13.23	16.19	29.06
		90	16.94	18.28	36.65	44.28
		105	32.87	24.23	72.81	58.14
		120	36.32	26.58	65.63	78.44

These results from Table 11 have been interpreted in the subsequent sub-headings.

3.2.1. Upstream Downstream Comparison

In the Maitighar-Tinkune direction, for lower values of maximum dwell time (60 sec and 90 sec), the delays at upstream positions are less by few seconds or very near to that of downstream positions. However, for higher values of maximum dwell time (105 sec and 120 sec), the delays at downstream positions are significantly less than at the upstream positions, particularly when the distance of bus stop from intersections are 80 m or less. These patterns are the same whether the bus loading area lengths are 40 m or 60 m.

On the other hand, in the Tinkune-Maitighar direction, for lower values of maximum dwell time (60 sec and 90 sec), the delays at upstream positions differ less to downstream positions. However, for higher values of maximum dwell time (105 sec and 120 sec), the delays at upstream positions are significantly higher than at the upstream positions, particularly when the distance of bus stop from intersections are 80 m or less. The extremely high delays for bus stops located closer to the intersections (less than 80 m) at the upstream positions are because of longer queues being generated due to high traffic volume in the Tinkune-Maitighar direction. The delays reduced when the distance of bus stop from the intersection increased, due to decreasing interaction between bus stop dwelling and queue at the back of intersection. Within the Tinkune-Maitighar direction, the delays were lower for 60 m loading area length than for 40 m.

3.2.2. Variation in bus stop parameters

Distance between start of bus stop and intersection stop line

At both the upstream and downstream positions of both Maitighar-Tinkune and Tinkune- Maitighar directions, when the distance between start of bus stop and intersection stop line is increased, the delay decreases provided the length of bus loading area and maximum dwell time remained constant. This can be interpreted as, the farther the bus stop loading areas are placed from the intersection, the dwelling public transport vehicles (bus, micro and tempo) interfere less with the queues formed at the intersection and arriving vehicles don't have to stop beneath. So, the blocking effects caused due to the dwelling vehicles are reduced.

Length of bus loading area

The delays for either 40 m or the 60 m values in the upstream and downstream positions of Maitighar-Tinkune directions are almost the same. However, for upstream position of Tinkune- Maitighar direction, there are significant reductions in delay when the loading area is increased from 40 m to 60 m. Similarly, in downstream position of Tinkune-Maitighar direction, the delays have slightly decreased for increase in loading area length. Greater loading area length occupies more public transport vehicles causing less queues to form behind bus stops.

Maximum dwell time

At the upstream and downstream positions in both the Maitighar-Tinkune and Tinkune- Maitighar directions, when the maximum dwell time is increased from the range of 60 sec to 120 sec, the delay increased significantly. This is obvious, as the more vehicles dwell at the stops near intersection, the more their own delay increases. Furthermore, the increasing vehicles dwelling time also block other approaching vehicles behind them for longer durations, thus increasing the delay of other vehicles too.

4. Conclusion

In this study, calibration and validation of a micro-simulation model to replicate the traffic conditions at the New Baneshwor intersection was done using VISSIM. Then, the effects on vehicular delays due to three bus stop parameters at upstream and downstream positions of curb side bus stops were analysed. Finally, the scenario for minimum vehicular delays was also obtained. For most of the simulation results, the downstream positions were found to have lesser vehicular delays than the upstream ones for higher values of maximum dwell times (105 sec and 120 sec). On the other hand, for lower values of maximum dwell times (60 sec and 90 sec), the vehicular delays for upstream positions were found to be lesser than or near to that of downstream positions. With respect to the bus stop parameters, the delay showed a decreasing trend when the distance between bus stop and intersection was increased from 40 m to 140 m. The bus loading area length didn't show any significant effect on delays. Increase in the maximum dwell time from 60 sec to 120 sec showed a significant increase in the delays. The results showing the scenarios for minimum delay have been summarized in Table 12.

Table 12. Scenarios with Optimum Bus Stop parameters for Minimum Delay

Direction	Position	Distance of Bus Stop from Intersection Stop line (m)	Length of Bus Loading Area (m)	Maximum Dwell Time (sec)	Average Travel Time (sec)	Average Delay due to Bus Stop (sec)	% Reduction in Delay from Existing Condition
Maitighar – Tinkune direction	Upstream	120	40	60	136.25	9.19	82.84 %
Tinkune-Maitighar direction	Upstream	140	40	60	111.84	15.72	75.67 %

When the vehicular delays in these optimum bus stop configurations and maximum dwell times were compared to that of existing conditions, the delays were found to reduce significantly by 82.84% for the Maitighar-Tinkune direction and by 75.66% for the Tinkune-Maitighar direction. This shows that curb side bus stops have significant impact on vehicular delays on their respective curb side lanes.

There are some limitations in this study, which should be analysed for better verification of the results. The effect of green time ratio of the intersection traffic signal and variation in saturation flow rate shall also be examined in addition to the bus stop parameters. The study could cover only morning time data. Analysis of day and evening periods shall also be carried out.

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Comparative analysis of different non-rigid crash barriers: A case study of Nepal

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Abstract

Crash barriers are one of the most important components for traffic safety. Despite their importance, there is no advancement in their tests in Nepal. As a result, the design standards for crash barriers are yet to be updated and further fails to include wire rope barrier system. This study aims to see effectiveness of three different types of non-rigid barriers namely, W-beam, thrie beam and wire rope barrier in context of Nepal analytically using finite element tool Abaqus FEA. The developed analytical model is first validated with a full-scale test from NCHRP report 350. Further, the validated model is used for the simulation of crash using Abaqus/Explicit for each type of barrier system. The behavior of the crash barriers is compared in terms of two major crash parameters: deflection and acceleration severity index (ASI). The results show thrie beam with smallest deflection of 0.871 m and largest ASI of 0.82. Wire rope barrier undergoes largest deflection of 1.408 m but incurs smallest ASI of 0.67 ensuring comparatively higher safety to the passengers. Despite the safety factor of wire rope barrier, location for provision of the barrier must be given utmost care as it requires large clearance beneath the barrier. The comparative analysis of the barriers further assists in formulation of revised design standards in Nepal. Furthermore, the study supports in evaluating the appropriateness of wire rope barrier which has been strictly limited to pilot application in Nepal.

Keywords: Crash barrier; Acceleration Severity Index; Finite Element Modeling; Abaqus

1. Introduction

Road safety is one of the major issues of concern for traffic engineers and officials. Every year road crashes take lives of numerous people around the world. As per global status report on road safety 2018, by World Health Organization [1], the number of deaths caused by road traffic crashes every year is around 1.35 million. Nepal is also a victim of high number of road crashes. In the fiscal year 2078/79 (BS), the number of deaths reported in the Kathmandu valley due to road crashes was 191, with 257 serious injuries out of 10,733 crashes [2]. Crash barriers play a major role in coping with the effects of such events. With proper choice of location and type of crash barrier, road safety can be significantly enhanced.

Different types of crash barriers are used in roads depending on location and surrounding. The commonly used types are W - beam barrier, thrie beam barrier, wire rope barrier and concrete barrier. Out of these, the former two are classified as semi-rigid barrier, wire rope as flexible barrier and concrete barrier as rigid barrier, classified as per their deflection behavior during crash. The provisions for use and specifications for these different types of crash barriers are provided in guidelines which are formulated by different countries. Different international guidelines have been developed by Indian Road Congress (IRC) [3], American Association of State Highway and Transportation Officials (AASHTO) [4] etc. National guidelines for crash barriers are Road Safety Notes 6 [5], Nepal Road Standard 2070 [6] and Standard Specifications for Road and Bridge Works [7]. Despite the availability of different literature on road safety in Nepal, wire rope barrier hasn't been introduced in any of them. Moreover, as compared to international guidelines, Nepalese guidelines seem less detailed with some shortcomings in each of

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them. This highlights the need for a well-detailed and specific guideline that satisfies the requirements of the present context in Nepal.

Analysis of crash barriers requires full-scale experiments to be conducted. Guidelines for tests are provided by different literature like National Cooperative Highway Research Program (NCHRP) Report 350 [8], Manual for Assessing Safety Hardware (MASH) [9]. Full-scale tests provide visual inspection as well as detailed results about barrier allowing detailed evaluation of the barrier. However, they incur a huge expense and different test runs. Despite the necessity of latest safety guidelines, development of full-scale tests in Nepal is little to none. A suitable alternative to full-scale test is numerical simulation. Vehicle crashes are usually simulated using finite element tools in order to obtain results fast and economically. The most commonly used finite element software is LS-DYNA [10]. One of the first numerical simulations in LS-DYNA was conducted by Ren et. al. [11]. The authors compared the computational results with experimental in order to prove the correctness of the computational model. Borovinsek et. al. [12] simulated vehicle crash conditions for high containment levels using LS-DYNA and found a good agreement between simulation and real crash tests. Besides LS-DYNA, Abaqus FEA [13] is also used for simulation of crash. Latorre et. al. [14] presented a correlation between simulation and full crash test in Abaqus modeling software. Ogamia and Tasel [15] investigated the use of Abaqus/Explicit for simulation of crash and verified the suitability of Abaqus/Explicit from the results. Sigdel [16] used Abaqus FEA to study the impact of vehicle crash on system foundation. The author calibrated the Abaqus model and used the calibrated model to analyze the foundation response.

This work aims to compare the non-rigid crash barriers: W-beam, thrie beam and wire rope barrier, in context of Nepal. As full-scale tests are costly, numerical simulation can be a feasible option for crash barrier analysis for Nepal. Having no such analyses done previously for crash barriers in a detailed manner, this research aims to pioneer numerical simulation studies of crash barrier in context of Nepal. W-beam and thrie beam are commonly used barriers in Nepal, while wire rope barrier is limited to one pilot application. Although concrete barriers are commonly found in Nepal, they require extensive modeling and therefore, are not included within the scope of this research. The barriers are compared based on two major crash parameters namely, deflection and Acceleration Severity Index (ASI). Performance of the crash barriers are evaluated using the above parameters so as to suggest the suitability of each type of barrier. Further, this research intends to provide suggestions for the formulation of latest safety guidelines.

2. Methodology

This research makes use of Abaqus FEA [13] for simulation of vehicle crashes. Different elements of crash barrier and vehicle were modeled in Abaqus CAE and were brought together to form an assembly. The complete FE model was run using Abaqus/Explicit to obtain the results. In the first part of research, the simulation performed was validated against a full-scale test: NCHRP Report 350 Test Level 3 (TL-3) [17]. The validated model was modified as necessary to represent simulation of other non-rigid barriers.

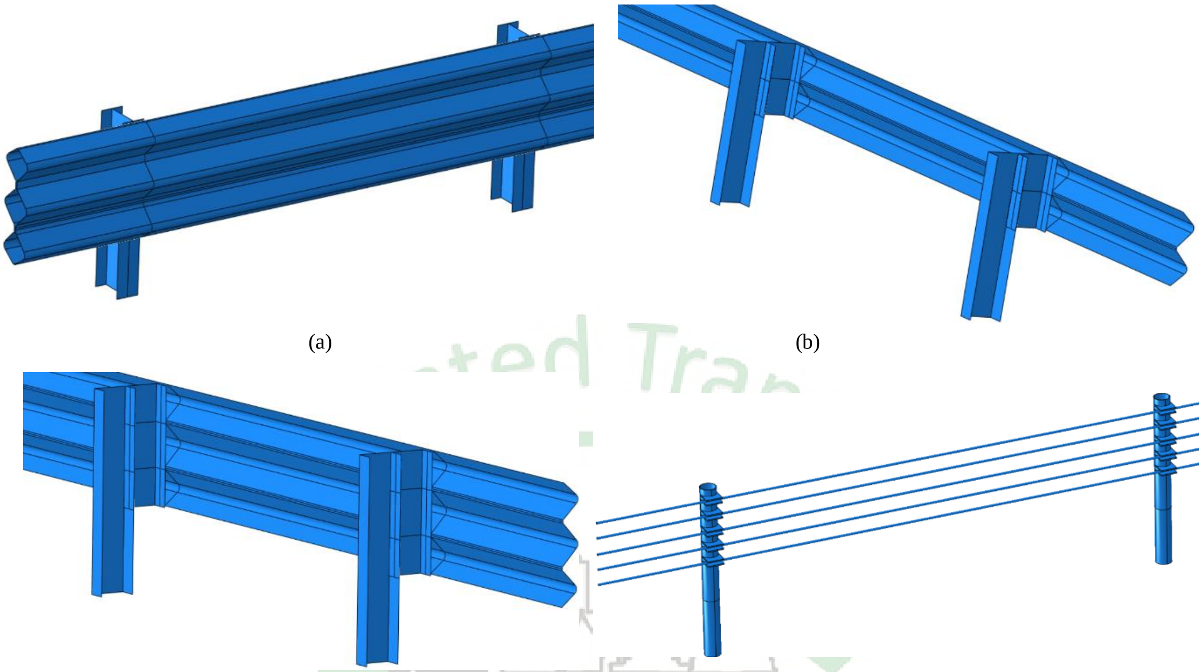
2.1. Finite Element Modeling

The geometry used for the crash barrier in the validation was as per the NCHRP Report 350 TL-3 [17]. The tubular thrie beam and vertical posts of I section were modeled using shell element of respective thickness. The material assigned to the beam and post was steel with properties as indicated in Table 1.

Table 1. Steel properties

Properties	Abaqus Input	
Elastic Modulus (MPa)	200000	
Yield Stress (MPa)	250	
Poisson's Ratio	0.26	
Density (Kg/m^3)	7850	
Plastic properties		
Stress (MPa)	250	475
Plastic Strain	0.00	0.20

The steel properties assigned are in compliance with the properties used by Ogamia and Tasel [15]. The W-beam and thrie beam used in the research were in accordance with the specifications of Standard Specifications for Road and Bridge Works [7]. Channel section of 75 mm x 150 mm and 5 mm thickness was used for steel post and spacer for both W-beam and thrie beam both of which were of thickness 3 mm. Both of the barriers were modeled using shell element with steel properties as indicated in Table 1. Wire rope barrier was modeled in accordance with the barrier available in Narayanghat-Muglin section. Cable of 20 mm diameter and hollow post of 140 mm diameter and 5 mm thickness was modeled using solid element with steel properties as earlier.



(a) (b)

(c) (d)

Figure 1: Abaqus model of barriers: (a) Tubular thrie beam (for validation) [17] (b) W-beam (c) Thrie beam (d) Wire rope

A 2000 Chevrolet C2500 pickup truck as described in full scale test, NCHRP Report 350 TL-3 [17] was used for vehicle model. For simplicity, vehicle was modeled as rigid solid element with inertial mass of 2051 kg keeping the dimensions same as that in full scale test as shown in Figure 2. Since the vehicle model is a standard test vehicle, same was used for validation as well as further analysis. The road was also modeled as rigid solid element.

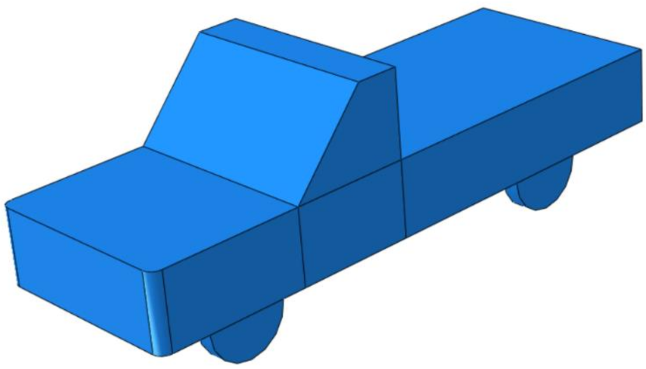


Figure 2: Abaqus model of vehicle

2.2. Interaction and Load

In order to simulate the contact between different surfaces coefficient of friction was set to 0.001 which was based on the report of Ogamia and Tasel [15]. Higher value of friction coefficient caused higher stress in vehicle tires resulting in deviation from actual behaviour [15,16]. Therefore, a low value was chosen. The posts in each of the barriers except wire rope barrier were fixed at bottom so as to represent the connection of posts to the ground. For the wire rope barrier, the post was pinned on the circumference of the part of the post below the ground. This was done due to low depth of penetration of posts in case of wire rope barrier. The bolt connections between posts and beam were represented using 'cartesian' connector available in Abaqus [13]. The stiffness of connector was set very high to a value of 100000000 N/m so as to transfer all the forces and the failure load was adopted from the report of Ogamia and Tasel [15]. As validation was done using the connector with aforementioned property, the use of connectors was justified.

Gravity load was assigned in form of acceleration of value $g = 9.81$ m/s^2 acting vertically downwards. The velocity of 100 km/h was assigned to the centre of mass of vehicle by resolving the velocity into lateral and longitudinal direction based on impact angle of 23.8°.

2.3. Validation

Different elements were brought together to form a complete model for validation as shown in Figure 3. The test parameters for validation were kept as follows: A 2051 kg pickup truck hit a tubular beam barrier with a speed of 100 km/h at an angle of 23.8° as indicated in the full-scale test. Since this test corresponds to test level 3 to NCHRP Report 350 [8], same test parameters were adopted for further analyses. The maximum permanent and dynamic deflection of the barrier in full-scale test were 1.69 ft (0.515 m) and 1.91 ft (0.582 m) respectively. The corresponding values from simulation were 0.529 m and 0.563 m respectively which differed by 2.72 % and 3.26% from the real test. The final state of beam in full-scale test and Abaqus simulation are compared in Figure 4. As deflection and ASI are the major parameters to be studied, the close agreement of deflection of barrier validates the use of Abaqus FEA for simulation of vehicle crash.

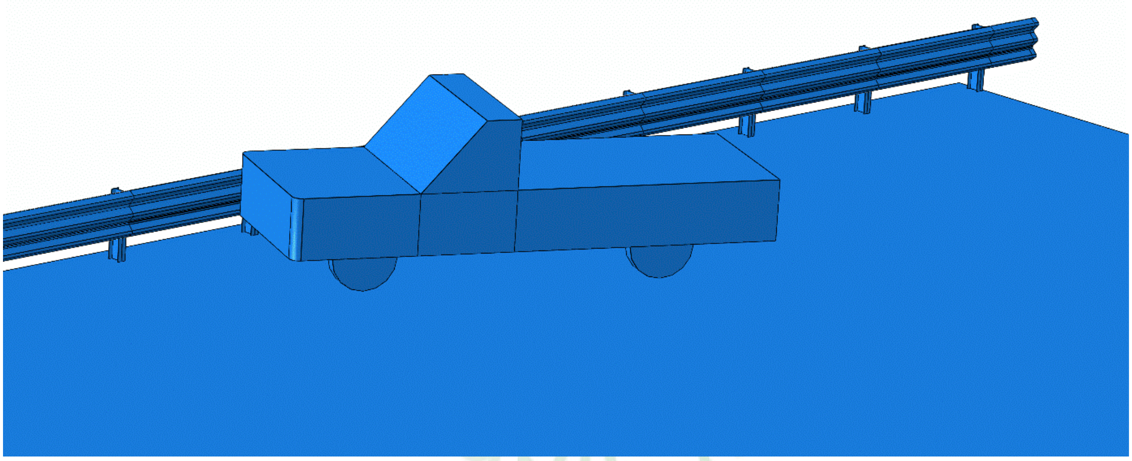
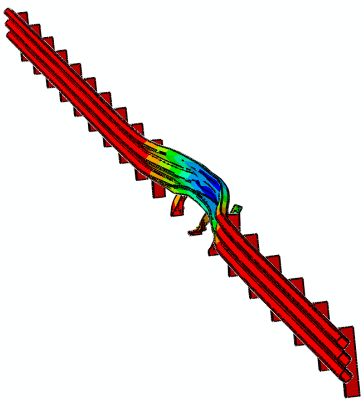


Figure 3. Assembled model for validation

(a)



(b)

Figure 4. Comparison of final state of beam: (a) Full scale test [17] (b) Abaqus model

2.4. Analysis

The validated model was used in analyses of non rigid barriers with modifications as necessary for the barrier. A sample of such model is shown in Figure 5 which represents wire rope barrier. As mentioned earlier, the test parameters were set similar to the ones used for validation purpose. The impact point was set at 0.3 m upstream of 5th post in all the cases. For each of the barrier, the maximum deflection was found from the analysis result. ASI was also calculated for each time using the methodology, which follows EN 1317 [18].

$$ASI(t) = \sqrt{\left(\left(\frac{a_x(t)}{\hat{a}_x}\right)^2 + \left(\frac{a_y(t)}{\hat{a}_y}\right)^2 + \left(\frac{a_z(t)}{\hat{a}_z}\right)^2\right)} \quad (1)$$

Where,
$a_x(t), a_y(t), a_z(t)$: Average 50 ms acceleration in longitudinal, lateral and vertical direction respectively
$\hat{a}_x, \hat{a}_y, \hat{a}_z$: Acceleration limit in longitudinal, lateral and vertical direction respectively
($\hat{a}_x$ = 12g, $\hat{a}_y$ = 9g, $\hat{a}_z$ = 10g; g = 9.81 m/s^2)

ASI is used to evaluate occupant risk in a vehicle crash. Higher ASI values represent higher risks for occupants and hence, crash barrier becomes more unsafe. Maximum value of ASI should preferably be less than 1 [18]. The results for ASI and deflection are compared for each of the test crash barrier.

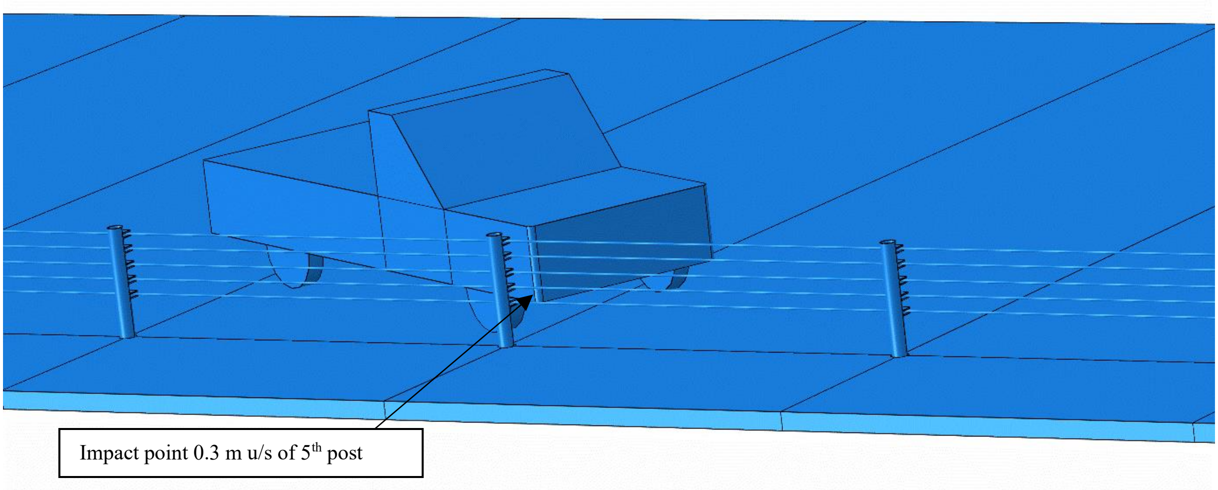


Figure 5. Assembled model for wire rope barrier

3. Results & Discussion

The simulation for each of the crash barrier was run for 0.3 s. Instant of maximum deflection for each of the barrier is presented in Figure 6, 7 and 8. Wire rope barrier experienced the most deflection of all the barrier systems, with maximum deflection of 1.408 m. Second to that is the W - beam barrier with maximum deflection of 1.211 m and lastly, thrie beam with maximum deflection of 0.871 m. A plot of deflection of each barrier at different time values is shown in Figure 9.

ASI values were calculated manually from the data of velocity at centre of mass of the vehicle. Thrie beam was found to have the maxium ASI value of 0.82 among the test barriers. W - beam resulted in ASI value of 0.72, and wire rope barrier had least ASI value of 0.67. Similar to plot of deflection, a plot of ASI at different times is shown in Figure 10.

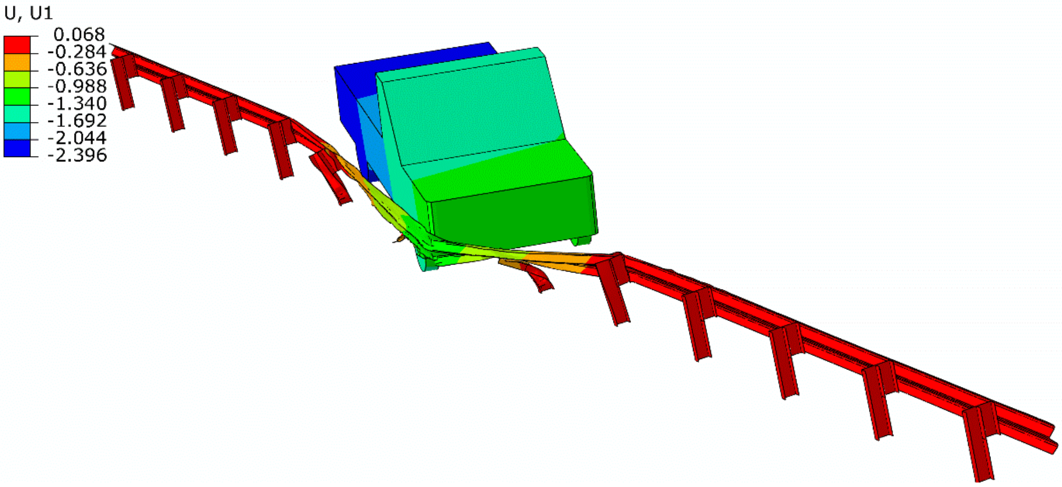


Figure 6. Maximum deflection of W-beam (0.2 sec)

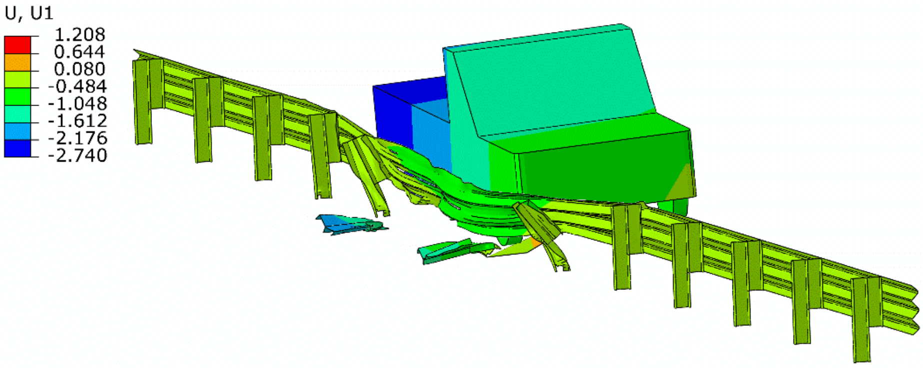


Figure 7. Maximum deflection of thrie beam (0.22 sec)

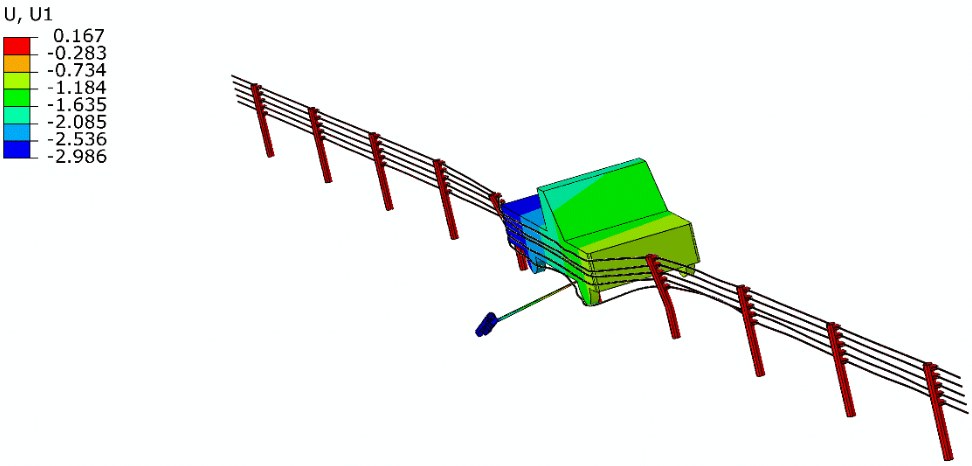


Figure 8. Maximum deflection of wire rope barrier (0.27 sec)

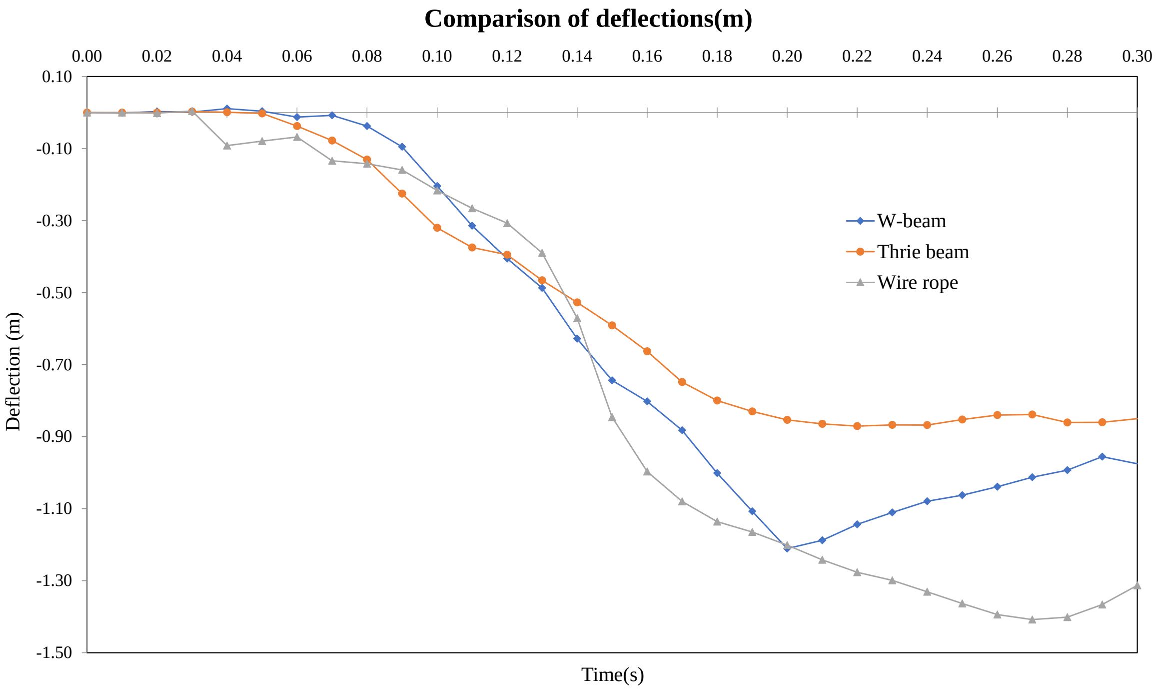


Figure 9. Deflection vs time for different barriers

W - beam and Thrie beam are relatively more rigid than wire rope barrier. This evidently caused them to deflect less than the wire rope barrier. Due to similar reasoning, the higher rigidity caused the vehicle to decelerate faster that eventually led to higher ASI value. Between W - beam and thrie beam, thrie beam offer more rigidity so that thrie beam experiences the lowest deflection and highest ASI.

