Two-Seater E-rickshaw Programme for Patna City

CSTEP
CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

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Executive Summary

Cycle rickshaw is one of the oldest modes of transport and has been known to provide livelihood opportunity to tens of thousands of rickshaw pullers across several Indian cities. The community of rickshaw pullers has traditionally suffered from several social, economic, and health-related issues. Also, cycle rickshaws, although environmentally sustainable, contribute to transport sector challenges such as traffic congestion. The increasing use of electric rickshaws (e-rickshaws) as a mode of intermediate public transport holds great promise for addressing these issues. In addition to being environment-friendly, e-rickshaws offer more convenience than cycle rickshaws not just for commuters but rickshaw pullers as well. Therefore, our work intends to explore the possibility of replacing cycle rickshaws with two-seater e-rickshaws for the welfare of the rickshaw-puller community.

In this report, we conduct extensive literature survey to understand the challenges faced by rickshaw pullers across various cities in India. We establish that these challenges are interconnected and most of them originate from their social characteristics and nature of occupation. We further assess the suitability of two-seater e-rickshaw as a viable solution for addressing challenges faced by rickshaw pullers. Our approach is focussed on analysing the operational impacts of replacing existing cycle rickshaws with two-seater e-rickshaws. The incremental financial benefits resulting from these impacts have also been quantified. Our study suggests that adoption of two-seater e-rickshaws will not bring in any disruptive changes in the typical business activity of rickshaw pullers. We also found that this intervention is likely to result in an increase of about 10 to 30 per cent in the average daily earnings of rickshaw pullers. On the other hand, our research finds a potential increase in expenditure on ownership, operation, and maintenance of the vehicle for majority of rickshaw pullers.

Based on our findings, adoption of two-seater e-rickshaw appears to be a feasible solution for improving socio-economic condition of rickshaw pullers. However, there are several external factors that would determine the success of large-scale adoption of e-rickshaws. It is, therefore, advisable to implement this programme on a pilot scale in Patna. This will be helpful in validating findings of this work as well as in evaluating suitability of different business models, planning approaches, and technology options. Also, the adoption of two-seater e-rickshaws should be encouraged through dedicated policies, programmes or schemes which take into account, a multi-stakeholder perspective.

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Chapter 1 – Introduction

Across many cities in India and other developing countries, cycle rickshaw is a popular mode of transport for covering short distances. The concept of "rickshaw" originated in Japan during 1860s (Saito, 1979) and was subsequently introduced in India in the 1870s; first in Shimla, and then in Kolkata (Khan, Hassan & Shamshad, 2014). With advancements in technology, the initially popular manually-pulled rickshaws were eventually replaced by the current internal combustion engine (ICE)-based rickshaws. The manually-pulled rickshaws can be categorised as hand-pulled and cycle rickshaws, both of which continue to operate in certain urban areas despite increased adoption of ICE-based rickshaws.

Since the introduction of cycle rickshaws in India, the socio-economic situation of rickshaw pullers has not improved significantly. Additionally, the adverse health impacts on them have somehow been overlooked (Rajvanshi, 2002). However, the advent of electric rickshaws (e-rickshaws) holds much promise for both rickshaw pullers and commuters. Unlike ICE-based rickshaws, cycle rickshaws are more environmentally sustainable as they produce zero operational emissions. E-rickshaws have zero tailpipe emissions and much lower overall emissions, compared to ICE-based rickshaws. They are also comparatively faster, safer, and more convenient, compared to cycle rickshaws.

Cycle rickshaws are an essential mode of transportation in Patna city and in the surrounding suburban areas. A large number of these cycle rickshaws operate daily in different areas of the city. Their slow speed sometimes aggravates traffic congestion, causing difficulties for other commuters. In a city like Patna, where most of the roads are narrow, replacing cycle rickshaws with e-rickshaws would help in easing traffic congestion. In addition, replacement of cycle rickshaws with e-rickshaws will eliminate the need for strenuous physical labour, thereby contributing to reduced health impacts on rickshaw pullers. Also, with improved speed and overall comfort of e-rickshaws, passengers may be willing to pay higher fares and assign greater preference to this mode of transport. This will improve the income levels of rickshaw pullers and, consequently, their quality of life. Thus, e-rickshaws would help in fulfilling objectives of the United Nations Sustainable Development Goals (SDGs) – particularly SDG 1 (No Poverty), SDG 3 (Good Health and Well-Being) and SDG 11 (Sustainable Cities and Communities).

Given this broad context, a feasibility study was carried out by the Centre for Environment, Energy and Climate Change (CEECC) at Asian Development Research Institute (ADRI), Patna in collaboration with the Center for Study of Science, Technology and Policy (CSTEP). The study evaluates impacts and benefits of introducing e-rickshaws from the perspective of rickshaw pullers. Key stakeholders such as the Bihar Industrial Area Development Authority (BIADA), e-rickshaw manufacturers, and the representatives of Bihar Rickshaw Union were actively involved in this study. The study intends to provide a strong foundation for the required policy framework for introducing e-rickshaws in Patna.

1.1. A Context to Bihar and Patna

1.1.1. Demographics

As per 2011 census, the population of the state of Bihar is nearly 104 million, with an average decadal growth rate of about 27%. The state is also ranked second in terms of total rural population, with close to 89% of the population living in rural areas. The urban population in Bihar is significantly lower in proportion to the national average of 31%. In addition, all districts in Bihar have a very small proportion of urban population, with the exception of Patna, where about 43% of the population lives in urban areas. As Patna is the capital of Bihar, most of the urban population is concentrated around the city. The Patna Urban Agglomeration (PUA) area includes Patna city, along with eight other neighbouring urban clusters, collectively amounting to 20% of the urban population in Bihar. The PUA has seen a non-uniform growth rate of urban population, with a maximum growth rate of about 50% during 1991-2001, which dropped down to just over 30% in the subsequent decade.

1.1.2. Economy

The Gross State Domestic Product (GSDP) of Bihar has grown between 2011-12 and 2016-17 at a compound annual growth rate (CAGR) of around 12%. The per capita GSDP stood at USD 598.29 in the FY 2016-17. The key industrial sectors contributing to this growth include food and beverages, rubber and plastics, transport equipment, chemicals, tobacco, textile, leather, dairy, etc. The agriculture sector contributes predominantly to the growth of the state economy. The state is known to be amongst the largest producers of fruits and vegetables, with about 80% of the population engaged in agriculture. With agriculture as their primary occupation, a majority of Bihar's population is involved in agriculture-related labour for some part of the year. This allows them to take up temporary occupations during rest of the year. Semi-skilled labour is relatively economical in the state, which makes a profitable case for industrial growth. The Bihar government has taken several initiatives to increase investment opportunities in medium and large-scale industries. An industrial investment promotion policy was introduced in 2016 to address key issues such as development of secondary infrastructure, adoption of state-of-the-art technology, development of domestic supply chain, skill development, etc. Patna, along with a few other cities, has emerged as a manufacturing hub, having the highest share of industries in the state.

1.1.3. Transportation

The transport sector in Bihar has shown remarkable growth, with a significant increase in the number of vehicles registered in recent years. About 7.50 lakh vehicles were registered in 2016-17, compared to about 4.4 lakh vehicles five years earlier (in 2011-2012). Among all Indian states, Bihar had one of the lowest numbers of motor vehicles per 1,000 population as of 2011-12. Till 2012, close to 25% of vehicles registered in Bihar were in Patna city. Despite the consistent growth in population and vehicle ownership, the transportation infrastructure and services in urban areas have not developed proportionately. As a result, urban areas such as Patna face issues like congestion, air pollution, and poor connectivity. The public transport facilities are inadequate to serve the growing demand. The Government of Bihar, in its Action Plan on Climate Change, submitted to the Ministry of New and Renewable Energy (MNRE), has emphasised the development of urban transportation infrastructure and promotion of sustainable modes of transportation in urban areas.

1.2. Rickshaw Pullers in India

Though there are a large number of rickshaw pullers in India, the sector as a whole remains unorganised, with majority of the work force comprising migrants from rural areas. It has also been observed that a majority of the rickshaw pullers don't own vehicles, but rent them out for a daily fee. Most of them are deprived of basic facilities such as health and hygiene, civic amenities, education, and accommodation.

We conducted a detailed analysis of the existing literature to get an overview of the socio-economic condition of rickshaw pullers and the challenges faced by them.

