Problem Statement: Reducing driver wait time during peak hours of the day, while balancing battery availability and station efficiency for Battery Smart's urban operations success

Meet Rohit!

Age: 26 **Location:** Delhi

Occupation: E-Rickshaw driver

Pain points:

Long waiting times

"Upto 1 hour during peak hours"

Reduced daily earnings due to limited operational hours

"Every hour Rohit spends waiting in line means fewer rides and less money to send back home, making it harder to fulfill his family's financial needs"

Impact Analysis

Number of swaps per station per day

# of swaps in peak hours of the day	=	# of peak hours/ Time taken in 1 swap	=	60
# of swaps in non-peak hours of the day	=	# of vehicles per hour/ # of non-peak hours	=	40

Total = 100 Batteries per station per day

Assumptions:

1. *Battery Smart stations operate 14 hours per day[1], with 4 peak-demand hours*
2. *Continuous vehicle inflow during peak hours*
3. *Swap time per vehicle: 4 minutes (2 minutes at 100% efficiency)*
4. *Average vehicle inflow per = 4*

Required number of swaps per station per day

# of drivers per station	=	# of battery smart drivers/ # of battery smart stations	=	40
# of swaps required by a driver per day			=	3

Total = 120 Required batteries per station per day

Assumptions:

1. *# of battery smart drivers = 55299 [2]*
2. *# of battery smart stations = 1411 [3]*
3. *# of swaps required by a driver per day = 3*

Demand Gap: Each station misses **20 battery swaps** per day or forces drivers to wait in long lines, affecting **17%** of total demand.

Revenue impact

- Revenue per swap: ₹125 [4]
- Total missed swaps in a day: 28220

₹3.4M **Potential daily Revenue loss**

Assumptions

- **Station Design:** Battery Smart stations are mostly enclosed spaces for indoor battery charging and storage
- **Staffing Model:** Each station is run by a single operator handling exchanges and inventory
- **Customer Base**: Primarily serves commercial drivers
- **Franchise Model:** Stations are franchise-owned; Battery Smart provides operational guidance but has limited control
- **Station Setup:** Battery Smart designs each station and transfers it to franchise owners for operation

* By studying about battery smart stations [1] [2] [3] [4]

Battery Smart

To get to the bottom of why the waiting might be so high, we can evaluate each component constituting wait time individually

$$T_{wait} = T_{queue} + T_{process} + T_{availability}$$

1 Factor affecting T_{queue}

This is the time spent waiting in line before service begins.

Insufficient number of stations

Battery Smart: *40 drivers per station[1]*

gogoro: *45 drivers per station[2]*

Poor station location planning:
Uneven station distribution can causes congestion leading to high waiting time in some areas

Uneven demand distribution:
- Geographic: Some high traction areas might have more demand then others
- Time-based: Peak hours see heightened demand

2 Factor affecting T_{queue}

This is the time required to complete the battery swap

Operator dependency:
Single operator setup creates bottlenecks during peak times

Manual battery handling:
Since the operator manually retrives the batteries here, this can become a bottleneck during peak hours

*Self-service vending machine-style stations swap batteries in **6 seconds**, while Battery Smart stations take **2 minutes** [3]*

Payment process:
With most payments made in cash, the need to provide change can extend checkout time

Battery identification and sorting:
Unorganized labeling can lead to delays in locating the correct battery

2 Factor affecting $T_{availability}$

This is the time spent waiting for a battery to become available

Limited battery stock:
Overall low battery inventory in the cycle can restrict availability during high-demand periods

Limited charging capacity:
Insufficient charging ports can restrict the number of batteries ready for use

Long charging times:
Slow chargers can increase the time taken to prepare batteries for swaps

Towards Solutions...

Based on Battery Smart's business model and prioritization through an impact vs. importance analysis, our solution should focus on the following factors:

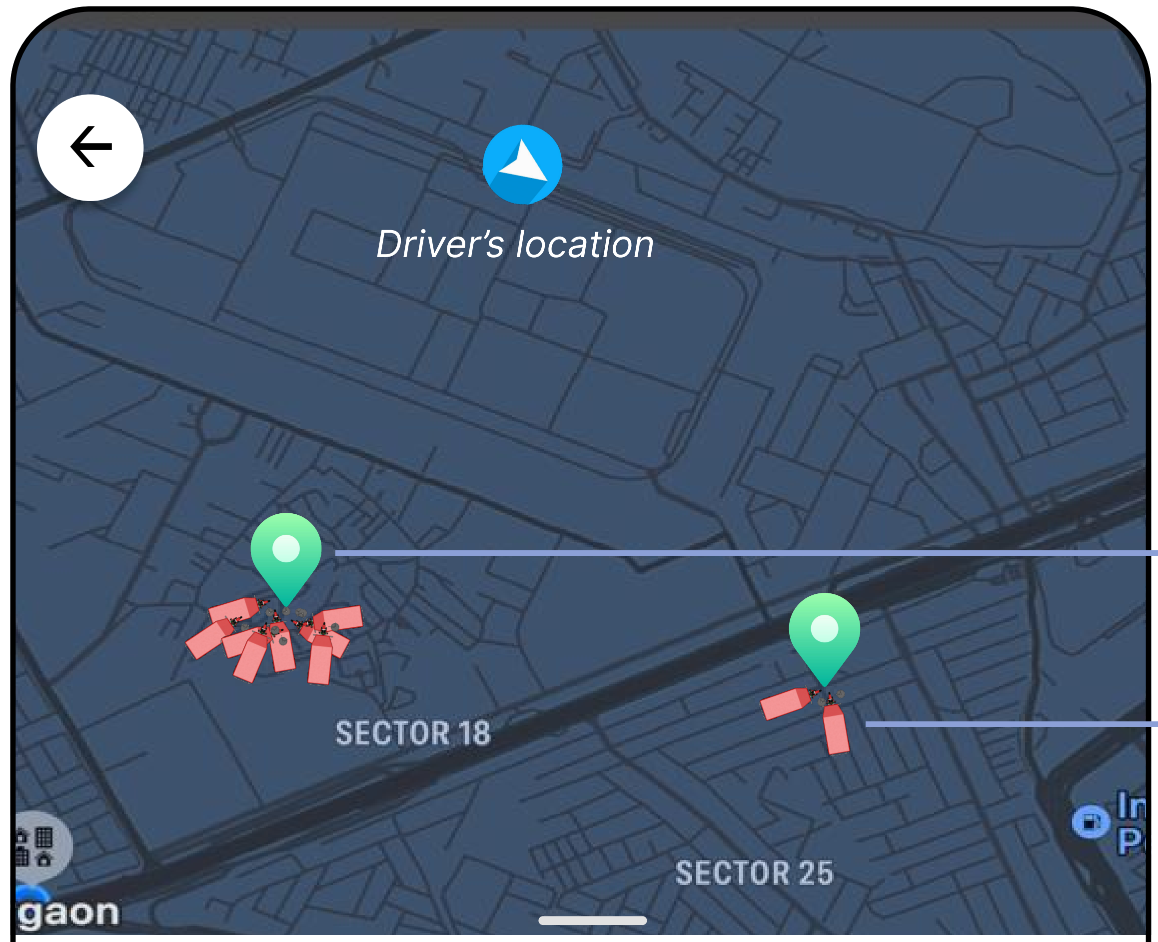
1. Even distribution of demand (Reducing T_{queue})
2. Availability of Batteries During Peak Hours (Reducing $T_{availability}$)

Resources: [1] [2] [3]

Battery Smart

1 Real-time traffic visualisation at stations

Driver's Interface



Near by Swap Stations

Swap Station, Sector 25
Distance: 4.4 Km
Low traffic: 2 EVs, 6 min

Swap Station, Sector 18
Distance: 3 Km
Heavy traffic: 8 EVs, 24 min

Swap Station, Sector 15
Distance: 7 Km
Moderate traffic: 5 EVs, 15 min

Notification

Battery Smart
Hey! Want to swap batteries?
Check for the traffic at stations first.

The map shows
- Battery smart stations near driver's location
- Live traffic at stations

This will help drivers make informed decisions

Priority of stations set:
- Station with least number of EVs present at a given time shown first
- Station **under 5 Km radius** shown first
- **Estimated waiting time** is shown by analysing real time traffic

Number of vehicles per station shown & traffic categorised into low, moderate & heavy