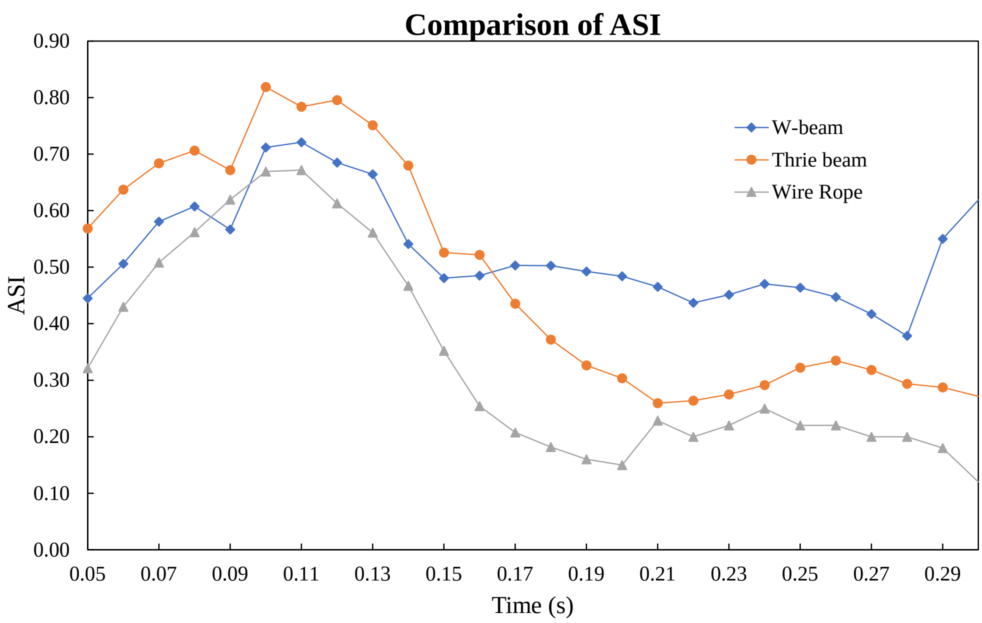


Figure 10. ASI vs time for different barriers

4. Conclusion

This study justifies the wide use of W - beam in roads of Nepal. With deflection less than wire rope barrier and ASI less than thrie beam, W - beam offers a good protection against crash and adequate safety for the passengers.

Thrie beam also forms a good crash barrier system with less damage and hence less maintenance than that of W - beam. Although wire rope barrier offers comparatively higher safety to the passengers, its high deflection limits its use in critical locations. Especially in the hill roads where sufficient clearance can't be ensured beyond the barrier, wire rope barrier may prove to be less effective. However, in roads with sufficient clearance and wide medians, wire rope barrier can prove to be the safest crash barrier system. For the formulation of latest road safety guidelines, inclusion of the wire rope barrier is a necessity, however, with proper provision and guidelines for the barrier.

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Role of Financing Institutions in the Time and Cost Performance Management of Road Infrastructure Construction in Nepal

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Abstract

Road project financing under the Department of Roads (DoR) is arranged by the Government of Nepal's own funding as well as multilateral and bilateral financing institutions. Those financings have substantial differences in project planning and implementation management approaches. This research analyses implementation management approaches adopted by three financing institutions and their effect on road projects' time and cost performance. First, descriptive statistics were used to analyze the contract implementation performance in each financing arrangement. Then, Kruskal – Wallis test was used to find the differences between the three financing institutions' roles. The data were further analyzed using the Mann – Whitney U test to compare each institution's role in the time and cost performance of road projects. The results showed that those three institutions have significant differences in project implementation management. Further, after comparing each financing arrangement in terms of time and cost overrun risks management, the results of the Mann – Whitney U test also supported the differences in mitigating delay risks. The time overrun was less under multilateral financing institutions financed projects. This result was supported by multilateral financers' involvement in planning, implementation management and capacity development of stakeholders. It can be concluded that the multilateral financing approach support minimizing the time overrun risk. In addition, proper adoption of key measures of multilateral financing is found worthful for the overall improvement of project management under the DoR. This suggests that DoR needs to internalize the best practices of multilateral financing institutions' approaches in project management to improve overall project performance.

Keywords: *Financing institutions; Resource management; Kruskal – Wallis method; Mann-Whitney U test; Project delay.*

1. Introduction

Infrastructure development projects have always the risk of time and cost overrun due to high risk and uncertainty. During the implementation of such projects, proper risk management approaches are incorporated into the system with due consideration of proper resource management. The institution that provides financial resources also has an influence on the implementation process as well as the project planning process. For road infrastructure projects under the central government of Nepal, financing arrangement is usually from the Government of Nepal (GoN), Multilateral Financing Institutions (MFI), or Bilateral Financing Institutions (BFI). Multilateral financing institutions are Asian Development Bank (ADB) and World Bank (WB), and the bilateral financers are the Export-Import (EXIM) Bank of India, China, and the Japan International Cooperation Agency (JICA). In this context, the best practices of multilateral financing institutions are not fully internalized in the GoN system of project management although there is continuous support from them on capacity development and project management. Delay is also common in multilateral and bilateral financed projects.

They are also facing time and cost overrun issues during their implementation. One study in the road sector of Laos identified that contractor's cash flow, delayed payment by the owner, difficulty in financing by the contractor, financial issues related to the owner, and insufficient vehicles and equipment for the work are the top five delay factors (Bounthipphasert, S. et al., 2020). A similar study on public sector infrastructure project delay in Saudi Arabia investigated that training and capacity development, weaknesses in supervision arrangement and lack of planning of projects by government agencies are the major contributing factors to time and cost overrun (Alsuliman, J. A., 2019). This indicates that human resource management is not adequate which ultimately affected the time and cost performance of the infrastructure projects. In developing and least-developed countries, road infrastructure projects are most likely to experience delays due to either financial issues, planning issues, or external influences related to the project's outside agents (Mejia G. et al, 2020).

The capacity of the financing arrangement from the government is one of the major factors of delay in most developing countries. One study in Turkey identified the financial arrangement of the government as one of the most prominent factors of time and cost overrun (Aydin, D., & Mihlayanlar, E., 2018). This gives the idea that institutional capacity development plays an important role in mitigating the time and cost overrun risks during the implementation of infrastructure projects, such as by improving the planning capability efficiency of the owner institutions (Khumalo, M. J., Choga, I., & Munapo, E., 2017). Another study identified financial resources assurance as one of the most critical delay factors in developing economies irrespective of the level of economy (Venkatesh, P. K., & Venkatesan, V., 2017).

Road projects around the world have different delay issues based on the country's context. Many of the delay issues are similar in the developing world. One of the studies of delay of road projects in 25 developing countries identified and categorized the delay reasons as owner-related, contractor-related, common and outside the control of the parties. Owner-related causes which are relevant in Nepal's case are delayed decision-making, slow decision and administration in the Client organization, protracted financial procedures, financial difficulties of the owner, low performance of the contractor, delay in progress payment, owner's lack of experience and involvement in the day-to-day activities. Inadequate contractor organization for the specific project and the experience of the contract manager of the contractor are a few highly influential delays causes from the side of the contractor. Changes in the project duration without accessing the proper cause of delay as per the contract and delayed relocation of utilities found during the execution of projects are reasons for the delay which showed they disobey the rule of law as agreed in the contract. Changes in the existing regulations and bureaucracy are found the cause delays which are not under the control of contracting parties (Rivera, L. et al.,2020). This comprehensive research highlighted the institutional and procedural weaknesses of government institutions and contractor organizations. Inadequate financing sources and lack of standardized practices within the contracting parties' institutions are the major problems faced by developing nations in infrastructure project executions. As a low-income country, Nepal is facing similar kinds of project management-related issues in the road sector. While considering the financing institutions' role, GoN-financed projects are implemented without due consideration of resource management aspects such as financial arrangement and human resource management. Project planning issues and financial assurances are not properly addressed during the implementation as committed during the preparation stage. Human resource management with a capacity development component is somewhat neglected in most of the GoN-financed projects. The final report published by the Office of the Auditor General (OAG), in 2021 highlighted the weaknesses in resource management, planning and coordination issues as the key factors for time and cost overrun of national pride projects in Nepal (OAG final report, 2021, pp. 15). The mid-hill highway project financed by GoN is an example which has faced planning and resource management issues during the implementation of construction works. Past research highlights the factors influencing the time and cost overrun of infrastructure projects. But, it is not assessed from the perspective of financing institutions' role in mitigating or managing time and cost overrun risk. It is because the government in developing countries have their own traditional system of project management while multilateral or bilateral institutions have a more standardized system of project planning and management.

The main objective of this research is to analyze the role of financing institutions in managing the time and cost performance of road infrastructure development projects in Nepal. It is analyzed from the perspective of technical and managerial support, legal and institutional aspects, planning, and standardized procedures. Data were collected from ongoing and completed contracts under the Department of Roads (DoR). The role of financing institutions in the time and cost overrun was analyzed including the government financing arrangement. The Kruskal-Wallis test was first applied to find the differences in project performance between projects with different financing institutions. The Mann-Whitney U test was then applied to examine the contribution of institutions in mitigating the risk of time and cost overrun.

The significance of this research is that project planning, capacity development, resource management and financial assurance aspects are somehow addressed by multilateral financing institutions. Such supports have a wider influence on the capacity development and implementation management of road projects. But, those standard approaches, technical capacity development and planning procedures are not fully internalized in the government management system. The results of hypothesis testing showed that there was a significant impact of financing institutions on time and cost overrun mitigation. Multilateral financing institutions' role was found most significant for mitigating the time and cost overrun risks in road construction contracts. Furthermore, this research suggests implementing the standard practices of project management applied by multilateral financing institutions in future projects so that GoN and bilateral financed projects can get benefit to improve the overall performance of the projects in Nepal. Ultimately, it will help to visualize the financing institutions' involvement towards improving the project performance through capacity enhancement, proper planning, and human and financial resource mobilization. It will also support for internalization of best practices of multilateral financing institutions in road project implementation under the DoR.

2. Methodology

2.1 Data Collection

This research was performed using the secondary data collected from the DoR under the GoN. The ongoing and completed road construction contracts under the DoR within the period of almost 10 years are considered for the analysis. Those contracts are handled by the central road agency but it includes the works which are the responsibility of the provincial or local government. Ongoing and completed road construction contracts whose original contract cost is greater or equal to NPR 100 million at the time of contract agreement prices are taken as samples for the analysis. Projects are selected from divisions and project offices to include the wider aspects of project delay issues. The collected sample data consists of 462 contracts under government financing, 57 contracts under multilateral financing and 24 contracts under bilateral financing arrangements totaling 543 samples. Accordingly, time and cost overruns in each category were carried out using the original contract duration, revised contract duration and price inflation during the whole period of the contract including scope change cost. In the case of ongoing contracts, the actual time and cost overrun values may change at end of the contract.

The sample size is taken from 2000 ongoing and completed road construction contracts having an original contract cost greater or equal to NPR 100 million. Out of 2000 contracts, 543 contracts are taken for this research purpose and sampling adequacy was tested using the following formula:

$$n = \lambda^2 p(1-p)/d^2 \tag{1}$$

Where,

n: sample size

λ: value based on the confidence level (confidence level of 95% is considered, λ = 1.96)

p: sample proportion (in this case 0.5)

d: margin of error (in this case 0.05)

Using the sample size estimation formula (equation (1)), the calculated sample size is 384. Hence, in this research, the considered sample size of 543 is found adequate for this research (Singh, A. S., & Masuku, M. B., 2014). The requirement of a minimum sample size for the Kruskal – Wallis H test is more than five samples in each category of the dataset. In the case of the Mann – Whitney U test, a smaller sample size of less than twenty uses the U value as test statistics whereas the sample size greater than twenty corresponds to a normal distribution and uses z statistics. In this research, the sample size in each category of the dataset has more than twenty data points which are found adequate for the analysis using Mann – Whitney U test.

2.2 Analysis Method

The time and cost overrun information for each contract after categorization in three financing arrangements were analyzed using descriptive statistics. Maximum, minimum, mean, median, standard deviation and coefficient of variation are calculated in each category and used for analyzing the distribution of the data set. Histograms were prepared to visualize the data distribution and determine the appropriate analytical approach. Considering the distribution of data as non-normal, Kruskal – Wallis test was performed to find the difference in three financing arrangements for time and cost overrun risk management. This test does not differentiate the best alternative. In this context, it is necessary to analyze two financing arrangements one at a time, such as GoN-MFI, GoN-BFI and MFI-BFI. Three hypotheses for time and cost overrun in different financing arrangements are established using Mann – Whitney U test. This test helped to access the best approach to financing and its role in improving project implementation performance. Ultimately, final conclusions were drawn based on planning and implementation approaches adopted by three financing arrangements in road construction contracts.

2.2.1 Kruskal – Wallis H Test

Kruskal – Wallis H test is used to determine whether or not there is a statistically significant difference between the medians of three or more independent groups. It is considered to be the non-parametric equivalent of the One-Way ANOVA. It merely tells that there is somehow a difference exists among the sets of data. So the researchers need to inspect the mean or median values of the dataset and interpret the results accordingly (Ostertagova, E. et al., 2014). In this research, the contracts in three financing arrangements with time and cost overrun values in percentages are compared using this test (Table 1). This test result helps to find the difference between the three types of financing arrangements on time and cost overrun risk management.

Table 1. Hypothesis using Kruskal – Wallis H test

Analysis aspects	Null Hypothesis H_0	Alternative Hypothesis H_1
Time overrun in Government financed, multilateral financial institution financed and bilateral financial institution-financed road construction contracts	No difference between the medians of the three financing arrangement road contracts	Differences exist between the medians of three financing arrangement road contracts
Cost overrun in Government financed, multilateral financial institution financed and bilateral financial institution-financed road construction contracts	No difference between the medians of the three financing arrangement road contracts	Differences exist between the medians of three financing arrangement road contracts

The rank of each data point was calculated in all data sets. Thus calculated rank values were added in each data set separately. Then, the following formula is used to calculate the H value:

$$H = \left[\frac{12}{N(N+1)} * \Sigma\frac{Tc^2}{n_C}\right] - 3 * (N+1) \tag{2}$$

Where,
N: Total number of samples in all groups (combined)
T_c: Total value of the rank number in each group of the dataset
n_c: Number of samples in each group of the dataset

For a sample size larger than five, the H value is treated as a chi-square equivalent and compared to the calculated and critical value from the standard chi–square table at a significance level of 0.05. The degree of freedom is calculated using the number of data sets (in this case number of data set is 3). If the critical value of chi–square is greater than the calculated value, then the null hypothesis is accepted. The follow-up test using Mann – Whitney U test was performed to assess the role of individual financing institutions in handling time and cost overrun risks. The role of each financing institution to mitigate the risk of time and cost overrun is further explained in detail on the result and discussion section.

2.2.2 Mann – Whitney U Test

The Mann – Whitney U test is a non-parametric test applicable for non-normal data distribution. It is used to compare the two independent samples using hypothesis testing. The difference between the two sample sets can be assessed through the difference in medians of those sample sets (McKnight, P. E., & Najab, J., 2010). In this test, the rank of each data point is calculated and summed up the rank values separately in each group of datasets. Thus calculated rank sum was used to calculate the U value of each group of datasets using the following formula:

$$U_1 = (n_1 n_2) + \frac{n_1(n_1+1)}{2} - R_1 \tag{3}$$

$$U_2 = (n_1 n_2) + \frac{n_2(n_2+1)}{2} - R_2 \tag{4}$$

Where,
n_1, n_2: numbers of data in each group of samples.
R_1, R_2: summations of the rank of each group of the dataset
U_1, U_2: Mann-Whitney U values for two sample sets.
The minimum value of U (Min. of U_1 and U_2) is used to calculate the z value. The z value is calculated for a sample size larger than 20 and assuming the normal distribution of the sample. The formula used for the calculation is:

$$z = \frac{U - \mu}{\sigma} \tag{5}$$

Where,

$$\mu = \frac{n_1 n_2}{2} \tag{6}$$

$$\sigma = Sqrt[((n_1 n_2)\frac{(n_1+n_2+1)}{12}] \quad (7)$$

Then, the above-calculated z value is used to test the hypothesis at a significance level of 0.05. The null hypothesis is accepted if the calculated z value is smaller than the critical value.

Three different hypotheses were established to find the significant differences between each two financing institutions' roles in time and cost overrun risk mitigation using Mann – Whitney U test (Table 2). The practices adopted by each financing institution in road project implementation management are assessed thoroughly for finding the role of particular financing arrangements. The details of the analysis results are explained in the results and discussion section.

Table 2. Hypothesis using Mann – Whitney U test

Analysis aspects	Null Hypothesis H_0	Alternative Hypothesis H_1
Time and cost overrun in Government financed and multilateral financial institution-financed road construction contracts	No difference between the medians of the Government financed and multilateral financial institution-financed road construction contracts	Differences exist between the medians of the Government financed and multilateral financial institution-financed road construction contracts
Time and cost overrun in Government financed and bilateral financial institution-financed road construction contracts	No difference between the medians of the Government financed and bilateral financial institution-financed road construction contracts	Differences exist between the medians of the Government financed and bilateral financial institution-financed road construction contracts
Time and cost overrun in multilateral financial institution-financed and bilateral financial institution-financed road construction contracts	No difference between the medians of the multilateral financial institution-financed and bilateral financial institution-financed road construction contracts	Differences exist between the medians of the multilateral financial institution-financed and bilateral financial institution-financed road construction contracts

3. Results & Discussion

3.1. Results of descriptive statistics

At first, time and cost overrun in percentage with respect to original time and cost were calculated. Then, government-financed, multilateral financed and bilateral-financed contracts are separated with their respective statistical values (Table 3). The mean value of cost overrun including the scope change is lowest for government-financed contracts (26.33%) and highest for bilateral financed contracts (37.50%). The mean value of time overrun is also highest in bilateral financing arrangements (123.43%) but lowest in multilateral contracts (53.57%). The maximum cost overrun is 59.17% and the time overrun of 280.82%, and government-financed contracts are the highest among the three. While analyzing the minimum values, the cost overrun of 4.25% is the lowest among the three financing arrangements. On the other hand, the time overrun of zero percent in government-financed and multilateral-financed contracts is the lowest value. The standard deviation and coefficient of variations are smaller in case of cost overrun while time overrun cases are in the higher range.

Table 3. Statistical distribution of data

Data Description (%)	Cost Var_GoN	Time Var_GoN	Cost Var_Multilateral	Time Var_Multilateral	Cost Var_Bilateral	Time Var_Bilateral
Mean	26.33	73.46	35.63	53.37	37.50	123.43
Maximum	59.17	280.82	45.27	188.22	55.39	272.43
Minimum	4.25	0.00	13.61	0.00	18.50	22.78

Median	26.24	60.14	35.30	41.15	39.17	112.30
Standard Deviation	10.77	65.39	8.90	44.13	11.78	89.61
Coeff. Variation	116.07	4276.21	79.25	1947.81	138.81	8030.59

3.2. Distributions of cost overrun

Firstly, the cost overrun pattern has been analyzed using the density histogram. The cost overrun was estimated considering the price inflation percentage from the start of the contract and the cost variation due to scope change during the performance of the contract. In government financed contract case, the distribution is almost normal having largest number of contracts falls within the range of 20-40% price inflation (Figure 1). In case of multilateral financial institutions financed projects, cost overrun pattern is different, with the largest number of contracts have 30-50% price inflation including the price of scope change (Figure 2). Similar to multilateral financing, bilateral

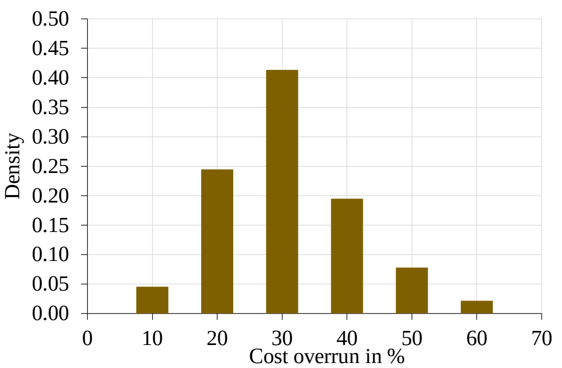

Figure 1. Cost variation during the contract period including scope change in government financed projects

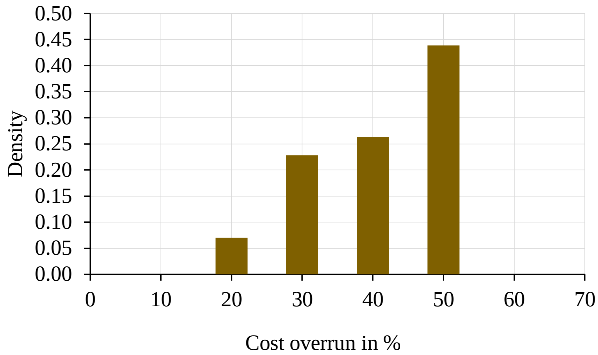

Figure 2. Cost variation during the contract period including scope change in multilateral financed projects

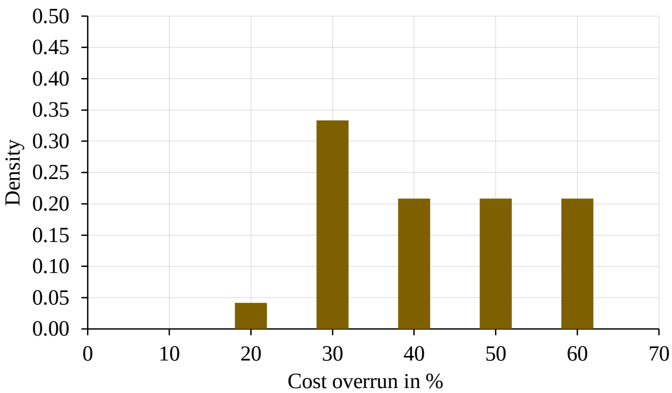

Figure 3. Cost variation during the contract period including scope change in bilateral financed projects

financial institutions financed projects having most of the contracts falls in 30-60% price inflation situation during the whole contract duration (Figure 3).

3.3. Distributions of time overrun

The distribution of time overrun in three financing arrangements is different from the cost overrun explained in the previous section. The projects financed by the government have a time overrun ranging from zero to a maximum of 270% of the original contract duration. The distribution is not normal having more proportion of contracts in the left corner of the histogram (Figure 4). The pattern of time overrun in multilateral financial institutions' financed projects is different. The distribution showed that most of the contract's time overrun ranges between 0-90%. Few contracts fall within the range of 90-120% and 190-210% of time overrun. The data distribution is also not normal as in the case of GoN-financed projects (Figure 5). But, the distribution pattern of time overrun in bilateral financial institutions' financed projects is not in a pattern similar to GoN financing or multilateral financing case. The distribution is not following any pattern and is distributed in different spots starting from about 20% to almost 290%. The spot distributions are 20-70%, 80-140%, 160-180% and 240-290% (Figure 6).

3.4. Results of Kruskal – Wallis H test

Based on the non-normal distribution of the dataset, the Kruskal – Wallis H test was performed. The results of this test showed that there are significant differences between the three financing arrangements in managing time and cost overrun issues. The critical value of H for large samples corresponds with the chi-square value. Then, from the standard chi-square table, the calculated value of H is compared with the critical value at a significance level of 0.05. In this analysis, the calculated value of H is larger than the critical value which is the condition to reject the null hypothesis (Table 4). The rejection of the null hypothesis means that there are significant differences between the three financing institutions for mitigating the time and cost overrun risks. But, it does not tell which financing arrangement is best for delay risk minimization. In this case, for the analysis of each individual financing institution's role, Mann – Whitney U test was required. The findings of the Mann – Whitney U test are explained in the next section.

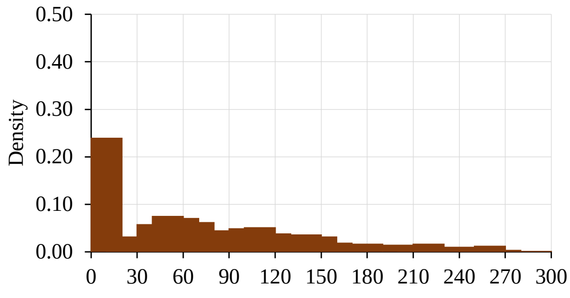

Figure 4. Time overrun in government financed projects

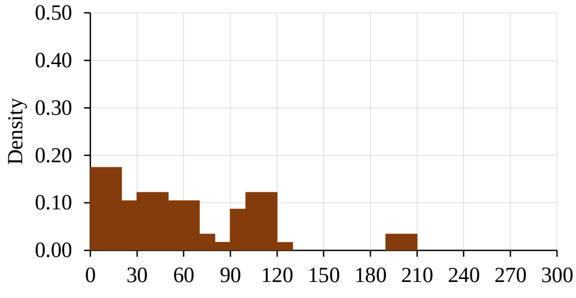

Figure 5. Time overrun in multilateral financed projects

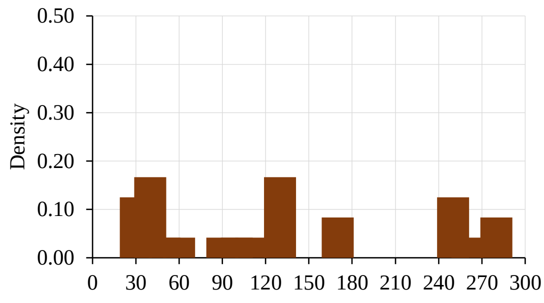

Figure 6. Time overrun in bilateral financed projects

Table 4. Kruskal – Wallis H test results

Analysis aspects	χ2 values at degree of freedom 2 at significance level 0.05		Decision
	calculated	critical	
GoN_MFI_BFI (N = 462+57+24 = 543) _cost overrun	53.943	5.991	χ2-calculated> χ2-critical, Reject H_0
GoN_MFI_BFI (N = 462+57+24 = 543) _time overrun	10.675		

3.5. Results of Mann – Whitney U test

For the study of each individual financing institution's role in managing time and cost overrun risk, Mann – Whitney U test was required. This test was performed three times between GoN-financed projects and multilateral financed projects, GoN-financed projects and bilateral financed projects, and finally multilateral financed projects and bilateral financed projects. The critical values of z statistics is lower than the calculated value of z in all three combinations of financing arrangements (Table 5). This is the condition for the rejection of null hypothesis. It gives the idea that there is significant difference between each combination of financing arrangements in mitigating time and cost overrun risks in road construction contracts. The existence of differences in each combination of financing arrangements while testing Mann-Whitney U test is supported by the descriptive statistics (Table 3).

Table 5. Mann – Whitney U test results

Analysis aspects	z values at significance level 0.05		Decision
	z-calculated	z-critical	
GoN_MFI (n_1 = 462, n_2 = 57) _cost overrun	3.76	1.96	z-calculated> z-critical, Reject H_0
GoN_MFI (n_1 = 462, n_2 = 57) _time overrun	5.32		
GoN_BFI (n_1 = 462, n_2 = 24) _cost overrun	5.37		
GoN_BFI (n_1 = 462, n_2 = 24) _time overrun	4.10		
MFI_BFI (n_1 = 57, n_2 = 24) _cost overrun	85.10		
MFI_BFI (n_1 = 57, n_2 = 24) _time overrun	78.70		

3.6. Discussion

Cost overrun in government-financed projects is on the lower side in comparison to the other two financing arrangements. It is because the collected dataset from the Department of Roads has no information about the price variation due to scope changes in most of the contracts. In the case of the other two financing arrangements, a scope change of almost 15% of the original contract cost and the price inflation during the whole period of the contract is considered. The highest average cost variation in bilateral financial institutions' financed projects indicates that projects are extended haphazardly without assessing the contractual clauses which ultimately adds more cost with time variation (Figure 6). The minimum to a maximum value of the cost overrun range is higher in government-financed projects. It is because few contracts are in the initial stage of implementation having lower price inflation and no scope change issue till the fiscal year 2021-22. The highest value of overrun indicates few contracts have specific site issues such as land acquisition, forest clearance and utility relocation. It is observed that the employer as well as the contractor has not handled those contractual issues properly. Specifically, the employer is more responsible for managing those project planning-related issues. This shows the poor performance of employers during the project planning process.

On the other hand, the time overrun in government-financed projects is in lower than bilateral financing arrangements. It may be due to harsh contractual provisions such as more than 50% of construction material must be from a financing institution/country of origin (Line of Credit Agreement with Export-Import Bank of India dated 25th November 2014) in bilateral financing. On the other hand, there is no direct involvement of financing institutions in capacity development and project planning issues in a comprehensive manner. Although, GoN-financed projects have similar kinds of capacity development and planning-related issues. The main difference between GoN financing with bilateral financing is the involvement of the bilateral financing institution in the certification of funds during the performance of a contract which takes more time for fund release. Poor planning of pre-construction activities and deployment of sufficient technical manpower is also lagging in GoN as well as bilateral financing. But, in the case of multilateral financing, those institutions have a robust system of project appraisal, planning of pre-construction activities and technical support for the implementation management through national and international experts (RSDP financing agreement, 2008). This differentiation can be seen in the lower range of average time overrun among the three financing arrangements (Table 3). Time overrun of minimum value zero indicates that few contracts are in the early stages of implementation or there is a lack of updated information on particular contracts. The maximum value of time overrun in GoN-financed projects indicates site-specific contractual and project planning-related issues in the specific locality which are not properly handled by the contracting parties. Furthermore, GoN central-level road department has additional work volume beyond its jurisdiction. It is because the institutions whose primary role is maintenance management are also involved in new construction. The additional work handled by the central government department is due to political influence in project planning (OAG final report, 2021). Almost 40% of the central road agency projects are within the jurisdiction of provincial and local governments (DoR annual program, 2022-23). The diversity of data distribution indicates that each project has specific issues of time delay. In certain circumstances, each project's critical risk factors are totally different from the other projects. Differing with the monitoring, human and financial resource management, and risk management capability of the project manager and contractor's resource mobilization capabilities differs in the time overrun values (Rivera, L. et al.,2020).

The results of hypothesis testing using the Kruskal – Wallis H test indicates that there is a significant difference exists between the three financing institutions' roles in project delay risk mitigation. Meaning that there is the role of financing institutions in the planning and implementation management of road projects. It means that they are supporting for mitigating the risk of time and cost overrun. Then, Mann-Whitney U test was used to compare the two financing arrangements once at a time. While performing Mann – Whitney U test, it was found that there is significant difference between GoN financing and multilateral financing. Similarly, the difference between multilateral financing and bilateral financing is found significant with the rejection of null hypothesis. Furthermore, the significant difference is observed between GoN-financed and bilateral financed projects in mitigating time and cost overrun risks. All six hypothesis support for the rejection of null hypothesis having calculated z value greater than the critical value of z at significance level 0.05 (Table 5). While comparing GoN and multilateral financing, the descriptive statistics showed that cost variation in GoN-financed projects is less. But, time overrun risk mitigation, multilateral financing institutions' role is found more effective with lower value of average delay time (Table 3). The cost overrun in GoN financed project was found less than the multilateral financing project may be due to a lack of updating of contract information by the department regarding price variation due to scope change. In comparing multilateral and bilateral financing, multilateral financing institutions' role is found more efficient in mitigating the time and cost overrun risks. While comparing GoN financing and bilateral financing, GoN financed projects were more efficient than bilateral financing institutions' financed projects to mitigate the time and cost overrun risks. Out of three financing arrangements, multilateral financing institutions have a long history of planning and capacity development support and continuation to date (SRCTIP, financing agreement, 2020). This supports project management capacity development in the road sector. The results also support for better management approach and standardized procedures of multilateral financing institutions in human and financial resources management as well as the planning of projects.

Finally, multilateral financing institutions provide financial support as well as the capacity development and planning of projects in a standardized manner applicable in the international sector. The road sector connectivity sector I project financed by ADB has capacity development, planning support and contract management support during the planning and implementation of the project (ADB, Project completion report, 2016). A similar kind of arrangement can be found in WB-financed projects. The engagement of WB in the road sector of Nepal through the Road Sector Development Project (RSDP) for the period of more than 12 years supported the institutional capacity development and standardization of contract management approaches (WB, Project completion report, 2020). They also used standardized procedures and guidelines which supersede the provisions of GoN (Public Procurement Act 2007, Clause 67). This provision makes use of well-established approaches adopted by multilateral financing institutions. They use well-defined procedures in every stage of project management, from the project conception to the project handover, and government regulations are often superseded by the regulations of multilateral financing institutions, which makes it easier to take prompt action when implementation issues arise. The establishment of project management institutions, continuous support for capacity development, development of social and environmental management frameworks, financial assurances, procurement transparency and project preparation technical supports are some significant contributions of multilateral financing institutions in road sector development (RSDP financing agreement, 2008). The effect of those contributions is visible in the policy, the legal and institutional arena of project management in Nepal. The evidence in policy and regulatory support for enhancing the procurement environment in Nepal is the support for e-GP system development (Electronic government in Nepal, 2003). Although, the effect of those contributions is not significant due to the lack of internalization of improvement measures in the DoR overall management system.

But, in the case of bilateral financing institutions finance projects have only financial support. Bilateral funding only provides financial support with complicated contractual provisions for implementation (Line of Credit Agreement with Export-Import Bank of India dated 25th November 2014). In some instances, those provisions are difficult to implement and negatively affect the time and cost performance relative to projects financed by multilateral institutions or the government of Nepal. This leads to poor performance due to a lack of capacity development and planning of projects.

