Road Design Guideline considering Three-Wheeler Slow-Moving Vehicles (Tri-SMV) for Urban and Rural Roads of Bangladesh

Final Project Report

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Abbreviations/Acronyms

FCDO	Foreign, Commonwealth & Development Office
HVT	High Volume Transport
Tri-SMV	Three-Wheeler Slow-Moving Vehicles
AASHTO	American Association of State Highway and Transportation Officials
RHD	Roads and Highways Department
LGED	Local Government Engineering Department
BRTA	Bangladesh Road Transport Authority
DGHS	Directorate General of Health Services
IUT	Islamic University of Technology
BUET	Bangladesh University of Engineering and Technology
DoE	Department of Environment
ADB	Asian Development Bank
iRAP	International Road Assessment Programme

Executive Summary

The Tri-SMV Road Design Guideline Project, generously funded by UKAID through High Volume Transport Applied Research project, and conducted by the Islamic University of Technology, aimed to address critical road safety and usability issues for three-wheeler slow-moving vehicles (Tri-SMVs) in Bangladesh. This initiative was prompted by recognition of the substantial role that Tri-SMVs play in daily transportation, especially in urban and rural environments where they are a primary mode of travel for short distances and small-scale cargo.

Throughout Bangladesh, Tri-SMVs such as pedal rickshaws, battery-operated rickshaws and easy bikes confront numerous challenges stemming from a road infrastructure that inadequately accommodates their operational characteristics. These challenges include navigating roads with inadequate lane widths, unsuitable speed bumps, unsafe road infrastructures such as open drains, and poorly configured intersections—all of which significantly increase the risk of accidents and reduce operational efficiency.

In response, the project utilized a multidimensional research approach that integrated detailed opinion surveys of Tri-SMV operators and users with quantitative field measurements of road conditions, and a thorough analysis of road-user interactions. This robust methodology enabled the team to identify specific areas where current road design fails to meet the needs of Tri-SMV users. It found, for instance, that conventional speed bumps often cause significant discomfort and potential injury to passengers due to the abrupt jolts they induce. Many Tri-SMVs lack sophisticated suspension systems that can mitigate these impacts.

To address this, the guidelines proposed redesigning speed breakers with a smoother, double-curved parabolic shape, limiting their height to four inches to ensure a gentler impact on Tri-SMVs, thus enhancing passenger comfort and vehicle stability. Another critical issue highlighted was the inadequate lane widths that do not cater to the unique dimensions and manoeuvring capabilities of Tri-SMVs. The project recommended adjusting lane widths to allow sufficient space for Tri-SMVs to navigate safely alongside other vehicles. This adaptation not only aims to reduce the frequency of collisions but also facilitates smoother traffic flow, decreasing the likelihood of traffic congestion and its associated environmental impacts. Intersection design was another significant focus of the project. Many existing intersections pose challenges for Tri-SMVs, particularly those that are muscle-powered, due to steep approaches that require high effort and pose high risk during stops and starts. The guidelines suggest regarding these intersections to create more gradual approaches and incorporating longer acceleration lanes to help Tri-SMVs navigate more safely and efficiently.

The implementation of these guidelines is expected to significantly enhance the safety and efficiency of road travel for Tri-SMV operators and passengers. Additionally, these new standards are poised to serve as a model for inclusive road design that could be adapted and implemented in other countries with similar transportation landscapes.

Looking ahead, the project team plans to closely monitor the implementation of the guidelines to gather feedback and assess their effectiveness. This iterative process will ensure that the solutions remain responsive to the needs of Tri-SMV users and can be refined over time to address emerging challenges or changes in urban development.

In conclusion, the Tri-SMV Road Design Guideline Project not only addresses immediate safety and usability issues but also contributes to broader objectives of sustainable and inclusive urban planning. By prioritizing the needs of one of the most vulnerable groups of road users, this project marks a significant step towards creating safer, more equitable roadways in Bangladesh and sets a precedent for global road design practices.

1. Introduction

Rickshaws and other Tri-SMVs are recognized as the key to accessibility to many (if not the most) communities in Bangladesh. The prevalence of these vehicles makes them the only mode of transport for many communities for trips of between 3 and 7 km (Hasan et al. 2018). In South Asian countries, especially in Bangladesh, the ubiquitious pulled (cycle) rickshaw, or pedicab, has become part of the cultural identity. There are many variations of rickshaws, from the perspectives of shape, handling, power, usage etc. Some pulled 'cargo' rickshaws (colloquially known as 'vans') with flat beds, utilize the same rickshaw chassis while being able to carry bulk goods as well as passengers. With increased access to technology, some pulled rickshaws are motorized using electric motors with rechargeable batteries, while keeping the chassis and operating characteristics essentially the same.

Three wheeled slow-moving vehicles have been serving Asian and African urban and rural communities as a low-cost taxi service and a small-scale goods carrier. While there are numerous variations, for simplification in the following discussion, lightweight three wheeled vehicles (motorized/ non-motorized), with a maximum speed less than 40 km/hr (operating speed 15-25 km/hr) will be termed as 'Tri-SMV's.

Tri-SMVs are dedicated to carrying passengers or goods and their power-to-weight ratio is much lower than that of other non-motorized or slow-moving vehicles, such as bicycles or tractors. Therefore, Tri-SMVs' requirement for road geometry, road cross-sectional design, and other facility designs are vastly different from both four (or more) wheeled motorized vehicles and non-motorized bicycles.

In fact, in most cities of Bangladesh, rickshaws make up as much as 80% of the traffic, while in the capital city Dhaka about 54% of all trips are made by Tri-SMVs. Dhaka itself sees about 400,00 rickshaws plying the streets each day (Hossain et al. 2011). Some unofficial estimates place their number as high as 1.1 million (in 2012, Hasan et al. 2018) and observe that about 7.6 million person-trips per day are made on rickshaws and other Tri-SMVs, which is about twice that of the London tube. In fact, 20% of Dhaka's 12 million inhabitants rely solely on rickshaws for their travels. The popularity and suitability of 'Tri-SMV's in a low-income county like Bangladesh can be attributed to the following: low manufacturing and operating cost, indigenous manufacturing, very low to no emissions, low skill requirement for driving, ability to drive on narrow streets and earthen village roads, door-to-door service, easy access, and low-cost trips. While it may be logical to adopt four-wheelers which are safer than Tri-SMVs, that change may take as long as a decade to come about, due to affordability concerns, technical capability, logistics and road type.

Tri-SMVs constitute the backbone of local transportation while being environmentally friendly and employing one of the highest numbers of low-skilled persons. The ubiquity of Tri-SMVs can be seen in Figure 1.

As Tri-SMVs have widely different dynamic characteristics to regular 4 wheeled motorized vehicles (which are generally considered as 'design vehicles'), Tri-SMV passengers (including physically vulnerable people) are faced with different issues of comfort and safety resulting from aspects of road geometrics, cross-sectional as well as roadside facility designs.

At present, Bangladesh's roads are built according to international and national guidelines, such as AASHTO Policy on Geometric Design of Highways and Streets (1993), AASHTO Roadside Design Guide (2011), Overseas Road Note 6 A guide to geometric design - TRL, and other national and local codes. A comprehensive search of the existing literature clearly identified the research gap, that is, almost all codes and standards are mostly suitable for four (or more)-wheeled motorized vehicles.

A recent rise in bicycle usage has resulted in the development and application of some guidelines which focused on cycles, scooters etc. Examples are 'AASHTO Guide for the Planning, Design, and Operation of Bicycle Facilities' (2012) and 'Towards Safer Roads in Developing Countries' by TRL (1991). The second document (by TRL) does address some major issues related to slow moving vehicles, but solutions or quantifications of the measures are not generally detailed.

Figure 1: Usage of Tri-SMVs in Bangladesh (a-d)

a) Rickshaw, CNG, Autorickshaw (L-R)

b) Nosimon ('van' with engine)

c) Passenger 'Van' being used for emergency access to heathcare

d) Loading 'Van', being pushed by a CNG

The need for a set of guidelines for Tri-SMV based road design has become urgent due to the fact that Tri-SMVs are critical to serve the low-and-middle income vulnerable population. People with mobility limitations (disability of any kind, pregnancy, immunodeficiency etc.), and people with concerns related to personal safety (specially females) are completely reliant on Tri-SMVs which ensure relative safety and access (Hossain et al. 2011). Even for access to medical care, as many as 63% of emergency patients routinely use three wheelers (Hossain et al. 2018). In fact, a rickshaw 'ambulance' is a well-accepted idea in some areas, which serves emergency patients and takes pregnant women to health complexes for their routine check-ups (Pouramin et al. 2020).

The research needs and challenges involved in providing safe and accessible transportation to vulnerable Tri-SMV users are discussed with a few examples in the following section. The various cases discussed below outline a common theme: that the design of a road facility considering exclusively motorized vehicles may lead to the hazardous operation of a Tri-SMV.

(1) Vertical Curve: Roads are allowed to have a certain gradient during grade adjustment due to natural terrain, intersection, or bridge approach road etc. Current guidelines prescribe certain values of allowable gradient of 3% to 6%, which is generally considered difficult for the weaker motors of auto-rickshaws while proven to be strenuous for pulled rickshaws and goods vans. Again, when the vehicle travels downhill, a high gradient leads to an increase in acceleration resulting in lack of control and possible accidents.

(2) Roadside Barrier and Edge Maintenance: In many cases roadside barriers are not continuous but discrete metal or concrete posts embedded into the hard shoulder. Gaps between posts are dictated by the width of a car but are wide enough for an out of control Tri-SMV to fall through.

In addition, the edges of pavements and hard shoulders tend to see the most damage due to loading and exposure to moisture, including edge erosion and increased shoulder drop. As three wheelers run along the pavement edges, such edge damage represents a major hazard for the users.

(3) Speed Bumps: Another important example can be seen with the use of raised speed bump. Their designs are suggested in many standards, despite acknowledging some serious safety issue. Despite the fact that speed breakers are not installed for controlling the speed of three wheelers, they are the unintended victims as travelling over the bumps on a Tri-SMV (usually without any shock absorbers) can create major distress for its passengers. In fact, even in the passenger cars, speed bumps are shown to increase the risk of injury to pregnant women and foetuses (Parizi et al 2021).

(4) Expansion Joints and Gaps: Many rural and urban roads are made with jointed concrete pavements which require a certain gap in between (generally filled to an extent by a filler material). Sometimes, a slight variation of level between two segments of pavement can occur due to construction and soil settlement issues. These joints create riding discomfort for car passengers, but they are a source of serious distress to Tri-SMV passengers who experience major bumps. Similarly, bridge expansion joints, manhole cover gratings, and similar subsurface access features including drainage outlets, exposed roadside drainage channels placed on or near carriageways, can result in significant passenger discomfort in a similar manner.

It is apparent from the above discussion that several aspects of the current road design practice require (Figure 2) significant adjustment to ensure a safe and comfortable ride for Tri-SMV users, especially mobility-impaired or physically vulnerable people.

Figure 2: Concerning road elements for Tri-SMVs in Bangladesh (a-g)

a) Speedbreakers are disproportionate for Tri-SMVs

b) Tri-SMVs undergo significant movement

c) Steep bridge approach road for Tri-SMV

d) Steep approach road may result lack of control; also notice the gap between edge barrier posts and sharp turn

e) Steep intersection approach may result uncontrolled entry to the intersection

d) Expansion joints as well as rigid pavement texture may result discomfort for Tri-SMV users while steep shoulder drop may result accidents

f) Vertical gap between bridge approach and bridge deck will create significant distress for Tri-SMV users

g) Wide bridge expansion joints will create passenger discomfort

2. Methodology

The proposed project intends to create a guideline which will suggest different geometric, cross-sectional as well as roadside facility design options and adjustments for the benefit of Tri-SMV passengers. Developing a dedicated road design guideline to address the needs of Tri-SMVs is critical for their safe operation on local roads. A guideline on Tri-SMV focused road design will help with the accessibility of people with limited mobility, reduce the number of non-fatal and fatal accidents, provide safer transport for pregnant women and other reduced mobility individuals, and maintain the well-being of all Tri-SMV users.