1.2.1. Social Characteristics

Various studies have reported that a majority of rickshaw pullers belong to backward castes (UNDP 2013, Nandhi 2011, Kurosaki et al., 2007). Illiteracy is also common amongst the rickshaw puller community. Studies estimate illiteracy at 48% in Delhi, 68% in Aligarh and 50% in Patna amongst rickshaw pullers. In addition, only a small proportion of the literate rickshaw pullers have completed secondary school level education (Ali, 2013; Saurabh, 2012; Nandhi, 2011; Khan, 2010). Thus, the low level of education of rickshaw pullers is responsible for their limited access to other employment opportunities.

Another consistent trend among rickshaw pullers across India is the large average family sizes of up to 5 to 6 members, with the rickshaw puller being the sole earning member of the family (UNDP, 2013; Saurabh, 2012; Nandhi, 2011; Khan, 2010). Rickshaw pullers generally prefer to minimise accommodation costs by living in slums and garages, on pavements, in Rain Baseras (government-funded night shelters), and abandoned places. Most of them stay in unhealthy environments, without access to basic facilities like potable water and sanitation (UNDP, 2012; Khan, 2010).

Inter-state and intra-state migration from rural areas to urban or semi-urban areas for better quality of life and improved earnings is fairly common among rickshaw pullers (Nandhi, 2011). Unemployment is the major factor for migration along with other factors such as poverty, economic deprivation, inadequate sources of livelihood, low income, small land holdings, illiteracy, and large family sizes (Khan, 2010; Kurasaki et al., 2007).

1.2.2. Economic Background

The income of rickshaw pullers varies according to season, weather, traffic conditions, road conditions, and their health condition. About 65% of rickshaw pullers in India are economically weak (UNDP, 2013). Several studies mentioned that although, on an average, rickshaw pullers earned between INR 6,000 to INR 8,000 per month, they are still vulnerable to variance in their daily income (Kumar et al., 2017; UNDP, 2013).

The volume of trips per day is affected by traffic and road conditions. Age also influences daily income, with young rickshaw pullers earning more by completing more trips per day. For seasonal rickshaw pullers, it is a secondary job, with many of them being primarily agricultural labourers, who take to rickshaw pulling during the off-season for agricultural activities.

The expenditure of rickshaw pullers can be classified into two categories – cycle rickshaw-related and personal. Cycle rickshaw-related expenditure mainly includes rent and maintenance of the vehicle on a daily or monthly basis. Personal expenses include food, cooking fuels, public toilets, celebrations, rent for accommodation, children's education, etc. (Ali, 2013; Saurabh, 2012; Nandhi, 2011; Khan, 2010) In most cases, rickshaw pullers pay for the repair and maintenance of their vehicles, particularly when it is minor. Average rent of the vehicle is INR 50 per day across India (Ali, 2013; Saurabh, 2012; Nandhi, 2011; Khan, 2010).

Formal saving is not a common practice among rickshaw pullers. The reasons may be the lack of money or lack of information about saving options (Kumar et al., 2017). The mode of saving is based on individual choices and accessibility to financial instruments like banks, micro-finance institutions, etc. Few rickshaw pullers consciously save money every day by optimising self-expenditures while others share daily expenditures to save money (UNDP, 2013). Usually after paying for the rent of the vehicle, the majority of the remaining portion is used for personal consumption, and the rest is sent to family, either on a weekly or monthly basis (Kumar et al., 2017; Nandhi, 2011). The lack of knowledge on banking services and benefits makes rickshaw pullers borrow money from informal lenders, which usually leads to them being overburdened by debt (Kumar et al., 2017).

1.2.3. Health Issues

On an average, rickshaw pullers work on almost all days of a week and spend between 8 to 10 hours per day on the road plying their trade (Nandhi, 2012; Khan, 2010). Therefore, good health is of great importance to rickshaw pullers. However, the origin of various health problems faced by rickshaw pullers can be traced to their occupation, income, working and living conditions, and other aspects related to their work.

Air pollution causes severe health issues among rickshaw pullers, due to the continuous exposure to ambient air pollutants. Approximately 6,70,000 deaths have been attributed to ambient air pollution in some of India's most polluted cities (Lim et al., 2013). Rickshaw pullers spend most of their working time on roads. In addition, cycle rickshaws have an open structure, and even the front cover—as available in ICE-based rickshaws—is absent. All of these result in higher exposure to ambient air pollution. Exposure to noise pollution is also a critical issue for rickshaw pullers. Studies indicate the impairment of the brainstem auditory pathway among transportation workers, including manual rickshaw pullers, due to prolonged exposure to noise pollution in the Indian subcontinent (Gathe et al., 2016; Ahmad & Rahman, 2015). A study conducted in Ranchi revealed that around 10% of the rickshaw pullers faced hearing problems (Kumar et al., 2016). In addition, rickshaw pullers are also exposed to adverse weather conditions, such as extreme heat, humidity, severe cold, and heavy rainfall, in the course of their work, increasing their susceptibility to various health problems. Pulling a rickshaw requires significant physical effort, often leading to musculoskeletal problems. A study on the health of rickshaw pullers reported musculoskeletal morbidity among 89% of rickshaw pullers working for over 5 years (Rodrigues, Gomes, Tanhoffer & Leite, 2014). Injuries due to road accidents are another commonly reported issue.

Many rickshaw pullers consume narcotics like opium, ganja (marijuana), and charas (hashish), which trigger instantaneous energy to take up intensive physical activities (Peele, 1980). In Ranchi, about 70% of rickshaw pullers reportedly spend money on alcohol every day and about 80% of them are unaware of the risks associated with unprotected sex (Kumar et al., 2015). The pressure of sustaining a family on a relatively low income, loans, rent for the rickshaw, and various other financial demands induces psychological distress among rickshaw pullers. To evade such pressures, rickshaw pullers adopt drug abuse as a way, leading to additional psychiatric syndrome and disorder (Morton, 1999). The ratio of physical hard work to nutritional intake for rickshaw pullers is high. Maintaining their health remains a major challenge due to constraints such as poverty, poor sanitation facilities, poor eating habits, poor nutrition, drug abuse, alcoholism, and the lack of health awareness. This, in turn, often leads to gastrointestinal diseases, body pain, fever, cough, and cold (Begum and Sen, 2004).

1.3. Rickshaw Pullers in Patna

Rickshaw pullers provide a critical service for last-mile connectivity and short-distance commute in Patna. The community of rickshaw pullers suffers from several socio-economic challenges. Despite putting in significant physical effort each day, they barely make sufficient money to meet their basic needs. In addition, they have to compete with other modes of transport including e-rickshaws, auto rickshaws, and public buses. The constant physical stress of pulling cycle rickshaws makes them highly susceptible to various health hazards. A focus group discussion conducted during the course of the study with relevant officials of the Patna Municipal Corporation, Department of Industries, Government of Bihar, and Association of Private Rickshaw Owners revealed that over 60% of rickshaw pullers in Patna are from marginal sections of the society.

A survey conducted in 2012 for a small sample population of rickshaw pullers in Patna found that the age of 45% of rickshaw pullers is more than 30 years (Saurabh 2012). In almost 80% cases, rickshaw pullers had families with more than four members and around 50% of them had three or more children. About 50% of rickshaw pullers have migrated to Patna. Most rickshaw pullers have poor educational background and, therefore, limited alternate livelihood prospects. A majority of them do not own the cycle rickshaws and instead, pay monthly rents to cycle rickshaw owners. The survey also determined that their monthly income is typically lower than INR 7,000, with most rickshaw pullers earning in the range of INR 4,000 to INR 5,000. A significant portion of this monthly income is spent on maintaining the cycle rickshaw and for health-related issues. About 50% of rickshaw pullers drive cycle rickshaws for 20 km to 30 km on a daily basis, while many others drive for more than 30 km. The report also noted that typically, rickshaw pullers operate for up to 10 hours, with average waiting times (time spent in waiting for next trip) ranging from 2 to 6 hours. Also, most rickshaw pullers have very few days off in a typical month.

Based on this overview, it can be noted that there are two interconnected challenges faced by rickshaw pullers—health hazards resulting from driving cycle rickshaws and poor income generation. Therefore, adoption of e-rickshaws as a potential solution will be justified if these issues are addressed to a satisfactory level.

1.4. Programme Objectives

This initiative aims to improve the livelihood of rickshaw pullers and eliminate heavy physical labour. Being a faster and more convenient mode of transport, E-rickshaws would offer citizens a non-polluting alternative for short-distance commutes. In addition, large-scale adoption of e-rickshaws can attract investments in the manufacturing sector in Bihar, contributing to the growth of the local and state economy.