However, government-financed projects are not free of issues, as those projects tend to experience clashing activities during the preparation stage, as well as face human and financial resource constraints because of the simultaneous implementation of multiple projects (DoR annual program, 2022-23). These situations occur mainly due to political pressure, which interferes with proper planning and creates time-consuming activities during the project preparation stage. Those misleading activities ultimately affect the project's performance once it enters the implementation stage. The poor performance of GoN-financed projects may be due to a lack of internalization of key aspects of multilateral financing arrangements towards the improvement of project performance. A report published by the McKinsey Global Institute (MGI) (Dobbs et al., 2013) highlights the importance of making the most of infrastructure investment by increasing the productivity of infrastructure. The report argues that by improving and adopting the best practices in selecting and delivering new infrastructure projects and by effectively managing the existing infrastructure, countries could obtain the same amount of infrastructure for 40% less investment.

In overall, the government should learn from the best practices of multilateral financing institutions' standardized practices, planning approaches, human and financial resource management and capacity-building approaches and replicate them in future projects. It will help to develop the capacity of the institution for improving the project's overall performance.

4. Conclusion

In conclusion, the descriptive statistics showed that time overrun risk is lower in the multilateral financing arrangement in comparison to the other two financing arrangements. While testing the hypothesis using Kruskal – Wallis H test, it was found that there are significant differences between the three financing arrangements in mitigating road construction project delay risks. On evaluating GoN-multilateral, GoN-bilateral and multilateral-bilateral financing and their roles in delay risk mitigation, hypothesis testing using the Mann – Whitney U test found significant differences between each combination of financing arrangements. It means that the role of financing institutions significantly differs in mitigating the time and cost overrun risks. Among of them, multilateral financing institutions' support for project planning, implementation management and capacity development has contributed more to reducing delay risk. The approaches adopted by multilateral financing institutions are more robust, internationally accepted and transparent (Procurement Regulations for IPF Borrowers, 2020). Its support is not only on the project basis but also in overall DoR's capacity development in project management (ADB, Project completion report, 2016). But, the results of descriptive statistics do not support the improved status of DoR in delay risk mitigation using its own financial resources. It may be due to a lack of proper utilization of international best practices and standards adopted by multilateral financing institutions and their internalization in the overall project management system of DoR. This research suggests adopting best practices of project planning and implementation for mitigating the time and cost overrun risks. At last, it can be concluded that proper planning and human and financial resource management in any type of financing arrangement will definitely contribute to improving the project implementation performance. Even though the best practices of project management in the international sector are adopted by the projects in multilateral financing, the implementation of projects is not found satisfactory. Those results showed that the government's international capacity building through international financing arrangements is found inadequate. This is the major lacking in capacity development of institutions which ultimately affects the time and cost performance of the overall organization. Specifically, the provisions in multilateral and bilateral financing projects assure the fund throughout the project period. There is always the provision of a dedicated team of supervision through national and international experts. Furthermore, the use of standardized planning and procurement approaches including the environmental management aspects exercised in this project added benefit for the GoN project implementation capacity (NIRTTP, Project completion report, 2019, World Bank, ICR, 2022).

The findings of this research are equally applicable to other developing nations using similar kinds of financing arrangements in the infrastructure development sector. The learning and sustainable capacity development of institutions for proper project management is a key lesson from this research. It will help to open the eyes of policy maker managing road project financing arrangements within the country. The main limitation of this research is that there is no assessment of underlying delay factors which may be more serious than the financing institutions' role. This is only focused on planning, human and financial resource management and a capacity-building component of road project implementation. So the inclusion of other delay factors with a detailed assessment of road projects will be the further research area for mitigating the time and cost overrun risk.

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Urban Intersection Modelling for Signal Coordination and Adaptive Traffic Control under Heterogeneous Traffic Condition: A Case study of Keshar Mahal and Durbar Marg Intersections

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Abstract

This study aimed to improve the operational performance of two closely-located intersections, Keshar Mahal and Durbar Marg, in Kathmandu, Nepal. The current traffic management system is ineffective in clearing the intersections quickly, causing extended wait times for vehicles that overflow into other intersections. Using advanced lane-based micro-analytical tools such as SIDRA INTERSECTION, simulations were conducted to evaluate different phase configurations and signal timing strategies under isolated and coordinated conditions for both pretimed and actuated signalization. The results revealed that pretimed signal coordination with an optimal network signal cycle was the most effective option. This strategy resulted in a 33.4% reduction in total travel time, a 48.8% decrease in total control delay, and an average control delay reduction of 49.2%. Additionally, it led to significant improvements in intersection performance, including a 62.1% decrease in the 95th percentile back of queue at the Keshar Mahal intersection and a 13.9% decrease at the Durbar Marg intersection. The study also compared the results to the existing network in terms of individual intersection performance and network-wide performance, showing the potential benefits of the proposed strategy in improving traffic flow and reducing delays at the intersections.

Keywords: Pretimed Signalization; Actuated Signalization; Signal Coordination; Spillback; Intermittent Stop; Travel Time; Queue Length.

1. Introduction

Traffic congestion is a common problem in many cities, including Kathmandu, Nepal. As the economy grows, the number of vehicles on the road increases, leading to a demand for wider roads. However, limited space and population growth make it difficult to widen roads, thus the need for more efficient traffic management systems. However, these systems developed in developed countries cannot be implemented directly in Nepal as traffic conditions are different. To improve traffic flow and reduce delays, travel time, and queue length in urban areas without building new infrastructure, optimizing traffic signal timing is important. In Kathmandu, most of the intersections are at-grade and traffic signals are installed in some of them but are not updated to current traffic conditions. During peak hours, traffic police manually control the signalized intersections as the existing timing is inefficient. This leads to intersection performance being dependent on the judgment and perspective of the traffic police without scientific analysis. This can lead to extended wait times and delays when the intersection is managed by a traffic police officer with limited experience Two intersections, Keshar Mahal and Durbar Marg, cause significant traffic congestion, particularly during peak hours. The current traffic management system is ineffective in clearing the intersections quickly, causing extended wait times for vehicles that overflow into other intersections. Improving the traffic control system at these intersections is necessary to improve traffic flow and reduce travel times.

This study aims to enhance traffic control systems at the Keshar Mahal and Durbar Marg intersections in Kathmandu by using advanced lane-based micro-analytical tools. The goal is to evaluate the current performance of the intersections, compare the performance of pretimed and actuated signal timing under isolated and coordinated signalization, and suggest the best signalization scenario. The study aims to improve traffic flow by reducing stops and delays, allowing large groups of vehicles to move smoothly, and preventing congestion from spilling over from one intersection to another. In addition, it aims to improve pedestrian mobility and safety, decrease vehicle emissions, reduce accidents, and improve emergency response times in the study area, and delay the need for street widening.

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Traffic signal retiming improves traffic flow and reduces congestion by adjusting the timing of traffic signals, resulting in shorter commutes, better air quality, fewer accidents, and less driver frustration (FHA, 2007). Inefficient traffic signals can cause delays, disobedience, increased use of less adequate routes and more rear-end collisions, which affects all road users. Improper or unjustified traffic signals are the root cause of these issues (FHA, 2009). Properly designed and timed traffic signals can improve the flow of people and vehicles, increase road capacity, decrease accidents, and enhance accessibility for pedestrians and side street traffic (Koonce & Rodegerdts, 2008). Retiming traffic signals is a cost-effective way to improve traffic flow along highways, with a typical benefit to cost ratio of 40:1 (Sunkari, 2004). Signal retiming at New Baneshwor intersection in Kathmandu resulted in a significant reduction in travel time and delay (Shrestha & Marsani, 2017).

Improvement of traffic signal timing and using traffic signal coordination are two of the most important strategies for reducing delay, travel time and queue length in urban area (Nesheli, Puan, & Roshandeh, 2009). Traffic signal coordination synchronizes multiple intersections to improve the flow of traffic. Factors such as proximity of intersections and traffic volume on coordinated streets are considered when deciding to implement coordination. Coordination is most effective when intersections are close and there is heavy traffic on the coordinated street. Typically, intersections within 800 meters of each other along a corridor should be coordinated, unless they operate on different cycle lengths (FHA, 2007). Traffic signal coordination establishes relationships between adjacent traffic signals using offsets (time difference in the start of the green phase between adjacent traffic control signals, in seconds) (MDOT, 2013). Coordinated signal systems self-regulate speed, where those driving too fast will arrive at a red signal and have to stop, and those driving too slowly will miss the green signal and not be able to proceed (Garber & Hoel, 1999). The "ideal offset" is the time gap between the start of the green phase of the signal at a downstream intersection and the arrival of the first vehicle in a platoon at that signal, assuming the platoon is moving through an upstream intersection (Roess, Prassas, & McShane, 2007). Coordinating signals with optimized offset values results in significant reduction in delay and travel time values (Bhattarai & Marsani, 2015).

Adaptive traffic control systems (ATCS) belong to the latest generation of signalized intersection control. It adjusts traffic signal timings in real-time based on current traffic conditions, demand and system capacity using algorithms that optimize signal's split, offset, phase length and phase sequences to minimize delays and reduce stops. It requires extensive surveillance and communication infrastructure with central and/or local controllers (Stevanovic, 2010). Adaptive traffic control systems adjust signal timings in response to changes in traffic flow to overcome the limitations of pre-timed control and adapt to fluctuations in traffic demand (Ravikumar, 2012).

2. Methodology

2.1. Study Area

The Keshar Mahal and Durbar Marg Intersections are two major intersections located in Kathmandu, Nepal. They are situated near significant landmarks such as the Royal Palace Museum, Indian Embassy, British Council, Thamel, and the historic Rani Pokhari. The intersections are located at coordinates 27.713601°N, 85.315389°E and 27.713127°N, 85.317840°E respectively. The Keshar Mahal Intersection has four approach legs - Jamal leg (520m south), Thamel leg (300m west), Lainchaur leg (350m north) and Durbar Marg leg (225m east). The Durbar Marg Intersection has three approach legs- Durbar Marg leg (335m south), Keshar Mahal leg (225m west) and Nag Pokhari leg (405m east).

Figure 1: Location Map of Study Area

2.2. Data Collection

The data collection methodology for this study included the use of multiple tools to gather both primary and secondary data. A drone survey was conducted with the aid of ground control points and DGPS in order to collect geometric details of intersections. Video cameras were also used to record traffic flow at intersections, and the recorded footage was used to count the classified traffic and pedestrian volume, as well as the phase timing. Drone video and imagery were also used to deduce data about vehicle movement, including measurements of queue space and vehicle length. In addition to these methods, data on traffic flow, speed, and capacity was also collected. Overall, this study employed a range of data collection tools in order to gather detailed and accurate information about the intersections being studied. The study also used secondary data, including the PCU factors adopted by the Kathmandu Valley Intelligent Traffic System Project (DOR, 2022) and Basic Saturation flow as suggested by Indian Highway Capacity Manual (Council of Scientific and Industrial Research, 2017). The specialized data collection methodology used in the study is further discussed;

2.2.1. Intersection Geometry

An unmanned aerial vehicle (UAV) survey, also known as a drone survey, was conducted to gather geometric details of intersections. This survey method involved the use of ground control points established with differential global positioning system (DGPS) technology, as well as the use of a drone to capture overlapping images of the survey area. The survey team used the “SW Drone” software to create a flight plan and mobilized to the field to fly the drone, a DJI MAVIC PRO, according to the predetermined flight plan. The drone imagery was then processed using photogrammetry software (Agisoft) and ortho-rectified using the DGPS-established ground control points. The resulting ortho-rectified, geo-referenced imagery had a resolution of 5cm per pixel and was used to extract the required geometric details.

2.2.2. Vehicle Calibration and Movement Data

Data relevant to vehicle movement at an intersection was gathered using a drone equipped with a video camera. The drone, a DJI MINI 3 Pro, hovered over the intersection for 40 minutes and captured video footage of the vehicles. From this footage, a number of measurements were made in AutoCAD, including queue space and vehicle length for different vehicle types.

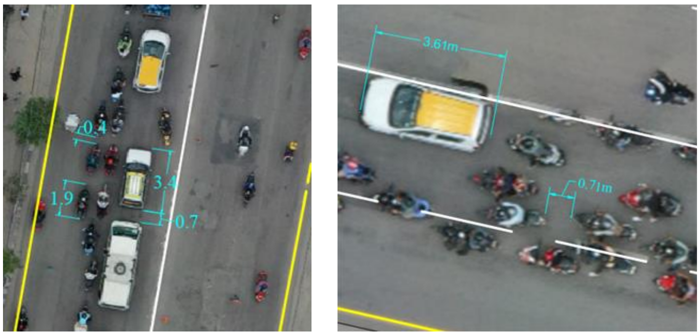


Figure 2: Sample for measurement of Queue Space and Vehicle Length

The drone video was also used to identify typical negotiation paths of vehicles and to measure the negotiation distance, radius, and downstream distance for each origin-destination (O-D) movement. The data collected from the drone video and imagery was ortho-rectified to an actual scale and used to deduce information about vehicle movement at the intersection.

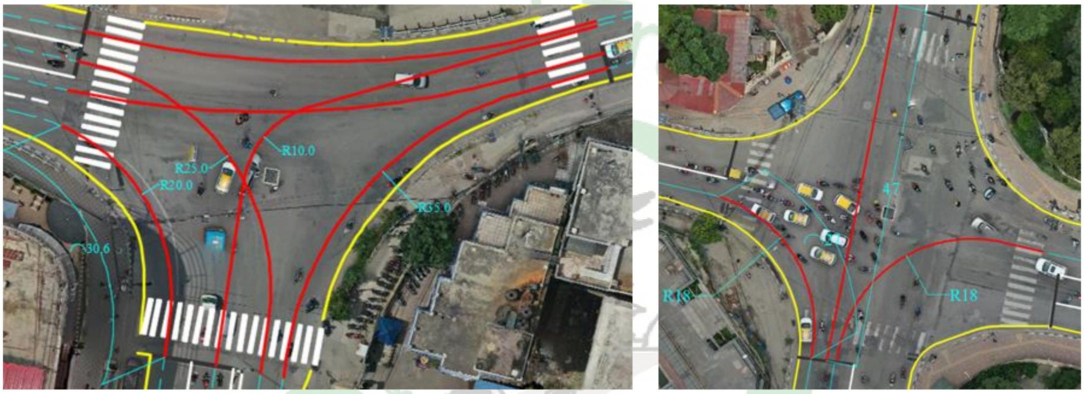


Figure 3: Sample of Negotiation Distance and Radius Measurement

2.2.3. Speed

The study used the manual short-base method to conduct speed survey and gather data on vehicle speeds. This method involved marking a 30-meter short base on the road with red spray paint, where vehicles passing over it were timed. A minimum of 75 observations were taken for each approach to estimate the speed, with all observations made during off-peak hours (12:00 PM to 3:00 PM) (TRB, 1993).

In addition to the cruise speed survey, a number of observations (more than 10 in each direction) of negotiation speed for different types of vehicles were made by timing the vehicles as they traveled the measured distance (negotiation distance for through-moving vehicles and negotiation radius for turning vehicles) from the approach stop line to the exit side stop line, along the typical vehicle path for each movement, using the recorded drone video. A number of observations (more than 10 in each direction) of saturation speed for different types of vehicles were also made by timing the vehicles as they traveled the baseline distance (30 meters) near the stop line for each movement, using the recorded drone video (V., Pandey, Rao, & B.K., 2016).

2.2.4. Back of Queue

To measure the distance from the back of a queue to the stop line at an intersection, seven people were deployed to the approaches of the intersection during the morning peak hour for three days. Using the “SW Maps” application on their mobile phones, they recorded the coordinates of the back of the queue in the field. These coordinates were then plotted in GIS software to measure the distance from the stop line.

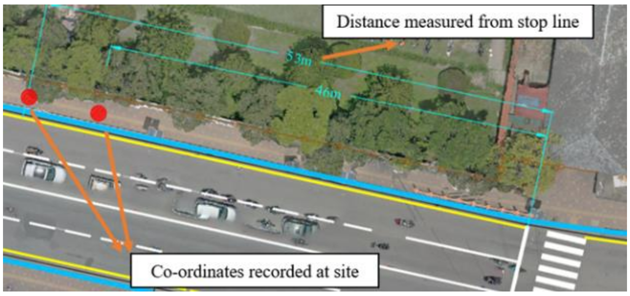


Figure 4: Sample of Back of Queue measurement

2.3. Data Analysis

The data collected for this study was analyzed using the SIDRA intersection model. SIDRA intersection is a software is used for designing and evaluating various types of traffic control systems, including signalized intersections, pedestrian crossings, roundabouts, single point interchanges, roundabout metering, two-way stop sign control, all-way stop sign control, and give-way/yield sign control (Akcelik & Besley, 2003). SIDRA Intersection is a traffic evaluation tool that provides estimates of capacity and performance statistics such as delay, queue length, and stop rate, using lane-by-lane and vehicle drive-cycle models, and an iterative approximation method. It is calibrated using the Highway Capacity Manual (HCM) version of SIDRA Intersection (TRB, 2000). Performance Index (PI) is a measure that combines several other performance statistics, and therefore can be used as a basis for choosing between various design options (the best design is the one which gives the smallest value of PI) (Akcelik and Associates, 2018).

$$PI = Tu + w1.D + w2.K.H/3600 + w3.N' \quad (1)$$

Where,

Tu	:	total uninterrupted travel time (veh-h/h),
D	:	total delay due to traffic interruption (veh-h/h)
H	:	total number of effective stops (veh/h)
K	:	stop penalty
N'	:	sum of the queue values (in vehicles) for all lanes, and
w1, w2, w3	:	delay weight, stop weight, and queue weight values, respectively

The study included calibration and validation of the model using field observations and traffic data. The model was then used to evaluate various operational performance measures for the existing intersection, including capacity, degree of saturation, delay, and level of service. Alternatives for improving the intersection configuration were also proposed and evaluated. The study also included a network analysis of the intersection, linking it with other intersections to evaluate the impact on overall traffic flow in the area. The results of the analysis were used to recommend improvements to the intersection.

2.3.1. Calibration and Validation

To calibrate the model, field observations of traffic volume and existing signal timing from Day 1 and Day 2 were used to compare the model's output queue length with the actual field queue length. The microsimulation analysis required the difference between simulated and field queue length to be within 20% to meet the calibration goal (FDOT, 2021). The calibration parameters were adjusted until the difference between the model output and field observation was less than 20%. The model was also validated, which is an independent check of the calibration, by comparing the model's output queue length with the actual field queue length from Day 3. This was done to ensure that the results produced by the model are representative of the observed situation (DPTI, 2017).

2.3.2. Intersection Analysis

The study evaluated the operational performance of each intersection as an individual site, without considering coordination with neighboring intersections. This evaluation was done using an existing base case scenario under traffic police operation during peak hour. Different alternatives of phase configuration and signal timing were simulated to determine the optimal operation option for each intersection during peak hour. The simulations were run using both pretimed and actuated signal control systems.

Use of HCM version of SIDRA allows calculations for Signal retiming under the methodology as discussed in HCM (Akcelik and Associates, 2018). The current operational design of the intersection only employs pretimed signal timing and traffic control under the supervision of traffic police. This study, however, explores the use of phase actuation as well, which necessitates the identification of specific phase actuation parameters. The parameters recommended by the Highway Capacity Manual (HCM) are used in the phase actuation analysis (TRB, 2000). The existing intersection does not provide any dedicated phase for pedestrians. This study incorporates pedestrian phases and assigns appropriate parameters for them. Since the existing intersection does not consider pedestrians, a calibration for them was not possible, thus, the parameters recommended by the HCM were used in this case (TRB, 2000).

The effective green time for each phase is assigned based on the ratio of the volume of the lane group to the total critical lane volumes of the intersection. The critical lane group volume for a phase is determined by the lane with the highest volume that has the right of way during the phase (TRB, 2000). Actuated signal timing calculations use the same method as for fixed-time signals, but use actuated signal degrees of saturation instead of practical degree of saturation to calculate the required green times, resulting in unequal degrees of saturation for critical movements. Unlike pretimed signals that use equal degree of saturation (EQUISAT) method as default, it doesn't use maximum cycle time constraint and maximum green times determine the largest possible cycle time (Akcelik and Associates, 2018).

2.3.3. Network Analysis

The study linked the intersections together to form a network, then evaluated the operational performance of this network under traffic police operation. Different alternatives of phase configuration and signal timing were simulated to determine the best operation option for the network during peak hour. The optimal simulations from the intersection analysis were then combined to form network options for further analysis. Both pretimed and actuated signal control systems were used in the simulations.

SIDRA uses time-based signal coordination which calculates the signal offset based on the routes assigned for coordination. This form of coordination uses non-interconnected controllers with time-based coordinators which keep time accurately using power company frequency. This allows coordination without the need for physical interconnection as all intersections use the same power source (Roess, Prassas, & McShane, 2007). SIDRA calculates the start time of "movement effective green times" based on the offsets determined by the program, which are used in modeling platoon patterns (Akcelik and Associates, 2018).

3. Results & Discussion

3.1. Calibration and Validation

The Keshar Mahal and Durbar Marg intersection models were calibrated and validated by comparing the queue length of field measurements to the model output for each leg. The comparison revealed that the difference between the model output and field observations was within the desired limit.

Table 1. Comparison of Observed and Model Estimated 95th Percentile Queue Length

Approach Lane	95th Percentile Queue Length		%	Day
	Observed (m)	Model Estimated (m)	Difference	
Keshar Mahal Intersection				
Jamal Leg (Shared Lane-TR)	404	377	7%	Day 1
Durbar Marg Leg (Shared-TR)	224	245	9%	
Lainchaur Leg (Shared-TR)	331	342	3%	
Thamel Leg (R)	105	114	9%	
Jamal Leg (Shared Lane-TR)	461	449	3%	Day 2
Durbar Marg Leg (Shared-TR)	222	247	11%	
Lainchaur Leg (Shared-TR)	365	382	5%	
Thamel Leg (R)	133	143	8%	
Jamal Leg (Shared Lane-TR)	424	415	2%	Day 3
Durbar Marg Leg (Shared-TR)	227	240	6%	

Approach Lane	95th Percentile Queue Length Observed (m)	Model Estimated (m)	% Difference	Day
Lainchaur Leg (Shared-TR)	325	339	4%	
Thamel Leg (R)	103	107	4%	
Durbar Marg Intersection				
Keshar Mahal Leg (R)	56	48	14%	Day 1
Durbar Marg Leg (R)	87	83	5%	
Nag Pokhari Leg (T)	175	158	10%	
Keshar Mahal Leg (R)	85	75	12%	Day 2
Durbar Marg Leg (R)	130	126	3%	
Nag Pokhari Leg (T)	147	148	1%	
Keshar Mahal Leg (R)	72	60	17%	Day 3
Durbar Marg Leg (R)	142	143	1%	
Nag Pokhari Leg (T)	176	172	2%	

3.2. Intersection Analysis

3.2.1. Keshar Mahal Intersection

Simulations of different alternatives of phase configuration and cycle timing were performed for the morning peak hour (10:00 – 11:00 AM). Various phase configurations suggested in SIDRA, as well as some additional configurations commonly used in intersections in Kathmandu, were tested in the simulations.

Table 1. Phase Simulations in Keshar Mahal Intersection

Options	Scenario	Cycle Length
A	5 Phase Existing Phasing	115
B	5 Existing Phasing with Optimum Cycle Time	100
C	4 Phase Split Phasing with Optimum Cycle Time	100
D	4 Phase Leading Right Phasing with Optimum Cycle Time	140
E	4 Phase Left Controlled Split Phasing with Optimum Cycle Time	150
F	5 Phase Left Controlled Split Phasing with Optimum Cycle Time	110
G	6 Phase Left Controlled Split Phasing with Optimum Cycle Time	140
H	6 Phase Left Controlled Split Phasing with Optimum Cycle Time and all red phase	150

The results of the simulations indicate that option F would result in the minimum queue length and lowest Performance Index (PI) when used as a Pretimed Signal Control option. Similarly, option F also yielded the best results as an Actuated Signal Control option.

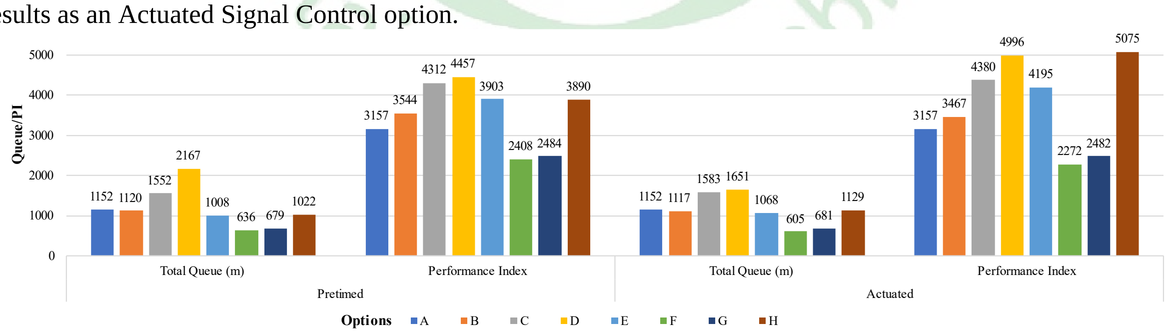


Figure 5: Total 95th percentile queue length and Performance Index in different simulation options in Keshar Mahal Model

The optimal simulation options in both the Pretimed and Actuated analyses (i.e., Option F-Pretimed and Option F-Actuated) were compared to determine the best scenario for the Keshar Mahal intersection when considered as an isolated intersection. The comparison revealed that the intersection would perform better with a lower PI and shorter queue length when operated under Option F of the Actuated analysis. Additionally, the comparison also showed that there would be fewer total effective stops and an improved effective stop rate when the intersection is operated under Actuated Control. Thus, it can be concluded that actuated signal control would be a better option for this isolated intersection.

3.2.2. Durbar Marg Intersection

Simulations of different alternatives of phase configuration and cycle timing were conducted during the morning peak hour (10:00 – 11:00 AM) using all the phase configurations suggested in SIDRA and some additional configurations commonly used in three-legged intersections in Kathmandu.

Table 2. Phase Simulations in Durbar Marg Intersection

Options	Scenario	Cycle Length
A	3 Phase Existing Phasing	116
B	4 Phase Split Phasing with Optimum Cycle Time	80
C	3 Phase Left Controlled Leading Right Phasing with Optimum Cycle Time	70
D	3 Phase Left Controlled Modified Leading Right Phasing with Optimum Cycle Time	90

The intersection performance was evaluated in terms of queue length in each leg for various alternatives. The results of the simulations indicate that option C would result in the minimum queue length and lowest Performance Index (PI) when used as a Pretimed Signal Control option. Similarly, option C also yielded the best results as an Actuated Signal Control option. The best simulation options from the Pretimed and Actuated analyses were then compared to select the optimal scenario for the Durbar Marg intersection when considered as an isolated intersection.

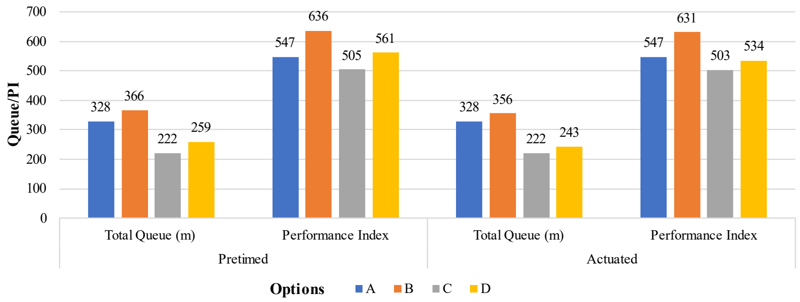


Figure 6: Total 95th percentile queue length and Performance Index in different simulation options in Durbar Marg Model

The comparison revealed that the intersection would have similar queue lengths under both pretimed and actuated control, but the PI would be slightly better in the case of actuated control. Thus, actuated signal control would be a better option for this isolated intersection. Additionally, the comparison also showed that there would be fewer total effective stops and an improved effective stop rate when the intersection is operated under Actuated Control. However, the difference in performance between pretimed and actuated conditions was not found to be significant as compared to the Keshar Mahal intersection. This may be due to the difference in traffic volumes at the Durbar Marg intersection which is comparatively lower than Keshar Mahal and also the existing performance is better. It is recommended to conduct further analysis during off-peak hours for both pretimed and actuated control to confirm this.

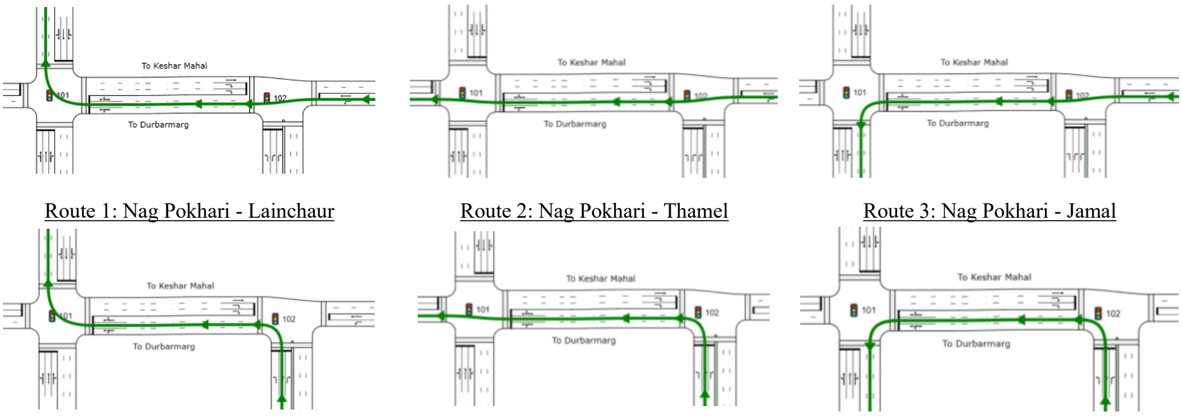
3.3. Network Analysis

Simulations were conducted to evaluate different alternatives for phase configurations and cycle timing during the morning peak hour. The two best options from the intersection analysis, Option G and Option F from Keshar Mahal intersection and Option D and Option C from Durbar Marg intersection, were linked to form network options.

Table 3. Network Simulations of Pretimed and Actuated Analysis

Options	Scenario
I	Option G Keshar Mahal - Option D Durbar Marg
II	Option F Keshar Mahal - Option D Durbar Marg
III	Option G Keshar Mahal - Option C Durbar Marg
IV	Option F Keshar Mahal - Option C Durbar Marg

Six routes, namely Nag Pokhari to Lainchaur, Nag Pokhari to Thamel, Nag Pokhari to Jamal, Durbar Marg to Lainchaur, Durbar Marg to Thamel, and Durbar Marg to Jamal, were selected for signal offset coordination as they have the highest traffic volume and were identified as the cause of spillback beyond the holding space.



Route 1: Nag Pokhari - Lainchaur | Route 2: Nag Pokhari - Thamel | Route 3: Nag Pokhari - Jamal
Route 4: Durbar Marg - Lainchaur | Route 5: Durbar Marg - Thamel | Route 6: Durbar Marg - Jamal

Figure 7: Routes assigned for Signal Offset for Coordination

The SIDRA model for the network coordinated the intersections and determined the signal offset to promote the smooth progression of groups of vehicles with reduced delays, wait times, and stops, resulting in more vehicles arriving during green signals. The comparison indicates that the network would operate more efficiently with Option I using Pretimed Signalization, while it would perform better under Option II with Actuated Signalization as they would result in the least queue length and the best Performance Index.

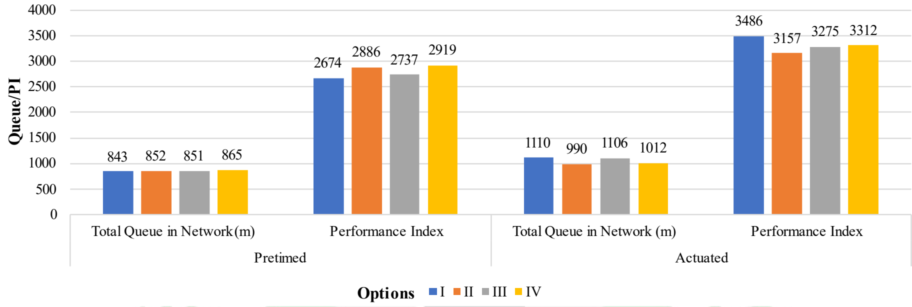


Figure 8: Total 95th percentile queue length and Performance Index in different Network simulation options

The current running intersection models of the Durbar Marg and Keshar Mahal intersection were connected to each other to form a network for analyzing the existing performance of the Keshar Mahal-Durbar Marg network. Similarly, the best results from isolated analysis were also linked to form a network to evaluate the performance of the network when it operates without signal coordination.