The innovation of this project lies in the fact that no previous study has focused on the incorporation of the comfort and safety of the users of Tri-SMVs in road design, especially considering low to middle income vulnerable people including pregnant women, who are Tri-SMV's key users, as seen in Figure 1 (c). To our knowledge, this will be the first study where geometric and roadside design aspects will be observed through the eyes of Tri-SMV drivers and passengers.

Several other studies have focused on the exposure to vibration of different machines and transport modes but none have focused on Tri-SMVs as these are mostly found on Asian and African streets. Therefore, this study will: i) acknowledge the need for Tri-SMV based road design, ii) quantify the issues created by the lack of an appropriate design standard, and iii) propose corrective measures and compile design guidelines suitable for roads with significant Tri-SMV traffic.

This study will include i) an opinion survey of Tri-SMV stakeholders to identify the points of concern and the elements of the design that need moderation, ii) measure the quantifiable issues of roads and connect them with concerns identified through the opinion survey, and iii) prepare design guidelines addressing these concerns.

Therefore, the project has two stages, firstly identification of the issues, and secondly mitigation measures

2.1 Identification and Quantification of the road hazards for the Tri-SMV

The first task of the project was to identify the concerns related to the operation of the Tri-SMV. It is apparent that many aspects of Tri-SMV's ridership went unnoticed during previous design guideline preparation processes and that a very small amount of research focused on Tri-SMVs. Therefore, aspects of Tri-SMV rider-friendly design were identified through surveys and observations.

At least 10 localities of Bangladesh, a combination of urban, semi-urban and rural areas, were selected as the survey areas. A selection of the localities were done upon consultation with the RHD engineers, one of the project supporters.

The Roads and Highways Department, RHD, is one of the largest engineering departments of Bangladesh, overseeing 22,476.28 km of national, regional and zilla Road. RHD constructs and maintains most of the busiest roads in Bangladesh, some of which see more than 45,000 AADT.

Areas of recently constructed paved roads were the primary interest as they are unlikely to have other areas of concern, except design or construction issues. This decision was made on the premise that it would be easier to identify design concerns, removing confounding issues such as potholes, cracks, ruts etc. which are mainly time and traffic dependent factors.

a. **Opinion Survey:** An opinion survey of Tri-SMV stakeholders constituted the preliminary framework of the proposed guidelines. The opinion survey included at least 10 drivers of each type of Tri-SMV under consideration at each locality. They were asked about the ease of driving, the locations they identified as concerns, practices they follow to ensure passengers' comfort etc.

To acknowledge the concerns of the vehicle users, we conducted interview of pregnant women, people with mobility issues, and children arriving at Upazilla Health Complex by Tri-SMVs. Other locations were also considered, such as a newly built roads, schools, shops etc. Interviews focused on their travel frequency, general and particular issues of the transport mode they are using, and any health concerns they correlate with road issues .

b. **Quantitative Field surveys:** Though user opinion constitutes one aspect of this study, it was supported and quantified by concurrent field surveys. Field surveys identified the potential as well as established issues (through opinion surveys) and provided quantitative measurements of each type of concern.

It was apparent, for example, that speed bumps were likely to come up as a concern for rider comfort and the safety of vulnerable passengers. During the field survey, different types of speed breakers were identified, and geometric measurements were taken. Then, vertical acceleration caused by each type of geometry, for each type of loaded Tri-SMVs, at different speeds were measured. Opinion surveys at the same location supported the quantitative observations. This data helped to establish the upper and lower bounds of acceleration where issues became clear concerns.

Quantitative measurements were taken through two types of survey.

i. **Geometric Survey:** For this survey, different points of concern related to road geometry were identified, such as gradient, shoulder drop, speed hump dimensions, joint width, signage heights, roadside barrier dimensions etc. This data was necessary to evaluate the concerns and potential remedial scopes.

ii. **Acceleration Survey:** Accelerometers were used to quantify the operating speed, lateral acceleration and most importantly, vertical acceleration. It was found that for pregnant women, vertical acceleration is the critical issue for riding comfort and safety. This acceleration or 'jerking' was correlated with geometric features measured during the survey. Clear distinction was made between issues related to 'discomfort due to damaged road' and 'discomfort due to design issues'. At the same time, we identified the margin at which a user is likely to feel the discomfort, which was the basis of our design solutions.

2.2 Identification of potential solutions

Knowledge gathered from the survey was compiled and compared with standard design practice. If a concern was noted in the field but design recommendation in the existing design code did not address the issue, it was added to the list of recommended practice with design guide.

Then, a solution framework was established to remedy each identified problem/concern. Each concern resulted in a suggestion and best practice guideline. It also included potential construction and management issues due proposed solution.

A flow chart of this process can be found in Figure 3.

In the case of speed bumps, data taken in the field such as height, approach gradient and corresponding acceleration at different speeds was modelled mechanistically, with the help of automobile researchers familiar with the mechanics of wheel and motion. The aim of the simulation was to optimize the speed breaker design to reduce the vertical acceleration for a slow-moving vehicle while ensuring the functionality of the speed breaker, namely, to reduce speed for faster vehicles. Reviewing the literature, we observed that exposure to whole-body vibration at ≥0.5 m/s^2 affects the foetus while acceleration in the range of 0.1-0.4 m/s^2 did not result similar concern (Parizi et al. 2021). Using this information, we identified which design of the speed breaker results in a safe range of vertical acceleration.

Similar solution methodology was used for other aspects of the design guide. Another example is the ramp segment of the road. Current specifications do not prescribe any limiting gradient/slope/grade for ramps on a bridge approach or intersection approach from a lower elevation road. However, it is not yet established how a gradient affects the operation and manoeuvrability of Tri-SMVs. In addition, for manually pulled Tri-SMVs, the length of the vertical curve and the rate of the slope are also concerns, as sustaining effort for a long uphill slope is likely to be an issue for the puller. Therefore, a rented Tri-SMV was moved up-and-down the gradient to observe the change of speed, respiration and heart rate of the puller during this manoeuvre, using phone-based sensors and accelerometers. This data was observed and ranked holistically along with the drivers' rating of the slope regarding ease of operation, and the geometry of the gradient.

The design solution was the proposition of a maximum allowable gradient and maximum allowable length of curve while using that gradient. In fact, in a cycle-focused guideline for Catalonia, (Bedoya 2008), 2% gradient is allowed for longer distances while <120m length of ramp is allowed for slopes >5%. In another guideline (Sustrans, 2014), it prescribes 3% gradient to be the preferred maximum for cycle lanes while a 5% gradient should not be for longer than 100m. However, it should be noted that a bicycle is lighter and does not carry passengers in comparison to Tri-SMV which is much heavier and carries one or two passengers (in general). These solutions were developed upon consultation with subject experts such as automotive engineers, medical professionals, pavement construction firms, local engineers and researchers.

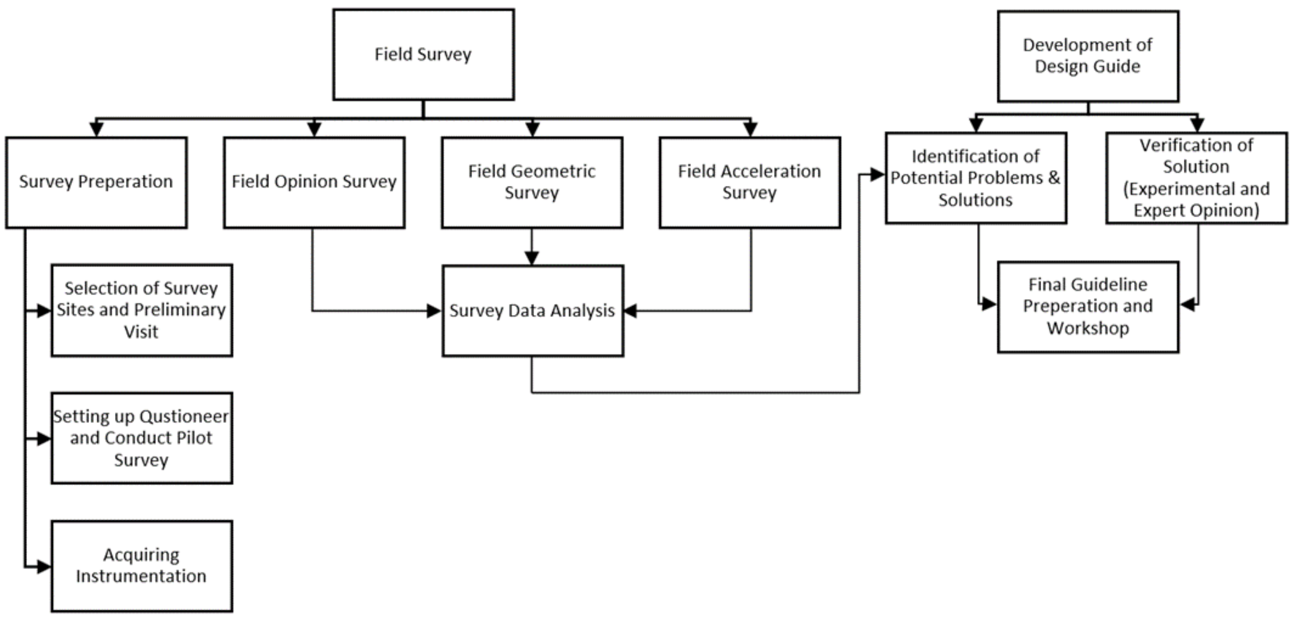

Figure 3: Research Flow Chart

What We Did:	What We Learned:
Interviewed Tri-SMV drivers	To identify the factors that bother drivers
Interviewed regular passengers	To understand the causes of discomfort and accidents
Interviewed pregnant women	To understand the vulnerable group's opinion
Set motion sensors on Tri-SMV	To measure the vibration of the Tri-SMVs
Evaluated speed bump profiles	To identify What types of bumps cause most problems
Measured acceleration, breaking and speed	To connect dynamic properties with driver behaviour
Integration of observations	Preparation of guidelines

3. Opinion Survey

3.1 Tri-SMV Drivers' Opinion Survey

Tri-SMV drivers are obviously key stakeholders of the ongoing research. Our survey strategy involved identifying places where drivers gather and operating the survey in the form of a focus-group discussion, followed by individual opinion. These locales, particularly active during lunch breaks, became instrumental platforms for engaging with a diverse range of drivers.

Most drivers were not only willing to partake in the study voluntarily, but they also showed immense passion in providing detailed feedback about their experiences on the road. Their eagerness to contribute to a study that could potentially improve their working conditions was enlightening and indicative of the opportunity for improvement.

The survey of Tri-SMV drivers was conducted in two stages: i) pilot survey and ii) opinion survey. Pilot survey was conducted on focus groups to understand the framework of the issues under discussion. Once the framework was established and the questionnaire was refined to extract desired information, the main opinion survey was conducted.

3.1.1 Pilot survey with Tri-SMV driver focus groups

The pilot survey responses spanned seven distinct areas - two in Gazipur and five in Dhaka city. During the pilot phase of the survey, most drivers, due to the unfamiliarity of the technical facets of road infrastructure, found it challenging to express specific road design-related concerns. The issue was anticipated as often infrastructure is considered as a given situation.

Dynamic factors such as driving faults or vehicle speed, generally take the blame for the mishap, despite the fact that inadequacy of the infrastructure design might have contributed to the event. However, the drivers articulated their experiences with accidents, navigation difficulties, and riding discomfort.

During the pilot survey, repair shop workers were identified as an important stakeholder. These 'mechanics' have firsthand knowledge of the accidents and their aftermath. They were consulted before initiating the user surveys to better understand the possible causes of the Tri-SMV accidents and the reasons behind most frequent routine maintenance works. Their input during the pilot stage of survey helped to identify potential roadway issues that necessitate Tri-SMV repair works.

3.1.2 Opinion Survey with Tri-SMV Drivers

To facilitate a better understanding of drivers' struggles with specific pavement conditions, we revised our questionnaire, after a pilot survey, to include pictorial representations of various road design-related issues. Visuals of different roadway conditions - speed bumps, open drains, uneven roads, etc. - were presented to the drivers.

