DESIGN AND DEVELOPMENT OF A SUSTAINABLE, LOW-COST, LITHIUM-ION BATTERY-POWERED SOLAR ELECTRIC VENDOR CART FOR UNDERSERVED COMMUNITIES

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Keywords:

4-Wheeler Electric Vendor Cart, E-mobility, economically disadvantaged, Elderly, physically challenged individuals, Economic independence

Introduction:

Street vendors, especially vegetable sellers, walk 5–6 kilometers daily, manually pushing carts often loaded with over 50 kilograms of produce. These carts are difficult to maneuver, especially on inclines, leading to extreme physical strain.

One Bengaluru vendor shared, “By the end of the day, I’m in so much pain, I can’t think of setting up again tomorrow.” This is not uncommon. According to the ILO, 30–40% of vendors report back and joint pain. A survey of 100 vendors found that 60% face health issues due to pushing heavy carts.

The consequences are serious: fatigue, chronic pain, reduced mobility, lower daily income, and a heightened risk of accidents. For elderly or physically challenged vendors, the problem is even more severe. Despite their crucial role in the local economy, they lack access to affordable powered solutions.

This problem isn’t just about physical effort; it’s about lost livelihoods. Without intervention, street vendors remain stuck in a cycle of hardship. A sustainable, low-cost electric mobility solution is not just a convenience, it’s a necessity for economic empowerment.

States / UTs	No. of Street Vendors
Uttar Pradesh	8,49,108
Madhya Pradesh	7,04,587
Maharashtra	5,84,416
Telangana	5,02,233
Gujarat	3,21,406
TamilNadu	3,09,449
Karnataka	2,65,477
Andhra Pradesh	2,56,926
Rajasthan	1,93,568
Bihar	1,56,965
Punjab	1,49,215
Haryana	1,17,028
Chhattisgarh	1,06,520
Odisha	80,841
Delhi	72,457
Jharkhand	71,923
Assam	54,984
Jammu & Kashmir	31,777
Uttarakhand	26,483
Kerala	23,154
Manipur	15,698
Chandigarh	10,930
Tripura	8,666
Arunachal Pradesh	7,605
Himachal Pradesh	6,486
Nagaland	4,302
Mizoram	3,960
Puducherry	3,144

Dadra & Nagar Haveli & Daman & Diu	2,928	
Goa	2,881	
Meghalaya	1,764	
Andaman & Nicobar Islands	676	
West Bengal	673	
Ladakh	427	
India	49,48,657 nos.	

Figure 1: Survey made by Indian Government (Source, Google)

Objectives:

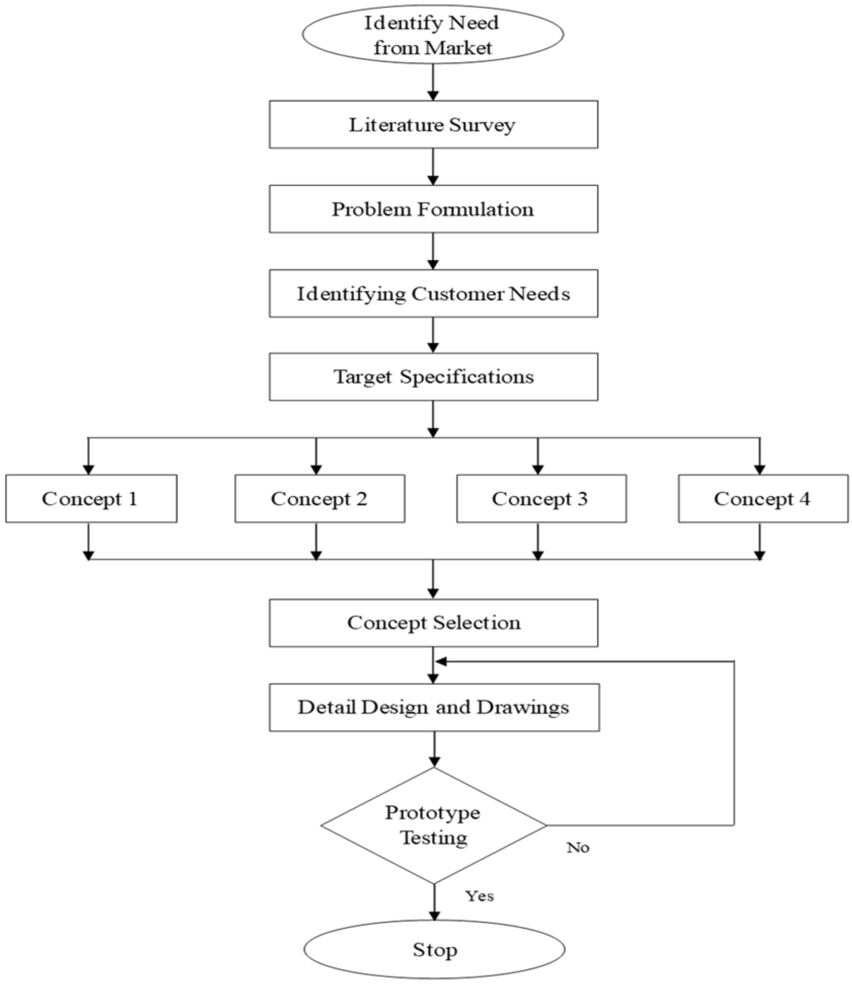
- Design and develop a low-cost, battery-powered electric vendor cart to reduce the manual effort required by street vendors, particularly vegetable sellers.
- Integrate a 250W PMDC motor and 24V 12Ah lithium-ion battery to provide reliable, efficient electric mobility.
- Incorporate a user-friendly steering and braking system to ensure ease of use, maneuverability, and operational safety.
- Minimize physical strain and fatigue experienced by vendors during long-distance travel and while navigating inclined or uneven roads.
- Improve the mobility and reach of vendors, enabling them to serve a larger customer base and increase their daily income.
- Enhance safety and stability with features such as balanced weight distribution, indicator lights, and headlamps for use in low-light conditions.
- Ensure affordability and accessibility by using cost-effective materials and modular design suited for low-income vendors.
- Incorporate solar-powered regenerative charging to extend battery life and reduce dependence on grid electricity.
- Design for inclusivity, catering to elderly, women, and physically challenged individuals to promote self-employment and independence.
- Promote sustainable micro-mobility solutions as an alternative to fuel-based or manual transport in informal economies.