Table 4. Simulated Networks for Comparison

Options	Scenario	Remarks
1	Existing Phasing (No Signal Coordination)	Existing
2	Option F Keshar Mahal - Option C Durbar Marg - Actuated (No Signal Coordination)	Best of Isolated
3	Option I (Pretimed) – (Signal Coordinated)	Best of Pretimed Signal Coordination
4	Option II (Actuated) – (Signal Coordinated)	Best of Actuated Signal Coordination

The comparison shows that the network will perform best and have the least queue length and the best Performance Index when using the "Best of Pretimed Signal Coordination" scenario, also known as Option 3. When comparing the progression quality of Pretimed and Actuated control methods, Pretimed control was found to have better progression quality and result in improved network performance.

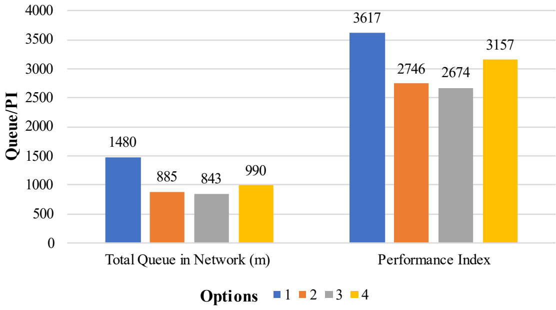


Figure 9: Performance Comparison between simulated Networks

One of the key factors that make Option 3 the most effective is the specific phase configurations of individual intersections in the network options. These configurations, which include different arrival types and platoon ratios, greatly impact the progression quality and probability of a green signal at key intersections, such as the Keshar Mahal intersection signal. Specifically, when using Option 3, the probability that vehicles traveling along the simulated routes will receive a green signal at this intersection is the highest.

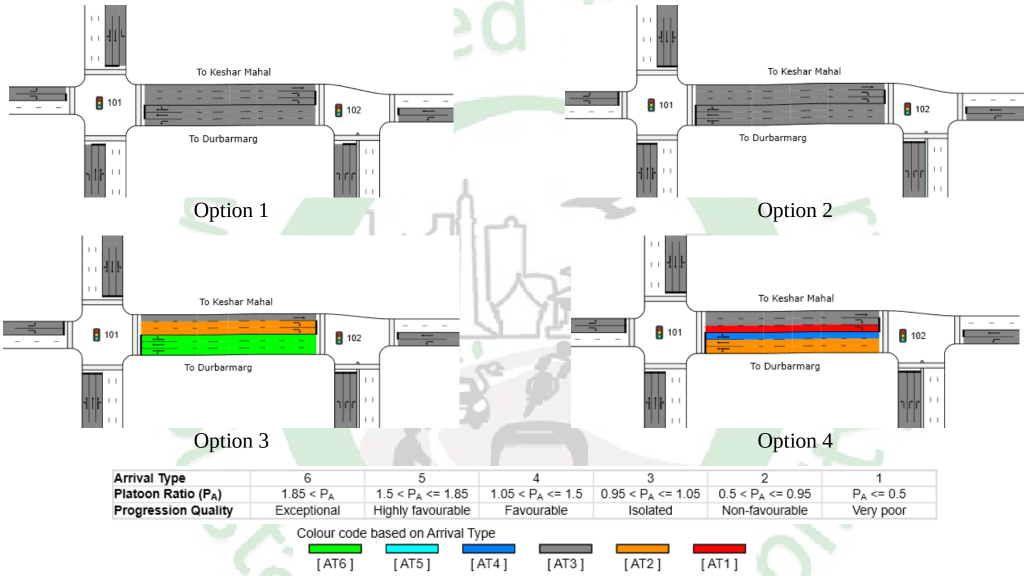
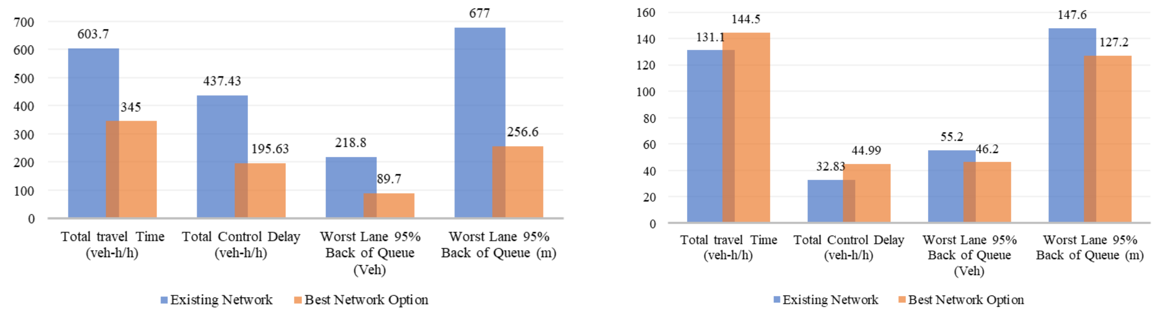


Figure 10: Arrival Type and Platoon Ratio of Simulated Network Options

3.4. Comparison of Existing Network with Best Network Option

The comparison of an existing network with the best simulated network option, called Option 3, shows that the best option would perform better in terms of individual performance and network performance. The best option would cause a reduction in operational performance at the Keshar Mahal intersection, with an average control delay reduction of 92.4 seconds (55.3%), an average travel time reduction of 258.7 seconds, a 95th percentile queue length reduction of 420.4 meters, and an improvement in the performance index of 1019.3 (33%). At the Durbar Marg intersection, the best option would cause a reduction in individual performance, with an average control delay increase of 12.17 seconds (37.1%), an average travel time increase of 13.3 seconds (10.2%), a 95th percentile queue length decreases of 20.5 meters (13.9%), and a worsening in the performance index of 75.9 (14.5%).



Keshar Mahal Intersection Durbar Marg Intersection

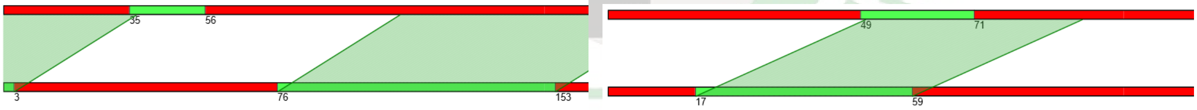
Figure 11: Intersection Performance under Existing Network and Best Network Options

However, the network as a whole would perform better with the best option, with an average travel time reduction of 245.4 seconds (33.4%), an average control delay reduction of 52.6 seconds (49.5%), and an improvement in the performance index of 943.4 (26.1%).

Table 5. Network Performance Comparison between Existing Network and Best Network Option

Performance Measure	Units	Existing Network	Best Network Option	% Difference
Travel Speed (Average)	km/h	10.7	16.1	50.8
Travel Time (Total)	veh-h/h	734.8	489.5	-33.4
Degree of Saturation		2.6	1.6	-39.4
Control Delay (Total)	veh-h/h	470.3	240.6	-48.8
Control Delay (Average)	sec	107.0	54.4	-49.2
Stop-Line Delay (Average)	sec	107.0	54.4	-49.2
Queue Storage Ratio (Worst Lane)		1.0	0.8	-25.1
Performance Index		3617.3	2673.9	-26.1

When the best Network Option is implemented, the vehicles will be able to travel along the simulated routes without interruption, resulting in better performance.



Existing Network Best Network Option

Figure 12: Time Space Diagram in Simulated Routes

4. Conclusion

In this study, the traffic control systems at two intersections in Kathmandu, Nepal were analyzed and optimized. Simulations were run to determine the most effective phase configuration and signal timing strategies for both isolated and coordinated intersections using pretimed and actuated signalization. The results showed that pretimed signal coordination with an optimal network signal cycle was the most effective option. This option was compared to the existing network in terms of individual intersection performance and network-wide performance. The use of this strategy resulted in a 33.4% reduction in total travel time, a 48.8% decrease in total control delay, and an average control delay reduction of 49.2%. It also led to significant improvements in intersection performance, including a 62.1% decrease in the 95th percentile back of queue at the Keshar Mahal intersection and a 13.9% decrease at the Durbar Marg intersection.

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Application of Markov Deterioration Hazard Model for Pavement Deterioration Forecasting of Strategic Road Networks in Nepal.

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Abstract

Road asset management (RAM) is a systematic process of maintaining, upgrading, and operating physical assets such as roads and bridges in a cost-effective way. The Department of Roads (DOR) is the responsible agency established for the RAM of Strategic Road Network (SRN) in Nepal. Maintenance planning and implementation activities are done by DOR to preserve and maximize the service periods of road assets. The DOR faces the challenge to maintain over 95 percent SRN in fair to good condition. The determination of the rates of deterioration of the road pavements is important for planning the appropriate maintenance approach. However, the pavement condition deterioration curve for SRN in Nepal is not available to forecast future deterioration. Based on the annual road condition survey data, an empirical method developed in the early 2000s is still being used to prepare the integrated annual road maintenance plan. The deterioration process and deterioration rates depend on the pavement's characteristics, use, and environmental factors. The Markovian deterioration hazard model can be applied to estimate and forecast the deterioration process of the pavement. In the model, the deterioration process is described by transition probabilities. The deterioration states are categorized into several ranks based on inspection results and their deterioration rates are estimated by the hazard models. The application of the Markov deterioration hazard model for describing the pavement conditions of SRNs in Nepal using the Surface Distress Index and International Roughness Index data set from 2014 to 2022 is presented in this paper.

Keywords: *Road asset management; Markov hazard model; exponential hazard function; Pavement deterioration; Prediction.*

1. Introduction

Road asset management (RAM) is a type of social infrastructure asset management that is applied to road assets, such as roads, bridges, and other road components. The main purpose of this concept is to implement a strategic management plan to minimize the life cycle cost of road assets through the action of regular inspection, degradation forecast, and implementation of suitable repair activities at the best time.

The implementation of RAM in Nepal can be traced to the Rana Regime (1846-1951). The road office named '*Bato Kaj Goshwara*' for road construction and '*Chhembhadel Adda*' for maintenance works was established which was later transformed into public work directive after the advent of democracy in 1951. Department of Roads (DOR) was separated from public work directive in 1962 and established as a service-oriented institution responsible for the construction and maintenance of Strategic Road Networks (SRNs) in Nepal (Department of Roads (DOR), 2022b). Recently, the modern road inventory management system with Geographic Information System interface is developed by DOR that is accessible to concerned planners and policy makers to help in qualitative and informed decision making for RAM. (Khatri P, 2022)

At present Nepal has 33,716 Km of road network constructed and maintained by various road agencies (RA) like the DOR, Department of Local Infrastructure (DOLI), Department of Urban

Development and Building Construction (DUDBC), municipalities, etc. (National Planning Commission, 2019). The DOR is identified as the key RA for the construction and maintenance of SRN. SRN includes National Highway, Feeder Roads, and Sub Urban Road Network of total length 14,618 km excluding the under-construction and planned highway of approximately 3,635 km (Department of Roads (DOR), 2022a). DOR Strategy, July 1995 highlights the departmental policy document that was developed with the strategies to attain the end goal - "*the reduction of total road transport cost*". This departmental end goal was also incorporated by National Planning Commission (NPC) into the 8th National Plan (1991/92). The total road transport costs are the sum of independent costs of road construction, road maintenance, and vehicle operating costs (Ministry of Works and Transport Department of Roads, 1995). The comprehensive guideline of maintenance activities adopted by DOR to preserve the road in a serviceable state for road users and defer the need for high-cost road maintenance activities are well described in policy documents (Department of Roads (DOR), 1994). There are four major performance measurements: i) surface roughness ii) surface distress iii) structural capacity and iv) pavement texture are suggested to determine how well the pavement is performing and meeting the serviceability of the road. (Department of Roads (DOR) & MRCU, 1995)

The annual budget for SRN maintenance is allocated by Roads Board Nepal (RBN). The road board fund is composed of direct road toll collected from the road user, fuel levy, and vehicle registration fee (Roads Boards Nepal, 2022). Under the funding of RBN, the DOR has been collecting inspection data for International Roughness Index (IRI), Surface Distress Index (SDI), and Annual Average Daily Traffic (AADT) on yearly basis. Based on these data, the simple empirical method developed in 1995 is used to prepare the integrated annual road maintenance plan for all roads division offices (Department of Roads (DOR) & Maintenance Branch, 2005). The Planned maintenance and the detailed methodology for the selection of the roads are explained in "*Standard Procedure for Periodic Maintenance Planning*", published in November 2005. The annual road condition survey conducted for SDI in 2022 indicates 73 percent of the road network is in fair to good condition (SDI range 0.0-3.0). DOR is facing the challenge to achieve one of its important maintenance policies to maintain over 95 percent of SRN in fair to good condition. In the future aging road infrastructure and an increase in traffic will add up more difficulties to achieving this target. Timely predictions on maintenance demands of the road assets in the future along with the appropriate financial plans to implement the optimal repair strategy are important to overcome this challenge. In addition, the rate of deterioration of the road pavement is important for planning the appropriate maintenance approach. However, the pavement deterioration curve for the condition of Nepal is not available to forecast future deterioration.

In this study, the Markov deterioration hazard model is applied for deterioration forecasting of SRN using road condition data set from 2014 to 2022. The deterioration model can be applied to estimate the hazard rates and residual life of pavement. Further, the average Markov transition probabilities (MTP) matrix, the hazard rate for each transition state, the life expectancy, and the expected deterioration path describing the average deterioration process during the life expectancy rating are presented in this paper.

2. Methodology

To forecast the deterioration progress of the pavement a statistical deterioration model based on past inspection results is applied. The Markov deterioration hazard model is a statistical model used to forecast the deterioration progress of pavement developed by (Tsuda et al., 2006). In this model, a rank order is assigned as a condition state depending on the result of the past inspection data. The Markov transition probabilities are estimated to represent the deterioration progress between the condition states. This model is widely preferred for sound maintenance strategies and budget management policies. In this paper, the application of the Markov deterioration hazard model for deterioration forecasting of SRN in Nepal using the SDI and IRI data set from 2014 to 2022 is presented.

The road condition data for the study is acquired from Highway Management Information System Unit (HMIS) under Planning Branch within DOR. The data set contains annual road inventory data recorded in the road register of SRN from 2014 – 2022 (Department of Roads (DOR), 2022a).

2.1 Model Description/Theory

The Markov deterioration hazard model helps to predict the hazard rate, life expectancies, and deterioration curves of roads given with the historical inspection results and other variables concerning various environmental impacts such as traffic volume, weather, temperature, axle loads, etc. These variables are termed explanatory variables. For the application of the Markov hazard model, the following assumptions must hold true (Kobayashi et al., 2010).

Assumptions of Markov model: -

1. There have been no maintenance and repair activities imposed and no measurement errors during the inspection period.
2. Deterioration process of the road section occurs naturally as its condition state getting worsens over the year.

This deterioration process is explained graphically in Figure 1 with blue round marks. At time τ_0 the condition state is in a good state with $i = 1$. Over the year condition state, i $(i = 1, 2, \dots, J)$ deteriorates and falls into a worse condition. Inspection is carried out at τ_A and τ_B. The condition state at inspection points is known but there is difficulty to trace exactly when the condition states transitioned, τ_1 and τ_2 in the figure, between the two inspection points. Thus, it is noted that condition state 2 at any arbitrary future time τ_1 cannot be deterministically predicted. Moreover, the condition state at each time point in the time axis is restricted to the time at which the inspection is done.

In figure 1, τ represents the calendar time. The deterioration of the road pavement starts immediately after its opening to the public use at initial time τ_0. The condition state is expressed by ranks representing condition state variable i $(i = 1, 2, \dots, J)$, where $i = 1$ represents the good or new situation. The increments of condition state i indicates progressing deterioration and $i = J$ indicate its service limit (absorbing state of the Markov chain). In Figure 1 with green round marks, for each discrete time τ_i $(i = 1, 2, \dots, J)$, on the x axis, we can observe the condition state changing from i to $i + 1$. Therefore, τ_i refers to the time at which the transition from condition state i to $i + 1$ occurs.

The data regarding the deterioration process can be obtained from the periodic inspection results. Since the continuous monitoring and inspection of infrastructure are difficult and cost consuming, therefore normal practice is to conduct discrete periodic inspections during the service life of the infrastructure. The model assumes two periodic inspections at times τ_A and τ_B on the time axis such that its interval is denoted by Z ($Z = \tau_B - \tau_A$).

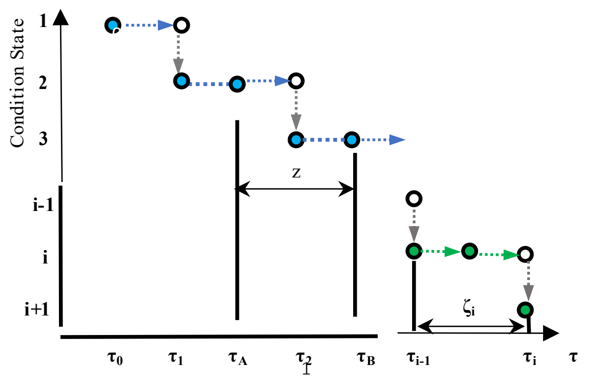

Figure 1 : Deterioration process and inspection.

Figure 1 also explains the deterioration path of pavement condition using the concept of the Markov chain. When deterioration status changes from i to $i + 1$ (refer to green round marks) at τ_i, the duration it remained at condition state i can be expressed by ζ_i ($\zeta_i = \tau_i - \tau_{i-1}$). The life expectancy of a condition state i is assumed to be a stochastic variable with a probability density function $f_i(\zeta_i)$ and distribution function $F_i(\zeta_i)$. The distribution function $F_i(\zeta_i)$ represents the cumulative probability of the transition in the condition state for i to i + 1 when i is set at the initial point $y_i = 0$ (time τ_{i-1}). The cumulative probability $F_i(y_i)$ of a transition in the condition state i during the time points interval $y_i = 0$ to $y_i \in [0, \infty]$ is defined as:

$$F_i(y_i) = \int_0^{y_i} f_i\ (\zeta_i) d\zeta_i \quad (1)$$

Accordingly, the survival function $R_i(y_i)$ becomes $R_i(y_i) = \text{prob}\{(\zeta_i \geq (y_i\} = 1 - F_i(y_i)$. By using the exponential hazard function, it is possible to represent the deterioration process that satisfies the Markov condition. The probability density $\lambda_i(y_i)$, which is referred to as the hazard function, is defined in the domain $[0, \infty]$ as:

$$\lambda_i(y_i) = \frac{f_i(y_i)}{R_i(y_i)} = \frac{\frac{dR_i(y_i)}{dy_i}}{R_i(y_i)} = \frac{e}{dy_i}(\text{-log}R_i(y_i)) \quad (2)$$

Using the hazard function $\lambda_i(y_i) = \theta_i$, the probability $R_i(y_i)$ that the life expectancy of the condition state i remains longer than y_i and its probability density function $f_i(\zeta_i)$ are expressed by the following

$$R_i(y_i) = \exp\left[-\int_0^{y_i} \lambda_i(u)du\right] = \exp(-\theta_i y_i) \quad (3)$$

$$f_i(\zeta_i) = \theta_i \exp(-\theta_i \zeta_i) \quad (4)$$

Referring to Figure 2, it is supposed that at time τ_A, the condition state observed by inspection is i $(i = 1, 2, \ldots, J - 1)$. The deterioration process in future times is uncertain. Among the infinite set of possible scenarios describing the deterioration path, only one path is finally realized. For simplicity there are four possible sample paths described as follows (Tsuda et al., 2006):

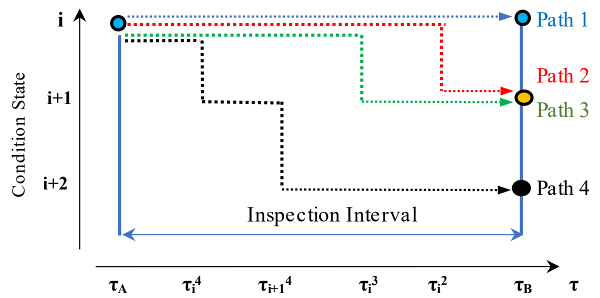

Figure 2 : Condition states and possible deterioration paths (Kobayashi et al. 2010)

- Path 1 indicates no transition in the condition state i during the periodic inspection interval.
- Path 2 indicates the transition of the pavement from condition state i to i + 1 at time τ_i^2.
- Path 3 indicates the transition of the pavement from condition state i to i + 1at time τ_i^3.
- Path 4 indicates the transition of the pavement from condition state i to i + 1 and i + 2 at time τ_i^4 and τ_{i+1}^4 respectively. The condition state observed at τ_B is i + 2.

The transitions in the condition state are observed only at the time of periodic inspections (at τ_A and τ_B) and it is not possible to obtain the information about the time in which those transitions occured (τ_i^4 , τ_{i+1}^4 , τ_i^3 , τ_i^2 etc.**)**

2.2 Markov Transition Probability

The transition process of the condition state for road pavement is uncertain and forecasting future states cannot be done deterministically. The Markov transition probability is used to represent the uncertain transition of the condition state during two points in time. In other words, Markov transition probabilities are defined to forecast the deterioration of pavement using the periodic inspection process shown in Figure 2. The observed condition state of the component at time τ_A is expressed by using the condition state variable $h(\tau_A)$. If the condition state observed at time τ_A = i, a Markov transition probability, given a condition state $h(\tau_A) = i$ observed at time τ_A, defines the probability that the condition state at a future time τ_B will change to $h(\tau_B) = j$, that is

$$\text{Prob}[h(\tau_B) = j \mid h(\tau_A) = i] = \pi_{ij} \quad (5)$$

The Markov transition probabilities matrix can be defined by using the transition probabilities between each pair of condition states (i, j) as:

$$\Pi = \left(\begin{bmatrix} \pi_{11} & \cdots & \pi_{1J} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \pi_{JJ} \end{bmatrix}\right) \quad (6)$$

Where, $\pi_{ij} \geq 0$

$\pi_{ij} = 0$ (when $i > j$) since the model does not consider the repair.

$\sum_{j=1}^{J} \pi_{ij} = 1$

The final state of deterioration is expressed by condition state J, which remains an absorbing state in the Markov chain if no repair is carried out. In this case $\pi_{JJ} = 1$.

2.3 Determination of Markov Transition Probabilities

From Figure 2 various deterioration paths are possible that are broadly classified into π_{ii} , π_{ii+1}, π_{ij} and π_{iJ}. The Markov transition probabilities for these possible paths are based on the exponential hazard model can be explained for the three cases considering the condition state observed at periodic inspection time point as shown in Figure 3.

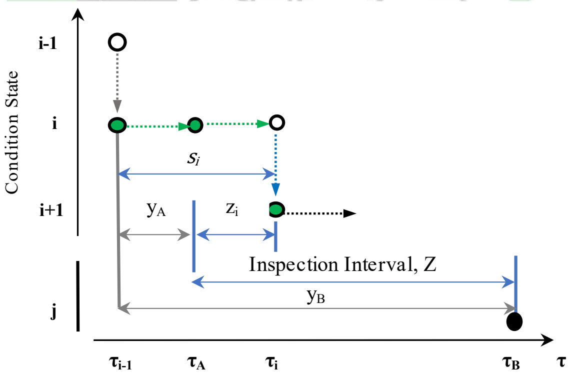

Figure 3 : Periodic inspection practice of the condition state.

Case 1 : The condition state i does not change during the inspection interval Z.

For a condition state i obtained at inspection time point y_A, the probability that the same condition state is observed at time point y_B (= $y_A + z$) is expressed by:

$$\pi_{ii} = \text{Prob}[h(y_B) = i \mid h(y_A) = i] = \exp(-\theta_i Z) \quad (7a)$$

The equation (7a) indicates that π_{ii} is dependent only on the hazard rate (θ_i) and inspection interval (Z). This shows it is also possible to estimate transition probability without using the deterministic value of the time points y_A and y_B.

Case 2 : The condition state changes from i to i + 1 during the inspection interval Z.

For a contion state i observed at inspection time point y_A to change to condition state $i+1$ at time point y_B, the transition is assumed to occur as 1) the condition state i remains constant between a time point y_A to a time point $s_i = y_A + z_i$, ($z_i \in [0, Z]$), 2) the condition state changes to $i+1$ at the time point $y_A + z_i$, and 3) it remains constant between $y_A + z_i$ and y_B. Although the exact time in which the condition state transition from i to $i+1$ cannot be traced by periodic inspection, it is assumed that the transition occurs at a time point $\bar{s}_i \in [y_A, y_B]$). The Markovian transition probability that the condition state change from i to $i+1$ during the time points y_A and y_B is expressed by:

$$\pi_{i\,i+1} = \mathrm{Prob}[h(y_B) = i+1 \mid h(y_A) = i]$$

$$\pi_{i\,i+1} = \frac{\theta_i}{\theta_i - \theta_{i+1}}\{-\exp(-\theta_i Z) + \exp(-\theta_{i+1} Z)\} \qquad \text{where,} \quad \pi_{i\,i+1} < 1 \tag{7b}$$

Case 3 : The condition state changes from i to j ($j \geq i+2$) during the inspection interval Z.

For a condition state i observed at inspection time point y_A to change to condition state j at time point y_B, the transition is assumed to occur as 1) the condition state i remains constant between a time point y_A, $\bar{s}_i = y_A + \bar{z}_i \in [y_A, y_B]$, 2) the condition state changes to $i+1$ at the time point $\bar{s}_i = y_A + \bar{z}_i$, 3) the condition state $i+1$ remains constant during the time interval $\bar{s}_i = y_A + \bar{z}_i$, $\bar{s}_{i+1} = \bar{s}_i + \bar{z}_{i+1}$ ($\leq y_B$), and at this time point changes to $i+2$. After repeating the same process 4) the condition state changes to j at some time point $\bar{s}_{j-1}$($\leq y_B$) remains constant until the time point y_B.

The Markovian transition probability that the condition state change from i to j ($j \geq j+2$) during the time points y_A and y_B is expressed by:

$$\pi_{ij} = \mathrm{Prob}[h(y_B) = j \mid h(y_A) = i]$$

$$\pi_{ij} = \sum_{k=i}^{j} \prod_{m=i}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} \prod_{m=k}^{j-1} \frac{\theta_m}{\theta_{m+1} - \theta_k} \exp(-\theta_k Z) \text{ , where} \tag{7c}$$

$$\prod_{m=i}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} = 1, \text{at } (k \leq i+1) \text{ and } \prod_{m=k}^{j-1} \frac{\theta_m}{\theta_{m+1} - \theta_k} = 1 \text{ at } (k \geq j) \text{ .}$$

In equation (7c) , π_{ij} $[0 < \pi_{ij} < 1]$, and π_{iJ} is arranged using the Markov transition probabilities conditions as follows:

$$\pi_{iJ} = 1 - \sum_{j=1}^{j-1} \pi_{ij} \tag{7d}$$

In equation (7a) ~ 7(d) the multistage exponential hazard model has been defined. However, considering the explanatory variable to estimate hazard rate θ_i which is defined as the function of explanatory variables x^k and unknown parameters β_i. where $\beta_i = (\beta_{i,1}, \ldots, \beta_{i,M})$, M (m = 1, 2, …, M) is the number of explanatory variable and k (k = 1, 2, …, K) is an individual sample of inspection data.

$$\theta_i^k = f(x^k : \beta_i) \tag{8}$$

In summary, the elements of MTP matrix π_{iJ} are estimated using $\pi_{iJ}(Z^k, x^k : \beta_i)$. The unknown parameter β_i (i=1, 2, …, J-1) is determined with Bayesian estimation method to obtain the hazard function θ_i^k (i =1, 2, …, J-1), the life expectancy of each condition state i can be defined by means of the survival function $R_i(y_i^k)$.

$$LE_i^k = \int_0^{\infty} \exp\left(-\exp(\theta_i^k y_i^k\right) dy_i^k = \frac{1}{\theta_i^k} \tag{9}$$

Life expectancy from i to J can be estimated using $\sum_{i=1}^{J-1} LE_i^k$.
(10)

For detailed description it is recommended to refer the reference (Tsuda et al., 2006).

2.4 Bayesian Estimation for determining unknown parameter β.

Bayesian estimation is an iterative method of statistical inference that involves using prior knowledge and data to estimate the parameters of a model. In the context of a Markov hazard model, Bayesian estimation can be particularly useful to estimate the unknown parameter β_i (i=1, 2, …, J-1) for several reasons:

- Incorporation of prior knowledge: In Bayesian estimation, it allows to use prior knowledge about the parameters of the model to inform our estimates. This can be particularly useful in case of some prior knowledge about the parameters that we are trying to estimate.
- Robustness to small sample sizes: Bayesian estimation can be more robust to small sample sizes compared to classical methods, as it allows us to incorporate prior knowledge and make use of partial information.
- Quantification of uncertainty: Bayesian estimation allows to quantify the uncertainty associated with estimates, which can be useful for decision making and risk assessment.
- Flexibility: Bayesian estimation is generally more flexible compared to classical methods, as it allows to specify different prior distributions and consider different model structures.

In Bayesian statistics, the posterior distribution of parameter is estimated by using a likelihood function, inspection data and an assumed prior distribution of the model parameters. Hence, the posterior distribution $\pi(\beta|\xi)$ is proportional to the likelihood function $L(\beta|\xi)$ and prior distribution $\pi(\beta)$ (Kobayashi et al., 2012). That is:

$$\pi(\beta|\xi) \propto L(\beta|\xi)\,\pi(\beta) \tag{11}$$

where, β is a probabilistic random variable with prior probability density function $\pi(\beta)$ and ξ is the observed inspection data. The posterior probability density function of unknown parameter β can be defined by the simplest form of Bayes Theorem as:

$$\pi(\beta|\xi) = \frac{L(\beta|\xi)\;\pi(\beta)}{\int L(\beta|\xi)\pi(\beta)\,d\beta} \tag{12}$$

Where, $L(\xi) = \int L(\beta|\xi)\pi(\beta)d\beta$ is the marginal probability of ξ, called the normalizing constant.

In conclusion, Bayesian estimation can be a useful method for estimating the parameters of a Markov hazard model, particularly with limited data or prior knowledge that need to incorporate into estimates.

Bayesian method for estimation can be summarized in 3 steps:
Step 1: defining of the prior probability distribution $\pi(\beta)$.
Step 2: defining the likelihood function $L(\beta|\xi)$ by using newly obtained data $\bar{\xi}$.
Step 3: modifying the prior distribution $\pi(\beta)$ using the Bayes' rule and update the posterior distribution $\pi\ (\beta|\xi)$ for parameter β.

In this paper we suppose that the observed data is defined by $\bar{\xi} = (\bar{\xi}^1, \ldots, \bar{\xi}^k)$ and the inspection information of the inspection sample k is $\bar{\xi}^k = (\bar{\delta}^k_{ij}, \bar{z}^k, \bar{x}^k)$. The likelihood function $L(\beta|\xi)$ based on Bayes Rule is defined by using $\pi_{ij}(z)$ such that:

$$L(\beta|\xi) = \prod_{i=1}^{j-1}\prod_{j=i}^{J}\prod_{k=1}^{K}\left\{\sum_{h=i}^{j}\prod_{l=i}^{h-1}\frac{\theta_l^k}{\theta_l^k-\theta_h^k}\prod_{l=h}^{j-1}\frac{\theta_l^k}{\theta_{l+1}^k-\theta_h^k}\exp\left(-\theta_h^k\bar{z}^k\right)\right\}^{\bar{\delta}^k_{ij}} \tag{13}$$

where, $\bar{\delta}^k_{ij}$ is a dummy variable, whose value is 1 when $h(\tau_A^k) = i$ and $h(\tau_B^k) = j$, otherwise 0.