The aim was to enable them to relate these visuals to their own experiences and identify and rate their discomfort associated with specific pavement conditions. It can be postulated that providing a list of roadway issues to a survey participant will inherently guide the person, provide limited options, and incorporate confirmation or framing bias. On the other hand, it can be argued that the pilot survey was unguided and the road conditions that were identified during the piloting were used to construct a liberal list of issues which were presented in the pictures. If a viable issue, not included in the pictorial list, came out during the interviews, it was planned to be included in future interviews- though none were proposed.

3.1.3 Tri-SMV drivers' Survey Outcome

i) Demographic Info: Following our preliminary survey, we have accrued responses from 52 participants, with a significant concentration in urban environments, specifically Dhaka (75%) and Gazipur (25%). All respondents are male, aligning with the gender roles commonly seen in the driving profession within these areas.

Age-wise, the respondents are fairly distributed across different brackets. A significant fraction (36.5%) fall within the age range of 25 to 32 years, while approximately a third (34.6%) are aged between 35 and 45 years. Older drivers, between the ages of 45 and 55, represent a smaller portion of the pool (15.4%). The youngest age group, from 18 to 25 years, constitutes the least representation (13.5%) shown in Figure 3. With respect to educational attainment, nearly half of the respondents (48.1%) have achieved a primary education level. A substantial proportion reported being illiterate (32.7%), with a minority (19.2%) having reached secondary education.

Most respondents were engaged in driving as their primary profession (72%), as opposed to a seasonal occupation (28%). When it came to daily working hours, close to half (48.1%) reported working approximately 8 hours per day, while the remainder were nearly equally divided between those working 4-6 hours and those working up to 10 hours per day.

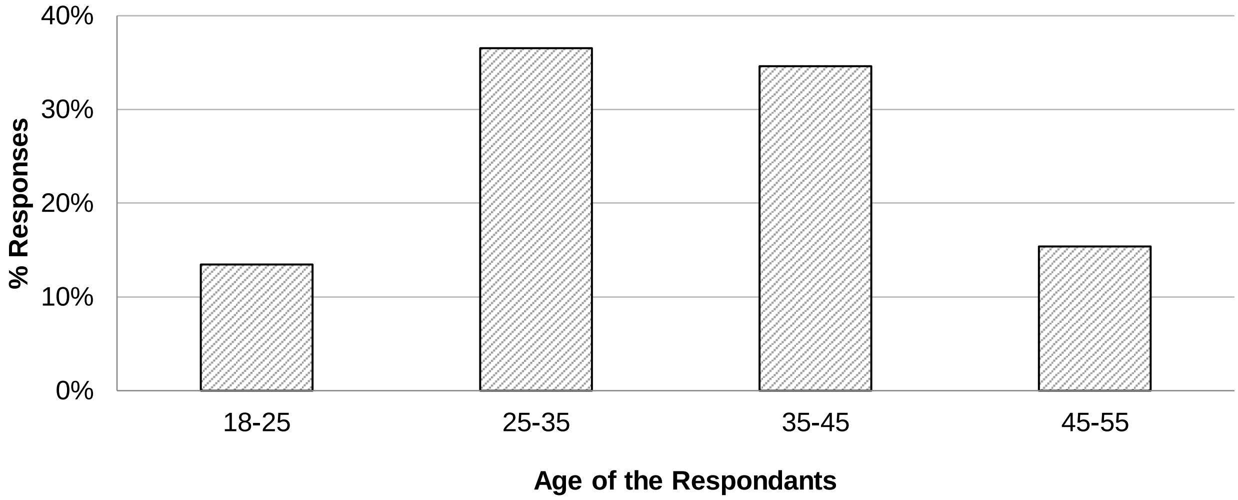

Figure 4 Age distribution of the respondents

In terms of professional experience, more than half (57.7%) had a span of 5 to 10 years in their respective fields. Experiences of 10-20 years were represented by around 28.8% participants, whereas newcomers to the profession, with less than 5 years of experience, form 13.5% of the respondents. Regarding the type of vehicle operated, a majority were traditional rickshaw drivers (55.8%), followed by battery rickshaw operators (34.6%). Easy bike drivers comprise the smallest segment (9.6%), likely reflecting the restricted operations of these vehicles within Dhaka, the primary site of our survey.

ii) Identification of the Sources of Hazard and Discomfort: The factor identification process involved extracting insights from driver feedback obtained during a preliminary survey, and aimed to pinpoint potential hazards that three-wheeler drivers encounter regularly. The focus was on discomforts and risks associated with different types of roadway-related issues. Ten issues were identified for further study as the primary hazard and discomfort sources. The issues are listed below with supporting images presented in Figure 5.

- Steep speedbumps: These bumps are placed for reduction of speed of faster vehicles. These can cause significant discomfort and vehicle instability, potentially leading to accidents.
- Steep slopes/ramps: Ramps are present on approach roads and intersections (where one road is at higher elevation). These require drivers to exert additional control, contributing to discomfort and elevated accident risk.
- Narrow roads: Limited space can complicate overtaking, passing, and stopping manoeuvres and increase accident risk.

- Open drains: Due to extreme rainfall, open storm drains are a common sight in Bangladesh, as they are easier to clean (removing sediments). These pose a considerable accident risk, particularly in poorly lit or heavily trafficked areas.
- Uneven manhole covers or pit slabs: Manhole access pods are not always flush with pavement surfaces. Such surface irregularities can destabilize vehicles, leading to discomfort and potential accidents.
- Bumpy roads (maintenance issues): Poorly maintained roads can lead to uncomfortable rides, vehicle damage, and increased accident risk.
- Insufficient shoulder width/pavement edge drop-off: A lack of adequate road edge width can make manoeuvring difficult, particularly during overtaking or avoiding other vehicles, increasing the risk of accidents. A height difference between the pavement and shoulder can cause accidents if a vehicle needs to move to the side, a common scene due to narrow urban and rural roads.
- Reckless driving: Behaviours such as speeding, neglecting to signal when turning, or violating traffic rules significantly heighten accident risks.
- Insufficient street lighting: Poor visibility due to inadequate lighting heightens accident risks.

- Competition with high-speed vehicles: As slower-moving vehicles, three-wheelers face increased risks of collisions and accidents when sharing roads with faster vehicles.

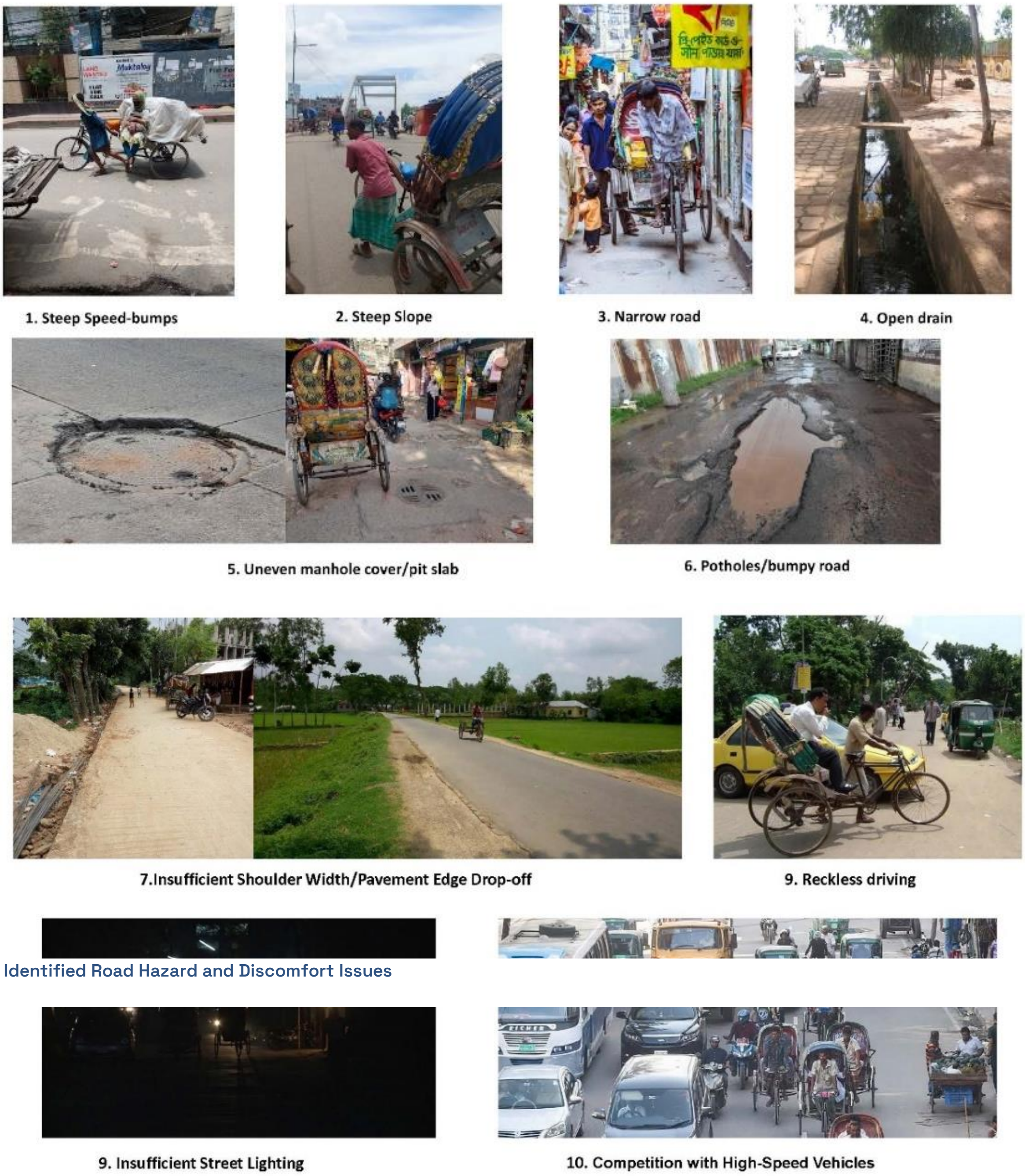

Figure 5: Identified Road Hazard and Discomfort Issues

Pictorial survey of roadway issues: Post categorization, these hazards were incorporated into a pictorial-based survey questionnaire. Each hazard was represented visually to aid drivers' understanding and recognition of these issues, presented in a 'menu' like format.

Drivers were encouraged to associate their individual experiences with the pictorial representations of these hazards. They were asked to rank these images based on their perception of primary, secondary, and tertiary causes of discomfort. In the same manner, they were asked to identify what they believed to be the leading three causes of accidents, in order. We then analysed these responses to gain a better understanding of drivers' perspectives on major roadway-related issues and to evaluate the severity and impact of these issues on their daily experiences.

iii) Quantification of the Sources of Hazard and Discomfort:

Discomfort Assessment: The drivers' survey data reveals several factors of discomfort significantly impacting drivers. Based on the responses, speed bumps, uneven utility holes, and potholes cause significant discomfort, with cumulative percentages of 90%, 81%, and 65% respectively (when percentages of rank 'primary', 'secondary', and 'tertiary' are combined). As shown in Figure 6, these discomfort ratings serve as an insightful tool to understand the real-world experiences of drivers and provide a roadmap for prioritizing improvements in road infrastructure.