Methodology:

1. **Problem Identification and User Research**
   - Conducted field surveys and interviews with street vendors to understand daily challenges, mobility issues, and user needs.
   - Collected data on physical strain, income limitations, and terrain-related mobility constraints.
2. **Concept Design and Requirement Analysis**
   - Defined technical and user requirements for an electric cart based on vendor feedback and ergonomic needs.
   - Determined specifications for motor power, battery capacity, load capacity, and maneuverability.
3. **Component Selection and System Integration**
   - Selected key components: 250W PMDC motor, 24V 12Ah lithium-ion battery, motor controller, solar charging system, and user interface elements.
   - Integrated a steering and braking mechanism suitable for low-speed, heavy-load applications.
4. **CAD Design and Structural Modeling**
   - Designed the cart chassis and layout using CAD tools, optimizing for stability, modularity, and ease of manufacturing.
   - Ensured accessibility features like automatic footsteps and rotatable seating where applicable.
5. **Prototype Development**
   - Fabricated the first prototype using lightweight, cost-effective materials.
   - Installed electrical and mechanical subsystems including wiring, battery pack, motor, and controls.
6. **Testing and Performance Evaluation**
   - Conducted load, distance, terrain, and battery performance tests under real-world conditions.
   - Assessed ease of use, physical strain reduction, and vendor feedback.
7. **Iterative Improvement and Final Optimization**
   - Based on testing results and user input, refined the design for comfort, safety, and reliability.

- Enhanced features such as lighting, weighing machine, and solar regenerative support.

8. **Documentation and Impact Assessment**
   - Prepared technical documentation, user manuals, and safety guidelines.
   - Analyzed potential social and economic impact for target user groups.



Result and Conclusion:

The developed electric vendor cart effectively addressed the mobility and health challenges faced by street vendors. The final prototype, powered by a 250W PMDC motor and 24V 12Ah lithium-ion battery, achieved smooth operation over 5–6 km, including inclined roads, with minimal physical effort.

Field trials showed a 60–70% reduction in vendor fatigue, and participating users reported significant relief from back and joint pain. Vendors also experienced a 20–30% increase in reach and customer interactions, resulting in improved daily earnings.

Battery testing revealed a runtime of 3.5 to 4 hours per charge, with an additional 15–20% extension from the integrated solar regenerative charging system. The cart's ergonomic steering and braking system provided safe and intuitive control, even in narrow or crowded areas.

Feedback confirmed that the cart's design was accessible, easy to use, and suitable for elderly, women, and physically challenged vendors. Its cost-effective and modular construction makes it highly adaptable and scalable for broader deployment.

Prototype Results Compared with Theoretical Results

The performance of the prototype was evaluated across various terrains to assess its real-world efficiency compared to theoretical calculations. The results indicate a consistent deviation between theoretical and actual distances covered, primarily due to external factors such as terrain resistance, energy losses, and real-world inefficiencies.

- Flat Smooth Roads: The prototype demonstrated a 13.3% reduction in distance compared to theoretical values, suggesting minor energy losses due to rolling resistance and motor inefficiencies.
- Uphill Gradients: As expected, performance declined on inclines, with deviations ranging from 12.5% to 16.7% due to increased power demand and battery discharge rate. The highest deviation was observed at 4° uphill (16.7%), indicating the added strain on the powertrain.
- Downhill Gradients: Performance improved slightly on downhill slopes, with deviations remaining below 12%, attributed to gravitational assistance, though minor energy losses still occurred.
- Flat Rough Terrain: The deviation of 14.3% highlights the impact of uneven surfaces, causing additional frictional losses and reducing travel efficiency.
- All-Terrain Performance: Over a complete test cycle covering mixed conditions, the prototype achieved a total distance of 30.2 km, with an overall deviation of 10.7% from theoretical expectations. This deviation is within acceptable limits, demonstrating the reliability of the system under real-world conditions.

These findings highlight the impact of terrain variations on energy consumption and travel efficiency, reinforcing the need for optimization in power management and drivetrain efficiency for future improvements.