Referring to step 1, to define the prior probability density distribution function of unknown parameter β, we defined a conjugate prior probability density function and assume that the prior probability density distribution function of unknown parameter β follows the conjugate multidimensional normal distribution such that $\beta_i \sim N_M$ $(\mu_i, \sum_i)$. This assumption is essential to overcome the computational problems related to non-convergence of estimation results and to derive the similar function for the posterior probability density function. Thus, we can express the probability density function of the M-dimensional normal distribution N_M (μ_i, Σ_i) as:

$$g(\beta_i|\mu_i,\Sigma_i) = \frac{1}{(2\pi)^{M/2}\sqrt{|\Sigma_i|}} \cdot \exp\{-\frac{1}{2}(\beta_i - \mu_i)\Sigma_i^{-1}(\beta_i - \mu_i)'\} \tag{14}$$

where, μ_i represents the prior expectation vector (or mean) of $N_M(\mu_i, \Sigma_i)$ and Σ_i is the prior variance – covariance matrix. The symbol $'$ denotes the transposition. Substituting the value from equation (13) and equation (14), the posterior density function $\pi(\beta|\xi)$ in equation (11) can be defined as:

$$\pi(\beta|\bar{\xi}) \propto L(\beta|\bar{\xi}) \prod_{i=1}^{j-1} g(\beta_i|\mu_i,\Sigma_i)$$

$$\pi(\beta|\bar{\xi}) \propto \prod_{i=1}^{j-1}\prod_{j=i}^{J}\prod_{k=1}^{K}\{\sum_{h=i}^{j}\prod_{l=i}^{h-1}\frac{\theta_l^k}{\theta_l^k-\theta_h^k}\prod_{l=h}^{j-1}\frac{\theta_l^k}{\theta_{l+1}^k-\theta_h^k}\exp(-\theta_h^k\bar{z}^k)\}^{\bar{\delta}_{ij}^k} \cdot \prod_{i=1}^{j-1}\exp\{-\frac{1}{2}(\beta_i - \mu_i)\Sigma_i^{-1}(\beta_i - \mu_i)'\} \tag{15}$$

However, the normalizing constant $L(\xi) = \int L(\beta|\xi) \prod_{i=1}^{j-1} g(\beta_i|\mu_i,\Sigma_i) d\beta$ is difficult to calculate. To overcome such limitation, we use Metropolis – Hasting algorithm often known as M-H algorithm in Markov chain Monte Carlo (MCMC) simulation to directly obtain the statistical value regarding the posterior distribution of parameters (Han et al., 2014). This method is suitable and can be applied when the normalizing constant for density function is not known or difficult to calculate (Train, 2002). The M-H algorithm operates as follows:

1. Define initial value of parameter vector $\beta(0)$.
2. Calculate current probability density $\pi(\beta(n))$ by using current $\beta(n)$.
3. Find a candidate value as $\tilde{\beta}(n) = \beta(n) + \varepsilon(n) \sim N(0,\sigma^2)$ where ε is the step width of the random walks.
4. Calculate the proposal density by using $\tilde{\beta}(n)$ as a candidate parameter $\pi(\tilde{\beta}(n))$.
5. Apply the updating rule by comparing $\pi(\tilde{\beta}(n))$ and $\pi(\beta(n))$ with the following conditions.

$$\beta(n+1) = \begin{cases} \pi(\tilde{\beta}(n)) > \pi(\beta(n)), \beta(n+1) = \tilde{\beta}(n) \\ \pi(\tilde{\beta}(n)) \le \pi(\beta(n)), \begin{cases} R \le r, \beta(n+1) = \tilde{\beta}(n) \\ \text{Otherwise}, \beta(n+1) = \beta(n) \end{cases} \end{cases} \tag{16}$$

Where, $r = \pi(\tilde{\beta}(n))/\pi(\beta(n))$, and R is a standard uniform for $R \sim U(0,1)$.

6. Do sufficiently large numbers of iterations from step 2 to step 5, until sequence β^n becomes a stationary condition (that is close to convergence).
7. Cut burn-in samples and take the average of sample parameters.

The M-H algorithm also generates Markov chains as the transition probabilities from $\beta(n)$ to $\beta(n+1)$ that independent of $\beta(0)$. The MCMC does not include any method to confirms that the initial value $\beta(0)$ reaches stationary distribution. To check the Markov chain reaches the convergence to a maximum, the Geweke's test is used. The Geweke's test takes two sample groups (n_1, n_2) from the first 10% and last 50% of the Markov chain. If the mean of the two groups is equal, it indicates the chain is stationary. A modified z-test can be used to compare the two samples and the resulting statistics is termed as Geweke's z-score. The detailed description for M-H algorithm and the Geweke's test to confirm the convergence of the Markov chain can be referred to (Han et al., 2014).

3. Empirical Analysis

Among the four measures identified for a performance measure, DOR considers the following two primary measures: i) surface roughness and ii) surface distress of pavement to determine how well the pavement is performing and meets the serviceability requirement of the road. The Bayesian estimation for the Markov hazard model is carried out with the actual inspection data based on these two performance measures of road pavement of SRNs. The inspection data set includes the result of two inspection interval: Z, and characteristic variable: x. To apply Markov transition probability the condition rating shown in Table 1 and Table 2 are used to rate the pavement based on SDI and IRI respectively. The characteristic variable for this study is average annual daily traffic. For analysis, all quantitative value of the characteristic variable is normalized so that the maximum value becomes 1. The total number of 3,723 sets of road section data based on SDI and 3,314 sets of road section data based on IRI satisfying the Markov condition were analyzed. These data are used in this paper to estimate the parameters of the exponential hazard function.

3.1 Surface Roughness

Surface Roughness is closely related to the pavement condition and the vehicle operating cost increases with an increase in the roughness of the road. IRI expressed in m/km is used to provide a common scale for recording road roughness. A vehicle-mounted Bump Integrator is a response-type instrument to measure the surface roughness annually (Department of Roads (DOR) & MRCU, 1995). The road condition and the condition state based on IRI is shown in Table 1.

Table 1: Road condition based on IRI

IRI Range	Condition	Condition State Ranking
<4	Good	1
4-6	Fair	2
6-8	Poor	3
>8	Bad	4

3.2 Surface Distress

Surface Distress provides a visual indication of pavement deterioration. The method adopted by DOR is a simplified procedure recommended by the World Bank which has been modified to suit the conditions in Nepal and the need for DOR. Detail procedure to the determination of SDI value for each road link is described in "*Road Pavement Management, MRCU*" (M. DOR, 1995). The road condition and the condition state based on SDI is shown in Table 2.

Table 2: Road condition based on SDI

SDI Range	Condition	Condition State Ranking
<1.7	Good	1
1.8-3.0	Fair	2
3.1-5.0	Poor	3

The Figure 4 below illustrates the Markov hazard model for pavement deterioration in Nepal.

Input →	Model →	Output
Pavement Condition Data		Markov Transition Probability (MTP)
Condition State Ranking	Markov Hazard Model	Hazard Rate (θ_i)
EV (AADT, Env. factors etc)		Life Expectancy (LE_i)

Figure 4: Markov hazard model

4. Results & Discussion

4.1. Results: MTP, Hazard Rate and Life Expectancy

The Markov transition probabilities matrix for each sample is estimated by using the exponential hazard model and the average Markov transition probabilities (MTP) matrix is determined which are presented in Table 3 and Table 4. The hazard rate for each transition and the life expectancy is expressed by equation 9 and equation 10 are presented in Table 5 and Table 6. The expected deterioration path can be represented by a graph describing the average deterioration process during the life expectancy rating are shown in Figure 5 and Figure 6.

Table 3: Markov Transition Probability Matrix based on SDI

Rating	1	2	3
1	0.491	0.464	0.045
2	-	0.845	0.155
3	-	-	1

Table 4: Markov Transition Probability Matrix based on IRI

Rating	1	2	3	4
1	0.573	0.340	0.076	0.011
2	-	0.655	0.290	0.055
3	-	-	0.718	0.282
4	-	-	-	1

Table 5: Hazard rate and life expectancy based on SDI

Condition State	Hazard Rate (θ_i^{av})	Life Expectancy (LE_i^{av})	Hazard Rate (θ_i^{STGB})	STGB (LE_i^{STGB})	Hazard Rate (θ_i^{AMGB})	AMGB (LE_i^{AMGB})
1-2	0.711	1.40	0.793	1.26	0.395	2.53
2-3	0.168	5.93	0.167	5.97	0.099	10.06
Total LE,Yrs		7.33		7.23		12.59

Table 6: Hazard rate and life expectancy based on IRI

Condition State	Hazard Rate (θ_i^{av})	Life Expectancy (LE_i^{av})	Hazard Rate (θ_i^{STGB})	STGB (LE_i^{STGB})	Hazard Rate (θ_i^{AMGB})	AMGB (LE_i^{AMGB})
1-2	0.556	1.79	0.758	1.31	0.293	3.41
2-3	0.423	2.36	0.427	2.34	0.302	3.31
3-4	0.331	3.01	0.329	3.03	0.307	3.25
Total LE,Yrs		7.16		6.68		9.97

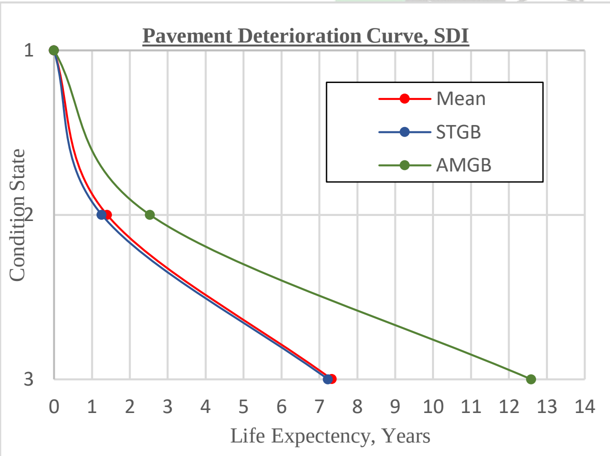

Figure 5: Pavement deterioration curve, SDI

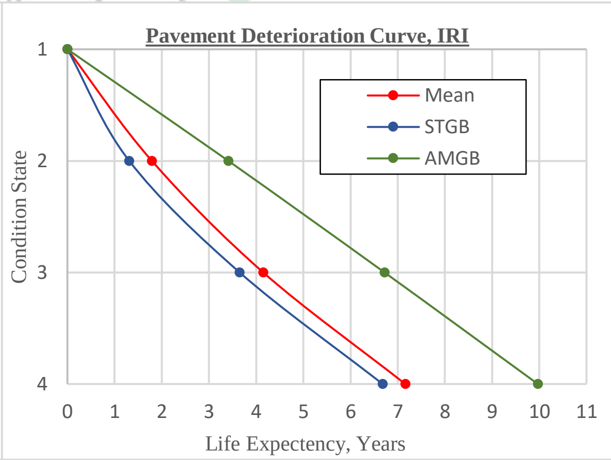

Figure 6: Pavement deterioration curve, IRI

5. Discussion

The deterioration curve corresponding to SDI and IRI shows life expectancy of the road networks. In context of Nepal only SDI is considered as the prime indicator for choice of road section for periodic maintenance works. Periodic maintenance complemented by routine and recurrent maintenance work are performed to improve and extend the service life of the pavement. There are two major types of pavements in Nepal: STGB (surface treatment over granular base) – type and AMGB (asphalt material over granular base)- type. The current practice suggests an interval of 5-8 years for periodic maintenance irrespective of the pavement type (Department of Roads (DOR) & Maintenance Branch, 2005). The deterioration curves indicates that the rate of deterioration is high, and this interval is leading to further degradation of the road condition beyond the scope of periodic maintenance. This is more significant for STGB type roads which will demand expensive maintenance alternatives such as rehabilitation and reconstruction in future to reinstate into good condition.

The life expectancies of STGB ($\mathrm{LE}_{\mathrm{i}}^{\mathrm{STGB}}$) and life expectancies of AMGB ($\mathrm{LE}_{\mathrm{i}}^{\mathrm{AMGB}}$) type road are shown in Table 5 and Table 6. The average deterioration period in years during the life expectancy of the rating i.e., from the time the rating is reached to the next ratting is attained is known. This information can provide actual time frame to plan efficient inspection interval and maintenance planning.

6. Conclusion

In addition to the construction of new road infrastructure, it is also necessary to implement the concepts of road asset management for effective and efficient utilization of road assets during its service life in future. In this study, Markov deterioration hazard model is applied for deterioration forecasting of SRN in Nepal. The study indicates the deterioration rate is high. The total life expectancy of road considering SDI and IRI is 7.33 years and 7.16 years respectively, which are similar. The deterioration curves presented in Figure 4 and Figure 5 can be used to forecast the future condition state of the road network and predict the remaining life expectancies. IRI, which is internationally accepted performance parameter for maintenance decision and prioritizing process but not considered in Nepal, can as well used in network level for screening of the road sections for periodic maintenance. Further, it is possible to choose IRI as performance measure over SDI for pavement decision making and prioritization process.

However, there are still many aspects for future study. First, the study is limited to only average annual daily traffic as the explanatory variable. The other variable like commercial vehicles is an observable characteristic variable, it cannot be included in this study due to insufficient data sets. Second, the environmental factors like rainfall and temperature can also be included as explanatory variable in future study. Third, the study presents the average deterioration process of the entire road network, but the road network itself is composed of heterogenous road infrastructures that can be grouped into different infrastructure groups considering categorical variables. By using the mixed Markov deterioration hazard model, the deterioration characteristics of individual group of road infrastructure can be studied. It is expected to include the above-mentioned explanatory variables in future with sufficient inspection data to expand the study for improved forecasting of the deterioration process of road infrastructure.

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Safety Evaluation of National Highway Using International Road Assessment Programme: A Case Study of NH14 (Rupani-Rajbiraj Section)

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Abstract

Road surface issues, human errors, mechanical problems are all contributing to Nepal's growing number of road fatalities, despite an action plan. In spite of the increase in road construction, safety measures are limited on the road, resulting in road fatalities. To reduce road fatalities to half by 2030, the Government of Nepal has committed to achieving UN Sustainable Development Goal (SDG) target 3.6. Consequently, road users such as vehicle occupants, motorcyclists, pedestrians, and cyclists should have a minimum three-star rating. The iRAP believes that achieving 3 stars on the road will reduce fatalities by half.

Researchers conducted this research in NH14 (Rupani-Rajbiraj section) in order to determine the existing star rating and score for the section. According to the official letter issued by the traffic police administration, six crash-prone locations were provided for the study. Using the iRAP methodology, the researcher studied three crash-prone areas among six.

Existing road conditions vary from two to three-stars for vehicle occupants, motorcyclists, pedestrians, and bicyclists. Star rating score (SRS) is found in the varying range of 6.85 to 17.29 for vehicle occupants, 9.61 to 21.82 for motorcyclists, 32.77 to 57.5 for pedestrians and 27.23 to 45.78 for bicyclists. In analyzing the results of all three studied locations, not a single location meets the target. All the three locations area can be improved by maintaining of damaged road, improving the delineation and providing the speed limit of the vehicle for reducing the risk of crash type like run-off either side of carriageway, head-on collision due to loss of control and while overtaking, crash at intersection, moving along the road, crossing through and side of the road. There is now a 3 stars rating for vehicle occupants, motorcycles, pedestrians, and bicyclists. Star Rating Score is found in the varying range of 5.74 to 8.9 for vehicle occupants, 8.28 to 11.27 for motorcyclists, 17.11 to 38.03 for pedestrians and 11.51 to 26.31 for bicyclists.

Keywords: Fatalities; Star rating; Star rating score; Sustainable Development Goal

1. Introduction

Road crashes are the eighth leading cause of death for people worldwide with one person dying on the roads every 25 seconds, nearly 3,700 per day, over 1.35 million per year and as many as 50 million injuries every year. (Sakarya & Of, 2018) Road traffic injuries are the leading cause of death among young people, aged 5–29 years world-wide. (Sakarya & Of, 2018) (World Bank & World Health Organization, 2013)

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Road crash fatalities and injuries are a growing problem in Nepal. The number of road fatalities in Nepal is increasing alarmingly despite an action plan. Nepal has pledged to reduce road fatalities by 50 percent and developed the Nepal Road Safety Action Plan (2013-20) to meet its global commitment of SDG target 3.6. (Plan, 2013) However, road fatalities in Nepal have been increasing at an alarming rate and reached 2,541 deaths in fiscal year 2017-18, which is equivalent to a rate of 8.59 per 100,000 populations. (Sakarya & Of, 2018) During the recent decades several major efforts have been made to improve the highway safety at various level. Numerous road fatalities have been found due to different factors related to road surface, human error, mechanical problem etc. till date. Loss of life and property due to the crash is undefined. In fiscal year 2020, 10030 numbers of crash, 153 numbers fatality, 240 numbers serious injuries and 6684 numbers normal injuries has been recorded in Nepal. (Nepal Police, 2018).

The rate of motor-related crashes in Nepal is found increasing day by day. At the same time construction of new roads is increasing day by day. Some roads have been constructed without considering the safety factors. This question has raised whether to construct roads in more quantity without considering the safety factor or construct less but safer roads. Hence the road going to be constructed in near future should be designed safe prior to construction and study should be conducted for each constructed road for making safer roads. Causes of road traffic crashes are multifactorial, arising from three sources: driver-related (speeding, drinking, overloading, and overworking), vehicle-related (mechanical and old vehicles) and road-related (narrow, steep, graveled, not repaired). Road crashes are reducible. Road safety experts believe that, with the right action, up to 5 million lives could be saved and 50 million injuries can be prevented in the coming 10 years. This would represent a reduction of about 50% on the predicted global death toll by 2020. (Amro et al., 2015) (Plan, 2013)

The Rupani-Rajbiraj road section is the section of NH14 that connects the E-W highway with Saptari, Rajbiraj's district headquarters. Rajbiraj is the center hub for the higher education, marketing, governmental major offices like court, land revenue office and medical facilities. Thus attraction of people for fulfilling their needs is high towards Rajbiraj and most of them travel through Rupani- Rajbiraj Road. Road edge is deteriorated with potholes in different sections. Lack of delineation, safety signs and signal, road marking and pedestrian crossing. Several losses of life and injuries have been found during road crashes along the Rajbiraj-Rupani road section. Six locations have been identified as fatal areas by the traffic police office in written reports. .(Traffic Police Office Rajbiraj ,Saptari Nepal Letter Date:7, 2020) To save life and property damage due to road crashes is a burning issue nowadays. Therefore, finding the star rating and star rating score of the selected location will help to make required improvements to make a better and safer road. There are three study areas: -Unique hospital area, Raipur area and Nahar chowk area (Gahil pump area)

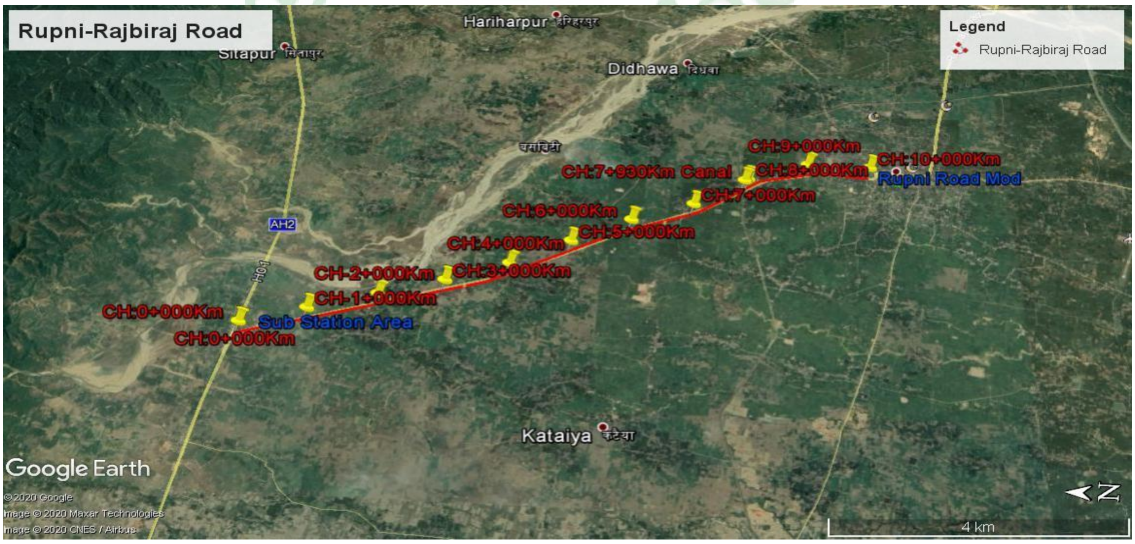

Figure 1: Location of study area (Google Earth, 2022)

Objectives

The main objective of the study is to conduct safety evaluation of the crash prone area at Rupani-Rajbiraj road section of NH14. The specific objectives of the study are:

- To determine the star rating (SR) and star rating score (SRS) at crash prone area of Rupani-Rajbiraj road section of NH14
- To identify the types of crash risk for the road users at study location.
- To identify the possible measures for improving the star rating to a minimum of 3 stars

2. Methodology

2.1 Theory

Star Ratings are based on road inspection data and provide a simple and objective measure of the level of safety which is 'built-in' to the road for vehicle occupants, motorcyclists, bicyclists and pedestrians. Five-star roads are the safest while one-star roads are the least safe. (iRAP, 2021) Star Ratings can be completed worldwide, in urban and rural areas and without reference to detailed crash data, which is often unavailable in low-income and middle-income countries, or is sparse in high-performing high-income countries striving for vision zero outcomes. (iRAP, 2019) (iRAP, 2021) (Rogers et al., 2012)

Table 1. Star rating of roads

Star Rating	Pedestrian	Bicyclist	Motorcyclist	Vehicle
★	No sidewalk, No safe crossing, 60km/h traffic	No cycle path, No safe crossings, Poor road surface, 70 km/h traffic	No motorcycle lane, undivided road, trees close to road, winding alignment, 90km/h traffic	Undivided road width, narrow centerline, trees close to road, winding alignment, 100 km/h traffic
★★★	Sidewalk present, pedestrian refuge, street lighting, 50km/h traffic	On-road cycle lane, good road surface, street lighting, 60km/h traffic	On-road motorcycle lane, undivided road, good road surface, >5m to any roadside hazards, 90km/h traffic	Wide centerline separating oncoming vehicles, >5m to any roadside hazards, 100km/h traffic
★★★★★	Sidewalk present, signalized crossing with refuge, street lighting, 40km/h	Off-road dedicated cycle facility, raised platform crossing of major roads, street lighting	Dedicated separated motorcycle lane, central hatching, no roadside hazards, straight alignment, 80km/h traffic	Safety barrier, separating oncoming vehicles and protecting roadside hazards, straight alignment, 100km.h traffic

(Sakarya & Of, 2018)

UN Global Action mandates member countries to develop their individual national plans for the decade from 2011 - 2020 incorporating interventions under the following broader themes: Road safety management, Safer roads and mobility, Safer vehicles, Safer road users, Post-crash response. To comply with the call made by the UN Global Action Plan, Road and Traffic Unit, the Department of Roads has started the preparation of Nepal Road Safety

Action Plan (2011–2020). And this document has been anticipated representing Nepal's national action plan on Road Safety. (Plan, 2013) (Report,2020)

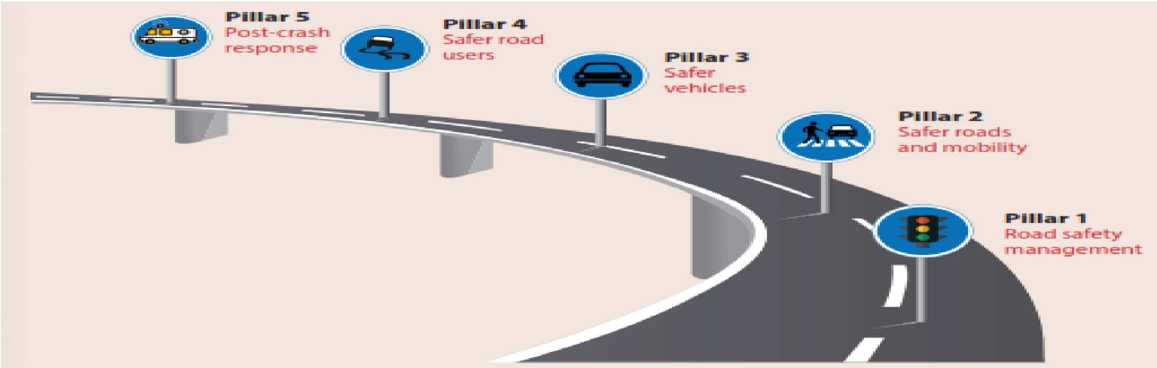

Figure 2 : Pillars of road safety (Consunji et al., 2018)

2.1.1 Study variables

The main purpose of the study is to evaluate and identify possible measures for improving to a minimum of 3 stars rating for the study section.

The study variables for star and star ratings evaluation are categorized into two categories. These are dependent variables and independent variables.

Dependent Variables

- ❖ Star rating and star rating score

Independent Variables

- ❖ Standard cross section of road
- ❖ Roadside attributes
- ❖ Mid-block
- ❖ Intersections
- ❖ Traffic Flow
- ❖ VRU facilities and land use
- ❖ Speeds

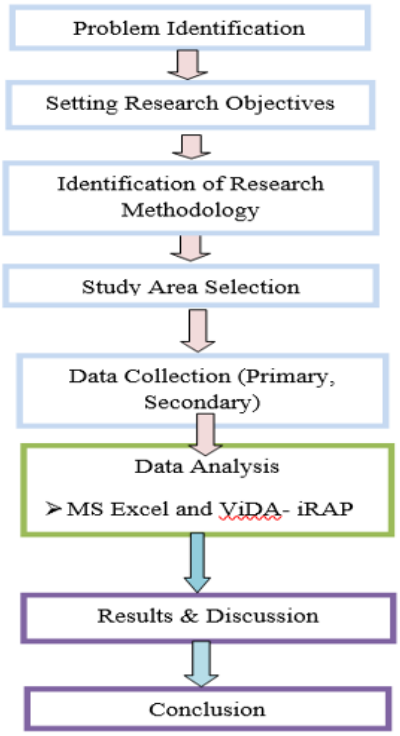

Figure 3: Research methodology of flowchart

Data Collection

To achieve the aim of the study different types of data are required and the data are categorized as; Primary data and Secondary data. The main primary data are: Traffic Count, Pedestrian peak hour Flow, Bicyclist peak hour flow, VRU facilities and land use, Operating Speed.

Data Analysis

MS-Excel and ViDA (Visualize, Design, Assess) software is used for data analysis in order to safety evaluation of the road section. ViDA (meaning 'life' in Spanish) is iRAP's online software. (International Road Assessment Programme [iRAP], 2022) ViDA is used to perform all iRAP star rating and safer road investment plan analyses. This study is use ViDA software for free. Referring the inventory data sheet of the study area, analysis has been made following the steps shown in processing diagram

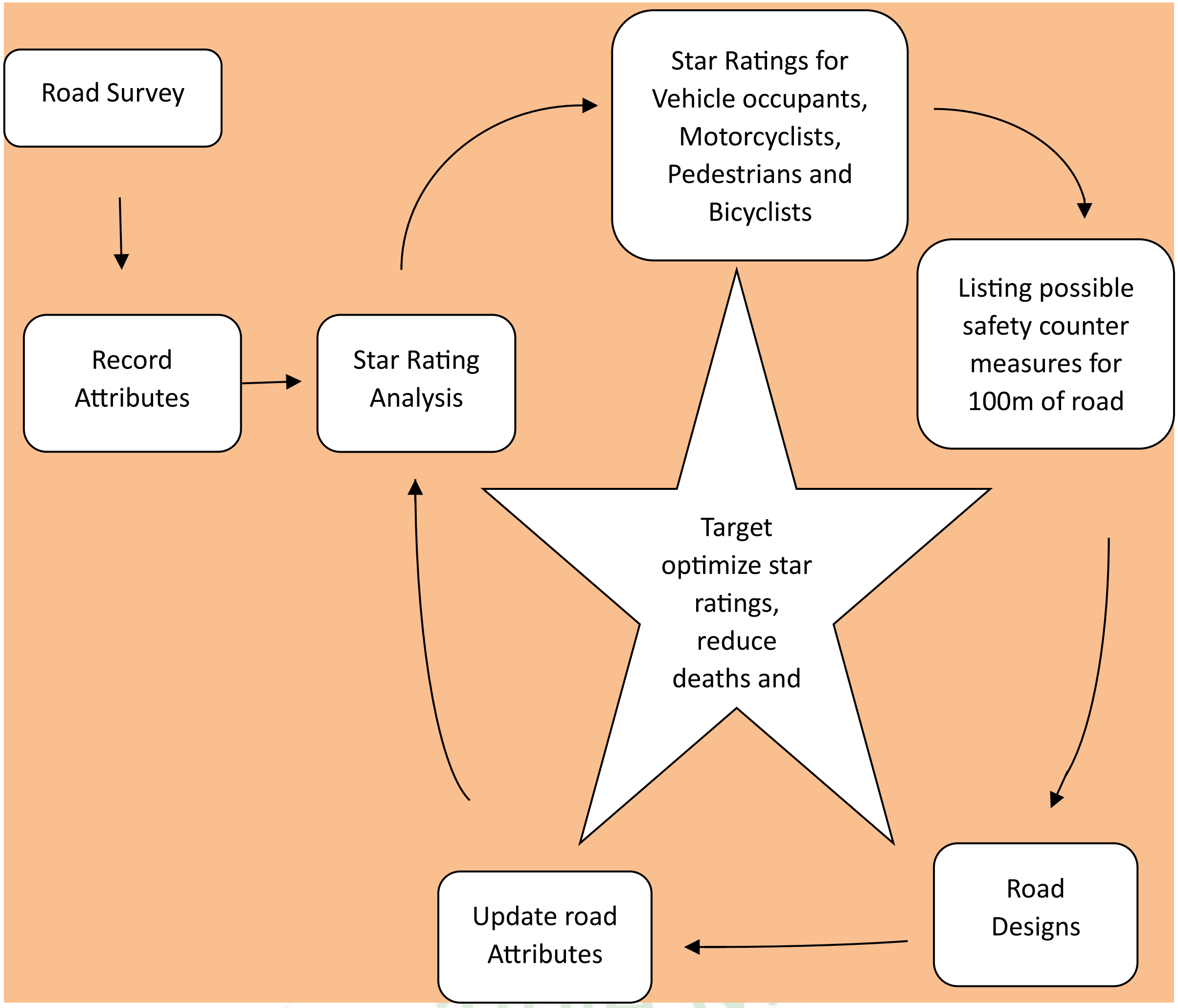

Figure 4: Star rating processing diagram (iRap, 2019)

As per iRAP road is said safer if the star rating for the vehicle occupants, motorcyclists, pedestrians and bicyclists in the study area is 3 star or more. Also the star rating score for the vehicle occupants at least in the range of 5 to< 12.5, for motorcyclists at least in the range of 5 to< 12.5, for pedestrians at least in the range of 15 to<40 and for bicyclists at least in the range of 10 to<30 indicates safer. For complete safety, the star rating of the study section for vehicle occupants, motorcyclists, pedestrians, bicyclists are 5star and star rating score for vehicle occupants, motorcyclists, pedestrians and bicyclists is zero (International Road Assessment Programme, iRAP, 2012) (Rogers et al., 2012) (Ambros et al., 2017) (EuroRAP, 2011). The Higher the star rating, the safer the road is for the users. Star rating score is found increasing if the star rating is low. Higher the star least is the score. Higher the star safer is the road. (EuroRAP, 2011) (iRAP, 2019) (IndiaRAP, 2020)

Table 2. Star rating bands and color

Star Rating (SR)	Star Rating Score (SRS)

	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists
5	0 to <2.5	0 to <2.5	0 to <5	0 to <5
4	2.5 to <5	2.5 to <5	5 to <15	5 to <10
3	5 to <12.5	5 to <12.5	15 to <40	10 to <30
2	12.5 to <22.5	12.5 to <22.5	40 to <100	30 to <60
1	22.5+	22.5+	100+	60+

(International Road Assessment Programme, iRAP, 2012)

3. Results & Discussion

In this section, the star rating as well as the star rating score for three study locations, as well as the type of risk of crash at existing and after improvement locations, are presented in tabular and histogram form.

The star rating, the star rating score, and the type of crash risk in Raipur

Raipur Area for the vehicle occupants, motorcyclists and pedestrians seems safer whereas bicyclist is found unsafe as the star rating for the vehicle occupants, motorcyclist and pedestrians is 3 star and bicyclist is 2 star. Star rating score for vehicle occupants, motorcyclists, pedestrians and bicyclists are 6.85, 9,61, 32,77 and 30.57 respectively. Figure 5 shows that the risk of crash type for vehicle occupants is run-off passenger side followed by run-off driver side, and head-on loss of control. Risk of crash type for motorcyclists is run-off passenger side followed by run-off driver side, head-on loss of control, intersection and along the road. Risk of crash type for pedestrians is while crossing through the road followed by along the road, and crossing side. Risk of crash type for bicyclists is along the road followed by intersections.