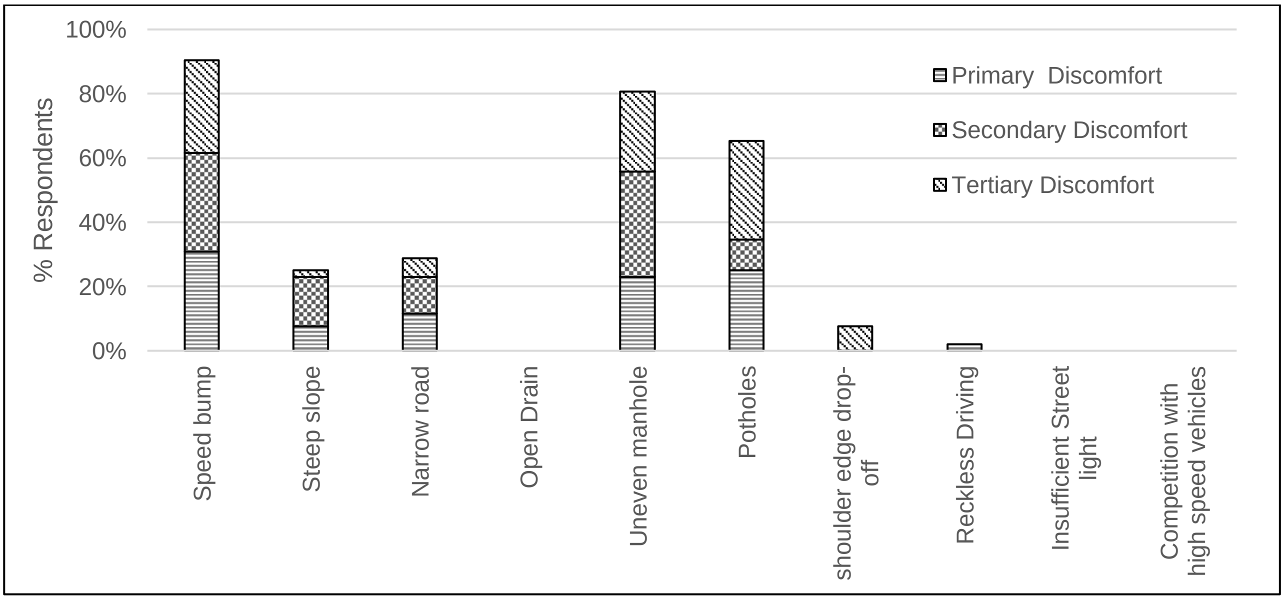

Figure 6: Distribution of identified discomfort factors based on responses

Some issues identified during this part of the survey require further discussion:

- **Unsettling experience: The case of speed bumps:** Speed bumps emerged as the most discomforting element, suggesting that a large majority of drivers encounter discomfort due to these traffic calming measures. While designed for safety, their current design might be disproportionately contributing to driver discomfort, potentially due to their size, frequency, or improper construction.
- **Maintenance concerns: The problem of uneven manholes and potholes:** Closely following the speed bumps are discomforts associated with uneven utility holes and potholes. These discomfort ratings underscore the importance of routine road maintenance, spotlighting the potential risks posed by these hazards.
- **Absence of roadways issues in discomfort rating:** Interestingly, elements like open drains, insufficient street lighting, and competition with high-speed vehicles did not register any discomfort among the respondents. However, it's worth noting that these factors can potentially lead to accidents, a point that will be further discussed in the next section with relevant data. Despite

most respondents having little or no formal education, their keen observational skills enabled them to differentiate between discomfort and hazard, or perceived causation of accidents.

- **Additional issues causing discomfort:** Beyond general discomfort ratings, we observed variations in responses based on driving area, vehicle type and other factors, leading to the emergence of several intriguing trends. As an example, some drivers identified insufficient shoulder width/pavement edge drop-off as a problem when considering the driving location. Interestingly, this issue was not reported by respondents within Dhaka city, indicating a higher prevalence in areas outside urban centres. When we assessed vehicle type, electric rickshaw drivers did not identify steep slopes as a discomfort source, a stark contrast to manual rickshaw drivers.
- **Accident assessment:** The survey data offers a perspective on various aspects of the driving environment that contribute to accidents in differing degrees, indicating a diverse range of causes, as seen in Figure 7

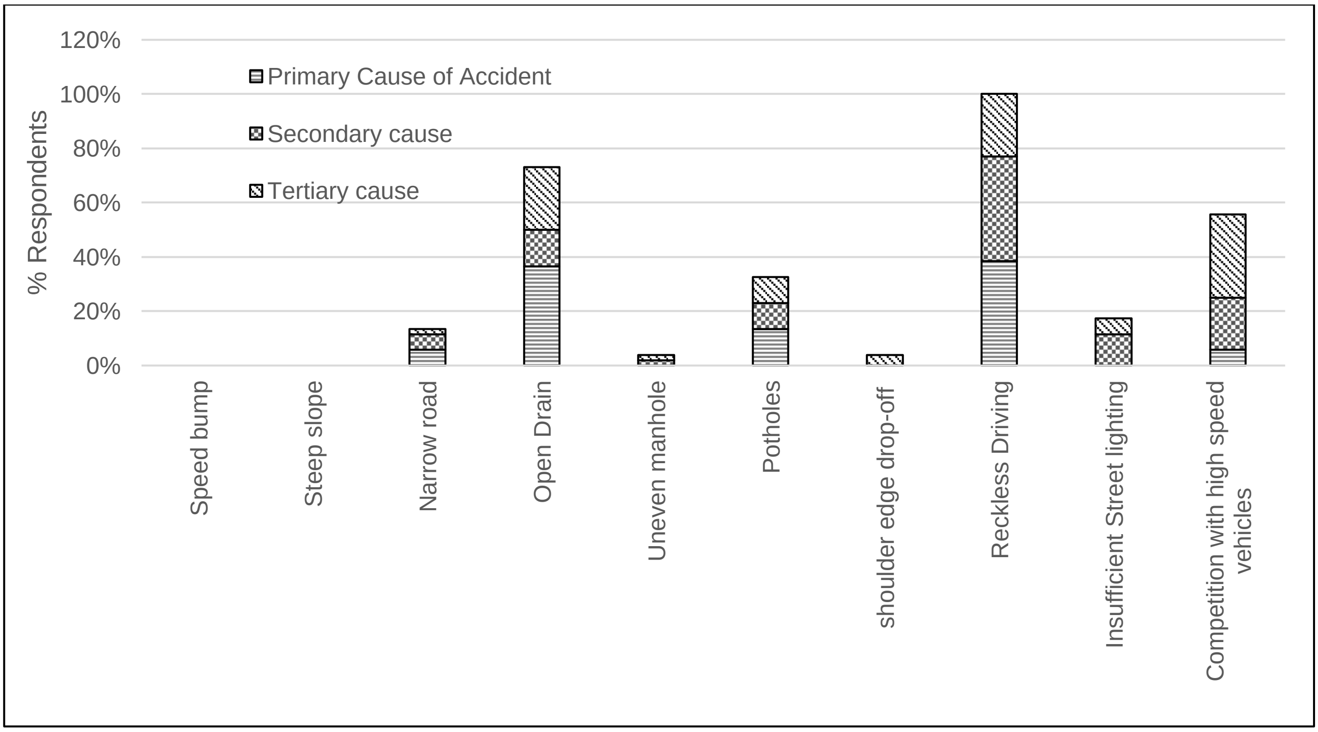

Figure 7: Distribution of identified hazard factors based on responses

Some issues identified during this part of the survey requires further discussion as the cause of accidents:

- **Driver behaviour:** Remarkably, reckless driving emerges as the most significant contributor to accidents, with a cumulative percentage of 100%. This result implies that every respondent identified reckless driving as either a primary, secondary, or tertiary cause of accidents. This underscores the urgent need for targeted interventions to improve driver behaviour and enhance traffic law enforcement. Strategies to improve road safety must, therefore, prioritize addressing reckless driving**.**
- **The threat of open drains:** Open drains stand as the second major cause of accidents, constituting a substantial 73.08% of all responses. This high value underscores a considerable infrastructure challenge that requires immediate redress. Accidents caused by open drains can be significantly harmful and potentially result in serious injury.
- **The danger of speed disparity:** Competition with high-speed vehicles is also a prominent concern, accounting for 55.77% of the responses. This indicates a considerable risk posed by slower vehicles sharing the same road space with faster, potentially larger vehicles. This finding

emphasizes the need for separate lanes or zones for slower traffic, improved road signage, and additional traffic calming measures.

- **Road quality:** Potholes and bumpy roads, indicative of road maintenance issues, account for a substantial 32.69% of the causes, emphasizing the need for improved road quality and regular maintenance.
- **Narrow roads and insufficient street lighting:** While narrow roads and insufficient street lighting have been identified as accident causes, they have relatively lower percentages, 13.46% and 17.31% respectively. These aspects, though less prominent, should not be overlooked in efforts to enhance road safety.
- **Urban vs. non-urban drivers:** On further analysis of the response data, interesting trends emerge when comparing different demographics and their perceived causes of accidents. About 15% of the drivers reported insufficient street lighting as a potential cause of accidents, which was not the case for drivers residing in urban areas. Hence, it is a more prevalent issue outside urban areas. Although the percentage is not high, a similar pattern can be observed for the issue of shoulder or road edge drop-off.

3.2 Tri-SMV Users' Opinion Survey

3.2.1 Identification of Concerns and Hazards: Passengers' survey

The most common demography of the three-wheeler's passengers is usually the middle-income population who need a comfortable and reliable alternative to expensive taxis. As the urban areas and city centres of Bangladesh face intense traffic congestion on a regular basis, Tri-SMVs are often more convenient compared to cars, buses, and other public transport due to their manoeuvrability and are particularly suitable for a short-haul ride. Due to their compact design, these vehicles can navigate through congested areas and alleyways with comparative ease.

Another category of users of these three-wheelers is females, the elderly and children who prefer comfort and are either unable to or choose not to walk to their destinations. As these vehicles are well suited for short trips, these are convenient options for those with mobility impairments. In tandem with the drivers' survey, we conducted the passengers' survey, as they are obviously the key stakeholder. While the objective was similar, that is identification of sources of roadway discomfort and hazard, the survey process was slightly different. The survey plan and the outcomes are discussed in the following section.

3.2.2 Survey Plan

As we wanted to develop a better understanding of roadway issues, we planned a thorough multistep survey of the passengers. Our survey was conducted in three distinct phases. In the first phase of the survey, we circulated an online questionnaire to gather participants. In the next step, we selected some participants at random within the pool of participants to conduct a pilot survey. After the pilot survey was done, we proceeded with the actual phone-based opinion survey. To ensure unbiased opinion and to protect the privacy of the participants, we refrained from collecting any form of identifiable personal information, except phone numbers (not stored after survey), gender, age, and mobility issues. The survey process is outlined in Figure 8.