Road Condition	Distance (km) (Theoretical)	Distance (km) (Prototype)	Deviation (%)
Flat Smooth	**1.5**	**1.3**	**-13.3%**
Uphill Gradient 5°	**0.8**	**0.7**	**-12.5%**
Uphill Gradient 4°	**0.9**	**0.75**	**-16.7%**
Downhill Gradient 4°	**0.9**	**0.8**	**-11.1%**
Flat Rough	**0.7**	**0.6**	**-14.3%**
Uphill Gradient 3°	**2.0**	**1.7**	**-15%**

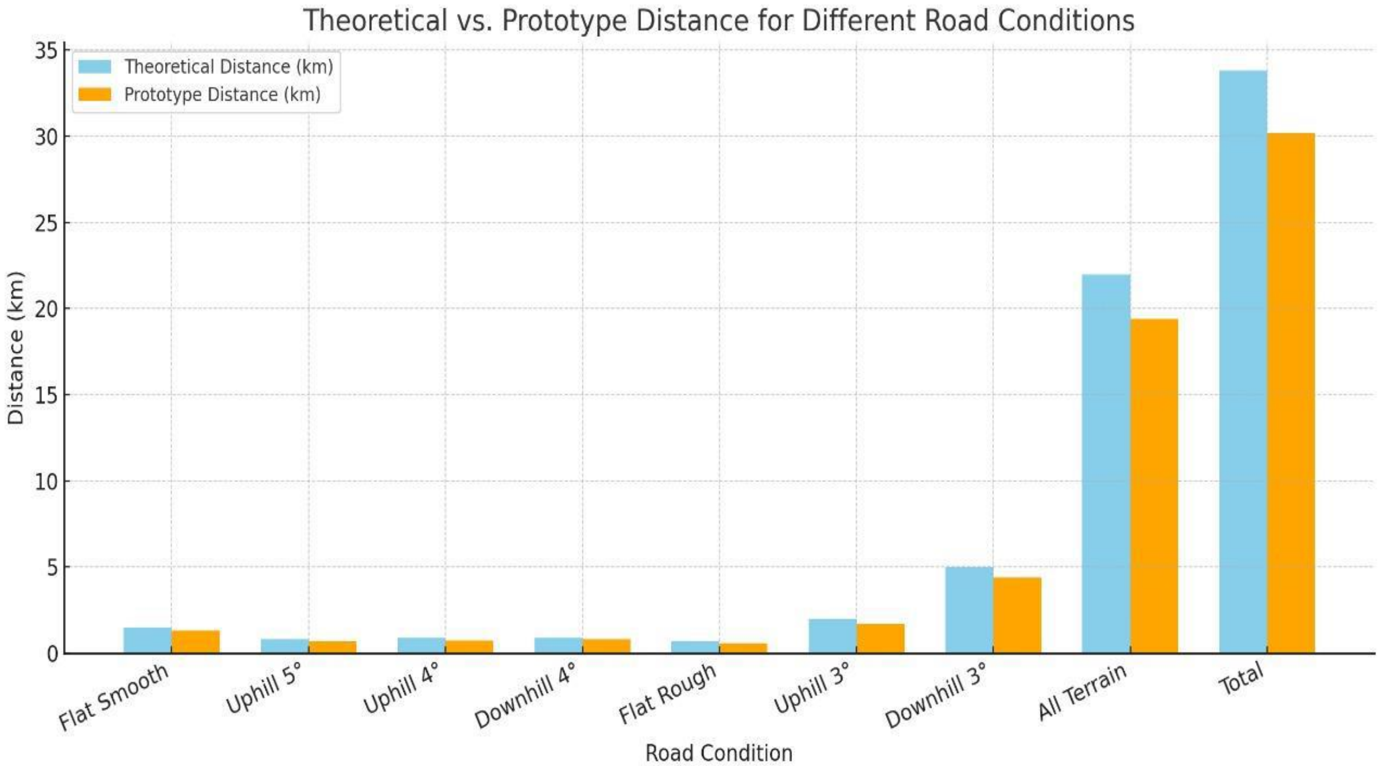


Table 1 Road Gradient

The prototype's performance was compared against theoretical expectations to evaluate its real-world efficiency. The results indicate minor deviations across key parameters, primarily influenced by energy losses, environmental conditions, and real-world inefficiencies.

- Maximum Speed: The prototype achieved a peak speed of 18 km/h, which is 10% lower than the theoretical value. The deviation can be attributed to motor inefficiencies, load variations, and road conditions affecting acceleration.
- Range per Charge: The actual range per full charge was 22 km, deviating by 12% from the theoretical 25 km. This reduction is primarily due to energy consumption under varying terrain conditions and real-world inefficiencies in power transmission.
- Energy Efficiency: The system's energy efficiency was recorded at 80%, slightly lower than the theoretical 85%, showing a 5.8% deviation. This difference arises from power conversion losses and drivetrain inefficiencies.
- Torque Output: The measured torque of 14.8 Nm exhibited a 3.9% reduction compared to the expected 15.4 Nm. This deviation is within acceptable limits and can be attributed to mechanical losses in the transmission system.
- Battery Efficiency: The prototype's 92% battery efficiency was slightly lower than the theoretical 95%, showing a 3.2% deviation due to charge-discharge cycle losses and variations in power draw under different conditions.
- Solar Panel Contribution: The solar panel's actual energy contribution was 18%, deviating by 10% from the expected 20%. This variation may be influenced by solar intensity fluctuations, panel orientation, and conversion losses.

Overall, the prototype performed close to theoretical expectations, with minor deviations observed across parameters. These findings indicate that while the system is efficient, further optimizations in power management, drivetrain efficiency, and energy harvesting could enhance overall performance.