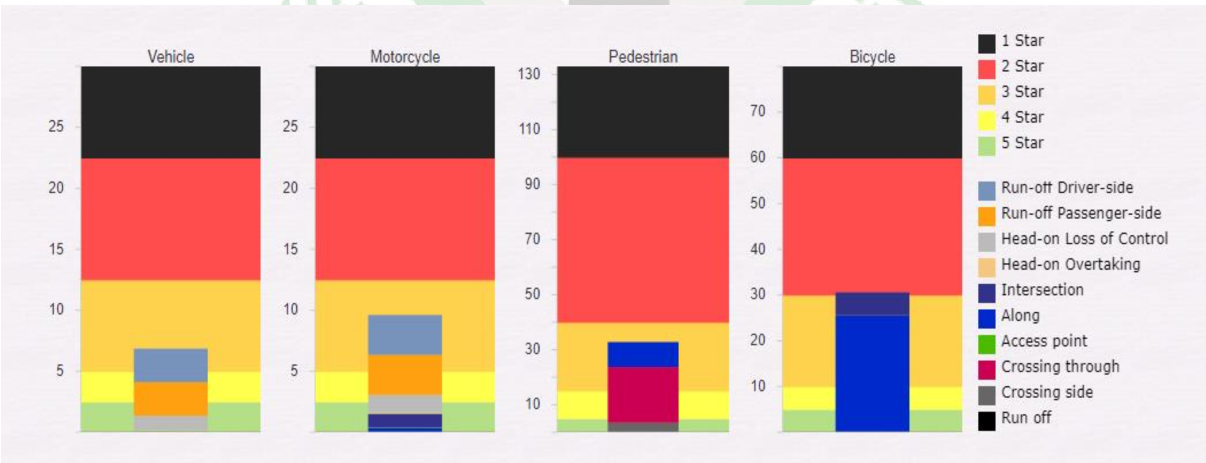

Figure 5: Existing star rate score and risk of crash type at Raipur area

Table 3. Existing star rating score and star rating score of Raipur area

Description	Star Rating				Remarks
	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists	
Star rating	3	3	3	2	Existing condition
Star rating score	6.85	9.61	32.77	30.57	

The counter measure is applied focusing on improving the star rating of bicyclists to achieve minimum 3 stars. A number of delineating factors could be improved, such as: center lines, lane markers, edge lines, guideposts, delineators, road studs, and hazard markers, as well as signage (on the road and posted). (Department of, 2022) (*Prevent Pedestrian Crashes : Parents and Caregivers of Elementary School Children*, n.d.)

Bicyclists are found safe as the star rating and star rating score is improved to 3 star and 26.31 respectively. From Table 4 it is clear that all the users are safe as the star rating and SRS for the users at Raipur area is improved to 3 star and 5.74, 8.28, 31.26 and 26.31 respectively. Figure 6 shows that the risk of crash type for vehicle occupants, motorcyclists, pedestrians is subsequently reduced by 16%, 14% and 5% respectively in compared to the existing result though the users were in safer range; whereas risk of crash type for bicyclist along the road is reduced by 14% in compared to the existing result to achieve the SDG target.

Table 4. Star rating and star rating score of Raipur area after improvement

Description	Star Rating				Remarks
	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists	
Star Rating	3	3	3	3	After applying counter measures
Star Rating Score	5.74	8.28	31.26	26.31	

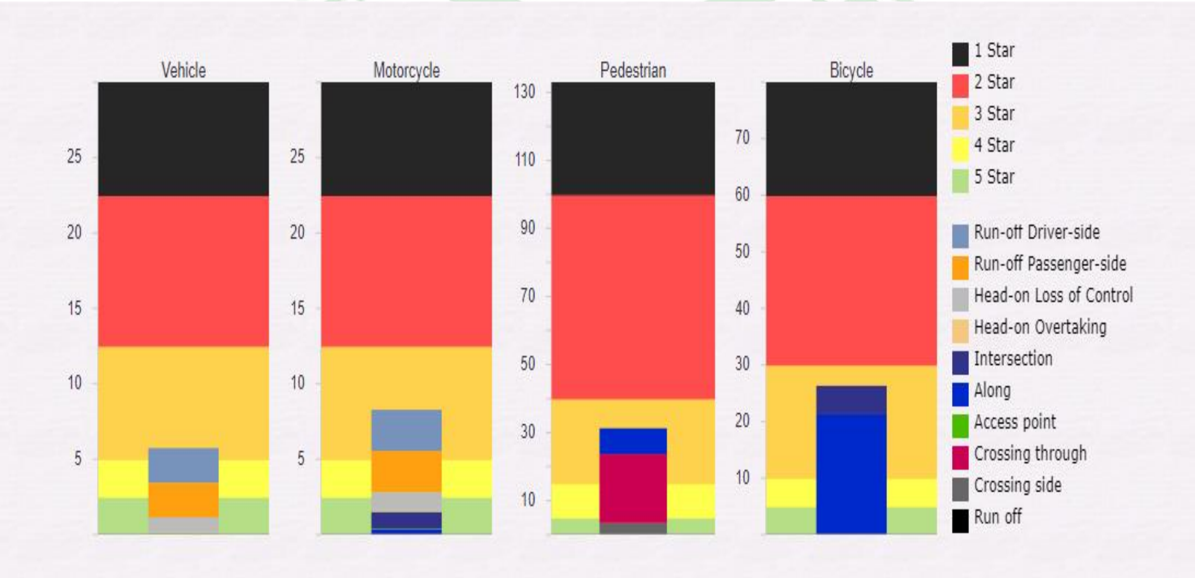

Figure 6: Star rate score and risk of crash type at Raipur area after improvement

The star rating, the star rating score and the type of crash risk in Unique hospital area

Unique hospital area is unsafe as the star rating of the vehicle occupants, motorcyclist, pedestrians, and bicyclist is less than 3 stars and the star rating score for vehicle occupants, motorcyclist, pedestrians and bicyclist are 15.12, 20.53, 57.5 and 45.78 respectively. Figure 7 shows that the risk of crash type for vehicle occupants is run-off passenger side followed by run-off driver side, and head-on loss of control. Risk of crash type for motorcyclists is run-off passenger side followed by run-off driver side, head-on loss of control, along the road and head-on overtaking least. Risk of crash type for pedestrians is while crossing through the road followed by along the road. Risk of crash type for bicyclists is only along the road.

Table 5. Existing star rating and star rating score of Unique hospital area

Description	Star Rating				Remarks
	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists	
Star rating	2	2	2	2	Existing condition
Star rating score	15.12	20.53	57.5	45.78	

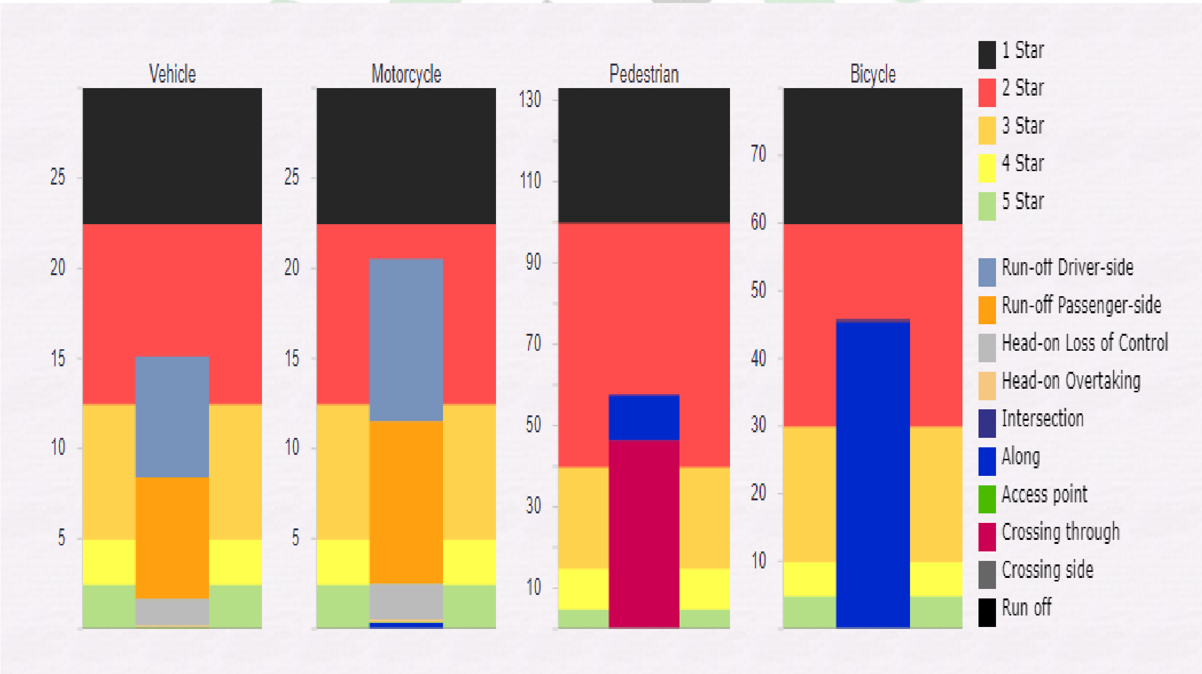

Figure 7: Existing star rate score and risk of crash type at Unique hospital area

The counter measure is applied focusing to improve the star rating of vehicle occupants, motorcyclist, pedestrians and bicyclist to achieve minimum 3 stars. Repair and maintenance of the damaged road edge pavement along with improved delineation will ensure the road section is safe for all road users. (Department of, 2022) (*Prevent Pedestrian Crashes : Parents and Caregivers of Elementary School Children*, n.d.) The table 6 clearly reflects the safer road section. Existing condition star rate and star rating score is improved to 3 star and 7.62, 9.36, 38.03 and 21 respectively for the vehicle occupants, motorcyclist, pedestrians and bicyclist. Figure 8 shows that the risk of crash type for vehicle occupants, motorcyclists and bicyclists is nearly reduced by half whereas pedestrians are reduced by 34% in comparison to the existing result to achieve the SDG target.

Table 6. Star rating and star rating score of Unique hospital area after improvement

Description	Star Rating				Remarks
	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists	
Star rating	3	3	3	3	After applying counter measures
Star rating score	7.62	9.36	38.03	21	

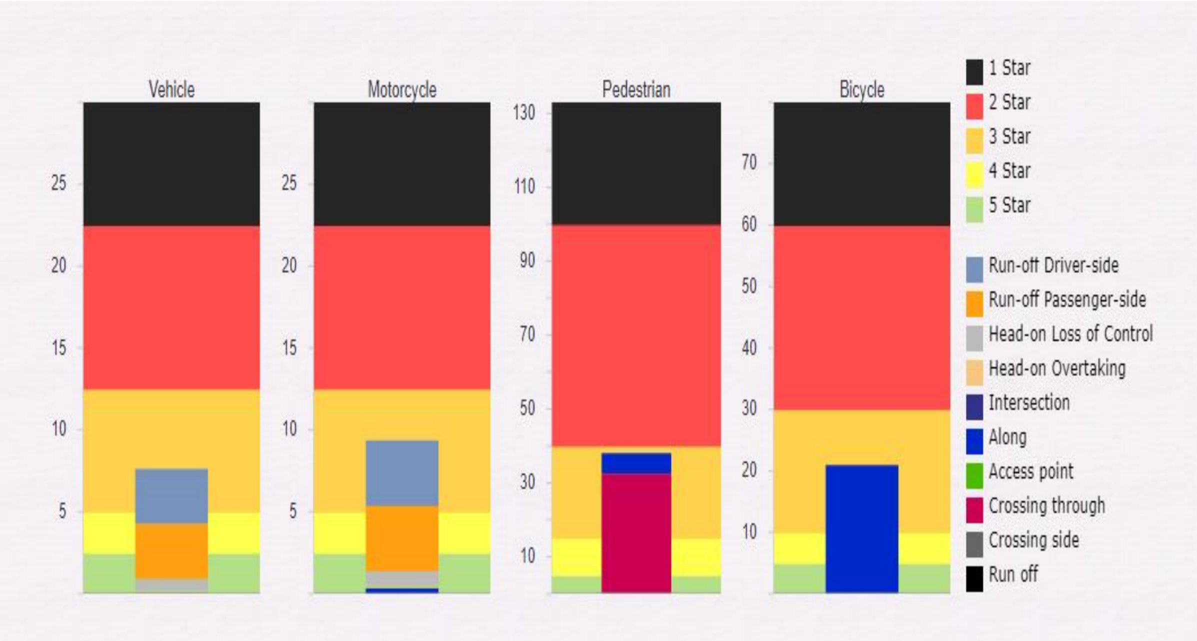

Figure 8: Star rate score and risk of crash type at Unique hospital area after improvement

The star rating, the star rating score and the type of crash risk in Nahar chowk area (Gahil pump area)

Nahar chowk area for the vehicle occupants and motorcyclist is unsafe as the star rating for this user in the section is less than 3 stars and star rating score for vehicle occupants and motorcyclist is 17.29 and 21.82 respectively. But pedestrians and bicyclist users are safe as the star rating and star rating score of the users are 3 stars and 36.74, 27.23 respectively. Counter measures should be taken for making the vehicle occupants and motorcyclist safe.

Table 7. Existing star rating and star rating score of Nahar chowk area (Gahil pump area)

Description	Star Rating				Remarks
	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists	
Star rating	2	2	3	3	Existing condition
Star rating score	17.29	21.82	36.74	27.23	

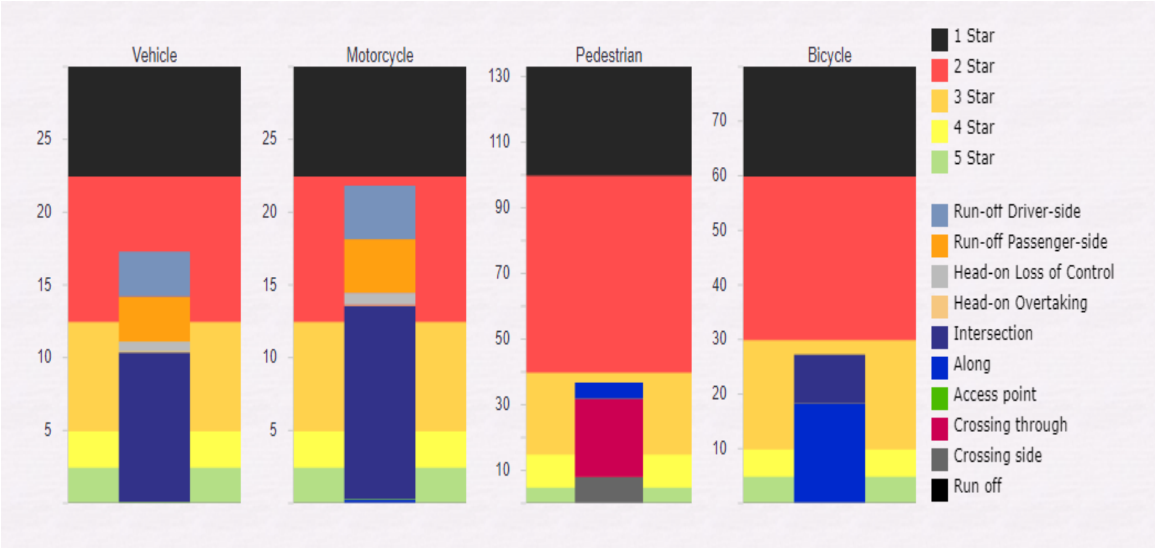

Figure 9: Existing star rate score and risk of crash type at Nahar chowk area (Gahil pump area)

As pedestrians and bicyclists already meet the 3-stars rating, the counter measure is applied focusing on improving the star rating of vehicle occupants and motorcyclists to achieve minimum 3 stars. Road safety can be improved by improving delineation and providing a speed limit of 45kmph (85 percentile speed) for vehicles to operate in. (Department of, 2022) Table 8 clearly reflects the safer road section. Existing condition star rating and SRS is improved to 3 star and 8.9, 11.27, 17.11 and 11.51 respectively for vehicle occupants, motorcyclist, pedestrians and bicyclist. Figure 10 shows that the risk of crash type for vehicle occupants and motorcyclists is nearly reduced by half whereas risk of crash type for pedestrians and bicyclist is reduced by 53% and 58% respectively compared to the existing result.

Table 8. Star rating and star rating score of Nahar chowk area (Gahil pump area) after improvement

Description	Star Rating				Remarks
	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists	
Star rating	3	3	3	3	After applying counter measures
Star rating score	8.9	11.27	17.11	11.51	

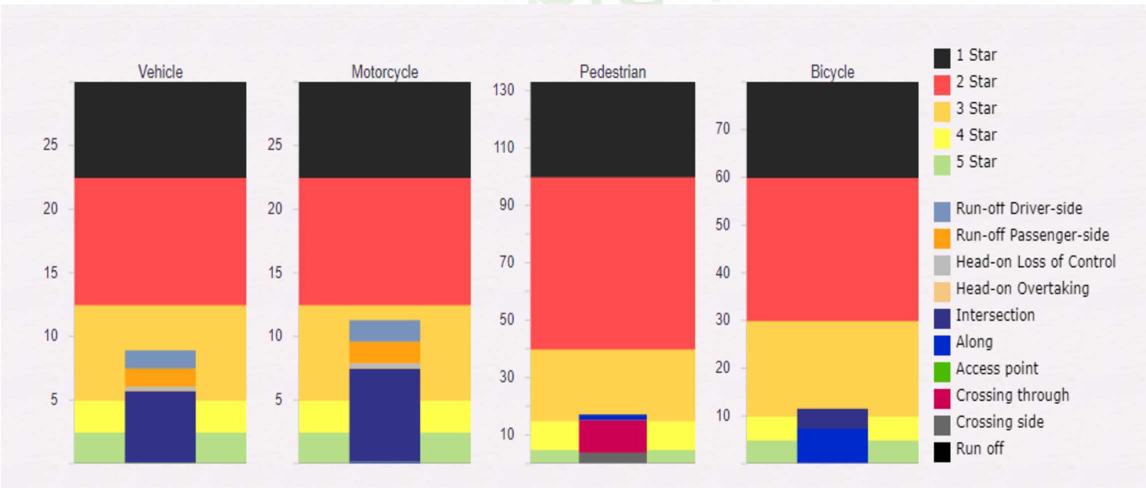

Figure 10: Star rate score and risk of crash type at Nahar chowk area (Gahil pump area) after improvement

4. Conclusion

The researcher identifies the crash prone location and records the various road attributes for finding the star rating and star rating score for the vehicle occupants, motorcyclists, pedestrians and bicyclist at the study location.

The study covers the three locations of selected roads. The three locations are: - Raipur area, Unique hospital area, Nahar chowk (Gahil pump) area. Based on the output results of the software and analysis of researcher following conclusions are drawn:

Star rating and star rating score for different road users at different crash prone locations was found. There were 2 stars to 3 stars for the existing road condition for vehicle occupants, motorcyclists, pedestrians and bicyclists whereas star rating score found in the varying range of 6.85 to 17.29 for vehicle occupants, 9.61 to 21.82 for motorcyclist, 32.77 to 57.5 for pedestrians and 27.23 to 45.78 for bicyclists. Star rating and star rating score of all study locations have not fulfilled the minimum requirement of the safer road. All three locations can be improved at low cost by repairing and maintaining the damaged road, improving the delineation and providing the speed limit of the vehicle. As a result of applying the stated countermeasures, improvements in the star ratings for vehicle occupants, motorcyclists, pedestrians, and bicyclists have been found to be 3 stars. Star rating score is found in the varying range of 5.74 to 8.9 for vehicle occupants, 8.28 to 11.27 for motorcyclists, 17.11 to 38.03 for pedestrians and 11.51 to 26.31 for bicyclists. It has been found that crash risk for different types of road users can be reduced by applying countermeasures, such as runoffs on the driver's side, runoffs on the passenger's side, head-on overtaking, crashes at intersections, crashes while walking along the road, crashes while crossing the road, and crashes while crossing the side of the road under existing conditions. As a result of the study, the road section can be improved to make it safer, minimizing the loss of lives on the road.

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Enhancing Road Safety by Infrastructure Health Monitoring using Mobile Mapping Systems

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Abstract

Infrastructure Health Monitoring (IHM) system is a method of evaluating and monitoring structural health. In this study, a novel method for monitoring road pavements using the Mobile Mapping System (MMS) and a deep learning crack detection system was presented. Furthermore, this study estimated life expectancy of the crack of asphalt road pavement using the Bayesian Markov Mixture Hazard Model. An optimal maintenance method through economic analysis was presented targeting the pavement sections of Sejong City of South Korea. As a result of monitoring the pavement conditions, it was confirmed that national highway, which are systematically maintained and managed through the Pavement Management System (PMS) are managed relatively well compared to roads managed by local governments. It can be confirmed that timely management leads to an extension of life expectancy of road sections.

Keywords: Infrastructure Health Monitoring; Mobile Mapping System; Deterioration Model; Bayesian Markov Mixture Hazard Model; Pavement Management System.

1. Introduction

Infrastructure of Korea has already started to deteriorate, and the proportion of infrastructure used for more than 30 years is expected to increase rapidly from 10.3% in 2016 to 25.8% in 2026 and 61.5% in 2036. In the case of local government-managed roads except for national highways and national roads, local governments should establish management and maintenance plans in consideration of their financial conditions. On the other hand, road condition monitoring is a very important management variable not only for traffic flow but also for improving safety.

Road safety is very important not only for the movement of drivers but also for the stable supply of logistics. Recently, studies for road condition inspection and safety improvement using infrastructure health monitoring (IHM) techniques are being actively conducted in developed countries. IHM has been widely applied in various engineering sectors due to its ability to respond to adverse structural changes, improving structural reliability and life cycle management (Aktan et al., 1998).

In this study, a novel method for monitoring road pavements using the Mobile Mapping System (MMS) and a deep learning crack detection system was presented. MMS is a technology for acquiring high-quality spatial information data by mounting a receiver, GNSS, laser scanner, and digital camera in a vehicle. In this paper, the deep learning system uses the YOLO-v2 algorithm to automatically determine the condition levels of the road pavement surface. In addition, in order to accurately estimate life expectancy, environmental variables such as traffic volume, equivalent single axle loads (ESAL), structural number of pavement (SNP), meteorological condition, and deicing were applied to retain reliability of the estimation result (Do, 2011).

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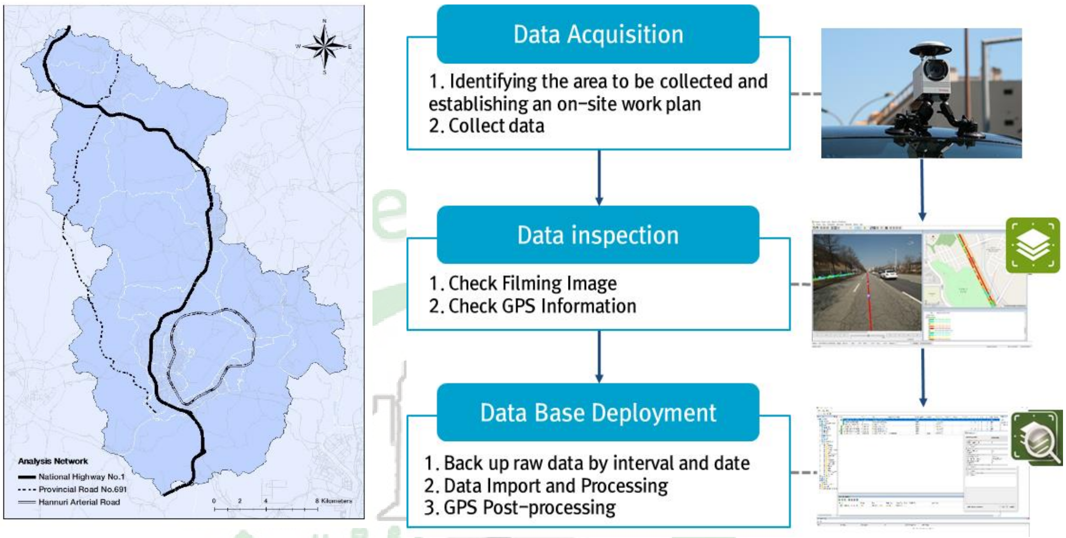
2. Methodology

The development of the deterioration model of road condition is a key process of long-term life cycle cost analysis. For the construction of deterioration model, national highway pavement monitoring data for about 10 years from 2007 to 2017 was used in this paper. Furthermore, this study estimated life expectancy of the crack of asphalt road pavement using the Bayesian Markov Mixture Hazard Model (Han et al., 2013).

Furthermore, an optimal maintenance method through economic analysis was presented targeting the pavement sections of Sejong City. Sejong city was founded in 2007 as the new planned special self-governing city of South Korea. Figure 1 shows the road network in the target area and the processing flow of pavement condition data for the study.



(a) Investigation Section (b) Data Acquisition Flow

Fig. 1. Overview of Survey

Ten years of national highway road pavement monitoring data fused with ESAL, SNP and average low temperature, total rainfall, deicing were used for the deterioration modeling. A deterioration modeling was performed through the Bayesian Markov Mixture Hazard Model.

A methodology to estimate the Markov transition probability model is presented to forecast the deterioration process of road sections in this paper. The deterioration states of the road sections are categorized into several ranks and the deterioration processes are characterized by hazard models. The Markov transition probabilities between the deterioration states, which are defined by the non-uniform or irregular intervals between the inspection points in time, are described by the exponential hazard models. Furthermore, in order to verify the validity of the proposed method, the applicability of the estimation methodology presented in this paper is investigated by using the empirical surface data set of the national highway in Korea (Kobayashi, et al., 2010; Han et al., 2016).

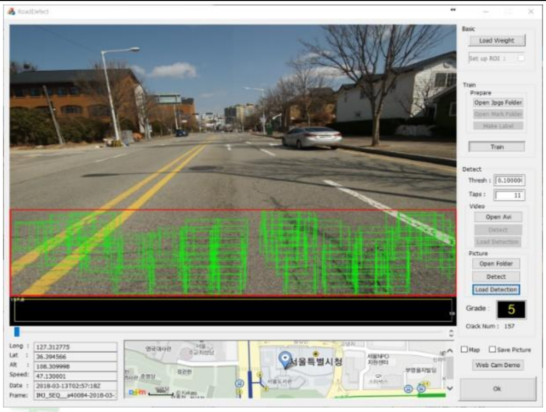
Table 1. Characteristics of Investigation Section

Name of Road	Length (km)	No. of Lanes	AADT (vol/day)	Composition of Traffic (%)			Acquired Image (pics)
				Small	Medium	Large	
National Highway No.1	26.9	4	36,254	83.9	1.2	14.9	29,093
Hannuri Arterial Road	11.5	6	8,355	87.6	2.5	9.9	13,259
Provincial Road No.691	16.5	2	2,370	84.7	0.8	14.6	19,963

Target roads are set for national highway, municipal road (Hannuri arterial road) and provincial road, and their characteristics are shown in Table 1. The road surface condition rates are divided into 5 levels as shown in Table 2. The field survey using MMS was conducted for one lane in both directions of each target route.

Table 2. Rating criteria by classified method

Rating	Classified criteria		
	Manual	Automatic	
		No. of Detected box	PPM
1	2% under	No. of Box < 10	10 under
2	2% ~ 10%	10 ≤ No. of Box < 100	10 ~ 97
3	10% ~ 20%	100 ≤ No. of Box < 250	97 ~ 245
4	20% ~ 30%	250 ≤ No. of Box < 400	245 ~ 390
5	30% Over	400 ≤ No. of Box	390 over



Source : Choi et al.,(2018).

The YOLO algorithm has the advantage of having relatively high searching speed and accuracy compared to the CNN method. In this paper, YOLO-v2 was used as deep learning algorithm to automatically determine the condition levels of the road pavement surfaces as shown in Figure 2 (Choi et al., 2018).

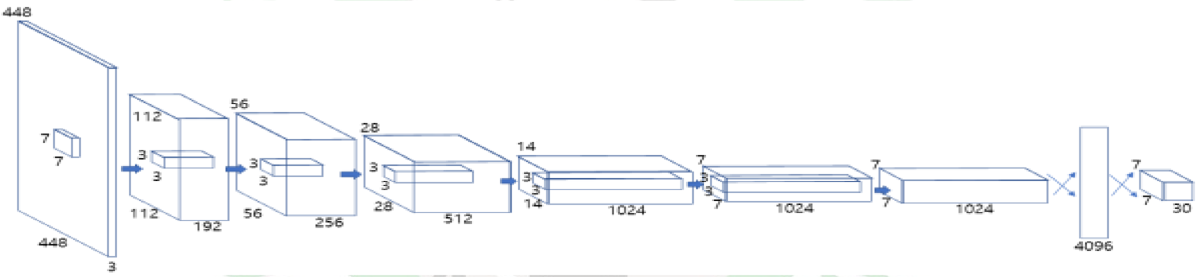


Fig. 2. Yolo V.2 architecture

In this paper, economic analysis was performed using the Korean pavement management system (KoPMS) developed for national highway pavement management. For user cost, vehicle operation cost, travel time cost, environmental pollution cost and noise cost were applied. The benefit is calculated as the difference between user costs when no maintenance is performed (do-nothing scenario) and when maintenance is performed. The authors tried to calculated the difference in user cost according to maintenance standards and pavement types.

3. Results & Discussion

As a result of monitoring the pavement conditions, it was confirmed that national highway, which are systematically maintained and managed through the pavement management system (PMS) are managed relatively well compared to roads managed by local governments. It can be confirmed that timely management leads to an extension of life expectancy of road sections.

In addition, economic analysis using the pavement deterioration model showed that the preventive maintenance method is the most economical in terms of maintenance costs and user benefits. The results of this study are expected to be used as fundamental reference for infrastructure management plans.

4. Conclusion

It was confirmed that maintaining the road pavement in the proper condition is the best way to reduce the travel time of road users (vehicles), save fuel costs, and reduce environmental pollution costs.

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Service Quality Assessment of Public Transportation along Kathmandu Ring Road (NH-39)

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Abstract

A 27 Km Ring Road of Kathmandu has become NH-39 of our country Nepal. Due to increasing motorization in Ring Road of Kathmandu, traffic congestion is increasing daily. Though, it is catered by many bus companies, their Service Quality is not seen satisfying. So, this study aimed to find out the existing Service Quality of the existing public bus (MahaNagar Yatayat, Orange Bus Sewa, Sundar Yatayat (known as Electric Bus) and Other Bus plying in the Ring Road of Kathmandu valley, based on SERVQUAL method. It is an important tool used for classifying Public Transportation under SERVQUAL evaluation criteria along the five dimensions; and they are: Reliability, Tangibles, Assurance, Empathy, and Responsiveness. Statistically significant number of samples at 95% confidence interval for every gender, age group, occupations was taken. A series of questionnaires was asked to each bus user. Since it is difficult for users to express their perception with a particular number, they were asked to respond to the questionnaires in linguistic terms and the results obtained from this questionnaire survey were converted to fuzzy numbers later. Altogether 20 numbers of sub- criteria under SERVQUAL dimensions were taken for perception evaluation survey. Using the linguistic terms, Defuzzification was done. Based on this value, user satisfaction was checked and the higher the score obtained lesser was the user satisfaction level among each criterion. So, using SERVQUAL method Service quality of Public Transportation along Kathmandu Ring Road was assessed.

Keywords: SERVQUAL, Fuzzy Numbers, Defuzzification

1. Introduction

Kathmandu, the Capital of Nepal, experiences an annual population growth rate of nearly 6.12% which makes it one of the fastest growing urban areas in South Asia, creating many complexes like traffic congestions, road traffic crashes, poor public transport system, and air pollution. There is a tremendous increase in the usage of vehicles inside valley, leading to the registered number of vehicles reaching more than 11, 72,413 in fiscal year 2075/76 (DOTM, 2017). Public Transportation operates on its fixed routes, and it may include any type of modes such as: bus, microbus, micros, Tempos, etc. A robust Public Transport Service makes efficient use of urban space. According to (Dube, Rosier, Theriault, & Dib, 2011), Public Transport plays a social role in the urban environment; it improves access to workplaces and services infrastructure and at the same time, it reduces travel expenses. Due to the lack of satisfaction users derive from the services of Public Transport; Reliability of Public Transportations is falling day by day, which are prompting the public to opt for private transport. Passenger's perception towards public transportation must be assessed to evaluate the existing status. It also helps to recommend improvement measures. The goal of public transport operators and authorities is to increase Passenger satisfaction and cost efficiency (Duwadi, Marsani , & Tiwari, 2019). The level of dissatisfaction with public transport is very high.