A preliminary feasibility assessment was conducted for city-wide deployment of two-seater e-rickshaws. As a first step, the study established baseline understanding of the present socio-economic condition as well as health issues faced by rickshaw pullers across India, including Patna. The literature survey presented in this chapter indicates sufficient evidence for the social, economic, and health challenges faced by the community of rickshaw pullers. It was inferred from the literature survey that various challenges faced by rickshaw pullers are closely interlinked and, therefore, cannot be treated in isolation. Lack of education among rickshaw pullers limits other livelihood opportunities open to them. Considering their typical family size, the income generated from rickshaw pulling is often insufficient to meet the basic needs. The daily income generated also depends on the physical capacity of the rickshaw pullers to ride the cycle. Long working hours, exhausting nature of the job, and continuous exposure to extreme weather adversely affect their health and well-being. This reduces their physical capacity and, thereby, their earning potential. In addition, rickshaw pullers have to spend a significant portion of their income on maintaining their health, which further reduces their net income. The nature of their work and lifestyle also affects their health indirectly by inducing stress and dissatisfaction, which further impacts their health.

Based on the above narrative formed from literature survey, we identified two fundamental problems, which can be considered as the 'root' of other challenges faced by rickshaw pullers: the need for strenuous physical effort and the disproportionately low income. Therefore, a potential solution should focus on reducing physical effort required for this activity and at the same time, increasing their income. E-rickshaws appear to be well-positioned for addressing both these challenges. On the one hand, they reduce the physical labour required, as the rickshaws use an electrical drive; on the other hand, they bring in new possibilities for increasing the income of rickshaw pullers. As e-rickshaws are more convenient than cycle rickshaws due to increased speed and comfort, it is possible that passengers may be open to paying a premium fare for their use. Also, e-rickshaws increase the ability of rickshaw pullers to complete more trips as their physical capacity is not a constraint for driving them. In short, introduction of e-rickshaws as a replacement for cycle rickshaws has the potential to be an effective intervention. However, this alternative needs to be further scrutinised from a techno-commercial perspective.

Therefore, as the next step, the study evaluated the suitability of two-seater e-rickshaw as an intervention for this purpose. This was done by studying the impact of e-rickshaws on the usual business operations of rickshaw pullers. These impacts were then translated into overall financial benefits to further assess their sufficiency for the intended outcomes of the programme. A survey of 500 rickshaw pullers in Patna was conducted to understand the various operational parameters for rickshaw pulling. In addition, certain design parameters of e-rickshaws were identified through interactions with manufacturers. This data was used to quantify operational impacts and their benefits.

Chapter 2 – Feasibility Study

E-rickshaws differ significantly from conventional cycle rickshaws in terms of capabilities and operational performance. Considering our primary objective of financial inclusion of rickshaw pullers, it is critical that introduction of e-rickshaws has a measurable and positive impact on the net income of rickshaw pullers. To assess and quantify such an impact, it is important to understand the present situation of rickshaw pullers, particularly the aspects related to their commercial activity. Along with several obvious benefits, the introduction of battery-operated two-seater e-rickshaws would also bring in a new set of constraints. In some cases, it may not be possible to accurately model or quantify certain impacts of introducing e-rickshaws. However, anticipating all possible impacts and further estimating their consequences would be equally valuable. This chapter presents analysis and key inferences based on the impact assessment, along with an overview of the research methodology.

2.1. Identification of Modelling Parameters

The first step in assessing operational impacts associated with e-rickshaws is to study the existing operation of rickshaw pullers. This can be done by identifying various operational parameters which collectively characterise the e-rickshaw business. Along with the cycle rickshaw pulling business, the operational and design characteristics of the proposed technology intervention (e-rickshaw in this case), should also be modelled. These models, along with operational and performance data, can be used to quantify various impacts. While there may be additional parameters that can be used to model the system in detail, the scope of this section is limited to parameters that are relevant to this study.

2.1.1. Parameters for Cycle Rickshaw Pulling Business

Under various state and local government initiatives in Bihar, rickshaw pullers and other such communities are provided with livelihood support in the form of shelter and subsidised meals. On a typical day, rickshaw pullers start their operation at a particular time of day and stop for rest in the evening or night. At night, rickshaw pullers park their vehicles at a particular location. Within their daily operating time, they complete a certain number of trips with a fixed fare based on the distance covered during any such trip. The selection of modelling parameters should capture all these aspects.

The following parameters were identified to model the cycle rickshaw business operations:

1. Location of Rain Basera
Almost every rickshaw puller is assigned to one of the many government-funded night shelters called "Rain Basera" across Patna.

2. Average daily number of trips
It is the number of trips a rickshaw puller would complete on a typical business day. A trip is defined as movement of passengers or goods from one location to another.

3. Average daily income

It is the amount of money earned by a rickshaw puller on a typical business day, exclusively through rickshaw pulling.

4. Areas covered

These are locations within Patna where rickshaw pullers most frequently complete trips on any given day.

5. Number of passengers per trip

It is the most frequent number of passengers carried by rickshaw pullers during each trip.

6. Start and end time of typical business day

These are the times at which the rickshaw puller typically starts and ends his business day.

7. Rickshaw parking location at night

It is the location where the rickshaw puller parks his cycle rickshaw overnight, at the end of his business day.

8. Monthly operational cost

It is the cost incurred by rickshaw pullers in repair and maintenance of the cycle rickshaws per month— from repairing punctured tyres, broken parts, etc.

2.1.2. Parameters for Proposed Technology Intervention

The two-seater e-rickshaw is similar to any typical electric vehicle with capabilities designed for specific application. Therefore, the parameters selected for modelling e-rickshaws are similar to those for other electric vehicles and are described below:

1. Range

Range can be defined as the maximum distance that can be travelled by a typical rickshaw while providing a mobility service.

2. Passenger carrying capacity

This is the maximum capacity of passengers for which the vehicle has been designed, excluding the driver.

3. On-board battery rating

These are the voltage and current ratings for the on-board battery as specified by the vehicle manufacturer.

4. Charging time

It is the time required for charging an on-board battery to a certain level with a dedicated equipment, as specified by the manufacturer.

2.2. Research Methodology and Data Collection

A preliminary literature review was conducted to build fundamental knowledge on the cycle rickshaw business in a typical Indian city. The literature survey provided a basis for identifying relevant attributes to characterise rickshaw pullers and their commercial activity. It was also acknowledged that two-seater e-rickshaw is not an established technology solution in the market. Several manufacturers are working towards designing and testing these rickshaws before launching them. Due to unavailability of recent data sources—on both the commercial activity of rickshaw pullers and two-seater e-rickshaws being developed—the collection of primary information through stakeholder interaction was proposed.

2.2.1. Survey of Cycle Rickshaw Pullers

The modelling parameters identified in the previous section were considered for overall data collection. The final questionnaire used for field survey is presented in Annexure A of this report. The questionnaire format was designed to be subjective in nature and not a typical multiple choice question (MCQ) format. This was helpful in collecting more granular information for responses of numerical datatype. However, the surveyors intuitively rounded off responses to certain questions for convenience. For example, income and expenditure values were expressed in multiples of 50 and time values were rounded off to the nearest integer. Statistical analysis is performed to ensure that these approximations do not significantly affect results. In addition, for some of the questions, a pre-established exhaustive list of response choices could not be identified and, therefore, MCQ format was not suitable. In addition, the perceived ability of respondents to provide accurate information was considered while designing the survey.

A survey of 500 rickshaw pullers was conducted across Patna city using this questionnaire and the responses were summarised in the form of a database. Some datapoints were adjusted to match the required datatype of a particular response. For example, few respondents provided a range of numerical values for income and expenditure-related questions. An average of the extreme values of this range was considered as a representative value in these cases.

2.2.2. Data Collection from Manufacturers

For characterising performance of the proposed two-seater e-rickshaw, technical specifications were collected from manufacturers. As the product is in the development and testing stage, manufacturers were apprehensive about sharing sensitive information. They provided basic technical and performance data for two different battery technologies; but detailed technical specifications were provided for only one. The basic details regarding the two e-rickshaw models with different battery technologies are presented in Table 1. The actual names of the product and manufacturer are not disclosed in the interest of maintaining privacy.

Table 1: General specifications of two- seater e-rickshaw models[1]

Sr. No.	Specifications	Model 1	Model 2
1.	Maximum Speed	25 Kmph	25 Kmph
2.	Mileage	100 Km	90 Km
3.	Battery Type	Acid-Rugged Battery	Lithium-Ion Battery
4.	Battery Rating	48V, 100 AH	48 V, 100AH

[1] Data provided by manufacturers

Detailed technical specifications of the battery used in Model 1 are presented in Table 2. The technical specifications received from manufacturers included multiple battery variants for a single vehicle. However, for the purpose of analysis, a generic specification has been identified as per Table 2.