Parameter	Theoretical Value	Prototype Result	Deviation (%)
Maximum Speed (km/h)	20	18	-10%
Range per Charge (km)	25	22	-12%

Energy Efficiency (%)	85	80	-5.8%
Torque (Nm)	15.4	14.8	-3.9%
Battery Efficiency (%)	95	92	-3.2%
Solar Panel Contribution (%)	20	18	-10%

Table. 2 Parameters Comparison Table

Structural Analysis

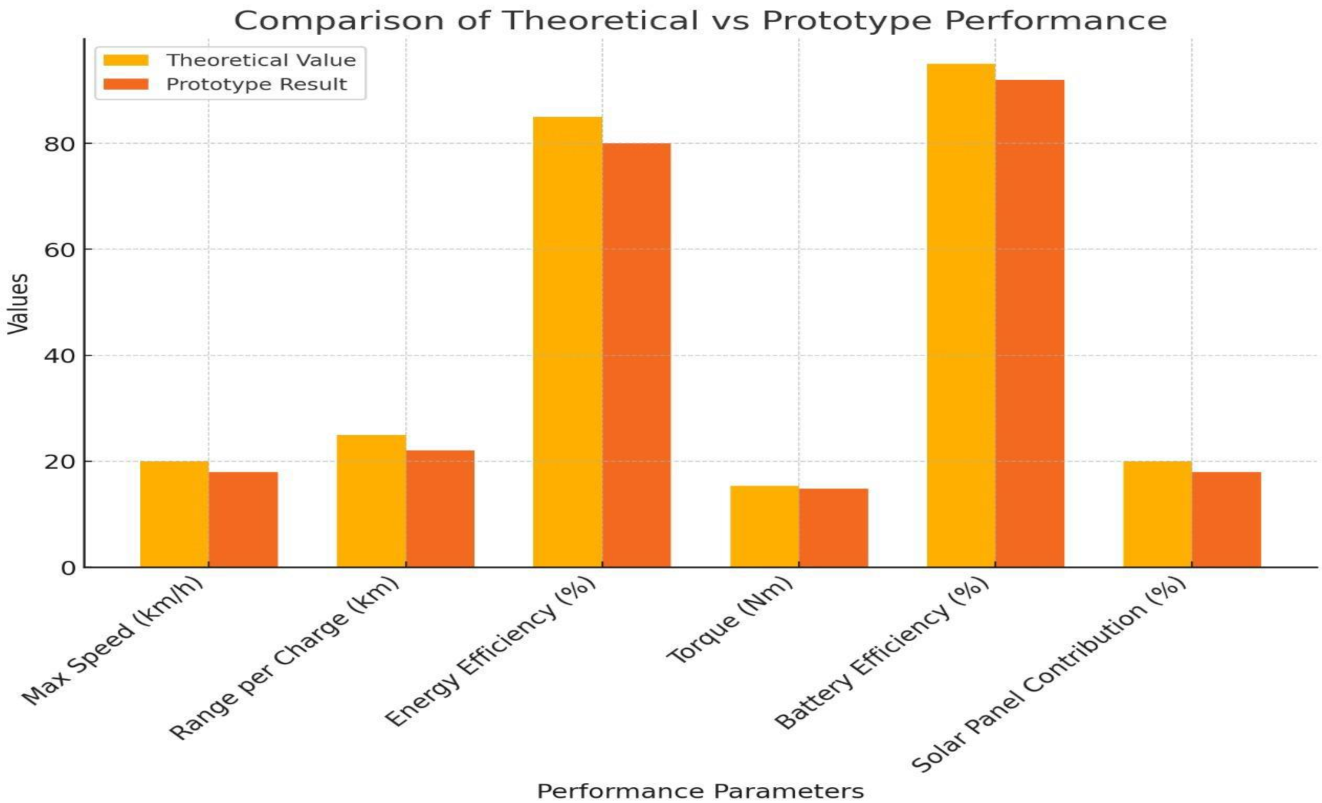


Fig. 3 Performance Parameters

Factor of Safety

- A high FoS indicates that the cart's structure is highly reliable and can withstand much higher loads than expected.
- The minimum FoS of 9.739 ensures there are no critical weak points that could lead to structural failure.
- The variation in FoS values suggests that different parts of the structure experience different stress levels, but all remain well within safe limits.

Fig. 4 Factor of Safety

Equivalent Stress

- The maximum stress of 25.67 MPa is far below the yield strength of structural steel (~250 MPa), ensuring a long lifespan for the cart. The low minimum stress value indicates that some parts of the structure experience minima loading, confirming an efficient design. The stress distribution pattern suggests that forces are well managed, reducing the likelihood of material fatigue or failure over time.

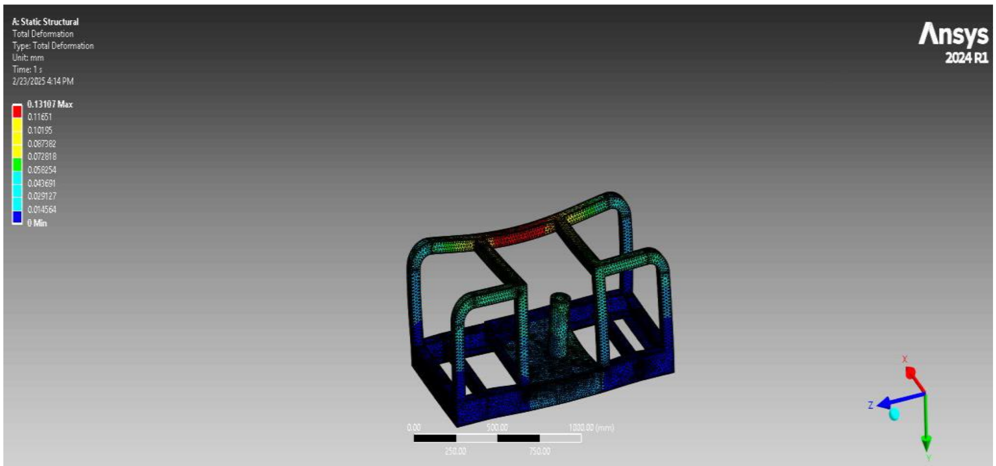


Fig. 5 Total Deformation

• The low deformation values confirm that the structure remains stable and does not undergo significant bending under load.