Thus, it is necessary to upgrade the performance of Public Transport in Kathmandu to maintain a sound transportation system and enhance the level of satisfaction of the public towards it.

Service Quality (SERVQUAL) is the degree of achieving the desired objective of service. It is one of the most important factors that increase the usage of Public Transport. Higher service quality can result in higher users' satisfaction. User satisfaction is an intrinsic aspect of any service and since Public Transport is a service-based supply, it has to be continuously assessed for user satisfaction. Ranking of Public Transportations in terms of quality of service is very important, to increase productivity and improve users' satisfaction. Although various models have been developed to measure service quality in service organizations, SERVQUAL is accepted as the basis for all the models (Saravanan, 2007). This approach consists of five dimensions: Reliability, Tangibility, Assurance, Empathy, and Responsiveness. Since, the criteria used for measuring the Service Quality are not only limited to quantitative aspects, but multi-Criteria Decision also Making (MCDM) approaches can be used to evaluate the Service Quality that includes quality dimensions which cannot be measured quantitatively. A number of outputs variables such as vehicle seating capacity, comfort, security, safety, cleanliness, waiting times, fare, driver recklessness, information, and feedback was used to evaluate bus service performance of Kathmandu Valley (Manandhar, 2023).

2. Methodology

2.1 Study Area

To this study, the whole Ring Road (Kalanki- Chabahel- Kalanki) was selected. This road runs outwardly connecting major Institutional and Business areas namely: Kalanki, Balkhu, Ekantakuna, Satdobato, Koteshwar, Airport Road, Gaushala, Chabahel, Gongabu, Balaju, Swayambhu covering about 27 km length. This road has considerable demand for transportation, as the catchment area of passengers at these junctions is huge. There are many buses plying on ring road, operating daily. In this study, a total of four bus alternatives were taken into consideration and they were: MahaNagar Yatayat; Orange Bus Sewa; Sundar Yatayat and Other bus. Nearly 80 MahaNagar Yatayat and 10 Orange Bus runs daily in this road (Bus Operator, 2020). Every type of passenger was expected to be using this route from Business propose to Institutional propose. Therefore, this route seemed very important to find user satisfaction level for mixed passengers.

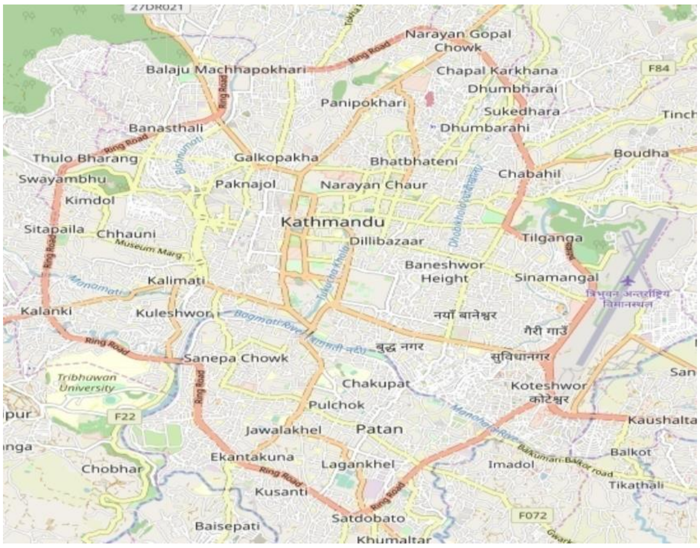

Figure 1 Study Area

2.2 Data Collection

Both primary and secondary data were used in this study. The main source of data collection was a primary source. The questionnaires used in this study were given to all types of people, but it was mentioned that the vehicle user who uses the Ring Road Bus were only asked to fill up the form. Data was collected during both peak hours and off-peak hours and at different locations, composition of in bus and at the bus stations of Ring Road. Data was collected through a questionnaire survey and the information on the five SERVQUAL dimensions was collected. The five dimensions are: Reliability, Tangibles, Assurance, Empathy, and Responsiveness.

As a secondary source, reports and articles published by other organizations were taken. Besides this, the information regarding vehicle registration in the study area and the types of vehicles and companies that are operating their service in the study area were obtained from the secondary sources.Statistically significant number of samples at 95% confidence interval for every gender, age group, occupations was taken, for all buses except for Sundar Yatayat. Since users of Sundar Yatayat were very few and buses themselves are in limited number, sample was taken for 90% Confidence Level. So, around 260 samples were taken for Sundar Yatayat Bus and around 390 samples were taken for other remaining bus alternatives.

2.3 SERVQUAL

SERVQUAL is a multi-dimensional tool to capture consumer expectations and perceptions of a service along the five dimensions that are believed to represent Service Quality (Awasthi, 2011). The dimensions of SERVQUAL are briefly summarized as follows:

A. Reliability: Relates to the ability of the service provider to perform the promised service dependably and accurately. The criteria under this dimension involved in the questionnaire are:
    - Punctuality
    - Bus Waiting Time at station
    - Sufficiency of standing and sitting areas
    - Passenger Density in the bus

- Security in the vehicles
- Risk of crash

B. Tangibles: Include the physical appearance of the service facility, the equipment, the personnel, and the communication materials. The criteria under this dimension involved are:
   - Seats, holders and general looks of vehicles
   - Position of doors in vehicles
   - Cleanliness
   - Suitability of bus for disabled and elderly people
   - Transportation Fare and fare collection System
   - Vehicles equipped with modern technology.
   - Environmentally Conscious Vehicles

C. Assurance: Refers to the knowledge and courtesy of employees and their ability to inspire trust and confidence. The criteria under this dimension involved are:
   - Driving ability of the drivers
   - Knowledge of drivers towards Traffic rules and regulations

D. Empathy: Refers to caring, individualized attention to customers. The criteria under this dimension involved are:
   - Solution of Passengers concern and request
   - Behavior of drivers/bus staffs towards passenger

E. Responsiveness: Is the willingness of the service provider to be helpful and prompt in providing service. The criteria under this dimension involved are:
   - Bus Frequency
   - Bus route Travel Time
   - Information about bus route

It is difficult for users to express their perception with a particular number, so they were asked to respond to the questionnaires in linguistic terms. And they were later converted to Fuzzy numbers. (Refer Table 1 & Figure 2)

Table 1: Linguistic Variables for Survey

Very Poor	(1,1,3)
Poor	(1,3,5)
Medium	(3,5,7)
Good	(5,7,9)
Very Good	(7,9,9)

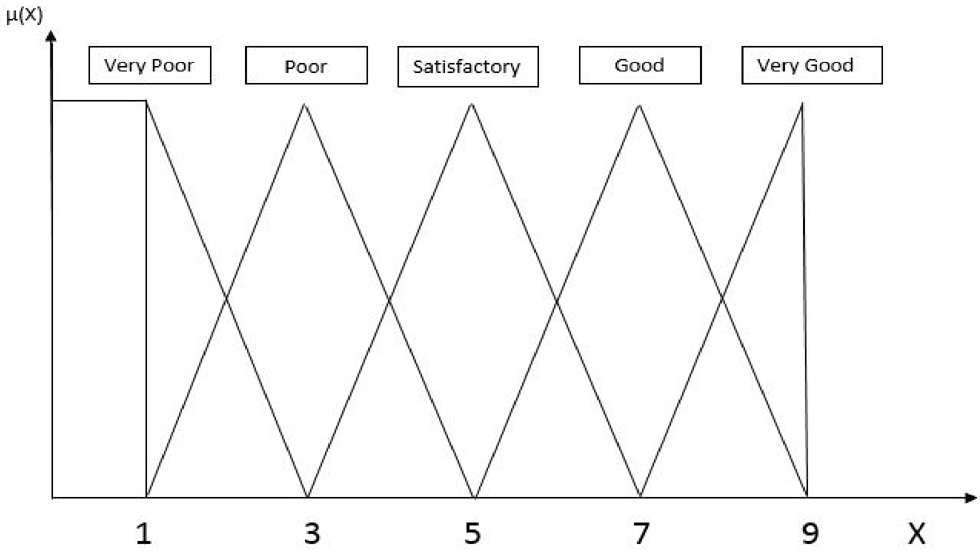

Figure 2: The Membership Function of Linguistic Terms *(Source: (Awasthi, 2011))*

The results obtained from the questionnaire survey was then converted numbers using the following steps as suggested by (Stefano, Filho, Barichello, & Sohn, 2015).

- Calculation of Total Perception Scores:
  Let A_i be the fuzzy score for sub-criterion i from the n^{th} interviewee and TA_i be the total score for Service Quality for sub-criterion i then:

$$TA_i = \sum_{i=1}^{i=n} A_i$$

- Calculation of Mean Scores: Let MA_i be the average Service Quality from N interviewees for the i^{th} sub-criteria of SERVQUAL dimensions, then:

$$MA_i = \frac{TA}{N}$$

The term MA represents the average Fuzzy scores for each sub-criteria under five dimensions of SERVQUAL which is Defuzzified using Graded Mean Integration Representation (GMIR).

For a triangular Fuzzy number, A= (a, b, c), the GMIR value is $P(A) = \frac{a+4b+c}{6}$

3. Results and Discussions

The surveyed data were analyzed to know both the demographic aspects as well as the perception of the users towards bus services. There is Mayur Yatayat, Gokarneshor, and Bhaktapur Bus operated in Ring Road, but they all do not run along the whole Ring Road, so they were not considered in this study. In Other bus, buses like Chakra path Parikrama Yatayat, City Bus, Swayambhu Yatayat, and Rachana Yatayat were taken for consideration due to their similarity on all bus services.

3.1 Overall Satisfaction Survey:

While doing the survey, impact of individual parameters in overall satisfaction of users were analyzed. And from the result, it was concluded that for "Bus Frequency" has the highest impact on overall satisfaction followed by "Risk of Crash", while "Knowledge of driver towards traffic rules and regulations" has comparatively less impact, as shown in table 2 below:

Table 2: Impact of Individual Parameters in Overall Satisfaction

Criteria	Highly Impact	Average	No Impact
Punctuality of Bus	36%	44%	21%
Bus Waiting Time at stations	23%	33%	45%
The sufficiency of sitting and standing areas	35%	45%	20%
The passenger density in the Bus	40%	49%	12%
The security in the vehicles	59%	28%	13%
Safety of vehicles (Risk of Crash)	61%	27%	12%
The seats, holders, and general look of vehicles	51%	35%	14%
Position of doors in the vehicle	24%	36%	40%
Cleanliness of vehicles	16%	36%	48%
Suitability of buses for disabled and elderly people	27%	45%	27%
Transportation fare and Fare collection system	22%	50%	28%
Vehicles equipped with modern technology	55%	28%	17%
Environmentally Conscious Vehicles	39%	51%	10%
The driving ability of driver/comfort during travelling	31%	45%	24%
The knowledge of driver towards traffic rules and Regulations	15%	27%	58%
The solution to passengers Concern and request.	20%	24%	56%
Behavior of driver/ bus staffs towards passenger	34%	53%	13%
Bus Frequency	64%	27%	9%
Bus route travel time including all sort of delays	39%	49%	12%
Information about Bus Route	20%	49%	31%

Survey related to overall service quality rating of all Bus Operators was also done. From the survey, as in below Table number 3, it was found that Females were more satisfied (66%) with Overall service Quality of MahaNagar Yatayat than Males (54%). Age groups within (45-60) were seen more satisfied by 74%. Similarly, people having education Under SLC were more satisfied (85%) than others. About 91% Housewives were seen satisfied, followed by Retired people (76%) as their sample size was small. Family having monthly income below 15000 were most satisfied by 81% while having more than 1 lakhs income were non-satisfied. Similarly, people who travel 2-3 times a week and having no any private vehicles were found more satisfied with this bus service.

Similarly, other interpretation can also be done for remaining vehicles, as shown in table 3 below:

Table 3: Overall Service Quality Ratings of all Bus Operators

Socio-Economic Characters	Variables	Overall Service Quality Rating							
		MahaNagar Yatayat		Orange Bus Sewa		Sundar Yatayat		Other Bus	
		Satisfied (%)	Dissatisfied (%)	Satisfied (%)	Dissatisfied (%)	Satisfied (%)	Dissatisfied (%)	Satisfied (%)	Dissatisfied (%)
Gender	Male	54	16	68	6	76	7	12	42
	Female	66	3	64	1	88	2	11	38
Age	15-30	46	20	52	9	76	11	9	40
	30-45	69	3	70	3	87	0	14	27
	45-60	74	0	69	0	91	2	15	45
	>60	68	4	73	1	76	0	8	53
Educational Status	Illiterate	72	3	78	1	88	0	24	33
	Under SEE	85	0	76	0	96	1	12	44
	10+2	65	1	70	3	94	0	7	33
	Bachelor	40	24	48	9	55	15	3	51
	Masters	40	16	27	4	70	10	14	43
Main Occupation	Unemployed	70	5	80	1	86	3	2	40
	Employed	31	22	38	8	63	12	6	46
	Business/ Trader	75	2	74	0	100	0	34	31
	Student	63	9	63	8	88	3	6	36
	Retired	76	0	59	0	75	0	4	53
	Housewife	91	0	100	0	92	8	0	70
Monthly Family Income	Below 15000	81	6	80	1	97	0	23	30
	15000-30000	65	7	70	5	92	3	`7	38
	30000-50000	51	9	54	2	68	5	10	46
	50000-100000	49	21	56	7	74	10	0	56
	Above 100000	0	20	0	0	25	25	0	80
Frequency of Using Public Vehicles	Everyday	52	11	64	5	92	2	15	33
	Once a week	57	8	62	3	79	8	4	50
	2-3 times a week	71	10	72	2	75	4	15	42
Main Purpose of Travel	School/ College	67	7	68	3	89	2	9	39
	Offices	45	15	61	6	69	7	25	33
	Entertainment	67	7	68	1	86	5	3	47
Number of private Vehicles	0	78	5	72	3	95	1	16	35
	1	46	13	62	4	68	11	11	38
	2 or more	51	10	58	2	83	0	1	61

3.2 MahaNagar Yatayat

After the data collection, perception survey was done in terms of linguistic values and later converted to fuzzy numbers as shown in table 4 below:

Table 1: Perception Evaluation for MahaNagar bus in terms of Fuzzy Numbers

S. No	Criteria	Fuzzy Numbers			Defuzzification
		Lower	Medium	Upper	
	Reliability	4.67	6.57	7.88	6.47
1	Punctuality	4.72	6.66	8.04	6.56
2	Bus Waiting Time at Stations	3.82	5.73	7.53	5.71
3	The sufficiency of sitting and standing areas	4.91	6.80	8.03	6.69
4	The Passenger Density in the Buses	4.53	6.40	7.72	6.31
5	The security in the Vehicles	4.76	6.62	7.80	6.50
6	Safety of Vehicles (Risk of Crash)	5.26	7.19	8.17	7.04
	Tangibles	5.12	7.04	8.10	6.89
7	Seats, Holders and General looks of the Vehicles	5.17	7.09	8.13	6.94
8	Position of Doors in Vehicles	5.44	7.41	8.29	7.23
9	Cleanliness of the vehicles	4.29	6.23	7.85	6.18
10	Suitability of buses for disabled and elderly	5.44	7.31	8.13	7.13
11	Transportation fare and Fare collection system	5.10	7.05	8.12	6.90
12	Vehicles equipped with modern technology	5.21	7.14	8.14	6.98
13	Environmentally-conscious vehicles	5.16	7.04	8.06	6.90
	Assurance	5.21	7.15	8.20	7.00
14	Driving Ability of the Driver/ Comfort during Travelling	5.25	7.19	8.22	7.04
15	Knowledge of Driver towards Traffic rules and regulation.	5.17	7.12	8.19	6.97
	Empathy	4.94	6.86	8.01	6.73
16	Solutions of passenger concerns and request	4.87	6.78	7.95	6.66
17	Behavior of driver/ bus staff towards passenger	5.02	6.93	8.06	6.80
	Responsiveness	4.92	6.86	8.13	6.75
18	Bus Frequency	4.36	6.30	7.96	6.25
19	Bus route travel time including all sort of delays	4.84	6.78	8.14	6.68
20	Information about Bus Route	5.57	7.50	8.29	7.31

As in above Table 4, under the dimension Reliability, users were seen more satisfied with the criteria "Risk of Crash" having weight of 7.04. While under Tangibles "Position of Doors in the vehicle" has the highest perception score of value 7.23. Similarly, under Assurance, the item "Driving ability of Drivers" has scored highest value of 7.04 and under Empathy "Behavior of Drivers towards passengers" has gained highest score of 6.80. Finally, "Information about Bus Route", which falls under dimension Responsiveness, have gained weight of 7.31. Among all, majority of passengers had rated the criteria "Information about Bus Route" with the highest weight of 7.31 and dimension under SERVQUAL having highest score is Assurance with a score of 7.00.

Sample calculation for Fuzzification:

TA (Punctuality)= 13(1,1,3) + 39(1,3,5) + 71(3,5,7) +146(5,7,9) +121 (7,9,9)

= (1842, 2596, 3134)

$$\text{MA (Punctuality)} = \frac{(1842, 2596, 3134)}{390} = (4.72, 6.66, 8.04)$$

$$\text{Defuzzification: P (Punctuality)} = \frac{4.72 + 4*6.66 + 8.04}{6} = 6.56$$

Therefore, this calculation of MahaNagar Yatayat was used for all criteria for all other bus alternatives.

3.3 Orange Bus Sewa

Table 5: Perception Evaluation for Orange Bus Sewa in terms of Fuzzy Numbers

S. N	Criteria	Fuzzy Numbers			Defuzzification
		Lower	Medium	Upper	
	Reliability	5.42	7.38	8.36	7.22
1	Punctuality	4.99	6.94	8.40	6.86
2	Bus Waiting Time at Stations	3.92	5.89	7.72	5.87
3	The sufficiency of sitting and standing areas	6.20	8.16	8.59	7.90
4	The Passenger Density in the Buses	5.77	7.74	8.50	7.54
5	The security in the Vehicles	5.67	7.61	8.38	7.41
6	Safety of Vehicles (Risk of Crash)	5.97	7.95	8.59	7.73
	Tangibles	5.42	7.40	8.39	7.23
7	Seats, Holders and General looks of the Vehicles	5.24	7.22	8.35	7.08
8	Position of Doors in Vehicles	5.89	7.87	8.56	7.66
9	Cleanliness of the vehicles	4.33	6.30	8.00	6.26
10	Suitability of buses for disabled and elderly	5.84	7.80	8.57	7.60
11	Transportation fare and Fare collection system	5.33	7.30	8.33	7.14
12	Vehicles equipped with modern technology	5.68	7.66	8.48	7.47
13	Environmentally-conscious vehicles	5.65	7.61	8.42	7.42
	Assurance	5.63	7.61	8.51	7.43
14	Driving Ability of the Driver	5.62	7.60	8.50	7.42
15	Knowledge of Driver towards Traffic rules and regulation.	5.65	7.63	8.53	7.45
	Empathy	5.03	7.01	8.25	6.89
16	Solutions of passenger concerns and request	5.05	7.02	8.26	6.90
17	Behavior of driver/ bus staff towards passenger	5.02	7.00	8.24	6.88
	Responsiveness	3.75	5.70	7.34	5.65
18	Bus Frequency	4.58	6.55	8.12	6.49
19	Bus route travel time including all sort of delays	4.99	6.97	8.38	6.88
20	Information about Bus Route	1.68	3.59	5.50	3.59

In this Orange Bus Sewa, as in above table 5, under the dimension Reliability, users were seen more satisfied with the criteria “Sufficiency of Standing and sitting areas” having weight of 7.73. While under Tangibles “Position of Doors in the vehicle” has the highest perception score of value 7.66. Similarly, under Assurance, the item “Knowledge of Drivers towards Rules and Regulations” scored highest value of 7.45 and under Empathy “Solution of passenger concerns” has gained highest score of 6.90. Finally, “Bus Route Travel Time”, which falls under dimension Responsiveness, has gained weight of 6.88. Among all, “Sufficiency of Standing and Sitting areas” in this bus service has the highest weight of 7.90 and dimension under SERVQUAL having highest score is Assurance with a score of 7.43.

3.4 Sundar Yatayat

Table 6: Perception Evaluation for Sundar Yatayat in terms of Fuzzy Numbers

S. N	Criteria	Fuzzy			Defuzzification
		Lower	Medium	Upper	
	Reliability	5.23	7.17	8.11	7.01
1	Punctuality	5.39	7.36	8.57	7.23
2	Bus Waiting Time at Stations	1.97	3.82	5.74	3.83
3	The sufficiency of sitting and standing areas	6.07	8.03	8.60	7.80
4	The Passenger Density in the Buses	5.57	7.53	8.46	7.36
5	The security in the Vehicles	6.09	8.07	8.66	7.84
6	Safety of Vehicles (Risk of Crash)	6.28	8.23	8.61	7.97
	Tangibles	6.27	8.25	8.72	8.00
7	Seats, Holders, and General looks of the Vehicles	6.33	8.30	8.73	8.04
8	Position of Doors in Vehicles	6.39	8.39	8.76	8.12
9	Cleanliness of the vehicles	5.77	7.75	8.69	7.58
10	Suitability of buses for disabled and elderly	6.26	8.24	8.68	7.98
11	Transportation fare and Fare collection system	6.30	8.27	8.77	8.03
12	Vehicles equipped with modern technology	6.39	8.36	8.72	8.10
13	Environmentally conscious vehicles	6.45	8.42	8.70	8.14
	Assurance	6.41	8.39	8.74	8.12
14	Driving Ability of the Driver/ Comfort during Travelling	6.46	8.43	8.74	8.15
15	Knowledge of Driver towards Traffic rules and regulation.	6.36	8.36	8.75	8.09
	Empathy	5.88	7.86	8.54	7.64
16	Solutions of passenger concerns and request	5.84	7.83	8.53	7.61
17	Behavior of driver/ bus staff towards passenger	5.91	7.89	8.56	7.67
	Responsiveness	5.01	6.98	7.92	6.81
18	Bus Frequency	3.03	4.95	6.66	4.91
19	Bus route travel time including all sort of delays	5.87	7.87	8.55	7.65
20	Information about Bus Route	6.12	8.12	8.56	7.86

As in table 6 above, Under the dimension Reliability, users were seen more satisfied with the criteria “Risk of Crash” having weight of 7.97. While under Tangibles “Environmentally Conscious Vehicle” has the highest perception score of value 8.14. Similarly, under Assurance, the item “Driving ability of drivers” scored highest value of 8.15 and under Empathy “Behavior of drivers/bus staffs” has gained highest score of 7.67. Finally, “Information about Bus Route”, which falls under dimension Responsiveness, has gained weight of 7.86. Among all, “Driving ability of drivers” in this bus service has the highest weight of 8.15 and dimension under SERVQUAL having highest score is Assurance with a score of 8.12.

3.5 Other Bus

Table 7: Perception Evaluation for Other Bus in terms of Fuzzy Numbers

S. N	Criteria	Fuzzy			Defuzzification
		Lower	Medium	Upper	
	Reliability	2.33	4.13	6.11	4.16
1	Punctuality	2.18	3.98	5.96	4.01
2	Bus Waiting Time at Stations	3.33	5.29	7.26	5.30
3	The sufficiency of sitting and standing areas	1.60	3.25	5.23	3.31
4	The Passenger Density in the Buses	2.24	4.04	6.02	4.07
5	The security in the Vehicles	2.07	3.72	5.71	3.78
6	Safety of Vehicles (Risk of Crash)	2.57	4.50	6.49	4.51
	Tangibles	2.30	4.15	6.13	4.17
7	Seats, Holders and General looks of the Vehicles	2.14	3.95	5.94	3.98
8	Position of Doors in Vehicles	2.31	4.21	6.18	4.22
9	Cleanliness of the vehicles	1.63	3.34	5.33	3.39
10	Suitability of buses for disabled and elderly	2.84	4.79	6.77	4.80
11	Transportation fare and Fare collection system	2.17	4.06	6.04	4.08
12	Vehicles equipped with modern technology	2.47	4.33	6.30	4.35
13	Environmentally conscious vehicles	2.50	4.36	6.34	4.38
	Assurance	2.53	4.47	6.45	4.47
14	Driving Ability of the Driver/ Comfort during Travelling	2.52	4.45	6.44	4.46
15	Knowledge of Driver towards Traffic rules and regulation.	2.54	4.48	6.45	4.48
	Empathy	2.24	4.12	6.10	4.14
16	Solutions of passenger concerns and request	2.27	4.14	6.12	4.16
17	Behavior of driver/ bus staff towards passenger	2.22	4.10	6.08	4.12
	Responsiveness	2.22	4.02	5.99	4.05
18	Bus Frequency	3.39	5.37	7.34	5.37
19	Bus route travel time including all sort of delays	2.05	3.94	5.89	3.95
20	Information about Bus Route	1.23	2.75	4.73	2.82

Under the dimension Reliability, users were seen more satisfied with the criteria “Bus Waiting Time at Station” having weight of 5.30. The criteria “Suitability of bus for disabled and elderly people” under Tangibles was highly valued by users having weight 4.80. Similarly, “Knowledge of Drivers towards Rules and Regulations” under Assurance was the most highly perceived criteria having score4.48 and under Empathy “Solution of passenger concerns” has gained highest score of 4.16. Finally, “Bus Frequency”, which falls under dimension Responsiveness, has gained weight of 5.37. Among all, “Bus Frequency” in this bus service has the highest weight of 5.37 and dimension under SERVQUAL having highest score is Assurance with a score of 4.47. In conclusion, comparing all the bus Companies, following results from Perception Evaluation were obtained as:

Table 8: Results of Perception Evaluation for all bus companies

Bus Operators	Parameter with Highest Perception Score	Parameter with Lowest Perception Score
MahaNagar Yatayat	Information about Bus Route	Bus Waiting Time at Stations
Orange Bus Sewa	Sufficiency of Sitting and Standing Areas	Information about Bus Route
Sundar Yatayat	Driving Ability of Drivers/ Comfort during Traveling	Bus Waiting Time at Stations
Other Bus	Bus Frequency	Information about Bus Route

In MahaNagar Yatayat, there were the facilities of GPS software that gives the location of bus, due to which, the parameter "Information about Bus Route" had scored high perception value. Similarly, the length of Orange Bus Sewa was found more than other buses, so the parameter "Sufficiency of Sitting and Standing Areas" had gained high score from users. Since Sundar Yatayat was seen to be well spacious and well ventilated, users found this bus too comfortable while traveling. But they were found in limited number, that's why their waiting time at station was found to be less satisfied by users.

4. Conclusion

This study dealt with the Service Quality provided by the bus companies: MahaNagar Yatayat, Orange Bus Sewa, Sundar Yatayat and Other Bus in Ring Road of Kathmandu Valley. Going directly to the result from SERVQUAL analysis, it was concluded that parameters with highest perception score were Information about Bus route; Sufficiency of Sitting and Standing Areas; Driving Ability of Drivers/ Comfort during Traveling and Bus Frequency for MahaNagar Yatayat; Orange Bus Sewa; Sundar Yatayat and Other Bus respectively. Similarly, Parameters with lowest perception scores were determined as: Bus Waiting Time at Stations; Information about Bus Route; Bus Waiting Time at Stations and Information about Bus Route for MahaNagar Yatayat; Orange Bus Sewa; Sundar Yatayat and Other Bus respectively. To be precise, if the users demand “Punctuality” as the foremost criteria in selecting a bus alternative for transit, Sundar Yatayat would gain increasing level of users’ satisfaction. When the users were asked about the overall satisfaction of those bus companies, most of them were satisfied to their Service Quality. When the data were thoroughly analyzed, the parameter “Bus Frequency” was seen to have high impact in Overall Satisfaction, while “Knowledge of driver towards traffic rules and regulations” has comparatively less impact. The Overall Service Quality of all the buses, based upon the perception of the users, was found average.

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Analysis of Road Traffic Crash Cost in Kathmandu Valley

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Abstract

The number of road crashes is increasing in the context of Nepal and Kathmandu Valley, which comprises of three district shares 7.8 % to 9.2 % of fatalities and 52.5 % to 60.5 % of crashes of Nepal; based on the crash database for the fiscal year 2007 to 2020 for a 95 % confidence interval. These increasing road crashes are imposing social and economic burdens. Lack of sufficient data on crash costing becomes essential on planning and budget allocation for road safety intervention, justification of investments, economic analysis of road projects, and overall burden of the cost of transport. In this context, this study seeks to review the crash data contribution of Kathmandu Valley and calculate the road crash costing. The detailed road crash database was collected from Traffic police. The primary data regarding vehicle damage cost and medical cost was obtained from purposive convenient sampling, whereas insurance data was collected from sampled companies. Human Capital Approach was used for calculation of crash costing. The average age of fatalities was found to be 34 years, which is an economically active age group. The total cost of road crashes in Kathmandu Valley for the fiscal year 2020 was calculated a NRs. 1827.67 million. Among various components of crash cost, the total cost of lost output share 46.28 %, Vehicle damage cost shares 36.27 %, Medical cost shares 2.16 %, Administrative cost shares 6.01 % and Quality of life shares 9.25 % respectively. These high contributions of road crash costing justify the investment in road safety intervention within the Kathmandu Valley.

Keywords: Crashes, Fatalities, Human Capital Approach, Road crash cost

1. Introduction

Road crashes, previously known as road accidents, are one of the existing most critical problems being faced by people and countries. The increasing number of traffic crashes is imposing significant social and economic burdens on the victims and various direct and indirect costs to individuals and the government. The increased population, vehicles, and the expanding road construction programs are some of the factors for increasing accidents/crashes (Alrukaibi, et al., 2015). Currently, road traffic injuries are the seventh leading cause of death for all age groups. Road traffic death is seen to be high among low- and middle-income countries concerning the size of their population and the number of motor vehicles in circulation. (WHO, 2018).

Kathmandu Valley, comprising of three districts and which serve as major economic hub is considered as study area. The number of vehicles operating is greater than the capacity of the road in the Kathmandu Valley. Although the number of fatalities is less as compared with other parts of Nepal, the number of crashes is seen to be maximum due to large vehicle proportion and all services are confined in the valley. Therefore, road traffic crash has become a serious issue in Kathmandu Valley (Dhakal, 2018). The model was developed for the relationship among various factor contributing to the crash in Kathmandu on the major blackspot location and found that around 50% goodness of fit was achieved considering speed, volume and % of two wheelers expressed as PCU (Tiwari, 2015)

Road traffic crashes can lead to huge losses to individuals, families, and the country due to untimely deaths, serious injuries, damage to properties, and loss of productivity. The road crash cost is estimated to understand the existing problem and to identify the economic impact of road crashes but there is no such data on crash costing of Kathmandu Valley, though few research have been done for estimating the crash cost of certain section of a highway as well as overall crash cost of Nepal. This study can be a tool for identification and determination of the extent and dimension of the road traffic crash cost which can provide a platform for better understanding socio-economic loss in Kathmandu Valley. It will further provide a decision-maker for road safety planning and budget allocation as well as evaluation of the road safety intervention.

2. Objective of Study

The main objective of this study is to determine the total economic burden and respective crash -cost components of road traffic crashes of Kathmandu valley based on Gross Output (Human Capital) Approach.

3. Approach and Methodology

The research is preliminary based on both qualitative and quantitative approach. The road crash data for the fiscal year 2007/08 to 2019/20 was collected from Traffic Police secondary database. Based on global acceptance, Gross Output (Human Capital) method was used for the road traffic crash cost estimation.

Primary data were collected for medical cost and vehicle repair cost. Medical cost data was collected using Key informant interviews with relevant doctors, nurses and inpatients of the selected four major hospitals covering both government and private within study area based on Purposive Convenient sampling technique. Vehicle repair cost data was collected from auto workshop, repair centers and one transport operator i.e., Sajha Yatayat. The number of categories of such workshop and repair center were selected based on vehicle involvement on road crash proportion. Vehicle crash related data was also collected from major non-life Insurance companies' data.