Note: Location and names of the stations are not taken with actual data

Technical Requirements

Requirements	Functionality	Impact
Real-time Traffic Visualization and Driver's Location Integration	• **Google Maps API** or Mapbox: Display nearby battery swapping stations on an interactive map, along with real-time traffic levels • **GPS tracking:** updates the driver's location dynamically	Guides drivers to less crowded stations, reducing overall wait times and enhancing the user experience by providing up-to-date traffic conditions
Estimated Waiting Time	• **Predictive model** (e.g., Gradient Boosting): Estimate wait times using real-time data & historical demand patterns • Updates continuously to reflect current station load and expected wait times	Provides accurate wait time estimates, reduce overcrowding, and help drivers choose stations with shorter queues
Station Priority Display	• **Backend logic:** Prioritize and rank stations based on factors like proximity, current traffic levels, & waiting times • Displays stations in order of lowest congestion and shortest distance, **refreshing in real-time** as conditions change	Directs drivers to optimal stations, balancing station load, minimizing wait times, and improving throughput across high-demand locations

Battery Smart

2 Introduction to slot booking system

Driver's Interface

SLOT BOOKING

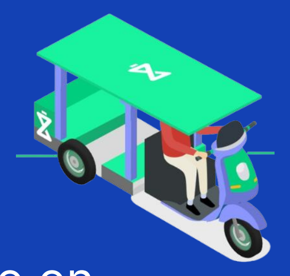
Station name ...

	4:30-5:00 PM	3 Slots
Today	**5:00-5:30 PM**	**5 Slots**
Tomorrow	5:30-6:00 PM	8 Slots
Mon, 4 Nov	6:00-6:30 PM	7 Slots
Tue, 5 Nov	6:30-7:30 PM	10 Slots

60%
Battery remaining

42 Km
Distance to go

Previous Analysis



Go on without booking

Notification

Battery Smart
Hey! Your EV's battery is about to die.
Book a slot to avoid long waiting time now.

Slots for a specific station is shown:
- Maximum of 10 slots available in half an hour (considering 3 mins/battery swap)
- Driver can book the slot for later days also, by **estimating battery usage** according to their activity

Shown here is the **estimated distance** the vehicle can cover with the amount of charge remaining in the battery

Analysis of previous rides shown: Average Battery lifecycle, Daily battery usage, Frequency of battery swaps

Slot booking is kept **optional** for drivers but priority will be given to booked slots

Technical Requirements

Requirements	Functionality	Impact
Real time availability tracking	• WebSocket, Node.js, Redis • **Real-time inventory managemen**t system: track & update availability of swapping slots dynamically • Integrate with existing station management systems to pull real-time data on battery availability	Instant updates on slot availability, reduced wait times
Battery usage estimation tool	• **Machine Learning**, Google Maps API • Estimates battery usage based on the user's daily activity and distance to be traveled • **GPS functionality:** Calculate distance and battery consumption based on vehicle performance data	Accurate battery consumption forecasts, optimized slot selection, convenient choice of time slot available
Booking Management & analytics	• Tableau, Python • **Backend analytics system:** collect data on user behavior, peak usage times, and slot booking trends • Provide management with reports on customer satisfaction, average wait times, and the impact of the slot booking system on throughput	Provides actionable insights for operational improvements and strategic decision-making; Traffic distributed efficiently

3 Proactive battery swapping

Driver's Interface

Notification

Battery Smart

Hey! Now you can swap your batteries even before it's completely discharged.

Say, if a driver swaps battery at 20% charge, the price will be 20% less for them

- Drivers will be given an option to swap batteries after it has reached a minimum charged percentage (say 40%)
- The price of the battery will be reduced by the percentage of charge remaining in battery

Technical Requirements

Requirements	Functionality	Impact
Battery usage estimation tool	• **GPS functionality:** Calculate distance and battery consumption based on vehicle performance data • Estimates battery usage based on the user's daily activity and distance to be traveled	Drivers can swap batteries before hand so they don't have to take breaks during peak hours Less or no breaks will ensure increment in working hours of driver, implying higher income
Booking Management & analytics	• **Backend analytics system:** collect data on user behavior, peak usage times • Provide management with reports on customer satisfaction, average wait times, no. of early battery swaps	Less demand during peak hours but daily average number of batteries remain same

Factors \ Proposed Solutions	Traffic Visualisation	Slot Booking	Proactive Battery Swapping
Level of Impact on drivers	4 *Real time traffic display to users, suggest changes*	2 *Can't check for the drivers coming without booking*	1 *Affect battery lifecycle*
Reach	4 *Low effort for drivers; convenient usage*	2 *An added effort to book; slots might not be available*	3 *Convenient, optional usage; Not all will do this*
Technical Feasibility	2 *GPS, real time tracking, predictive model*	3 *Allowing users to see traffic at desired stations*	4 *Allowing users to see traffic at desired stations*
Overall Score	3.3/5	2.3/5	2.6/5