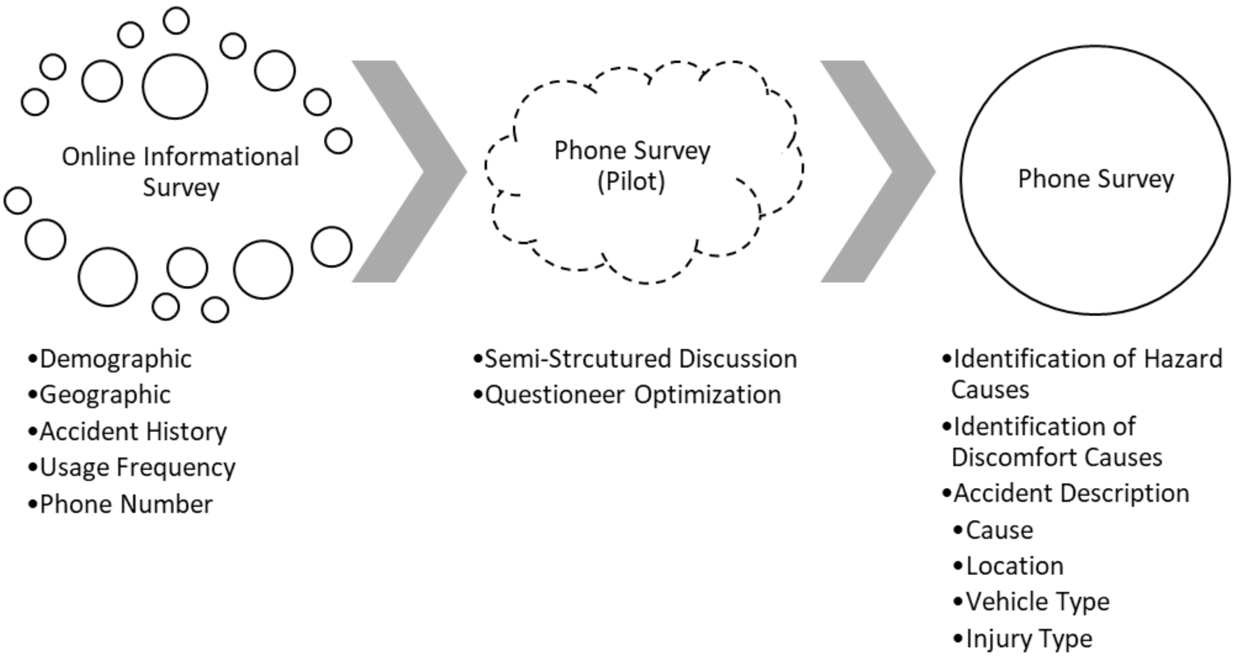

Figure 8: Distribution of identified hazards based on responses

- **Online questionnaire survey**: To collect interested participants for our survey, we reached out to people online who willingly provided us with their information and consented to be contacted. The questionnaire was circulated via Facebook. We kept our online questionnaire small and precise to ensure maximum participation. The participants were asked a set of basic questions such as demographic, geographic and exposure to Tri-SMV accidents. These data were eventually used to separate them into representative groups.
- **Conducting pilot survey**: Before starting the actual survey, we conducted the pilot survey to evaluate our questionnaire and to tailor it to better suit our participants. We intended the pilot survey to be semi-structured so that we can explore the topic in depth.
- For our **pilot phone survey**, we selected fifteen participants at random, most of whom were university students. They were asked a series of basic questions followed by some open-ended questions to get in-depth information. Participants were encouraged to talk about issues they faced while using slow-moving three-wheeler vehicles. During the interviews, it was noted that the issues were difficult to narrow down in an open-discussion setting. We were particularly challenged to communicate our study focus on roadway issues without data being skewed through confirmation or framing bias. This issue is similar to that experienced during the drivers' survey. Therefore, the inputs required interpretation and explanation from the survey participants. From the discussions, we identified some of the key issues in terms of comfort and hazard. The issues identified during the passengers' and drivers' pilot study were merged for the subsequent phone survey.
- **Phone-based opinion survey:** After completing the pilot survey, the respondents of the online survey were contacted via phone and requested to give a short interview. We separated our participants into two distinct groups based on their exposure to accidents. The participants were asked basic demographic questions and encouraged to enter into open-ended discussions on the issues they faced while using Tri-SMVs. They were also asked in detail about the accidents they faced. The interview was concluded by asking them to rank the top three causes of discomfort as well as potential hazards from a list of issues that were identified during the pilot survey.

3.2.3 Passengers' Survey Outcome

i) Demographic data and usage characteristics: To ensure representative opinion, we ensured that we had a similar number of respondents from both traditional genders. We had 52% female participants and

48% males, in a sample size of 50 survey participants. Most of our participants (44%) were young, belonging to the age group of 25 to 35 years old. The next largest group of participants (26%) belonged to the age group of 18 to 25 years old. The 3rd largest group was the age group of 45 to 55 years which made up 16% of the participants, as seen in Figure 9.

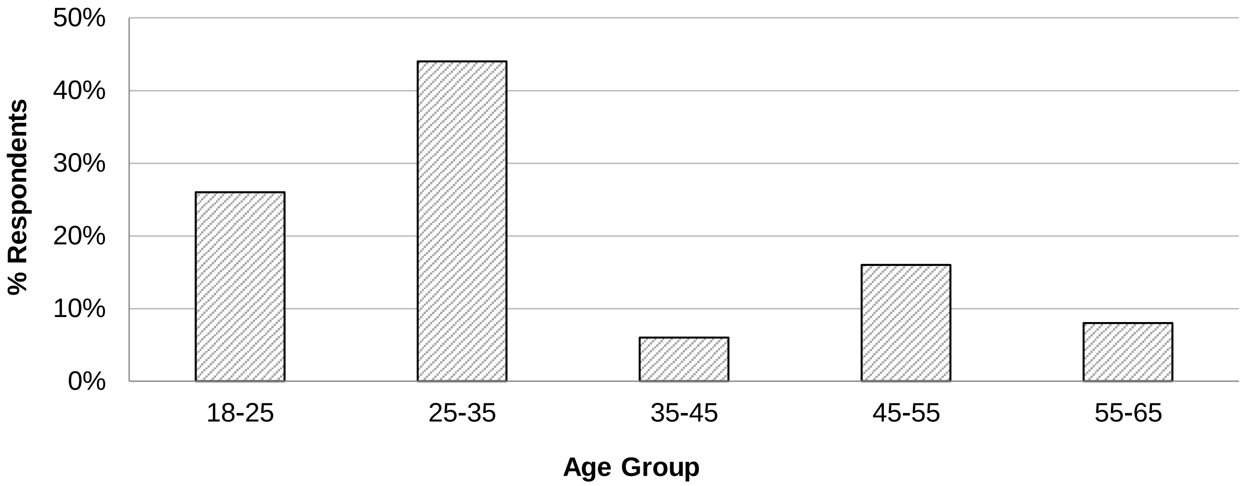

Figure 9: Age distribution of the respondents

We collected opinions from people of all educational backgrounds. However a vast majority, around 88%, already had or were studying for a graduate degree. The next most populous category had a higher secondary degree and made up 6% of the participants. About 4% of our participants were illiterate i.e., had no formal education. The rest of the participants only had a secondary degree. The observed bias is likely because the distribution of the online questionnaire was initiated by university Facebook groups.

We found that most (92%) of our participants were residents of Dhaka city, and the rest were residents of locations other than Dhaka. 4% of our participants were hailing from urban areas except Dhaka city. The rest were from semi-urban and rural areas. Each of these categories is composed of 2% of the participants. As before, the bias originated from the fact that the primary survey was initiated through the university Facebook pages which were frequented by students and alumni mostly based in Dhaka. It implies that the issues that would be identified through this survey will be urban in nature and would not be representative of rural scenarios.

Our participants mostly used Tri-SMVs as their main mode of transportation, as seen in Figure 10. Around 62% used it as their main mode of transportation for commuting. About 18% of the participants used public buses as their main mode of transportation. Another 10% used other forms of public transport such as human haulers, ride-sharing services, etc. The remaining 10% used private cars as their main mode of transportation. Interestingly, it was reported by many that they preferred to use Tri-SMVs as their main mode of transportation despite owning private cars. The reasoning behind preferring Tri-SMVs included factors such as insufficient parking and Tri-SMVs being relatively cheap and capable of navigating heavy traffic.

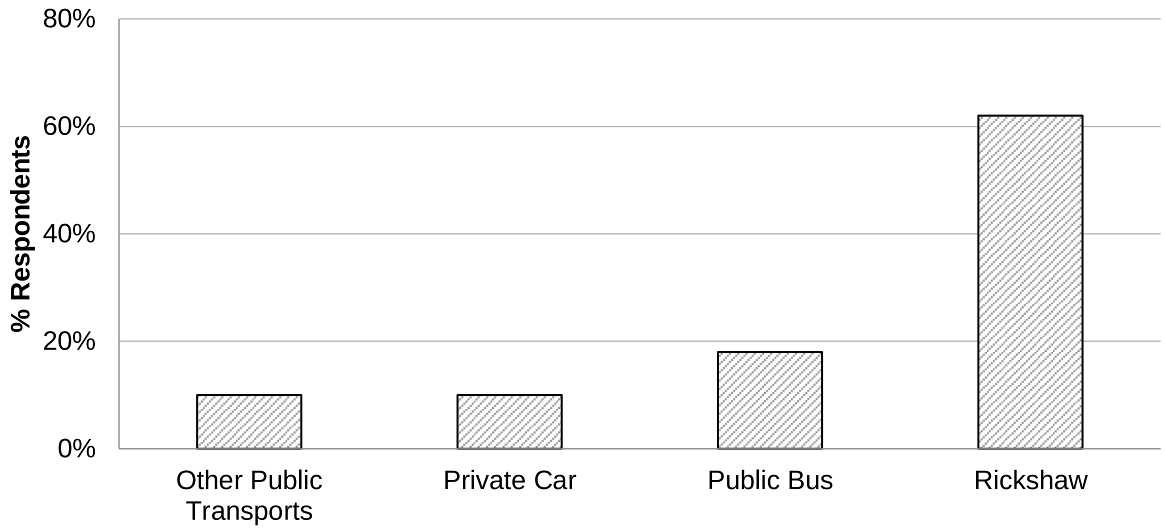

Figure 10: Distribution of mode of transport used by the respondents.

All the participants of our survey had used a Tri-SMV before and many used them daily. Around 46% of the participants used it frequently and as often as every day. The remaining 52% used it infrequently but at least once a week. However, most of them were users of manual rickshaws. As most of the participants were residents of Dhaka city, they either did not have or had limited access to other types of three-wheelers, due to regulatory issues.

ii) Accident rate and type: When asked about accidents, we found that most of our participants had either faced accidents themselves or knew someone who faced accidents while using a three-wheeler. Only 16% of our participants said that they hadn't had an accident themselves or knew anyone who had had accidents in a Tri-SMV. As our participants were mostly Dhaka based where most other forms of Tri-SMVs are strictly regulated, it was found that most of the accidents occurred while on a rickshaw (73.81%).

The reported accidents on manual rickshaws were mostly minor accidents where only one or two were injured. In most cases, the injuries were minor such as minor cuts or scrapes. However, some accidents were severe resulting in nonfatal serious injuries. Most of these accidents lead to fractures or sprains. Usually, these occurred due to the vehicle overturning and landing on the passengers. The rest of the reported accidents occurred in battery-operated rickshaws (19.05%) or easy bikes (7.14%). These types of accidents resulted in more severe injuries and vehicle damage. In some cases, the injured had to undergo major surgeries and bear the consequences of the accidents for life. Common types of accidents, reported during the survey are outlined below:

- **Collisions**: The majority (65.85%) of the reported accidents were caused due to collisions with another vehicle. In most cases with another rickshaw. These collisions occurred due to the other vehicles abruptly breaking in the middle of the road or while crossing intersections. Another identified cause of collisions was the inability to brake due to speeding. It was found that these accidents were most frequent at intersections or places with heavy traffic. We identified intersection design to be a critical geometric factor for the same operation of Tri-SMVs.
- **Overturning:** The next most common accident (29.27%) was overturning. In many cases, these accidents were caused due to poorly maintained road surfaces and potholes. Potholes with water logging were identified as an especially dangerous combination. Battery-operated rickshaws and easy bikes are more prone to this type of accident due to their higher speed and lighter weight. These factors combined with inadequate braking systems make such vehicles easily lose control. These accidents are likely to be influenced by poor maintenance and road geometry. Turning at higher speed resulted in frequent accidents, which may be delegated to lack of speed control measures and sharpness of the turn.
- **Passengers falling out**: The other type of common accident was caused by passengers falling from the vehicles due to abrupt hard breaks. Passengers of easy bikes and battery-operated

rickshaws were found to be more vulnerable to this problem. Their higher speed (compared to manually driven rickshaws) makes them unstable even at minor disturbances. These are common in busy urban streets and usually happen at intersections, due to sudden braking. These events are aggravated by the lack of safety restraints in seats as well as the open-cabin layout of Tri-SMVs.

- **Miscellaneous**: Another type of accident many participants complained about was parts of dresses getting stuck in the wheels of rickshaws which lead to choking and other similar injuries. In one reported case this led to the death of a passenger. Though this type of accident is unlikely due to the pavement or design of roads, it is a very common issue and is mostly experienced by women and children.

iii) Phone Survey Identification of Issues and Their Rating:

Passenger discomfort assessment: Our participants were provided with a list of eight options and asked to rank the top three based on the level of discomfort caused by them. Survey outcomes are presented in Figure 11. Steep speed bumps were chosen as the number one most uncomfortable element of the road by most of our participants. About 82% of the participants (cumulation of percentages as rank 1, 2, or 3) chose it as a significant cause of discomfort.

The second main cause of discomfort was found to be the uneven road surface i.e., roads with potholes and poorly maintained roads. It was selected by 60% cumulatively. It was also found that the presence of high-speed vehicles on the same road as three-wheelers caused anxiety and safety concerns and was labeled as a major discomfort by 56% of the cumulative ratings. Sharp turns and open drains were regarded as the next most uncomfortable elements of roads. Both received 26% and 28% of the votes across all three categories. Other than these, steep slopes and dark roads were also regarded as sources of major discomfort by 24% and 12% of the cumulative votes. Narrow roads were also identified as a hazard by 12%.