Table 2: Detailed technical specifications of e-rickshaw model

Sr. No.	Parameter	Specification
1	Kind of Electro – Chemical Couple	Pb –PbO2-H2SO4
2	Nominal Voltage (V)	48 V (12Vx 4 Battery)
3	Maximum Discharge Power (kW) (30 Minute, Constant Power)	1 kW
4	2-hour Discharge Performance (Constant Current)	30A (Constant Current) for 2 hours
5	Charging Time (0% to 80% energy restoration)	8 Hours
6	Charging Time (0% to 100% energy restoration)	10 Hours
7	End of Discharge Voltage Value (V)	42V
8	Battery Status Indication format	100% Needle Pointing to Green 70 % Needle Pointing to Yellow 30% Needle Pointing to Red

As a general practice, batteries are charged at a constant current, when the quantum of energy stored is in the range of 0% to 80% of total energy capacity. From 80% to 100% of energy storage levels, they are charged at a constant voltage which is much slower than constant current charging. However, in this case, the data provided by the manufacturer is in contradiction with the usual battery charging practice. The battery status indication format is a needle indicating the remaining energy within the on-board battery. Practically, batteries are not discharged after the available energy is reduced beyond a certain point. This is to prevent damage to batteries and reduction in battery life in the long run. For the batteries used in Model 1, the range of stored energy levels, in which further battery discharge is not recommended, is from 0% to 30%. For convenience, the level of stored energy, below which further battery discharge is not recommended, is considered as 20%. This assumption is justified, as rickshaw drivers would need to carry their vehicle to the nearest charging station as the battery status indicator reaches the red zone from the yellow zone. In addition, a total charging time of 10 hours is considered for charging batteries from a stored energy level of 20% to 100% based on discussions with e-rickshaw manufacturers.

2.3. Impact Assessment

Conventional cycle rickshaws are pulled manually and, therefore, don't consume any form of fuel. The distance covered by a cycle rickshaw is completely dependent on physical ability and willingness of the rickshaw puller. However, battery operated e-rickshaws use stored electrical energy from on-board batteries. As batteries can store only a finite amount of energy at a given time, e-rickshaws can only cover a certain distance with the battery fully charged. Charging of batteries may require a significant amount (4 to 10 hours) of time and a dedicated electric vehicle supply equipment (EVSE). This imposes restrictions on any movement of the vehicle, and consequently, on commercial utility of e-rickshaws during this period. The electricity required for battery charging on a daily basis contributes to additional operational costs which are not associated with cycle rickshaws. However, e-rickshaw being a more convenient mode of transport, is likely to attract more passengers in Patna, resulting in increased ridership even at a higher per-trip fare. Factors that collectively impact commercial operation of rickshaw pullers are discussed in detail below.

2.3.1. Range Limitation

Range limitation of various e-rickshaw models is an important factor that will impact the routine operation of rickshaw pullers. Usually, rickshaw pullers complete a certain number of trips on a daily basis. While there are variations on a day-to-day basis, considering the day of week, significance of the day, etc., an average number can be considered as a representative value for typical number of trips completed by rickshaw pullers on a daily basis. The sum of distance travelled during each trip gives the overall distance covered by rickshaw pullers in a day. There are two approaches for estimating daily distance covered by rickshaw pullers – the theoretical maximum value and the average value. The theoretical maximum value corresponds to the daily distance covered by a rickshaw puller if all trips in a day are between two locations farthest from each other. The average value corresponds to the average of mutual distances between all the locations. Both these approaches have been considered in our analysis.

Table 3: Summary of frequently travelled locations and distribution of respondents

Group	Respondents	Frequently Travelled Locations	Rain Basera
1	36	Gola Road, Big Bazar, Jag Dev Path, Paars Hospital	Ashiyan Nagar (36)
2	63	Kankarbagh, Dinkar Golambar, Bazar Samiti, Saidpur, NIT Patna, Rajendra Nagar Station, Ashok Raj Path	Bahadurpur Stadium (60), Mourya Lok (3)
3	189	Bas Stand, Postal Park, Mithapur, Gardani Bagh, Colony More, Dak Bungalow, Exhibition Road	Karbigaiya (27), Patna Jn (162)
4	71	NIT Patna, Patna Jn., Boring Road, Rajaour, Kurzi, Dak Bungalow, Exhibition Road	Bansh Ghat & Gol Ghar (24), Sabjibagh (46), Mourya Lok (1)
5	141	Patna Jn, GPO, Boring Road, Golghar, Gandhi Madian, Dak Bangla, Kurzi	China Kothi (139), Karbigaiya (2)

In our analysis, the total distance covered on a typical day is modelled as the product of daily average number of trips and a representative value for distance covered per trip. To estimate the representative value, locations within Patna where rickshaw pullers make frequent trips were identified. Each rickshaw puller responded with several such locations, and based on similarities, the responses were organised into five groups. Each group contains a set of locations where frequent trips are completed. Table 3 presents a summary of locations within each group, along with the corresponding number of respondents. The distribution of respondents of each group based on the "Rain Baseras" where they rest at night is also recorded in Table 3.

The distance covered per trip is defined as the length of the shortest path between two locations within each group and is determined from Google Maps. As the exact location was not pointed out by the rickshaw pullers, certain approximations had to be considered while using Google Maps. A distance matrix was developed, detailing the distance of every other location from a particular location. A key assumption here was fixed length of path between two locations within a group, irrespective of source or destination of the trip. A sample distance matrix for group 2 is shown in Figure 1 below. Distance matrices for other groups are presented in Annexure B of this report.

	Kankarbagh	Dinkar Golambar	Bazar Samiti	Saidpur	NIT Patna	Rajendra Nagar Station	Ashok Raj Path
Kankarbagh	-	3.8	5.2	2.3	6.1	2.7	8.9
Dinkar Golambar		-	2.6	1.3	2.4	1.4	6.9
Bazar Samiti			-	3.9	3.9	2.1	3.8
Saidpur				-	3.4	3.4	8.1
NIT Patna					-	4.1	3.2
Rajendra Nagar Station						-	5.7
Ashok Raj Path							-

Figure 1: Distance matrix for Group 2 defined in Table 3

Based on the literature survey, rickshaw pullers reportedly cover an average distance of 3 km in a single trip. However, from Figure 2, it can be observed that the distance recorded between various locations ranges from 1.3 km to 8.9 km. Therefore, it can be assumed that trips between certain locations are not feasible. In our analysis, we have used a feasibility criteria for filtering trips which have an extremely low probability based on behavioural aspects related to rickshaw pullers and passengers. It was assumed that trips with distances within the range of 750 m to 4.5 km are feasible. The upper limit of this range has been determined considering a 50% margin over the average trip distance reported in literature. The lower limit of the range has been assigned, considering that passengers would prefer walking for shorter trips. The differently shaded cells of the distance matrix in Figure 1 are trips which are considered not feasible and were excluded from further analysis.

Using the distance matrix for each group, maximum and average trip distance values are identified. The estimated maximum and average daily trip distance values were populated for each rickshaw puller, across all five groups, using the following equations:

$$\begin{matrix}\textbf{Estimated maximum} \\ \textbf{daily distance travelled}\end{matrix} = \begin{pmatrix} Maximum\ feasible \\ trip\ distance \end{pmatrix} * \begin{pmatrix} Number\ of\ average \\ daily\ trips\ completed \end{pmatrix}$$

$$\begin{matrix}\textbf{Estimated average} \\ \textbf{daily distance travelled}\end{matrix} = \begin{pmatrix} Average\ of\ feasible \\ trip\ distances \end{pmatrix} * \begin{pmatrix} Number\ of\ average \\ daily\ trips\ completed \end{pmatrix}$$

Collectively, this gives maximum and average distance travelled in a day for each rickshaw puller across all groups. Figure 2 presents a box plot summarising the statistical distribution of the estimated maximum and average distance travelled by 500 rickshaw pullers on a typical day across different groups. Each bar in Figure 2 indicates five distinct values corresponding to a particular distribution. The horizontal lines at the two extremities represent the minimum and maximum values with outliers neglected. The lower and upper sides of the box represent first and third quartiles, respectively. An "x" mark inside the box represents the mean value of the distribution. The outlier points for each distribution have been identified as points with a difference of over 1.5 times the interquartile range from the nearest quartile value.