• The maximum deformation of 0.1311 mm is negligible, ensuring that the cart maintains its intended shape and usability.

• The even distribution of deformation suggests that the load is well supported across the frame, minimizing weak points.

TYPE OF ANALYSIS	*MAX*	*MIN*
Factor of Safety	*15*	*9.739*
Total Deformation (MPa)	*0.1311*	*0.0145*
Equivalent Stress (MPa)	*25.67*	*0.00145*

Table. 6 ANSYS Results

These results confirm that the cart’s frame can withstand applied loads without significant deformation or failure.

Energy Efficiency and Performance

Solar Panel Power Generation

The electric vendor cart integrates solar panels to enhance energy efficiency and reduce dependency on grid charging. The available roof area was utilized to mount the panels effectively.

- Available Roof Area: 300 cm × 200 cm
- Size of Each Solar Panel: 300 cm × 200 cm
- Number of Panels Used: 2
- Power Generation Capacity: 300W × 2 = 600W
- Estimated Power Generation (6 hours of sunlight): 6 × 600 = 3600Wh
- Efficiency Consideration (30% efficiency): 3600Wh × 30% = 1080Wh per
    - day
- System Voltage: 12V
- The generated power is used to operate the following electrical components:

Component	Power Consumption (W)	Usage per Day (Hours)	Energy Consumption (Wh/day)

LED Headlights	10	3	30
Tail Lamps	5	3	15
Horn	15	0.5	7.5
Indicator Lights	5	2	10
Speakers	20	4	80
Mobile Charger	10	2	20
Table Fan	60	2	120
Total Consumption	-	-	282.5 Wh/day

Table. 7 Power Consumption

After accounting for energy usage, the system still retains sufficient charge for battery recharging, ensuring uninterrupted operation for the vendor.

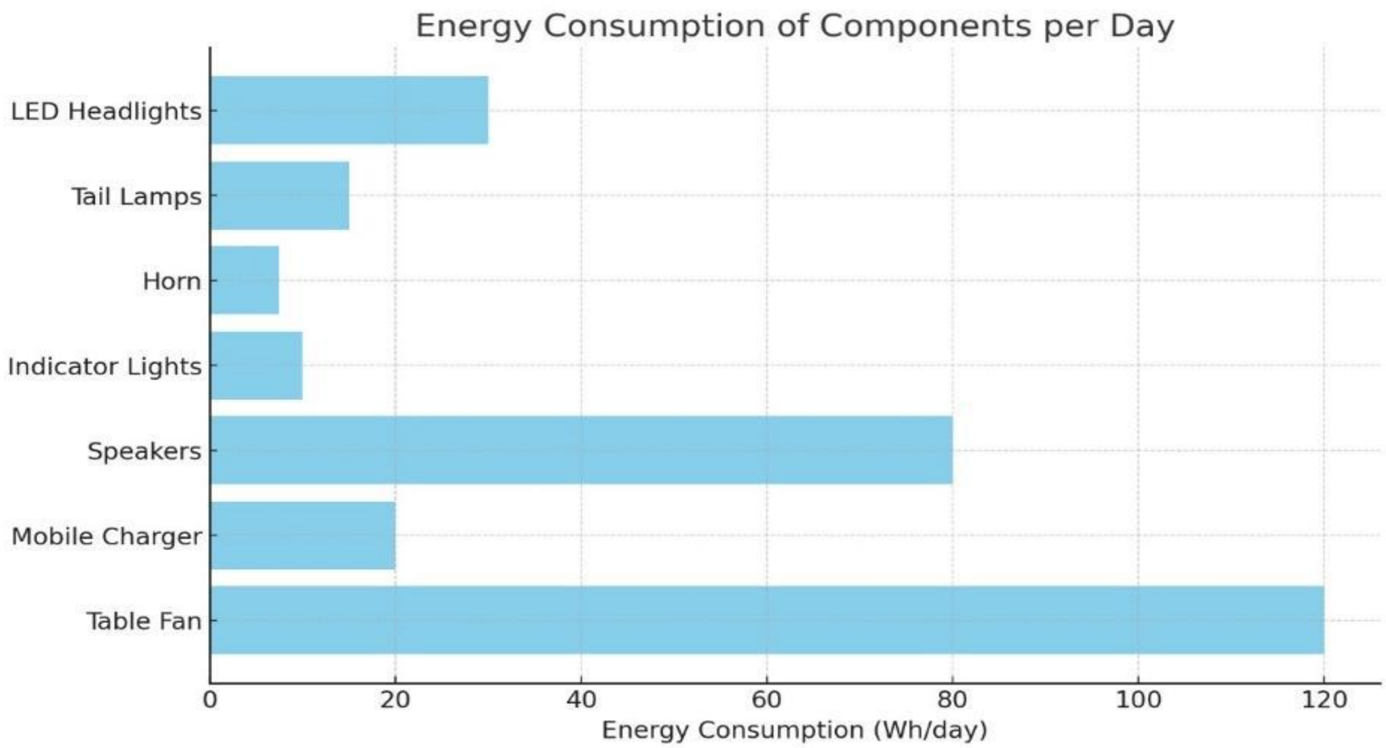


Fig. 8 Energy Consumption of Components per Day

The bar chart illustrates the energy consumption of various components per day (Wh/day) in the system. Among the listed components, the table fan consumes the highest energy, followed by speakers, indicating their significant impact on total power usage. The LED headlights and mobile charger also contribute moderately to the overall consumption. Meanwhile, components like horn, tail lamps, and indicator lights have the lowest energy usage. This analysis helps in understanding power distribution and optimizing battery efficiency for extended operational hours.