From the ratings, it is obvious that the biggest source of discomfort for users is the steep speed bumps, uneven road surfaces i.e., roads with potholes, poor maintenance, and the presence of high-speed vehicles. This is understandable as steep speed bumps cause heavy jerking as three-wheelers cannot control speed easily and the braking system of Tri-SMVs is not advanced. This usually leads to back aches and general discomfort which would be aggravated for people with any health issues including pregnancy.

The other identified source of discomfort is the presence of high-speed vehicles on the same road. Even though this is a psychological issue, it can also be attributed to the design of roads. Three-wheeled vehicles are much slower compared to cars, buses, etc., and thus can be severely damaged in case of collision. This type of accident often leads to severe injury and can cause casualties in extreme cases. In the same manner as steep speedbumps, uneven road surfaces cause heavy jerking leading to discomfort, aches, and in serious cases injuries. Moreover, this can lead to passengers falling out of the vehicle and in some cases may lead to overturning of the vehicle.

Passenger hazard assessment: Survey participants were asked to rate the top three causes of accidents in three-wheelers, like the discomfort survey discussed before, with a similar set of issues. Since accidents in slow-moving three-wheelers are common, we also asked the participants who did not face any accident to rank the top three causes. Figure 12 summarizes our findings from this survey. From the ratings, we identified uneven road surfaces to be the leading cause of accidents. It was chosen by 62% cumulatively. The next most common cause of accidents was found to be sharp turns which was chosen by 56% cumulatively. The third leading cause of accidents was found to be narrow roads which was selected by 48% of the votes. Other than these, water-logged roads, steep speed bumps, and dark roads were also selected as a major cause of accidents by many. Water-logged roads were selected 38% of the time as a cause of accidents. Steep speed bumps and dark roads were selected 34% and 16% of the time respectively. Open drains were selected as a source of hazard by 22% cumulatively.

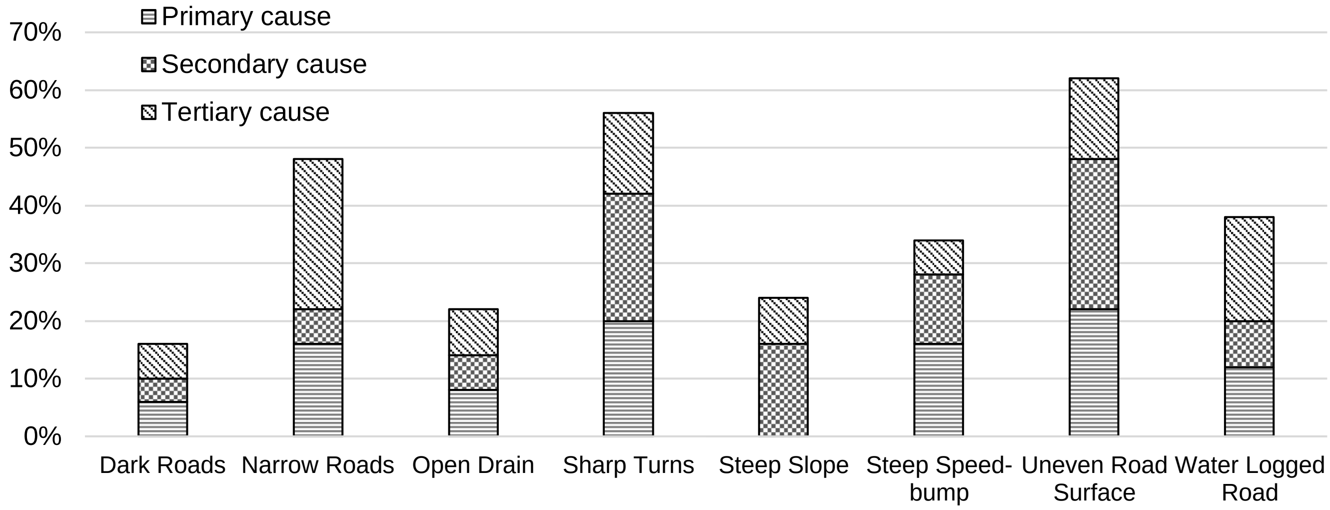

Figure 12: Distribution of identified discomforts based on responses of passengers

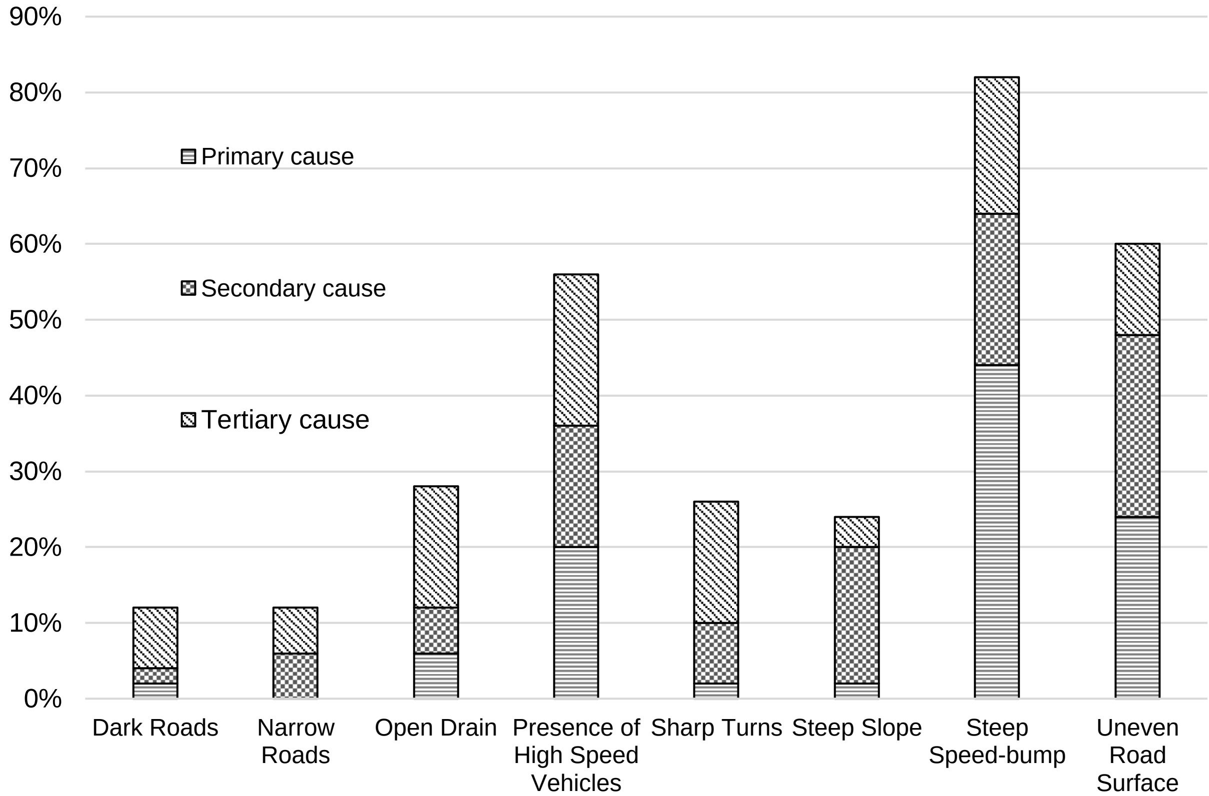

Figure 11: Distribution of identified hazards based on responses of passengers

4. Quantitative Measurement

In the comprehensive study of road design adjustments for Three-Wheeler Slow-Moving Vehicles (Tri-SMVs), a variety of sophisticated measurement techniques were employed to gather accurate and relevant data. Each technique is chosen for its ability to provide detailed insights into different aspects of Tri-SMV operation and interaction with road infrastructure.

The use of Inertial Measurement Units (IMU) and Global Positioning System (GPS) devices forms the backbone of dynamic vehicle data collection. IMUs, which integrate accelerometers and gyroscopes, are critical for measuring direct acceleration forces and angular velocities. These forces are prevalent in Tri-SMVs due to their lighter build and less stable construction compared to four-wheeled vehicles. By measuring how these forces change over time, IMUs can track the Tri-SMV's speed, direction, and orientation changes, providing a comprehensive profile of its dynamic behaviour on various road surfaces. This data is crucial for understanding how Tri-SMVs respond to different road conditions, including their stability and safety.

Figure 13: IMU Sensors Attached to Rickshaw Frame (Marked by White Circle)

Figure 14: IMU Sensors attached to searts (marked by white circle)

Parallel to IMU data, GPS devices deliver high precision location tracking by calculating the vehicle's position from signals received from satellites. This positioning helps determine the Tri-SMV's speed and trajectories over time, enabling the analysis of how these vehicles navigate through traffic, respond to road geometries, and adhere to traffic regulations. Combining GPS data with IMU readings allows for a detailed analysis of movement patterns and identifies potential safety issues arising from operational practices.

For measuring vibrations that Tri-SMV passengers experience, accelerometers specifically designed to capture the frequency and amplitude of oscillatory movements are used. These devices are essential for evaluating the comfort levels in Tri-SMVs as they traverse different road textures and encounter irregularities such as potholes and speed bumps. The severity of the vibrations, which directly correlates with the roughness of the road surface, can significantly impact passenger comfort and is a critical factor in designing roads that are more accommodating to Tri-SMVs.

Speed measurement was conducted using GPS devices attached to various types of Tri-SMVs, including pedal rickshaws, battery-operated rickshaws, and easy bikes. This setup enabled the collection of precise data regarding the vehicles' speed over time under various road conditions and traffic scenarios.

The GPS technology used in the study operates on the principle of triangulation between satellites and the GPS receiver. As the Tri-SMV moves, the GPS device records its position at regular intervals, allowing for the calculation of speed by determining the distance travelled over time. These speed data are crucial for analysing how Tri-SMVs interact with different road geometries, traffic densities, and infrastructural features such as speed bumps and road inclines.

To complement the speed data, acceleration and braking characteristics were also monitored using Inertial Measurement Units (IMUs). These devices measure the linear accelerations and angular velocities, providing insights into the dynamics of Tri-SMVs as they navigate through traffic and respond to road features. This combination of GPS and IMU data helps in understanding the behaviour of Tri-SMVs in real-world conditions, which is essential for designing roads that are safe and comfortable for these vehicles.

For example, detailed speed profiles were created to illustrate how Tri-SMVs accelerate and decelerate in different settings. This was particularly important for understanding their capacity to handle urban traffic conditions, where frequent stopping and starting are necessary, and in rural areas, where roads may have different characteristics that impact vehicle speed.

Additionally, the braking distances for both hard and soft braking were recorded, providing valuable data for assessing the safety margins needed in road designs to accommodate the stopping capabilities of Tri-SMVs. These measurements are critical for determining appropriate distances between road features and necessary buffer zones to enhance safety.

In the context of the Tri-SMV Road Design project, measuring the speed of Tri-SMVs manually over a fixed distance was an essential method employed alongside more sophisticated techniques like GPS and IMU sensors. This manual method provided a practical and straightforward approach to validate the data obtained from technological devices or to gather speed data when high-tech equipment was not available.

The manual measurement of Tri-SMV speeds involved a simple setup with a stopwatch and a tape measure, offering a cost-effective and easily replicable means to collect essential data. First, the team selected a suitable section of road that was representative of the typical operating environments for Tri-SMVs. This area needed to be relatively straight and free from traffic interruptions that could affect the speed measurements.

A specific distance, commonly 50 meters or 100 meters, was marked clearly on the road using a tape measure. These lengths were chosen as they provide enough distance to allow the Tri-SMV to reach a stable speed while remaining manageable for timing accurately. The starting and finish lines were marked visibly on the pavement to ensure they were clearly identifiable to both the Tri-SMV drivers and the observers.

For each test, two team members were positioned: one at the starting line and the other at the finish line. The observer at the starting line was equipped with a stopwatch. As the Tri-SMV passed the starting line, the stopwatch was started. As soon as the Tri-SMV crossed the finish line, the stopwatch was stopped. The time recorded represented how long it took for the Tri-SMV to travel the measured distance. The speed is typically calculated in meters per second (m/s). If needed, the speed could be converted into kilometres per hour (km/h) by multiplying the result by 3.6.