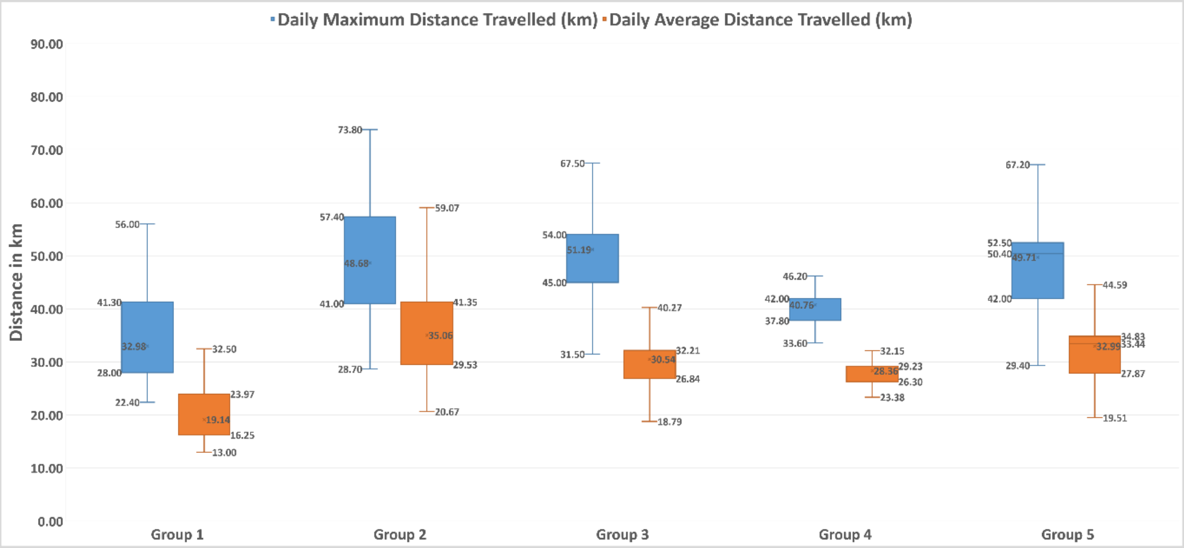

Figure 2: Group-wise distribution of estimated daily maximum and average distances

From the above figure, it can be observed that the estimated daily maximum distance travelled by rickshaw pullers across different groups does not exceed 75 km. In reality, not every trip completed will be between the same two locations for every business day. Therefore, average daily distance travelled is a better representation of the actual distance covered by rickshaw pullers daily. As observed from the graph, the average daily distance estimate is not more than 60 km for any of the five groups.

The data collected from two-seater e-rickshaw manufacturers claims a range of 100 km with full battery discharge and 90 km with 80% discharge. Despite assuming the lower value, it is about 15 km more than the estimated daily maximum distance and 30 km more than the estimated daily average distance travelled by rickshaw pullers. This corresponds to a margin of about 20% for maximum distance estimate and over 50% for average distance estimate. There is, thus, a sufficient margin for rickshaw pullers to complete additional daily trips with e-rickshaws as compared to trips completed with cycle rickshaws.

2.3.2. Passenger Carrying Capacity

The proposed e-rickshaws can carry a maximum of two passengers per trip as opposed to the conventional cycle rickshaws, which carry up to three or four passengers. Therefore, passengers who travel in groups of three or four will not be able to use two-seater e-rickshaws. This may result in reduced number of trips that can be completed by rickshaw pullers. However, if the rickshaw pullers carry two or lesser number of passengers on all of their trips, the reduced passenger carrying capacity will have no impact on the number of trips completed by them. In order to assess the impact, the percentage of trips with two or lesser passengers and three or more passengers should be analysed. However, considering possible inaccuracies in responses, we used an alternate approach. Therefore, a typical value had to be established for the number of passengers carried per trip by rickshaw pullers. This methodology is sufficient to assess the impact in terms of proportion of rickshaw pullers affected due to reduced passenger capacity of two-seater e-rickshaws. However, the methodology fails to quantify actual impact in terms of number of trips lost due to inadequate passenger carrying capacity. Figure 3 shows responses for typical number of passengers per trip.

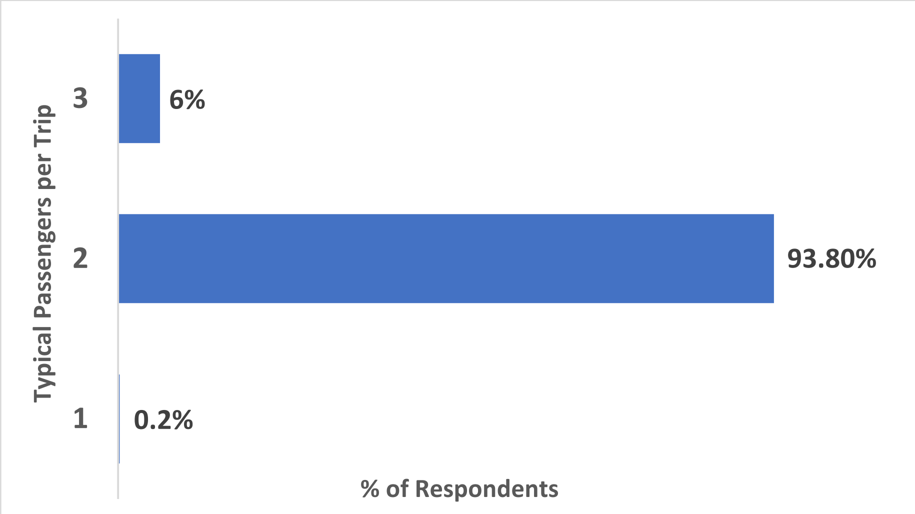

Figure 3: Responses for the average number of passengers per trip for rickshaws

As shown in the figure, about 94% rickshaw pullers reported two or fewer passengers per trip as a typical value, against 6% rickshaw pullers who reported three passengers per trip as a typical value. Therefore, only a small proportion of rickshaw pullers will be affected due to the lower passenger carrying capacity of e-rickshaws.

2.3.3. Charging Time Requirement

As discussed earlier, the on-board battery of e-rickshaw needs to be recharged after the stored energy has been used for trips. This study will consider the scenario of night-time battery charging, when the rickshaw pullers park their vehicles after completing their work for the day. If the charging time required is more than the night-time parking duration, the rickshaw pullers will either have to end their business day sooner or will have to start later on the following day to allow the battery to be charged completely. This may result in rickshaw pullers losing certain trips which would have otherwise occurred during this period. The actual quantification of trips lost will require knowledge of number of trips completed on an average in various time slots over the day. However, within the scope of this study, it was proposed to only assess the existing night-time parking durations for different rickshaw pullers and comment on the suitability of charging batteries in this period. The night-time parking duration is defined as the difference between number of hours in a day and the daily operational duration of rickshaw pullers. The daily operational duration is obtained as the difference between start and end time of business on a typical day.

Based on analysis of data for all 500 rickshaw pullers, it was noted that the night-time parking duration for nine respondents was 17 to 20 hours. It was also noted that all these rickshaw pullers started their day sometime between 12 pm to 5 pm. Therefore, it is possible, in case of these respondents that either the cycle rickshaw is driven by another rickshaw puller during the remaining period, or these respondents have an alternate source of income. This corresponds to an actual commercial activity of 4 to 7 hours. This is lower than the standard operational time for most businesses. For the purpose of our analysis, these nine responses were removed as outliers.

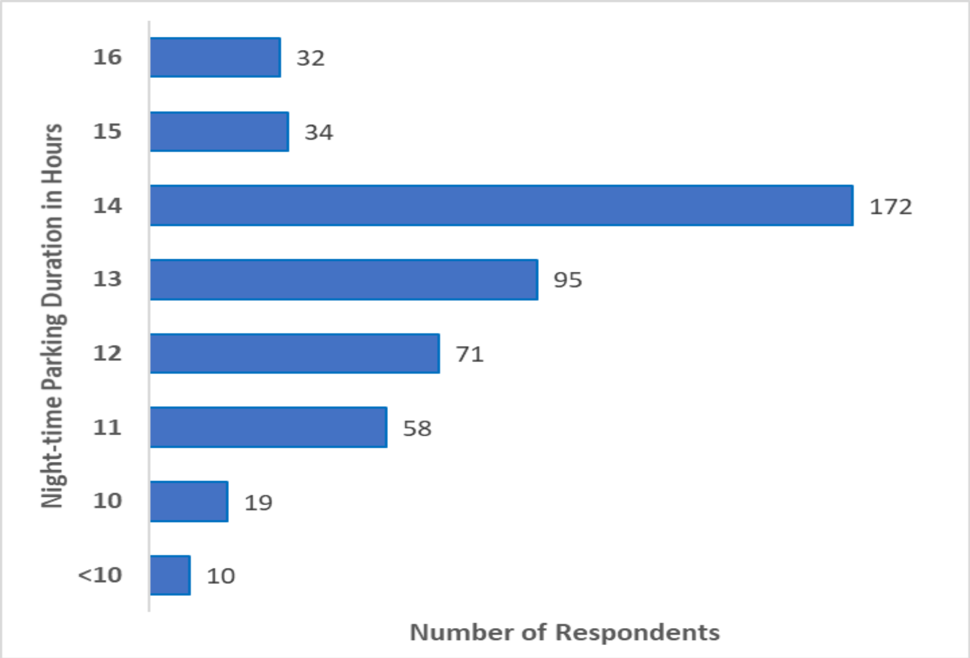

Figure 4: Distribution of night-time parking duration (in hours)

The graph in Figure 4 shows distribution of existing night-time parking duration for 491 rickshaw pullers. It can be seen that a majority (172 or about 35%) of the rickshaw pullers park vehicles for a duration of 14 hours. About 98% of rickshaw pullers park their vehicles for a duration of more than 10 hours. As per two-seater e-rickshaw manufacturers, an on-board lead acid battery of 100 Ampere Hours (Ah) would require 10 hours to be charged completely. Therefore, the charging time requirement of e-rickshaws will not significantly affect their regular operational routine.