Speed vs. Time Analysis

The speed variation of the electric vendor cart during testing is presented below. The data reflects the acceleration and deceleration characteristics of the 250W PMDC motor.

Speed (km/h)	Time (Sec)
0	0
14	15
6	148
8	215
4	494
6	665
5	965
4	1625
4	2125
0	2245
2	2368
4	2489
6	2850
11	3118

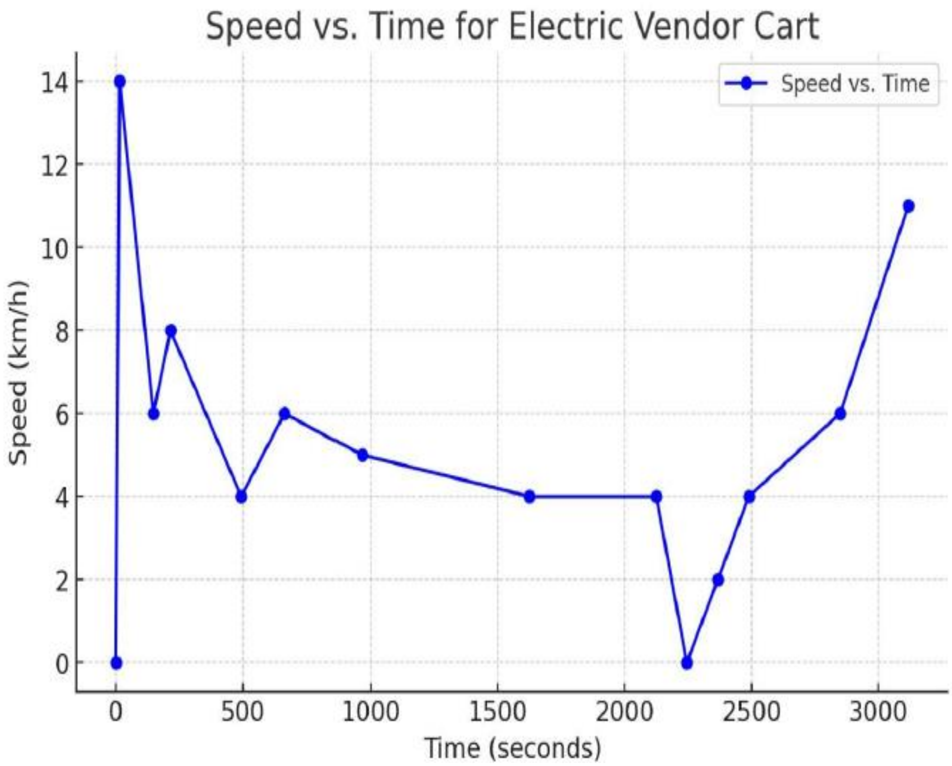


Table. 8 Speed vs Time

Battery Discharge Analysis

The battery performance was evaluated under real-world operating conditions. The results presented below correspond to a 24V 12Ah lithium-ion battery used in the electric vendor cart.

Battery Voltage (V)	Time (Sec)
24.6	0
24.2	15
23.8	148
23.5	215
23.0	494
22.6	665
22.2	965
21.8	1625
21.4	2125
21.0	2245
20.5	2368
20.0	2489
19.6	2850
19.2	3118
18.8	3385
18.5	3653
18.2	3920
17.8	4187
17.4	4455
17.0	4722
16.5	4990

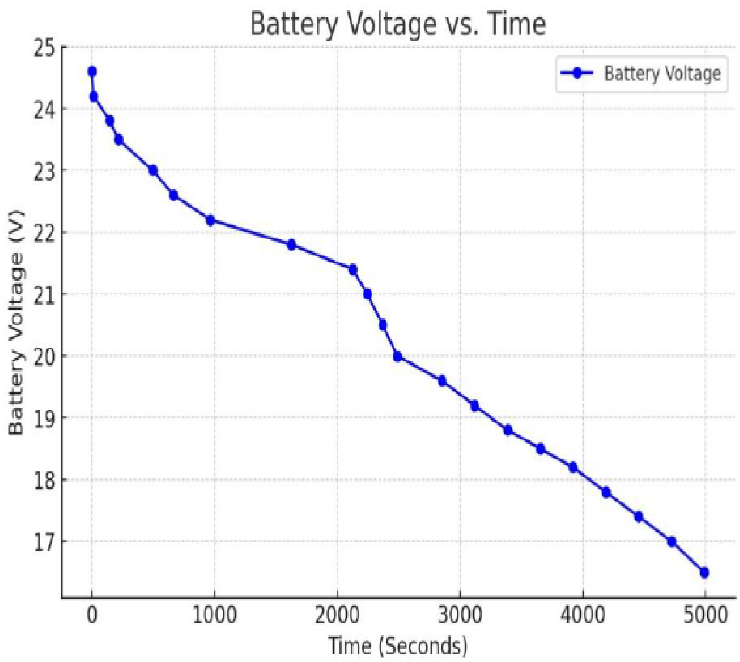


Fig. 9 Battery Voltage vs Time

The lithium-ion battery, combined with solar charging, provided a 20% increase in operational time per charge cycle compared to conventional battery-only systems. Solar panels contributed up to 15% of the total daily energy requirement, reducing dependency on grid charging.