Multiple trials were conducted to ensure the accuracy and reliability of the measurements. By averaging the speed results from these trials, the team minimized the potential for anomalies caused by external factors or measurement errors. This averaging also helped account for slight variations in Tri-SMV acceleration or deceleration that might occur at the start or end of the measured distance.

This manual method of measuring speed was particularly valuable in providing a check against the electronic data collection methods. It ensured that the technological measurements were accurate and could be trusted for further analysis. Moreover, this approach was useful in situations were setting up sophisticated equipment was impractical due to environmental constraints or when a quick assessment was needed.

By integrating this manual speed measurement into the broader data collection framework, the project team was able to develop a well-rounded understanding of Tri-SMV dynamics. This comprehensive dataset informed the development of road design guidelines that are sensitive to the speed characteristics and safety requirements of Tri-SMVs, enhancing the overall effectiveness of the transportation infrastructure tailored for these vehicles.

Figure 15: Rickshaw Speed and Acceleration Measurement

Figure 16: Breaking Distance Measurements

5. Observations: Analysis of Tri-SMV Data

The speed profiles of Tri-SMVs, such as easy bikes, battery-operated rickshaws, and pedal rickshaws, reflect their powertrain capabilities and the physical effort required to operate them. Easy bikes, with their larger battery and motor capacity, exhibit higher sustained speeds, making them suitable for longer distances. This capability, however, brings a safety concern in densely populated areas where higher speeds might increase the risk of accidents.

Acceleration data is crucial for understanding how quickly a vehicle can respond to traffic conditions. Quick acceleration is advantageous at intersections and traffic lights, allowing vehicles to efficiently move without causing delays. However, for Tri-SMVs, especially pedal rickshaws, the ability to quickly accelerate is limited, which can lead to congestion, particularly in areas where these vehicles share lanes with faster, motorized traffic.

In contrast, easy bikes and battery-operated rickshaws with better acceleration capabilities must be managed to ensure that their quicker start does not pose a hazard to pedestrians and other slower-moving traffic. Road designs might need to include adequate sight distances and possibly advanced signal systems that account for the mixed acceleration capabilities of different vehicle types.

Speed and Acceleration Behaviour:

- Easy Bikes: These vehicles show a faster acceleration curve, which could be attributed to their more powerful electric motors and larger battery capacities designed for carrying more passengers over greater distances. The faster acceleration and higher top speeds require road designs that include longer sight distances, wider lanes, and smoother pavement to safely accommodate the increased momentum and stopping distances needed.
- Battery-Operated Rickshaws: The moderate acceleration capabilities suggest that these vehicles are powered adequately for urban environments but may not handle steep inclines or rough terrains effectively. This moderate performance necessitates road designs that minimize steep gradients and ensure that urban roads have regular maintenance to avoid disruptions in traffic flow and safety.
- Pedal Rickshaws: The slower acceleration and speed profiles highlight the human-powered nature of these vehicles. The variability in their performance, especially on inclines and uneven surfaces, underscores the need for flat and well-maintained road surfaces, along with dedicated lanes that allow them to operate away from faster and more aggressive traffic, thus reducing the risk of accidents.

Braking Dynamics:

Braking data reveals the distance and time a vehicle takes to come to a complete stop. Effective braking is critical for safety, particularly in urban settings where unexpected obstacles and stop-and-go traffic are common. Tri-SMVs, with varying braking efficiencies, highlight the need for road designs that provide ample space for these vehicles to stop without causing rear-end collisions.

Pedal rickshaws, with potentially the least effective braking systems, might require more conservative speed limits or specially designed zones with traffic calming measures to mitigate the risk of accidents. Meanwhile, easy bikes, with better brakes, still need road designs that consider their higher operating speeds.

The braking data across all types of Tri-SMVs, particularly the differences in stopping distances between hard and soft braking scenarios, indicate the need for a comprehensive understanding of their braking systems' efficiency. Hard braking scenarios show significantly shorter stopping distances but may not be consistently reliable due to the physical limitations of the braking systems in Tri-SMVs and the potential for skidding or loss of control.

- Causation and implications: The less sophisticated braking systems of Tri-SMVs, combined with potentially high loads (especially in easy bikes), can lead to longer stopping distances under soft braking conditions. This factor is crucial in urban planning where traffic conditions can force sudden stops. Implementing rumble strips before critical intersections and designing gradual speed reduction zones can help in mitigating risks associated with insufficient braking capacities.

Environmental and Road Surface Factors:

The impact of road surface quality on Tri-SMV operation, especially for pedal rickshaws, cannot be overstated. Poor road conditions can drastically reduce the efficiency of pedal rickshaws and increase the risk of accidents for all types of Tri-SMVs.

- Causation and implications: Uneven surfaces can lead to increased vibration, which not only affects passenger comfort but also vehicle stability and control. Effective drainage systems and regular pavement maintenance are essential to prevent water accumulation and surface deterioration, which pose significant hazards to Tri-SMVs

6. Mitigation Framework and Resolutions

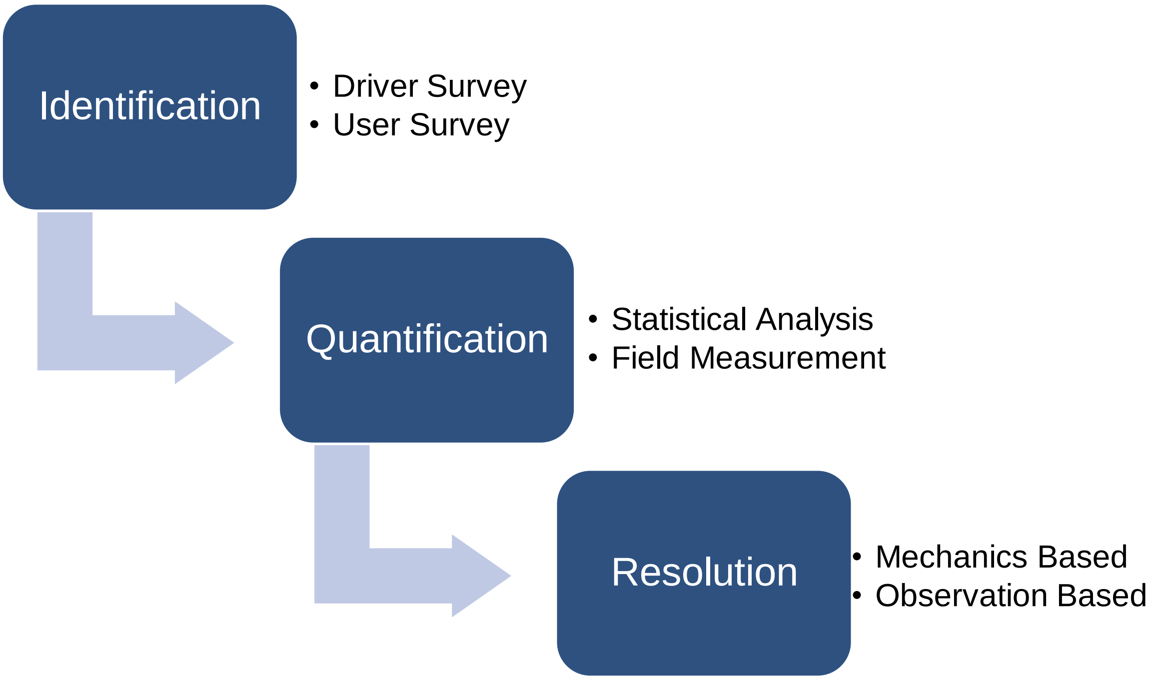

Figure 17: Mitigation Framework

6.1 Identification and Resolution Plan of Hazards

6.1.1 Safety Hazards

Inadequate Lane Widths:

- Impact: Constricted lane widths not only increase the risk of collisions but also contribute to traffic congestion. This can lead to longer commute times and increased emissions from idling vehicles, exacerbating urban air pollution and stress among commuters.
- Solutions: Implement dynamic lane management systems where the widths and directions of lanes can be adjusted based on traffic flow and time of day, specifically accommodating peak hours for Tri-SMV traffic.

Improperly Designed Speed Bumps:

- Impact: Incorrectly designed speed bumps can lead to increased maintenance costs for Tri-SMV operators due to vehicle damage. Frequent repairs can make Tri-SMV operation economically unfeasible, reducing transportation options for low-income commuters.
- Solutions: Develop and deploy modular speed bumps with adjustable heights and damping characteristics tailored for different vehicle types, including Tri-SMVs. Use innovative materials that absorb impact without transferring excessive force to the vehicle.

Unsafe Roadside Barriers:

- Impact: Inadequate barriers not only pose a direct risk of accidents but can also lead to severe injuries or fatalities when accidents occur. This compromises public safety and can lead to significant medical and legal costs.
- Solutions: Introduce smart barrier systems that include shock-absorbent materials and designs that redirect the vehicle's momentum upon impact, reducing the likelihood of severe injuries.

6.1.2 Operational Challenges

Steep Road Gradients:

- Impact: Challenging gradients particularly impact fuel efficiency and can increase operational costs for motorized Tri-SMVs. For manual or pedal-powered Tri-SMVs, steep gradients can be a severe hindrance, limiting their operational range and excluding potential users.
- Solutions: Engineering alternative routes that circumvent steep areas or employing terraced road designs in hilly terrains can minimize the gradients encountered by Tri-SMVs. Additionally, installing power-assist stations at intervals where drivers can recharge or receive mechanical assistance could be innovative.

Narrow Lanes and Tight Curves:

- Impact: These design issues not only cause immediate risks of collisions but also discourage the use of Tri-SMVs for fear of safety, potentially shifting users to less sustainable modes of transport.
- Solutions: Utilize traffic calming techniques such as chicanes or bulb-outs that naturally slow down traffic before tight curves, making these areas safer for Tri-SMVs. Ensure these modifications are well-signalled to inform all road users.

Poor Road Surface Conditions:

- Impact: Beyond discomfort and vehicle damage, poor road conditions can deter tourism and local business activities in areas heavily trafficked by Tri-SMVs, affecting local economies.
- Solutions: Implement a regular monitoring and maintenance schedule using IoT sensors to detect and prioritize repairs in real-time. Employ advanced materials like polymer-modified asphalts for longer-lasting road surfaces.

6.1.3 Comfort Concerns

Hard Speed Bumps and Rough Surfaces:

- Impact: Continuous exposure to hard bumps and vibrations can lead to long-term health issues for passengers and drivers, including back pain and other musculoskeletal problems.
- Solutions: Design roads with "green wave" speed planning for Tri-SMVs, where speed bumps are minimized, and traffic lights are synchronized to create a smoother ride at optimal speeds for these vehicles.

Exposure to Environmental Hazards:

- Impact: Long-term exposure to environmental hazards can lead to chronic health problems for Tri-SMV passengers and drivers, impacting public health and increasing healthcare costs.
- Solutions: Design urban green corridors with dense vegetation along major Tri-SMV routes to act as natural air filters, reducing pollution exposure. Incorporate covered paths in particularly dusty or polluted areas.

Lack of Adequate Shelter at Stops:

- Impact: The lack of proper infrastructure at stops can decrease the overall attractiveness of public transport systems, leading to reduced ridership and increased reliance on private vehicles.
- Solutions: Develop smart shelters equipped with real-time information displays about Tri-SMV schedules, solar panels for lighting and charging stations, and weather-protected seating, enhancing the user experience and comfort.

6.2 Resolution

As the key objective of the project, identifying and resolving risks associated with the operation of Tri-SMVs on urban and rural roads is crucial to enhancing safety and improving transportation infrastructure. An expanded analysis of these risks with detailed resolution strategies is presented below:

Sharp Turns:

Sharp turns pose significant risks for Tri-SMVs due to their inherent instability and difficulty manoeuvring. The presence of open drains, lampposts, or other obstacles near these turns can obstruct the path or catch the vehicles unexpectedly, leading to accidents. To mitigate these risks, the approach to sharp turns can be redesigned by flaring the entry and exit points, which provides Tri-SMVs with more room to manoeuvre safely. Implementing tactile and visual cues such as painted road markings or raised textured surfaces alerts drivers to upcoming changes in road alignment, helping them navigate turns more safely. Removing unnecessary roadside obstacles and ensuring that turning radii are sufficiently wide to accommodate the slower and more deliberate turning motions of Tri-SMVs also enhances safety.