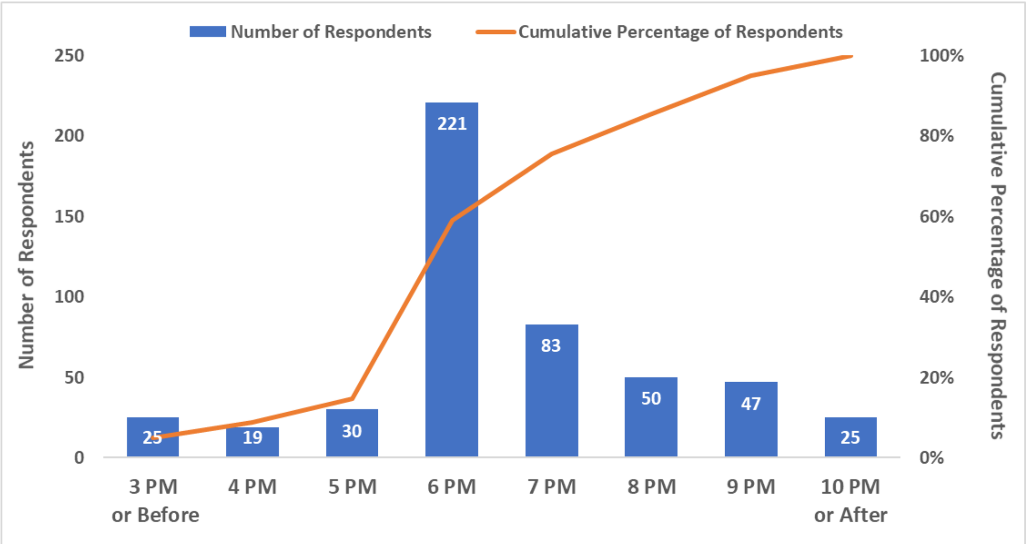

Figure 5: Distribution and cumulative percentage of respondents closing operation

Figure 5 shows the distribution of closing time for daily operation reported by 500 rickshaw pullers along with cumulative percentage of rickshaw pullers closing operation at a particular time of day. It can be observed that a maximum number of rickshaw pullers stop driving rickshaws by 6 pm on a typical day. Another important observation is the incremental change in cumulative percentage of rickshaw pullers closing operation from 5 pm to 6 pm is the highest and reduces gradually in the consequent time intervals. This means that there are lesser number of rickshaw pullers willing to continue operation after 6 pm, which could be a result of diminished commercial utility of driving rickshaw after 6 pm from the perspective of rickshaw pullers. The commercial utility of operating a transport service is correlated with the density of passengers during a particular period and is independent of the vehicle technology. Various external factors such as population growth and urban development may govern passenger density in the future, but are not considered here.

2.3.4. Energy Consumption

Operational cost is important while introducing technological interventions. A cycle rickshaw uses a simple drive system which is more prone to failure compared to other more complex drive systems used in electric vehicles or ICE vehicles. The same is true for other components of cycle rickshaws such as vehicle frames, tyres, etc. As a result, there is a need for periodic repair and maintenance of cycle rickshaws. Figure 6 shows the distribution of repair and maintenance costs reported during the survey.

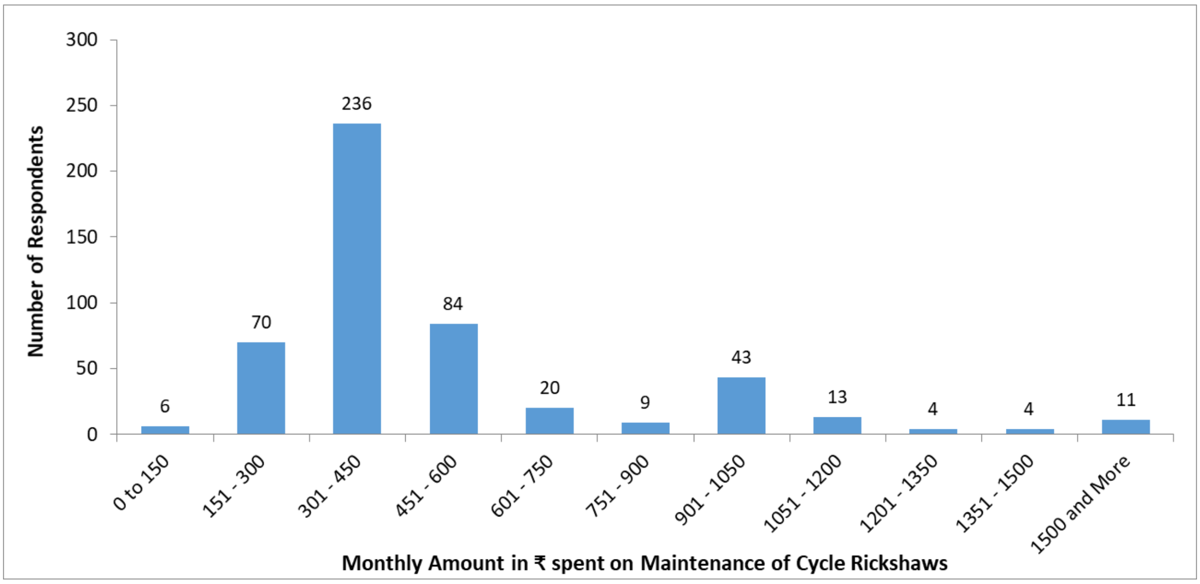

Figure 6: Distribution of respondents based on monthly amount spent for maintaining cycle rickshaws

As can be seen from Figure 6, a maximum number of rickshaw pullers—about 47% (236 respondents)—spend between INR 300 and INR 450 per month on maintenance. A total of 78% rickshaw pullers spend between INR 150 and INR 600 monthly, whereas about 21% of rickshaw pullers spend more than INR 600 per month, and 40% spend between INR 900 and INR 1,050 per month.

The e-rickshaws use a more reliable electric drive along with robust structural components. Therefore, monthly maintenance costs may be considered negligible in case of e-rickshaws. However, an important operational cost associated with e-rickshaw is the cost of electricity used for charging on-board battery on a daily basis. This can be quantified by estimating energy used by an on-board battery of the e-rickshaw while charging on a daily basis.

A set of assumptions need to be considered while evaluating the impact of electricity consumption of e-rickshaws on operational costs.

The following assumptions are considered for evaluating the monthly energy costs:

1. E-rickshaws consume 80% of the battery energy storage capacity on a typical day.
2. The battery is charged up to 100% without significant conversion losses in the electric vehicle supply equipment.
3. A single electricity tariff for charging purpose is considered at a rate of INR 5.50 per kWh with no demand charge.
4. An average month is assumed to comprise 28 working days for rickshaw pullers.

As per the details provided by manufacturers, an on-board battery capacity of 100 Ah is considered along with a terminal voltage of 48 V. The overall energy capacity in kWh can be roughly calculated using the following formula:

$$\textbf{Energy Storage Capacity} = \begin{pmatrix} Battery\ Terminal \\ Voltage \end{pmatrix} * \begin{pmatrix} Rated\ Ampere \\ Hours \end{pmatrix} / 1000$$

Using the above formula, the battery capacity can be calculated as 4.8 kWh. It is important to note that this formula is used only as an approximation and the actual energy storage capacity of battery may vary based on several factors. As per our first assumption, 80% of stored energy is used in driving the e-rickshaw on a daily basis. This corresponds to 3.84 kWh of daily energy demand. Considering our second assumption, the same amount of energy will be required to completely charge the battery. This corresponds to an electricity requirement of 3.84 kWh, as conversion losses in EVSE are assumed to be negligible. The monthly energy costs can be calculated using the formula given below:

$$\textbf{Monthly Energy Cost} = \begin{pmatrix} Daily\ Electricity \\ Consumption\ in\ kWh \end{pmatrix} * \begin{pmatrix} Energy\ Rate \\ per\ kWh \end{pmatrix} * \begin{pmatrix} Number\ of \\ Working\ Days \end{pmatrix}$$

Considering assumption 3 and 4, the monthly energy cost can be calculated as INR 591.36 and is approximated as INR 600. While this represents the maximum cost of electricity, the actual monthly cost of energy may be lesser (80% of battery energy may not be required every day). It is important to note that 78% of rickshaw pullers spent less than INR 600 per month for maintaining cycle rickshaws. In addition, costs will be incurred by rickshaw pullers for paying monthly rent for the rickshaws. Due to insufficient data on the possible monthly rental charges for e-rickshaws, these costs have been excluded from analysis.