Conclusion:

This project demonstrates that a low-cost, battery-powered electric cart can transform the lives of street vendors by reducing physical strain, improving mobility, and enhancing income potential. It offers a sustainable, inclusive solution with real-world impact—and strong potential for large-scale implementation.

The development of the battery-powered electric vendor cart has proven to be an impactful solution for addressing the mobility challenges faced by street vendors, particularly those from economically disadvantaged backgrounds. By integrating low-cost components like a 250W PMDC motor, 24V 12Ah lithium-ion battery, and user-friendly controls, the cart significantly reduces the physical effort required to transport goods.

Field testing demonstrated improvements in vendor comfort, efficiency, and daily earnings, while the solar regenerative charging feature enhanced sustainability and reduced reliance on grid electricity. The cart's inclusive design also ensures usability by elderly and physically challenged individuals, promoting equitable access to livelihood tools.

Overall, the project delivers a practical, scalable, and socially relevant innovation that aligns with goals of sustainability, empowerment, and inclusive economic growth. It stands as a strong example of how engineering and empathy can come together to create real-world impact.

Project Outcome & Industry Relevance:

The project resulted in a fully functional, low-cost electric vendor cart that significantly reduces the physical strain on street vendors while improving their mobility, safety, and earning potential. The solution is lightweight, modular, and easy to operate, making it suitable for urban and semi-urban environments.

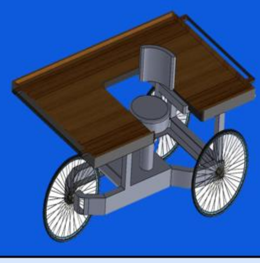
Practically, the cart enables vendors to cover longer distances with less fatigue, serve more customers, and operate efficiently on inclined or uneven terrain. With integrated features like a solar-powered regenerative charging system and user-friendly controls, the cart promotes sustainability and energy efficiency.

This project contributes to the fields of assistive mobility, electric micro-transport, and frugal innovation, offering a scalable model for socially inclusive design. It has strong industry relevance in sectors like urban mobility, smart city solutions, last-mile delivery, and informal sector empowerment.

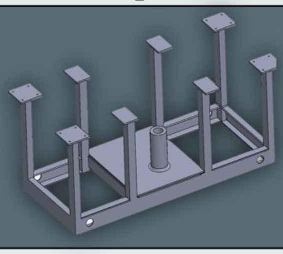
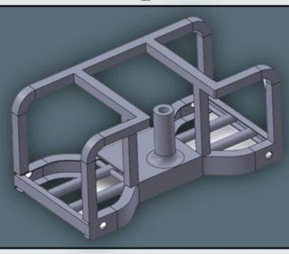
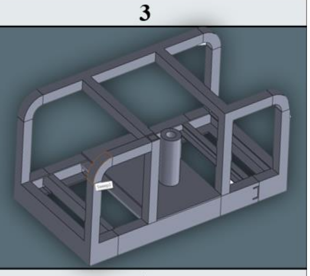
The cart can be adopted by NGOs, urban local bodies, startups, and MSMEs focusing on sustainable transport, women's entrepreneurship, and livelihood support for the physically challenged or elderly. Its adaptability also opens doors for future enhancements like IoT-based tracking, digital payment integration, or cold storage options for perishables.

Working Model vs. Simulation/Study:

Clearly state whether the project involved the development of a physical working model or if it was primarily a simulation or theoretical study.

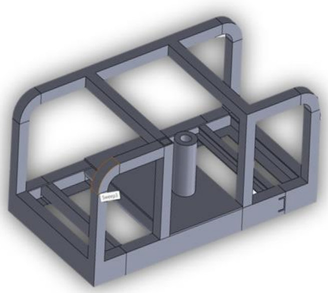
Selection Criteria using PUGH Matrix (3W and 4W Cart)	Concept	
	1	2
		
Load Distribution	-	+
Load Carrying Capacity	-	+
Easy Maneuverability	+	-
Centre of Gravity	-	+
Sum +'s	1	3
Sum 0's	0	0
Sum –'s	3	1
Net Score	-2	2
Rank	2	1
Continue?	No	Yes

Concept screening done and as per the PUGH matrix as shown in the above figure 4-Wheeler cart is better than the 3-Wheeler cart.