Speed Breakers:

Traditional speed breakers can cause severe discomfort to Tri-SMV passengers, particularly those with medical conditions or pregnant women, due to the vehicles' limited suspension capabilities. To address this, speed breakers should be redesigned to include a double-curved smooth parabolic shape that allows a more gradual ascent and descent over the bump. This design minimizes the impact on Tri-SMVs and improves passenger comfort. The height of speed breakers should be limited to 4 inches, with a gradual incline that extends far enough to allow the vehicle to adjust without abrupt changes in speed or trajectory. Strategic placement ensures that speed breakers do not force Tri-SMVs to come to a full stop right before intersections, where they need momentum to cross safely.

Lane Widths:

Conventional lane widths are often optimized for cars and larger vehicles, which can leave Tri-SMVs with too much or too little space, encouraging unsafe lane sharing or forcing unsafe overtaking manoeuvres. Adjusting lane widths to specifically accommodate Tri-SMVs alongside regular vehicles can reduce the need for risky overtaking and enhance the overall traffic flow. Introducing dedicated Tri-SMV lanes or mixed-use lanes with appropriate width ensures safer and more efficient traffic movement. Clear visual indicators and physical dividers can help define these spaces clearly, reducing confusion and potential collisions.

Intersection Approaches:

Intersections that involve elevation changes can pose significant challenges for Tri-SMVs, especially those that are muscle-powered or equipped with basic electric systems. The lack of power can prevent these vehicles from accelerating quickly enough to clear the intersection safely, creating traffic delays and increasing accident risks. Designing intersections with gradual slopes and providing acceleration lanes for Tri-SMVs can facilitate smoother transitions. Adjusting traffic light timing to give Tri-SMVs more time to cross and adding additional signage and signals can also mitigate these risks.

Manhole and Road Patching:

Improperly sealed manholes or uneven road patches can cause sudden jolts or loss of control for Tri-SMVs. Ensuring that all manholes and patches are flush with the road surface is crucial for preventing these hazards. In cases where achieving a level surface is not possible, these areas should be marked clearly as minor obstacles. Standardized protocols for road repairs, including smoothing and sealing techniques, can prevent these issues from arising and ensure a safer driving surface for all vehicles.

Road Cross-Slope:

Inadequate road cross-slope can lead to water pooling on the roadway, increasing the risk of hydroplaning. For Tri-SMVs, which may lack the weight and tyre tread to displace water effectively, this risk is heightened. Designing roads with a consistent, gentle cross-slope ensures better water drainage and reduces the risk of standing water. This slope should be subtle enough not to impede the stability of

Tri-SMVs, with additional drainage solutions such as strategically placed gutters and drainage channels aiding in effective water management.

Open Drains:

Open drains near roads pose significant risks of accidents, especially in conditions of poor visibility or when roads are flooded. Installing safety barriers and ensuring that drains are covered or positioned below the road level can prevent accidents and improve safety for Tri-SMV operators and passengers.

7. Capacity Building through Research

The Tri-SMV Road Design Guideline Project has been instrumental in fostering significant capacity building among the research team and stakeholders involved. The process of conducting this research has led to numerous educational and professional growth opportunities for the team members and other participants. The capacity building aspects of the research have been achieved through two processes. The first one is implicit capacity enhancement of the research team and research participants as well as stakeholders. The second one is explicit capacity building of the diverse stakeholders through a structured workshop session.

7.1 Learning and Professional Development of the Research Team

1. Enhanced Technical Skills:

The research team gained advanced skills in data collection and analysis using sophisticated tools like Inertial Measurement Units (IMUs) and Global Positioning System (GPS) devices. These tools were pivotal in gathering precise data on the speed, acceleration, and braking characteristics of Tri-SMVs. Team members learned to interpret complex datasets, integrate various types of data, and derive meaningful insights that informed the development of the road design guidelines.

2. Improved Survey Methodologies:

Conducting detailed opinion surveys with Tri-SMV operators and users provided the research team with invaluable experience in qualitative research methodologies. The team developed expertise in designing survey instruments, conducting field surveys, and analysing qualitative data. This experience is critical for future research projects that require a deep understanding of user perspectives and behaviours.

3. Interdisciplinary Collaboration:

The project required collaboration across multiple disciplines, including transport engineering, urban planning, mechanical engineering, and public health. Team members worked closely with stakeholders such as local authorities, Tri-SMV drivers, and passengers, gaining insights into the practical challenges and considerations in road design. This interdisciplinary approach enriched the team's understanding and highlighted the importance of holistic solutions in transportation projects.

4. Fieldwork Experience:

The extensive fieldwork involved in this project, from surveying road conditions to measuring vehicle dynamics, provided hands-on experience that is invaluable for any transportation research. Team members enhanced their skills in practical problem-solving and real-world data collection, which are essential for implementing effective infrastructure projects.

7.2 Dissemination Events

The dissemination of research findings and recommendations was a crucial component of the project, ensuring that the knowledge gained was shared with a broader audience and could influence policy and practice.

1. Workshops and seminars:

The project organized a final workshop to present the research findings to key stakeholders, including government officials, urban planners, and transportation professionals. It provided a platform for discussing the practical implications of the research and for gathering feedback from various experts in the field.

2. Publications and reports:

A detailed report and research paper were produced to document the findings and recommendations. These publications are intended to serve as reference materials for policymakers, urban planners, and engineers. The dissemination of these documents through academic and professional networks ensures that the research findings are accessible to a wide audience.

3. **Media Engagement:**

The project actively engaged with various media outlets and social platforms to disseminate the research findings. Articles were published in newspapers, highlighting the impact of road design changes on reducing rickshaw-related accidents and enhancing safety for all road users.

4. **Video Content:**

To reach a broader audience, the project team produced a video detailing the research findings and proposed solutions. This video was shared on YouTube, providing an accessible and engaging format to explain the project's impact. The video covered key aspects of the research, including the importance of redesigned speed bumps, lane adjustments, and improved signage for enhancing Tri-SMV safety. A shorter version of the video was also created to summarize the findings for quick dissemination through social platforms, which were well received.

8. Potential Uptake and Future Research Options

8.1 Potential Uptake

The project provides actionable insights and recommendations that can be adopted by various government and non-government entities to enhance road safety and usability for Tri-SMVs in Bangladesh.

1. **Government and Policy Implementation:**

The Roads and Highways Department (RHD) and the Local Government Engineering Department (LGED) of Bangladesh are pivotal agencies for the implementation of these guidelines. These departments can incorporate the recommendations into national and local road design standards, ensuring that both new constructions and existing road upgrades are Tri-SMV friendly. The Ministry of Road Transport and Bridges can play a critical role by endorsing these guidelines and integrating them into national road safety policies.

2. **Urban Planning and Development:**

Municipal authorities in major cities like Dhaka, Chittagong, and Sylhet can adopt these guidelines in their urban planning processes. By doing so, they can create safer and more efficient urban environments that cater to the needs of Tri-SMV users. Urban planners can design road networks with appropriate lane widths, safe intersections, and well-placed speed breakers tailored for Tri-SMVs.

3. **Transportation and Public Health Sectors:**

Organizations such as the Bangladesh Road Transport Authority (BRTA) can leverage these findings to promote safer road designs that reduce accidents and improve public health outcomes. BRTA can ensure that road safety regulations are updated to reflect the new guidelines and can advocate for road designs that reduce the incidence of road traffic injuries and related health issues.

4. **Academic and Research Institutions:**

Institutions like the Bangladesh University of Engineering and Technology (BUET) and the Islamic University of Technology (IUT) can use the project's comprehensive data for further research. These institutions can explore advanced methodologies to enhance road safety for Tri-SMVs, develop new technologies for vehicle safety, and provide training programs for engineers and planners.

5. **Community and Advocacy Groups:**

Organizations such as BRAC, Safe Roads for Bangladesh, and other non-governmental organizations can use the research findings to advocate for improved road safety measures. These groups can engage in public awareness campaigns, lobbying efforts, and community outreach to ensure that the needs of Tri-SMV users are prioritized in infrastructure projects.

8.2 Future Research

While the current Project has established a solid foundation, several areas warrant further exploration to optimize road safety and usability for Tri-SMVs. Some of the areas that need further research are as following:

1. **Technological Innovations:**

Exploring technological advancements in Tri-SMV design, such as enhanced braking systems, better suspension, and integrated safety features, can further reduce risks. Partnerships with automotive research centres and companies could yield innovative solutions tailored to the unique needs of Tri-SMVs.

2. Environmental and Sustainability Studies:

Research on the environmental impact of improved road designs can align future projects with sustainability goals. Collaboration with the Department of Environment (DoE) can help evaluate how better road conditions influence fuel efficiency, emissions, and the overall environmental footprint of Tri-SMVs.

3. Behavioural Studies:

Understanding how Tri-SMV drivers and passengers adapt to new road designs is crucial. The Bangladesh Road Transport Authority (BRTA) and local universities can conduct behavioural studies to gather insights on user adaptation, compliance, and overall satisfaction with the new infrastructure.

4. Geographical and Contextual Adaptations:

Comparative studies between urban and rural implementations can highlight specific challenges and solutions unique to each environment. The Local Government Engineering Department (LGED) can focus on adapting the guidelines for rural settings, ensuring that the solutions are versatile and widely applicable. International contextual applications can be sought as well, specifically in East and South-east Asia. Some adjustments to the guidelines that were produced can be extended to other modalities such as bikes, hand-carts etc.

5. Collaboration with International Bodies:

Engaging with international organizations like the World Bank, Asian Development Bank (ADB) and the International Road Assessment Programme (iRAP) can facilitate the exchange of knowledge and best practices. Comparative studies and collaborative projects can enhance the global understanding of Tri-SMV dynamics and effective road design solutions.

9. Conclusion

The Tri-SMV Road Design Guideline Project, supported by UKAID and executed by the Islamic University of Technology, marks a significant advancement in transportation engineering in Bangladesh, specifically addressing the needs of three-wheeler slow-moving vehicles (Tri-SMVs). This project focused on creating safer and more inclusive roadways that cater to the unique challenges faced by these vehicles in both urban and rural settings.

Throughout the course of this research, we have identified multiple challenges that Tri-SMVs face daily, such as inadequate lane widths, improperly designed speed bumps, dangerous open drains, and sharp turns. These issues not only pose risks to the safety and comfort of Tri-SMV operators and passengers but also impede the operational efficiency of these vehicles. The comprehensive analysis included opinion surveys from Tri-SMV users, technical measurements of road conditions, and field studies to explore the interaction between these vehicles and road infrastructures.

The project culminated in the development of detailed guidelines aimed at reconfiguring road geometries and infrastructural elements to better suit the dynamics of Tri-SMVs. These include redesigning lane widths to accommodate Tri-SMVs alongside other vehicles, creating speed breakers with smoother profiles to reduce the impact on passengers, enhancing intersection designs to facilitate easier navigation, and installing adequate signage and barriers to guide and protect Tri-SMV users.

The implications of these guidelines are profound, extending beyond the immediate benefits of safety and accessibility. By fostering a more inclusive road environment, these changes support the daily transport needs of a significant portion of the population, including economically vulnerable and physically impaired individuals who rely heavily on Tri-SMVs for mobility. Furthermore, the project sets a precedent for future urban planning and road construction initiatives, highlighting the need for a holistic approach that incorporates the needs of all road users.

Looking ahead, there is a clear pathway for the continuation of this work. While the guidelines developed offer a robust foundation, ongoing feedback from their implementation will be crucial for refining these recommendations. Additionally, the methodologies and insights gained from this project have potential applications in other regions with similar transportation landscapes, suggesting the possibility of adapting and applying these guidelines more broadly.

In closing, this project has not only addressed critical gaps in the current road design practices but has also paved the way for future advancements in road safety and inclusivity. The continued focus on integrating the needs of Tri-SMV users into the broader context of road design and urban infrastructure is essential for building more resilient and equitable transportation systems. Thanks to the extensive support from local authorities, community stakeholders, and international agencies, the Road Design Guideline for Tri-SMVs in Bangladesh is set to make a lasting impact on the way cities and rural areas accommodate the unique challenges of slow-moving vehicular traffic.

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