4. Crash Cost Components

The framework for the cost component is designed as per the availability and reliability of data. The total crash cost for this study is divided into three components, viz. Human Cost, Vehicle Damage Cost and Administrative Cost. Vehicle damage cost is analyzed based on collected data from insurance companies and workshop/repair center. The administrative cost for fatal crashes, major crashes and minor crashes was taken as 0.2 %, 4% and 14% of the total resource cost respectively (Silcock and Transport Research Laboratory, 2003).

Human Cost components, which comprises for all kind of injuries (minor, major or fatal) share a major portion of the total crash cost which is further subcategorized into three components:

a. Cost associated with Loss of Productivity/Lost Output

b. Cost associated with Quality of Life

c. Medical Cost

A. Loss of Productivity/Lost Output

The total value of the productivity loss cost per fatal crashes and injury crashes was obtained by multiplying the average lost output per casualty in a road crash with the number of distributions of road traffic crash casualties. The lost output per fatal casualties calculated through summing all future years lost output using:

Loss of productivity /lost output = $\sum_0^n w/(1+r)\hat{}n$………………….... Eq. (1)

Here, w = average yearly wage rate

r = discount rate

n = average number of years of lost output per fatal casualties

B. Quality of Life / (Pain, grief, and suffering):

The quality cost for life/ pain, grief, and suffering for each type of severity of the crash was taken as 20% of the total loss of productivity of each type of severity of a crash (ND LEA Inc. et al., 2008; Banstola et al., 2020)

C. Medical Cost:

As the data based on date of admission and date of discharge, average length of inpatients was determined, and the average medical cost per in-patient per day is calculated based on average length of inpatients at hospital medical cost per outpatients for minor and major cases is calculated as per the number of follow-ups with average medical cost. Based on these calculations, the average medical cost per road traffic crash casualty is calculated.

Cost of damage only road traffic crash:

The cost for those vehicles having the minor type of damage which generally involved in road traffic crash but doesn’t report for a claim in insurance companies were obtained from auto-workshop and repair center. The total cost of damage only road traffic cost was calculated as the product of the number of vehicles involved in damage only crashes with the weighted average unit cost of vehicles. The cost of the road traffic crash of Kathmandu valley was calculated as the sum of causalities cost and damage only cost.

5. Crash Assessment

Crash trend assessment of last 13 years between 2008-2020 shows an average of 56.5% of total crashes occurs in Kathmandu valley with standard deviation of 4% (within limit of 52.5% - 60.5%) at 95 % confidence interval. Similarly, Kathmandu valley shares an average of 8.4 % fatalities with a standard deviation of 1.2% of the total fatalities of Nepal at 95% confidence interval. A total of 18,057 numbers of vehicles were involved in a road traffic crash where percentage contribution for Motorcycle (40%), Bus (11%), Truck (10%), Micro (1%), Car/Jeep (36%), Tractor and Tempo and others (less than 1%) were frequently involved in Road Traffic Crash in Kathmandu Valley for the fiscal year 2020.

Table 2 Proportion of vehicle involvement on road crashes in Kathmandu Valley

Vehicle type	Number of vehicles involvement	Proportion(%)
Commercial (Bus/ Truck)	4188	23
Car/Jeep/Taxi	6562	36
Two-wheeler	7163	40
Others	144	1
Total	18057	100

6. Crash Cost Components Analysis

6.1 Human Cost

Lost output

The average age of fatality was calculated as 34 years and the retirement age as per government norms is 58 years; thus, the lost output is calculated equivalent to 24(=58-34) years. The average wage rate of causality was taken as the average wage rate/day of three districts of Kathmandu valley which was found to be NRs. 859/day and NRs.309,240/year. The average cost of lost output for the fatality was calculated as NRs. 5.546 million considering the wage rate to be constant throughout the number of years of lost output. Based on assessment, the average length of stay in the hospital for treatment is determined as 7 days and home recovery days were taken as 20 days in line with 2017 Road Traffic Injury (RTI) costing studies in Nepal, which gives the average output loss per major injury as NRs. 23,193. Similarly, the average lost output per minor injury was calculated as NRs. 2,577.

Table 3 Average lost output per Road Traffic Crashes

Lost output	Lost Time	Cost\unit	Cost (NRs.)
Fatality	24 years	NRs.309,240 discounted @ 3%/yr.	5,546,387
Major	27 days	NRs. 859/day x 27	23,193
Minor	3 days	NRs. 859/day x 3	2,577

The total crashes are further divided into fatal crash, injury crash and damage only crash. Based on detail assessment of all crashes, there were 135 fatal crashes and 4167 injury crashes. Further assessment shows that there are 1.13 fatalities, 0.1 major injuries and 0.9 minor injuries per fatal crashes. Previous research had modified the factor based on international research but for this current study, the arrived factor was used for analysis. Therefore, the overall cost of productivity loss was calculated as NRs. 845.95 million.

Table 4 Total cost of lost output of Road Traffic Crashes

Casualty	Fatal Crash		Cost (NRs.)	Injury Crash		Cost (NRs.)
	Cost per casualty (NRs.)	No of casualty involved		Cost per casualty (NRs.)	No of casualty involved	
Fatality	5,546,387	1.13	6,101,026	-	-	-
Major	23,193	0.1	2,319	23,193	0.05	1,160

<table>
<tr><th rowspan="2">Casualty</th><th colspan="2">Fatal Crash</th><th rowspan="2">Cost (NRs.)</th><th colspan="2">Injury Crash</th><th rowspan="2">Cost (NRs.)</th></tr>
<tr><th>Cost per casualty (NRs.)</th><th>No of casualty involved</th><th>Cost per casualty (NRs.)</th><th>No of casualty involved</th></tr>
<tr><td>Minor</td><td>2,577</td><td>0.9</td><td>2,319</td><td>2,577</td><td>1.57</td><td>4,046</td></tr>
<tr><td colspan="3">Cost of lost output per fatal crash</td><td>6,105,664</td><td colspan="2">Cost of lost output per injury crash</td><td>5,206</td></tr>
<tr><td colspan="2">Total cost of lost output for fatal crashes</td><td>135</td><td>824,264,687</td><td>Total cost of lost output for injury crashes</td><td>4167</td><td>21,691,485</td></tr>
<tr><td colspan="4">Total cost of lost output of RTC</td><td colspan="3">845,956,172</td></tr>
</table>

Quality of Life

The cost of quality of life per fatal crash was calculated as NRs. 1,221,133 and injury crash was found to be NRs. 1,041. The total cost of Quality of life for a fatal crash was calculated as NRs. 164,852,937 and injury crash was calculated as NRs. 4,338,297.

Medical Cost

The average daily medical cost for in-patients was calculated as NRs. 10,400 and average per visit medical cost for out-patient in case of major / minor injury was NRs. 1,675 based on assessment of hospital database. The average medical cost for an outpatient in case of major injury was found to be NRs. 5,025 and NRs. 3,350 in case of minor injuries. The average medical cost per in-patient was calculated as NRs. 72,800. The average medical cost for major injury was determined as the sum of the cost of inpatient and cost of major injury of the outpatient which was NRs. 77,825. With the values of average medical cost for major and minor injury, the medical cost per fatal crash and injury crash is determined as NRs. 10,798 and NRs. 9,151 respectively. The total medical cost for fatal crashes and injury crashes is calculated as NRs. 1,457,663 and NRs. 38,131,175, giving a total medical cost of the road traffic crash as NRs. 39,588,838.

6.2 Vehicle Damage Cost

The vehicle cost data has been analyzed based on data obtained from insurance companies and workshop/repair centers. Detailed assessment of the collected data yields the mean value of the cost of commercial vehicles, cars and Two wheelers are NRs. 154,615, NRs. 102,593 and NRs. 61,983 respectively.

Table 5 Average damage cost of different kinds of vehicles

Source	Average Cost (NRs.)		
	Commercial	Car	Two-wheeler
Sagarmatha Insurance	78,853	69,314	42,830
Everest Insurance	51,527	110,709	80,963
Siddhartha Insurance	123,081	72,016	93,754
Auto Repair Workshop	365,000	158,334	30,385
Overall average	154,615	102,593	61,983

Source: Corresponding Insurance Companies, Auto-workshop and repair center

The net vehicle damage cost is calculated by adding a survey fee with obtained overall mean value with deduction of salvage value and duties and a value-added tax of the spare parts. In this study, the cost of the spare parts was assumed as two thirds of the cost of repair with including 25% Duty and 13% VAT in line with 2007 RTC costing. The salvage value is taken as 10% as per inquiry with insurance companies and the amount for survey fee for insurance claims was based on inquiry of this rate from insurance companies. Therefore, Net Vehicle damage cost for commercial, car and two wheelers were calculated as NRs. 114,634, NRs. 74,121 and NRs. 45,740 respectively. The average cost of vehicle repair per vehicle damage was determined by summing the weighted value of the net vehicle damage cost which was calculated as NRs. 71,345.

Table 6 Net vehicle damage cost based on vehicle category

Vehicle Type	**Repair Cost (NRs.)**	**Duty and Vat on Spare Parts (NRs.)**	**Estimated Salvage (NRs.)**	**Survey Fee (NRs.)**	**Net Vehicle Damage (NRs.)**
Commercial	154,615	42,519	15,462	18,000	114,634
Car	102,593	28,213	10,259	10,000	74,121
Two-wheeler	61,983	17,045	61,98	7,000	45,740

The total number of vehicles involved in fatal crashes is found to be 210 based on crash data assessment of 2020. The number of vehicle involvement per fatal crash and injury crash (number of vehicle involvement/number of fatal crashes) is determined as 1.5 and 1.8 respectively. The vehicle damage cost per fatal crash is calculated as NRs.107,018 and injury crash as NRs. 128,421 respectively. Similarly, the total vehicle damage cost for fatal crashes and injury crashes is calculated as NRs. 14.447 million and NRs. 535.13 million respectively. The total vehicle damage cost of RTC is calculated as NRs. 549.577 million.

Table 7 Total vehicle damage cost of crashes of Kathmandu valley

<table>
<tr><th colspan="4">Fatal Crash</th><th colspan="3">Injury Crash</th></tr>
<tr><td rowspan="2">Vehicle damage cost</td><td>Average Repair cost (NRs.)</td><td>No of vehicle involve</td><td>Cost (NRs.)</td><td>Average Repair cost</td><td>No of vehicle involve</td><td>Cost (NRs.)</td></tr>
<tr><td>71,345</td><td>1.5</td><td>107,018</td><td>71,345</td><td>1.8</td><td>128,421</td></tr>
<tr><td colspan="3">Total number of fatal crashes</td><td>135</td><td colspan="2">Total number of injury crashes</td><td>4167</td></tr>
<tr><td colspan="3">Total vehicle damage cost for fatal crashes</td><td>14,447,363</td><td colspan="2">Total vehicle damage cost for injury crashes</td><td>535,130,307</td></tr>
<tr><td colspan="6">Total vehicle damage cost of RTC</td><td>549,577,670</td></tr>
</table>

6.3 Administrative Cost

The total resource cost per fatal crash is calculated as the sum lost output, medical cost, quality of life, and vehicle damage cost which is calculated as NRs. 7,444,612 and total resource cost per injury crash are NRs. 143,818. With administrative costs of 0.2%, 4% and 14% of the total resource cost, it gives the total administrative cost for fatal crashes and injury crashes as NRs. 2.010million and NRs. 107.872million respectively.

7. Total Crash Cost Assessment

The total cost of road crashes is divided as injuries associated crash cost and damage only cost.

7.1 Injury based Crash Cost

The average cost per fatal crash and injury crash in Kathmandu Valley is NRs. 7,459,501 and NRs. 169,706 respectively.

Table 8 Average cost for fatal and injury crash

Cost Components	Fatal Crash (NRs.)	Injury Crash (NRs.)
Lost Output	6,105,664	5,206
Medical Cost	10,798	9,151
Vehicle damage	107,018	128,421
Administrative cost	14,889	25,887
Quality of life	1,221,133	1,041
Average cost per casualty crash	7,459,501	169,706

Additional of all the crash cost components resulting in casualties, the total cost of casualty crashes in Kathmandu valley for the year 2020 is NRs. 1.714 billion.

Table 9 Total cost of Road traffic crash resulting in any form of injuries

Cost Component	Total Cost (NRs.)
Lost Output	845,956,172
Medical Cost	39,588,838
Vehicle damage	549,577,670
Administrative cost	109,882,473
Quality of life	169,191,234
Total	**1714,196,387**

7.2 Damage Only Cost

The average cost of vehicle repair for damage was only calculated as NRs. 5,850 for Motorcycle, NRs. 11,000 for Car/Jeep/micro, NRs. 30,200 for Truck, NRs. 20,000 for Bus as per the information collected regarding minor damage of vehicles from the auto- workshop and vehicle fleet operators. Then the weighted value of the average cost of each type of vehicle was determined by multiplying with percentage involvement for each type of vehicle in a road traffic crash, will gives the average repair cost for damage only crash as calculated as NRs. 11,740.

As the number of vehicles involved per damage only crash is 1.8 in total of such crashes of 5370 in year 2020, the cost per damage only crash of vehicles is NRs. 21,132 which gives the total damage only crash cost of the vehicle is calculated as NRs. 113,478,840.

7.3 Total Cost of Road Crash

The total cost of casualty crashes in a road crash of Kathmandu Valley is calculated as NRs. 1.714 billion and total damage only crash cost of the vehicle is NRs. 113.478million. Thus, the total cost of road traffic crashes of Kathmandu Valley is calculated as NRs. 1.827 billion.

Table 10 Contribution of various road crash cost components proportion

Cost Component	Total Cost (NRs.)	Proportion (%)
Lost Output	845,956,172	46.28
Medical Cost	39,588,838	2.16
Vehicle damage	663,056,510	36.27
Administrative cost	109,882,473	6.01
Quality of life	169,191,234	9.25
Total	**1,827,675,227**	**100**

The lost output shares a greater percentage (46.28 %) of the total cost of the road crash which is nearly consistent with recent 2017 RTI costing studies in Nepal (41.88%). The reason for the higher value of the cost of lost output in a road crash is as future productive income loss of the victims for twenty-four years is determined. Similarly, vehicle damage cost-share the second highest value (36.27 %) after lost output. The number of vehicles involved in road crashes in Kathmandu Valley for the fiscal year 2019/20 is 18,057 and the number of vehicles involved in road crashes in Nepal is 25789. This shows that Kathmandu Valley shares about 70% of the total number of vehicles involved in a road crash in Nepal. Therefore, the cost of vehicle damage cost is seen more in Kathmandu Valley. As the number of minor injuries is found to be more in Kathmandu Valley, the medical cost shares a minimum percentage (2.16 %) of the total cost of a road crash.

The total cost of lost output for casualty crashes is calculated as NRs. 845,956,172. Similarly, the total medical cost for casualty crashes is calculated as NRs. 39,588,838, total vehicle damage cost for casualty crashes is NRs. 549,577,670, the total cost of quality of life (pain, grief, and suffering) for casualty crashes is NRs. 169,191,234 and total administrative cost for casualty crashes are calculated as NRs. 109,882,473. The total human cost for casualty crashes in a road crash is calculated as NRs. 1,054,736,245. The total cost of casualty crashes is calculated as NRs. 1714,196,387 and the total damage only crashes is calculated as NRs. 113,478,840. Finally, the total cost of a road traffic crash in Kathmandu Valley is calculated as NRs. 1,827,675,227 (i.e., 1827.67 million).

The recent study by (Banstola *et al.*, 2020) gives the following value for the different cost components of road traffic crash cost in Nepal for the year 2017 as shown in Table 10 below and as per the value derived in 2017 RTI costing studies in Nepal, the value of Kathmandu Valley is generated by multiplying the factors with each category of cost as mentioned in 2017 RTI costing studies. The factor is obtained by dividing the number of fatalities in Kathmandu Valley by the number of fatalities in Nepal. This factor is used to generate the cost of Lost Output, Medical cost, administrative cost and Quality of life for Kathmandu Valley. In the case of Vehicle damage cost the factor is obtained by dividing the number of vehicles involved in road traffic crashes in Kathmandu Valley with the number of vehicles involved in road traffic crashes in Nepal.

Table 11 Generated Road traffic crash cost of Kathmandu Valley

Cost components	Cost of Nepal (NRs.)	Generated cost of Kathmandu Valley (NRs.)
Lost Output	9,569,065,000	730,524,258
Medical Cost	155,705,000	11,886,875
Vehicle damage	1,177,698,280	700,985,413
Administrative cost	1,231,010,000	106,496,594
Quality of life	1,913,744,030	146,104,852
Total	14,047,222,310	1,695,997,990

8. Conclusion

Road crash costing is very crucial for decision-makers for economic analysis of the road projects which will give decision-makers an idea about the importance of road safety intervention. The total cost of road traffic crashes of Kathmandu Valley is calculated to be NRs.1827.67 million which is nearly consistent with the generated cost for Kathmandu Valley from the cost figure of 2017 RTI costing studies for the fiscal year 2019/20. Further breakdown of the cost shows that the lost output cost shares a greater percentage (46.28 %) of the total cost of the road crash as the productive year loss of the fatal was found to be 24 years. This shows the huge economic loss due to a road crash and requires proper consideration from decision-makers to be more focused on proper road safety intervention to reduce the road traffic crashes.

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Extended Summary

EVALUATION OF PUBLIC TRANSPORT SYSTEMS FOR SUSTAINABILITY

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Abstract

Sustainable development is a holistic practice that includes efforts to mitigate negative effects on every part of the road infrastructure and transportation system which are generally ignored in traditional transportation system planning. Sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs. The concept of sustainability is composed of three pillars: economic, environmental, and social. Sustainable transportation system should consider the interconnected issues under social, economy and environment areas. The social and economic issues lead to equitable; social and environment leads to bearable; and economic and environment leads to viable solutions. If a system considers parameters related to all the three pillars i.e. social, economic and environment simultaneously, then it would be called a sustainable system. Sustainable transport includes public transportation, such as electric buses and trains and BRT systems that can carry people far more efficiently than cars. Sustainability performance measures or indices are required to link actions of stakeholders (urban development authorities or transport corporations or public transport operators) to their overall mission and goals. These are intended for use in benchmarking, in identifying areas of success, and in identifying areas of opportunity for improvement. Ministry of Urban Development (MoUD), Government of India has created a Service Level Benchmark procedure which evaluates the system against well set targets or best practices. In general, the factors considered relate to availability, efficiency, accessibility, quality, coverage, affordability, safety, environment, demand management and financial sustainability of transport system. A combination of these factors may be used to evaluate the sustainability of the systems like public transport (PT), pedestrians and their facilities, non-motorized transport (NMT) facilities, parking facilities and intermediate public transport (IPT) facilities. The factors that are important for evaluation of a Public Transport System are: Presence of organized PT, Supply, Coverage, Wait time, Comfort level, and Fleet utilization. Traffic safety and pollution level are other factors that are important for sustainability. This presentation will discuss the broad framework and general guidelines for development of a sustainable Transportation in a city.

SPATIAL EQUITY OF HIGH-SPEED RAIL ACCESSIBILITY IN CHINA: AN OPERATION FREQUENCY BASED APPROACH

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Abstract

The spatial equity of high-speed rail (HSR) accessibility in China has been a research topic for years. Most of current researches do not consider the impact of HSR operation frequency on accessibility. This study proposes an improved accessibility measurement taking frequency as an important factor, then analyzes the HSR accessibility and its spatial equity in China for the years of 2015, 2018, and 2021. Having defined spatial equity as the disparity of accessibility distribution, this study applies the Theil index to explore spatial equity and its changes over the three stages, as well as the regional difference among city groups based on geographical locations and administrative levels. The results demonstrated that the spatial distribution of HSR services accessibility in China was high in the East and low in the West. Only a few cities have the highest level of IAS (Improved Accessibility Score) which leads to a strong polarization in frequency-based accessibility. Spatial equity of accessibility has improved from 2015 to 2021, but HSR services developed more equally than HSR infrastructure networks from 2018 to 2021. When grouped by geographical locations, the West region has the worst spatial equity regarding IAS, however, the Northeast region has the worst spatial equity of OAS (Original Accessibility Score) in 2021. When grouped by cities' administrative levels, the group of provincial capitals has better spatial equity regarding IAS but did not have better spatial equity of OAS until 2021.

SUSTAINABLE TRANSPORT POLICY BY HYDROGEN MOBILITY IN KOREA

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Abstract

Korea initiated hydrogen mobility policy by announcing 'Hydrogen Economy Roadmap of Korea" in January 2019 to target 81,000 hydrogen cars and 310 hydrogen stations in 2022 for short term and 6.2 million hydrogen cars and 1,200 hydrogen stations in 2040 for the long term in Korea. In 2020, 'Hydrogen Economy Committee' launched and 'Hydrogen Economy Act' enacted, '2050 Net-Zero' declared in 2021. Ministry of Land, Infrastructure and Transport (MOLIT) of Korea announced 'Hydrogen Transport Complex' in 2022 and 'Hydrogen City Pilot Project' in 2019. This presentation will review recent hydrogen mobility policies in Korea which is leading in the world and will consider possibilities for the developing countries.

IMPACT OF ECO-DRIVING VARIABLE MESSAGE SIGNS ON THE BEHAVIOR CHANGE IN AHMEDABAD

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Abstract

Variable message signs (VMS) are one of the important devices for the dissemination of real-time traffic information. Unlike traffic broadcasts for the overall road network or navigation guidance systems for individual drivers, VMS provides real-time traffic information for drivers in specific areas. Several VMS have been installed in Ahmedabad, however, the effectiveness of VMS on drivers has not been verified. In addition, appropriate display of VMS design and text on the road may help drivers drive more efficiently and comfortably. The research questions are how the design of VMS influences the driver's mind and how mind change leads to driving behavior. This study aims to identify drivers' attention and recognition of VMS of eco-driving (e.g. 1) No idling, 2) More fuel more carbon, 3) Do not brake or start suddenly, and 4) Keep your distance from the car in front of you) to know they are effective in changing driving behavior and to clarify the difference in implementing eco-driving behavior with prior learning.

FACTORS CONTRIBUTING TO THE SEVERITY OF MOTORCYCLE REAR-END CRASHES IN THAILAND

Phanuphong Phajongkha [a], Kunnawee Kanitpong [a*], Auearree Jensupakarn [b]

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Abstract

Motorcycle (MC) rear-end collisions cause many serious injuries and deaths for MC riders .In Thailand, the MC crash investigation data revealed that 18 percent of all MC crashes were rear-end collisions, which accounted for 18 percent of all fatalities as well .The aim of this study was to investigate the causes of injuries and deaths from MC rear-end collisions and factors that contribute to their severity level .Between 2016 and 2020, 141 MC rear-end crashes were thoroughly investigated throughout Thailand .The ordinal logistic analysis was conducted to analyze factors contributing to severe injuries .The analysis to rear-end collision models comprised four categories :M1(n=141)is all types of rear-end collisions to MC, and M2(n=114) is the rear-end collision due to other vehicles(OV)collided by MC, M3(n=72)is the rear-end collisions for traveling OV collided by MC, and M4(n=42)is the rear-end collision for MC hitting the parked OV .When a MC collides with the rear of another vehicle, there are more fatalities than when other vehicles collide with the rear of a MC .Furthermore, the probability of death is higher if MCs collide with the rear-end of parking vehicles .As for the primary crash contributing factor, motorcyclists' perception failure was the most frequent .Experience, license status, driving conditions, speed, the time of the crash, the areas of the crash, and types of other vehicles involved significantly influence the severity of rear-end crashes .In severe crashes, riders with perception failure are more likely to be involved .Based on the findings of this study, some policies and countermeasures can be drawn to prevent MC rear-end crashes and reduce their severity.

Conference Attendees

Name	Nominated By/Organization
Hon'ble Narayan Kaji Shrestha	Deputy Prime Minister, Ministry of Physical Infrastructure and Transport
Hon'ble Bikram Pandey	Minister, Ministry of Urban Development
Mr. Keshab Kumar Sharma	Secretary, Ministry of Physical Infrastructure and Transport
Hon'ble Dr. Dinesh Chandra Devkota	Member of parliament, Bagmati Province
Mr. Sushil Bhatta	CEO, Investment Board Nepal
Dr. Hari Bhadur Darlami	President, Nepal Engineers' Association
Mr. Birendra Bahadur Deoja	Former Secretary, Government of Nepal
Dr. Chandra Bahadur Shrestha	Director, NTDRC
Prof. Dr. Thusitha Chandani Shahi	Director NEC-cps
Prof. Dr. Padma Bahadur Shahi	President, SoTEN
Mr. Rajendra Raj Sharma	Vice President, SoTEN
Mr. Hemant Tiwari	General Secretary, SoTEN
Mr. Shrawan Kumar Thapa	Secretary, SoTEN
Mrs. Sambriddhi Shrestha	Treasurer, SOTEN
Dr. Surya Raj Acharya	EC Member, SoTEN
Dr. Hare Ram Shrestha	EC Member, SoTEN
Dr. Rojee Pradhananga	EC Member, SoTEN
Mr. Saroj Kumar Pradhan	EC Member, SoTEN
Mr. Krishna Nath Ojha	EC Member, SoTEN
Mr. Amit Kumar Sharma	EC Member, SoTEN
Mr. Vibek Gupata	EC Member, SoTEN
Mr. Shuva Raj Neupane	EC Member, SoTEN
Mr. Prabhat Kumar Jha	Joint Secretary, MoPIT
Mr. Arjun Jung Thapa	DG, Department of Roads
Mr. Rohit Kumar Bisural	DG, Department of Railways
Dr. Tok Raj Pandey	DG, Department of Transport Management
Mr. Ganesh Bahadur KC	ED, Roads Board Nepal
Mr. Surendra Mohan Shrestha	DG, DUDBC
Mr. Ishwor Chandra Marahatta	DG, Department of Local Infrastructure
Mr. Pradeep Adhikari	DG, Civil Aviation Authority of Nepal
Mr. Lal KC	Immediate Past President, SOTEN
Prof. KIM Hyun	Korea National University of Transportation

Name	Nominated By/Organization
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Prof. Sigon Kim	Seoul National University of Science & Technology, Korea
Dr. Tissa U. Liyanage	Sri Lanka Society of Transport and Logistics
Prof. Satish Chandra	IIT Roorkee, India
Dr. A. Mohan Rao	CRRI, India
Dr. Shengchuan Zhao	Dalian University of Technology, China
Prof. Shinya Hanaoka	Tokyo Institute of Technology, Japan
Prof. Dr. Kunnawee Kanitpong	Asian Institute of Technology, Thailand
Mr. Pawan Karki	ADB, Manila
Mr. Sagar Onta	
Dr. Madan B. Regmi	UN ESCAP
Ms. Wei Shiuen Ng	UN ESCAP TREN
Mr. Devon Farmer	Korea National University of Transportation
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Seheon Kim	Department of Urban Engineering Hambatd National University
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Manish Man Shakya	Graduate School of Engineering Osaka University
Mohan Dhoja KC	Nepal Engineering College
Samikshya Rijal	Nepal Engineering College
Amul Shrestha	Nepal Engineering College, TDF
Nhuja Bajracharya	Nepal Engineering College
Devon Farmer	Korea National University of Transportation
Mr. Ram Hari Pokhrel	Deputy Director General, Develpoment Cooperation Implementation Branch
Mr. Bhuwan Adhikari	Deputy Director General, Mechanical Branch
Mr. Umesh Bindu Shrestha	Deputy Director General, Bridge Branch
Mr. Naresh Man Shakya	Deputy Director General, Maintenance Branch
Mr. Nabin Man Shrestha	Director, Quality Research and Development Centre
Dr. Bijay Jaisi	Superintendent Engineer, Federal Supervision and Monitoring Office
Mr. Shusil Babu Dhakal	Project Directorate, ADB

Name	Nominated By/Organization
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Mr. Shyam Kumar Khadka	Project Directorate, North South Trade Route Improvement Directorate
Mr. Dharmendra Jha	Acting Project Director, Postal Highway Directorate
Mr. Rabindra Lal Das	Acting Project Director, Suryabinayak Dhulikhel Baridbas Road Project
Mr. Ajay Kumar Mul	Senior Divisional Engineer, Bridge Branch
Mr. Bel Bahadur Bhujel	Senior Divisional Engineer, Road Safety and Traffic Unit
Mrs. Pushpanjali Khanal	Senior Divisional Engineer, Geo-Environment and Social Unit
Mr. Rajesh Poudel	Senior Divisional Engineer, North South Trade Route Improvement Directorate
Mr. Krishna Raj Adhikari	Senior Divisional Engineer, Bridge Branch
Mr. Khadga Lal Shrestha	Senior Divisional Engineer, Quality Research and Development Centre
Mr. Saurabh Bajracharya	Senior Divisional Engineer, Quality Research and Development Centre
Mr. Nati Babu Khadka	Senior Divisional Engineer, Maintenance Branch
Mr. Shyam Kumar Yadav	Senior Divisional Engineer, Planning Monitoring and Evaluation Unit
Mr. Sujan Adhikari	Senior Divisional Engineer, Highway Management Information System – ICT Unit
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Mr. Dipesh Munakarmi	Engineer, Pushpalal Midhill Highway Project
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Mr. Shailendra Kumar Chaudhary	Engineer, Road Division, Lalitpur
Ms. Anjali Shilpakar	DOR, Engineer
Mukunda Raj Adhikari	Division of LP
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Mrs. Chandmala Shrestha	Manager, NPP, CAAN
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Mr. Shiva Prasad Nepal	Joint Secretary, Development Cooperation and Quality Standard Division, MoPIT
Mr. Arjun Prasad Aryal	Joint Secretary, MoPIT
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Mr. Suresh Shrestha	S.D.E, Transport Management Division, MoPIT
Mr. Binod Kumar Khadka	Under Secretary, Monitoring and Evaluation Division, MoPIT
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Mr. Roshan Kumar Deo	Engineer, DoRW
Mr. Bikesh Bhattarai	Engineer, DoRW
Mr. Ekraj Chaulagain	Legal Officer, DoRW
Mr. Ram Chandra Poudel	Director, DoTM
Mr. Rahul Panjiyar	Engineer, DoTM
Mr. Sanjay Baniya	Section Officer, DoTM
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Mr. Chetna Thapa	Director-Administration, Road Board Nepal
Mr. Sagar Gnawali	Technical Director, Road Board Nepal
Mr. Sanu Babu Prajapati	Sr. Engineer, Road Board Nepal
Mr. Dharma Raj Upadhyay	Engineer, Road Board Nepal
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Mr. Rabi Bhusan Jha	NEA
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Mr. Deepak Raj Shah	Volunteer, SOTEN
Mr. Sanjay Luitel	Volunteer, SOTEN
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Mr. Roshan Devkota	Volunteer, SOTEN
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Mr. Deepak Bahadur Kunwar	Volunteer, SOTEN
Ms. Sitan Shrestha	Volunteer, SOTEN
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Mr. Subash Dhungel	Traffic and Transport Unlimited Solution

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Mr. Kishor Bagale Thapa	R.I.D Engineering Consultancy
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Mr. Shree Ram Dhakal	Engineering Centre Nepal P Ltd
Mr. Sunil Poudel	World Bank, Nepal
Mr. Shiva Hari Sapkota	Former Director General, DOR
Mr. Kamal Pandey	Individual Expert
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Mr. Kshitiz Dhakal	Student, Pulchowk Campus
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Mr. Ashim Gautam	Acme Engineering College
Mr. Sagar Gautam	Acme Engineering College
Mr. Saurav Shrestha	Kantipur Engineering College
Mr. Abhash Acharya	Aryan School of Engineering & Management
Mr. Saha Dev Bahadur Bhandari	Individual Expert
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Mr. Rabindra Pokhrel	Ministry of Water Supply
Mr. Sushil Khadka	Sunkoshi RM
Mr. Saroj Khanal	Road Safety Society
Mr. Jagdish Dhungana	Individual / Freelancer
Mr. Rabindra Kumar Shrestha	Lama Construction Company P. Ltd.
Mr. Guru Dutta Adhikari	Realpath Engineering Consultancy Pvt. Ltd
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Mr. Gopal Gautam	Nepal Eng College
Mr. Sanjay Tandan	KNUT
Mr. Gautam BS Tamrakar	Pulchowk Campus
Mr. Nischeet Maharjan	Water Asia
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Ms. Mandakini Karki	SCAEF
Mr. Dilman Singh Basnet	SSTN
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Mr. Ashish Banstola	DUDBC

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