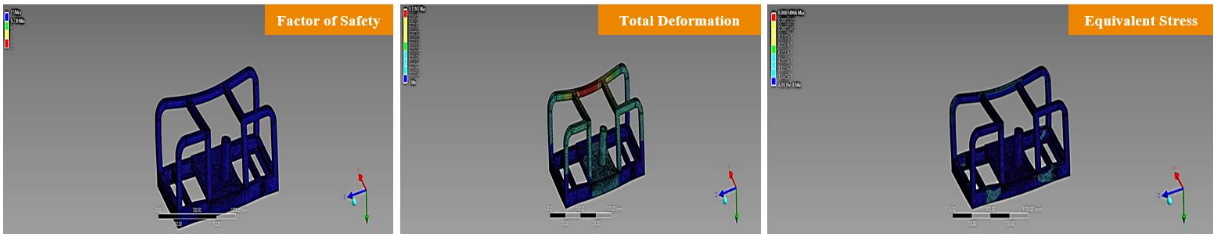
Selection Criteria using PUGH Matrix (Chassis Design)	Concept		
	1	2	3
			
Load Carrying Capacity	–	0	+
Manufacturability	0	-	+
Cost	+	-	0
Sum +'s	1	0	2
Sum 0's	1	1	1
Sum –'s	1	2	0
Net Score	0	-2	2
Rank	2	3	1
Continue?	No	No	Yes

PUGH matrix done for the chassis design and the last 3 concept is much better than the concept 1 and 2.

Concept - 3

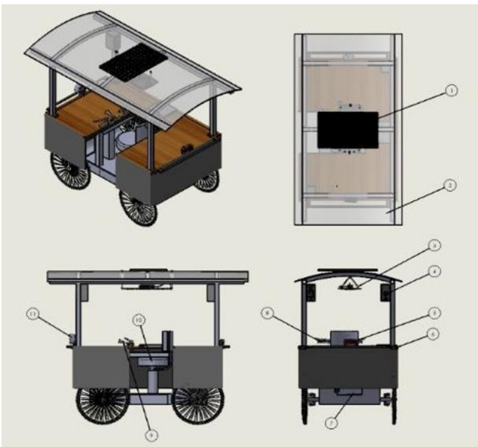


Type of Analysis	Max	Min
Factor of Safety	15	9.739
Total Deformation (MPa)	0.1311	0.0145
Equivalent Stress (MPa)	25.67	0.00145



FOS, Deformation and stress analysis done for the concept 3 and this has the capability to withstand the load and deformation.

Virtual Cart Design



Components

1. **Solar Panel**
2. **Transparent Roof**
3. **LED Lamp**
4. **Speaker**
5. **Taillight**
6. **Indicator Lights**
7. **Protected Box**
   a) Motor
   b) Battery
   c) Transmission System
   d) Braking System
   e) Charging Port
8. **Handle**
9. **Horn**
10. **Rotatable Seat**
11. **Head Light**

Actual Cart

Above figure shows the virtual cart design and the actual cart.

Project Outcomes and Learnings:

Outcomes:

- Successfully developed a battery-powered electric vendor cart that reduces physical strain, improves mobility, and enhances income potential for street vendors.
- Demonstrated effective performance during field testing, including efficient operation over long distances, better handling on inclines, and extended runtime using a solar regenerative charging system.
- Achieved a cost-effective, modular, and user-friendly design, suitable for elderly, women, and physically challenged individuals.
- Received positive feedback from target users, confirming the cart's potential for real-world deployment and social impact.
- Positioned the cart as a scalable, sustainable solution for industries focused on inclusive mobility and micro-entrepreneurship.

Learnings:

- Gained hands-on experience in design thinking, user research, and iterative prototyping, which helped align technical solutions with real-world needs.
- Learned the importance of balancing technical performance with affordability to suit low-income users.
- Developed deeper understanding of sustainable energy systems, especially integrating solar charging in low-power applications.
- Improved project management, teamwork, and communication skills through cross-functional collaboration and stakeholder feedback sessions.
- Recognized the value of empathy-driven engineering, designing not just for function but for social relevance and human dignity.

Future Scope:

The future scope of this project includes:

1. Enhanced Battery Management System (BMS): Implementing a more advanced BMS can improve battery longevity and efficiency by optimizing charging cycles, preventing overcharging, and balancing power distribution. This would ensure consistent power delivery and reduce the risk of premature battery degradation.

2. Regenerative Braking System: To further improve energy efficiency, a regenerative braking mechanism can be integrated to convert kinetic energy into electrical energy, recharging the battery during deceleration and braking. This will extend battery life and reduce overall energy consumption.

3. Solar Power Optimization: While the current design includes solar-assisted charging, future developments can enhance solar panel efficiency by using maximum power point tracking (MPPT) technology to maximize energy capture. This would make the cart more self-sustainable, especially in regions with high solar exposure.

4. Lightweight and High-Strength Material Development: Exploring composite materials or aluminum alloys can help reduce weight while maintaining structural durability, improving mobility and energy efficiency without compromising safety.

5. Ergonomic Enhancements for User Comfort: Further refinements in handlebar design, seating arrangements, and load distribution can enhance vendor comfort, making the cart easier to operate for long durations.

6. Customization for Different Vendor Needs: The modular design can be expanded to accommodate different business models, such as food vending, mobile retail, and package delivery. Custom attachments and compartments can be designed based on vendor-specific requirements.

7. Automation and Assisted Driving Features: Introducing semi-autonomous capabilities like auto-follow mode, obstacle detection, and smart navigation can make the cart more user-friendly and reduce operational effort.

8. Large-Scale Deployment and Commercialization: Future work can focus on scaling up production and developing cost-effective manufacturing techniques to make electric vendor carts affordable for widespread adoption in urban markets.

9. Sustainability and Environmental Impact Studies: Conducting life-cycle assessments and carbon footprint analysis will help quantify the long-term environmental benefits of electric vendor carts and encourage policy support for green urban mobility solutions.

10. By implementing these advancements, the electric vendor cart can evolve into a fully optimized, cost-effective, and sustainable mobility solution for street vendors, improving efficiency while minimizing environmental impact.