2.3.5. Behavioural Changes

Manually-pulled cycle rickshaws have certain limitations as a mode of transport. Their overall operational capability is limited by the ability of rickshaw pullers driving them. This can vary depending upon the health of the rickshaw puller from time to time. Also, the speed of a cycle rickshaw is lesser than that of most other mechanically-driven vehicles. This limits the overall earning potential of rickshaw pullers as well as the willingness of the passenger to pay for each trip. E-rickshaws, on the other hand, can travel much larger distances over an entire day, and at a higher speed. This can potentially increase the income of e-rickshaw drivers. Two immediate impacts that can be anticipated are: increase in number of trips per day and increase in per-trip fare. However, the exact quantification of these impacts will require a more detailed study of passenger mobility across Patna.

2.4. Evaluation of Benefits

Based on the extensive assessment performed in the earlier section, the following impacts can be identified:

1. Change in average daily number of trips
2. Change in operating schedule
3. Change in per-trip fare
4. Change in operational costs

The change in operational costs has already been quantitatively established in 2.3.4 to some extent. As a consequence, the net monthly expenditure of rickshaw pullers is bound to be affected. However, for accurately quantifying the change in net monthly expenditure, knowledge of proposed business model for e-rickshaws and existing rental charges for cycle rickshaws is required. At this stage of the programme, analysis of the business model is not considered within the scope of the study. On the other hand, the impact on average daily number of trips and per-trip fare directly translates into daily income generated by rickshaw pullers. As these two impacts cannot specifically be quantified with the information available, the actual income changes cannot be estimated. However, from the impact assessment in sub-section 2.3, it can be assumed that consequence of these impacts in terms of daily income generated will be incremental in nature. Therefore, instead of quantifying actual benefits for rickshaw pullers, this section focuses on estimating incremental benefits of these impacts. A total of four scenarios have been considered for capturing these incremental benefits:

1. Scenario 0: Base Case Scenario
In the base case scenario, the mean value of daily incomes reported by respondents is established. This value is used as a base to quantify incremental impact of e-rickshaws on daily income earned by rickshaw pullers.

2. Scenario 1: Increased number of trips
In this scenario, the incremental impact on income is evaluated with one additional trip per day as compared to trips completed in base case scenario. In this scenario, the per-trip fare is considered to be the same as that for base case scenario.

3. Scenario 2: Increased per-trip fare
In this scenario, the incremental impact on income is evaluated with a fare increase of INR 5 per trip as compared to per-trip fares in base case scenario while maintaining daily average number of trips to be the same as the base case scenario.

4. Scenario 3: Combined Impact
In this scenario, the incremental impact on income is evaluated considering the effects in both Scenarios 1 and 2. This implies an increment of one trip per day and a per-trip fare increase of INR 5.

The per-trip fare is calculated for all rickshaw pullers by dividing their average daily income with the corresponding average number of daily trips completed by them. A distribution of per-trip fare reported by the respondents is presented in Figure 7 below.

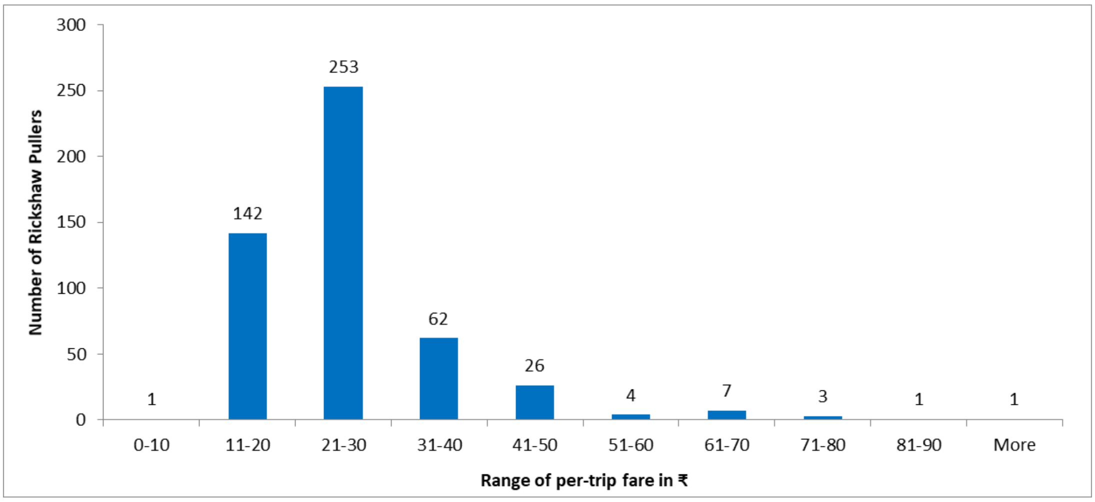

Figure 7: Distribution of rickshaw pullers based on per-trip fare

The values of per-trip fare and number of trips were modified as per scenarios 1, 2 and 3. The average values of the resulting distributions are considered for further analysis. Figure 8 shows the average daily income of rickshaw pullers in each scenario along with the incremental percentage change in average daily income as compared to base case scenario.

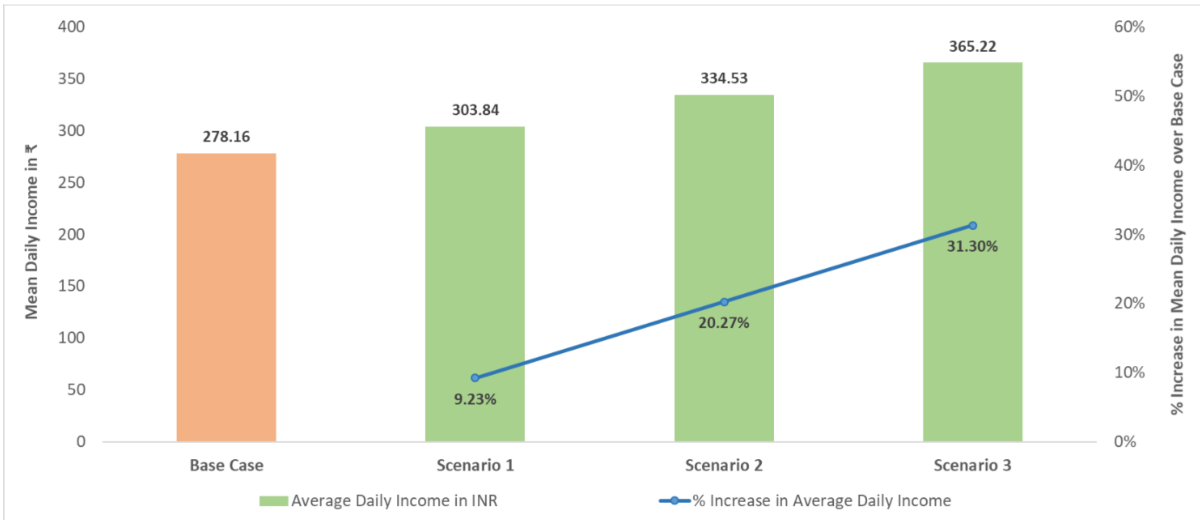

Figure 8: Mean daily income and incremental change under various impact scenarios

It can be observed that there is an increase of about 9% in the average daily income with the addition of one trip per day. With an increase of 20% in average daily income, per-trip fare change has a greater impact on income as compared to incremental changes in the number of trips. The combined impact on income can be seen in Scenario 3, with an increase of about 31% in the average daily income. Therefore, it can be inferred that a small change in number of trips completed on a daily basis and the per-trip fare will have a significant impact on the income levels of rickshaw pullers.

2.5. Summary of Inferences

Based on analysis in sections 2.3 and 2.4, the following key inferences can be drawn:

1. The range of proposed e-rickshaws is more than sufficient to accommodate the same number of trips completed by rickshaw pullers on an average day. In fact, there is a significant margin available for completing additional trips or trips over longer distances, which were earlier not possible due to limitations on physical ability of rickshaw pullers.
2. Reduced passenger carrying capacity of e-rickshaws will not necessarily prove to be an influencing factor for reduction in average daily trips completed by rickshaw pullers.
3. The current night-time parking duration will be sufficient for charging e-rickshaws. Considering the utility of driving e-rickshaws at night, this will be applicable despite possible reductions in night-time parking duration.
4. Although monthly repair and maintenance costs can be avoided, the energy costs resulting from use of e-rickshaws will increase the overall monthly operational costs for most rickshaw pullers. Subsidies or proportionate increase in revenue are some measures that can help rickshaw pullers manage these costs.
5. It can be seen that a mere INR 5 increase in the per-trip fare results in a 20% average increase in the daily income generated. Adding just one trip to the daily average number of trips can increase the average daily income by 30%. On the other hand, with only increasing the number of trips per day, the increment in average income is a mere 9%. This indicates that the per-trip fare needs to be increased to achieve a considerable increment in the average income of rickshaw pullers.

Chapter 3 – Way Forward

The feasibility of introducing two-seater e-rickshaws from the perspective of rickshaw pullers has been discussed extensively in this report. While the initial results may appear favourable, it is important to validate them in actual conditions. Also, the financial impacts of this intervention on rickshaw pullers have been captured in terms of changes in operational costs and incremental earning potential. *However, the actual financial viability of a large-scale deployment programme would depend on several factors including purchase cost of e-rickshaws, financing mechanisms, business models, etc., which need to be assessed separately.* Another crucial point for consideration is planning and deployment of battery-charging facilities in Patna for the proposed e-rickshaws. While this report assumes only night-time charging scenario, it may also be possible to charge the vehicles during free time available during day. For planning charging infrastructure, constraints posed by electricity distribution system in Patna need to be considered. It is also important to note that all these aspects are strongly interconnected, and, therefore, extremely difficult to model accurately. Thus, future work should incorporate a multi-stakeholder perspective and prioritise pilot-scale deployment to evaluate, study, and validate various assumptions and hypotheses. This chapter identifies critical challenges in full-scale deployment of two-seater e-rickshaws, and provides recommendations for moving forward.

3.1. Implementation Challenges

1. Validation of Impacts and Benefits

As discussed earlier, it will be important to strike a balance between possible increase in operational costs associated with e-rickshaws and the anticipated increase in daily income. Considering higher purchase costs, the monthly rental charges for e-rickshaws would also be higher than those for cycle rickshaws. Therefore, a proportionate increase in income generated is essential for meeting the financial feasibility criteria. The increase in income will result from increased number of average daily trips or from increase in per-trip fare. Both these factors depend significantly on passenger behaviour, perception and willingness to pay and are difficult to model. Various assumptions considered in the study need to be thoroughly validated through experimentation.

2. Charging Infrastructure

Charging infrastructure is a general requirement for all types of electric vehicles. In case of e-rickshaws, the charging infrastructure could include a pre-installed dedicated charging equipment or a simple plug for connecting an on-board charger. The capabilities of charging infrastructure will have an impact on the overall fleet operation. Also, charging of e-rickshaws will affect the power and energy demand at the location. Some of the important considerations while planning charging infrastructure are scale, technology selection, distribution infrastructure capacity, location, and operational model.

3. Business Models

This study focuses on assessing financial benefits from the perspective of rickshaw pullers and doesn't consider the overall economic feasibility of the e-rickshaw business. Significant investments would be required in the purchase of two-seater e-rickshaws and associated charging infrastructure. Appropriate cost recovery mechanisms need to be introduced to ensure returns on the initial investments.

Without addressing these challenges, the Two-Seater E-rickshaw Programme may not generate expected outcomes and may further aggravate the problems of the rickshaw puller community. To address these challenges, key recommendations for an action plan are discussed in Section 3.2.

3.2. Recommended Action Plan

1. City-wide charging infrastructure

In this study, battery charging is considered to be occurring at night time. As a result, charging stations need to be located at typical parking areas. However, the power distribution infrastructure supplying these areas may not be capable of accommodating additional power. The alternate approach is to have charging stations distributed all over the city at locations frequently travelled by rickshaw pullers. This will enable them to charge e-rickshaws during the day, which may also be helpful in reducing overall battery capacity of the e-rickshaws, thereby reducing initial investments. Therefore, a comprehensive charging infrastructure plan should be prepared considering city-wide power distribution infrastructure capacity and feasibility of charging schemes. The plan should also consider the alternate use of proposed charging stations for private electric vehicles.

2. Pilot design and implementation

A controlled experiment with pilot-scale deployment of e-rickshaws would be the most suitable method of validating the findings of this study. There are several interconnected parameters which will affect the programme outcomes and cannot be accurately modelled to theoretically quantify the impact. An analytical framework should be developed for monitoring and evaluation of various impacts and benefits. This is also important for building confidence among potential investors and testing different business models.

3. Policy and Programme Design

Once the pilot experiment is completed with satisfactory outcomes, a dedicated policy framework and a programme or scheme should be published by the government. The policy framework should not only address adoption of two-seater e-rickshaws but also focus on supporting manufacturers to establish manufacturing facilities in Bihar. The policy should contain clear directions on roles and responsibilities of various stakeholders. A programme or scheme should be introduced to provide necessary incentives to investors and rickshaw pullers to drive adoption of e-rickshaws. The programme should also influence technology selection and product design to address various challenges.

Considering the vast scope of work to be undertaken, it will be important to map all the stakeholders beforehand and have regular interactions with them before and during the project phase. This will ensure incorporation of a multi-stakeholder perspective into the research framework. E-rickshaw manufacturers should be actively involved in the pilot implementation not only as solution providers but also to adapt product design and technology choice based on outcomes of pilot experiments. The Bihar Industrial Area Development Authority should also be involved in the policy design exercise to come up with suitable incentives to attract manufacturers.

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Annexure A: Survey Questionnaire

- On an average how many trips are covered in a day and between which locations do these trips occur more frequently?
- On an average how many passengers do you carry per trip and what is your daily income from this business?
- What is the typical resting time (including lunch break or afternoon when trips do not usually occur) and location during daytime?
- What is the start and end time of business day for you and where do you park vehicles at night?
- What is the average life of the manual rickshaw and how much do you have to spend annually to maintain your vehicle?
- From your perspective, what are the benefits and drawbacks of driving battery-operated rickshaws?

Annexure B: Distance Matrices for Trip Location Groups

Distance Matrix for Group 1:

Locations	Gola road	Big Bazar	Jag Dev Path	Paras Hospital
Gola road		2.2	2.2	2.8
Big Bazar			0.8	0.55
Jag Dev Path				1.2
Paras Hospital				

Distance Matrix for Group 2:

Locations	Kankarbagh	Dinkar Golambar	Bazar Samiti	Saidpur	NIT Patna	Rajendra Nagar Station	Ashok Raj Path
Kankarbagh		3.8	5.2	2.3	6.1	2.7	8.9
Dinkar Golambar			2.6	1.3	2.4	1.4	6.9
Bazar Samiti				3.9	3.9	2.1	3.8
Saidpur					3.4	3.4	8.1
NIT Patna						4.1	3.2
Rajendra Nagar Station							5.7
Ashok Raj Path							

Distance Matrix for Group 3:

Locations	Bus Stand	Postal Park	Mithapur	Gardani Bagh	Colony More	Dak Bungalow	Exhibition Road
Bus Stand		1.2	1.5	6.8	2.7	3.6	4.4
Postal Park			0.35	5.2	2.5	3.8	4
Mithapur				5.2	2.2	2.5	2.4
Gardani Bagh					4.5	3.6	4.6
Colony More						1.7	1.6
Dak Bungalow							0.75
Exhibition Road							

Distance Matrix for Group 4:

Locations	NIT Patna	Patna Junction	Boring Road	Rajapur	Kurji	Dak Bungalow	Exhibition Road
NIT Patna		8.4	7.5	6.4	7.7	4.8	4
Patna Junction			5.5	6	7.3	2.3	2.2
Boring Road				2.7	3.2	3.3	3.6
Rajapur					1.8	4.2	4.1
Kurji						5.7	5.5
Dak Bungalow							0.75
Exhibition Road							

Distance Matrix for Group 5:

Locations	Patna Junction	GPO	Boring Road	Golghar	Gandhi Maidan	Dak Bungalow	Kurji
Patna Junction		1.2	5.3	3.7	2.9	2.3	7.3
GPO			4.2	2.6	3	1.8	6.2
Boring Road				3.7	5.7	3.9	2.9
Golghar					1.8	2.1	3.9
Gandhi Maidan						1.8	5.5
Dak Bungalow							5.7
Kurji							