- **Real time traffic visualisation** is the most prioritized feature due to high expected impact and high utility over current operational method
- **Sprint prioritization** will pick Proactive battery swapping and then in the end slot booking

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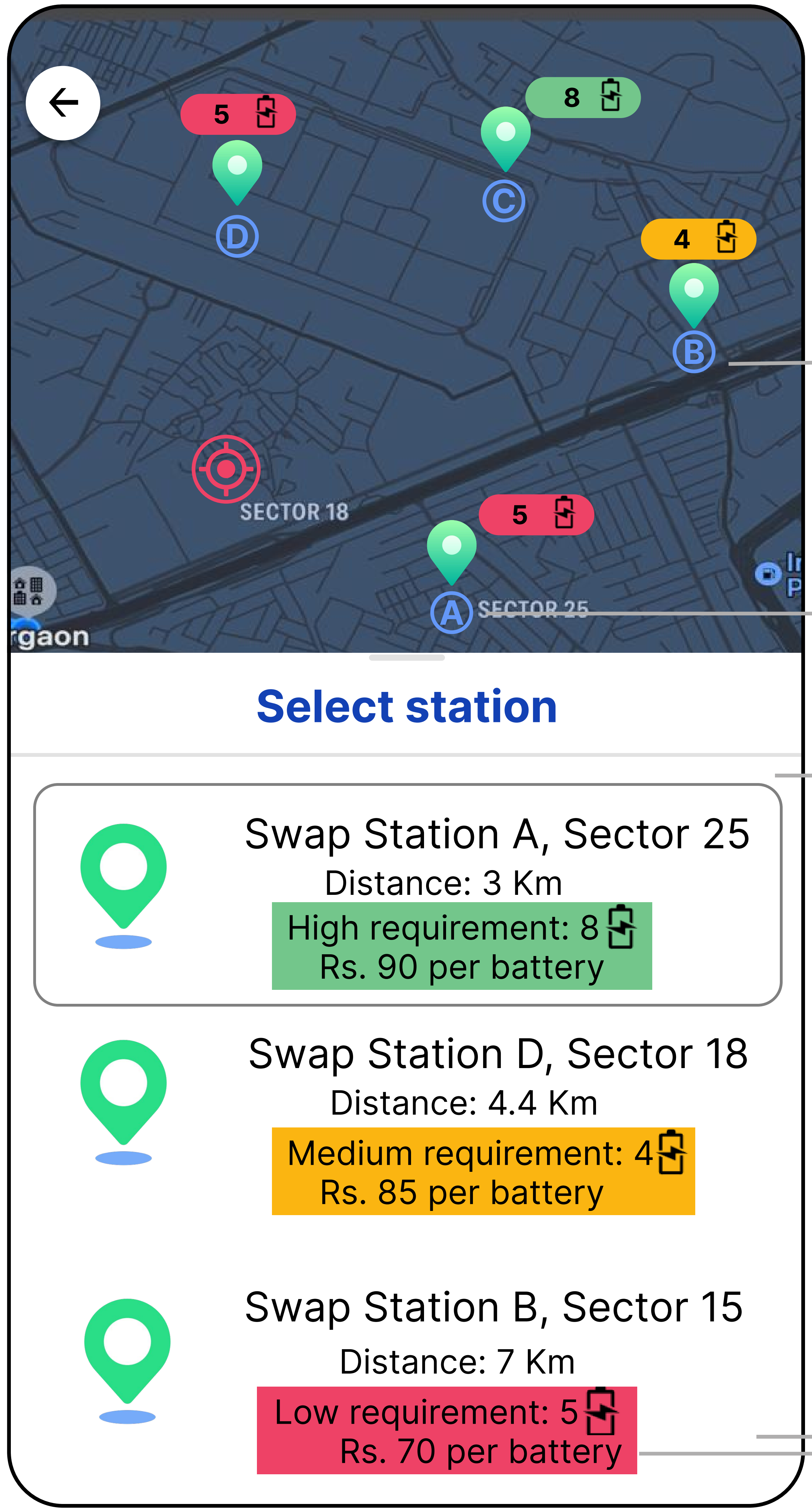
1 Distribution of charged batteries based on station demand

Partner's Interface



Partner's have the option to sell their batteries at other stations during non peak hours

Notification

Battery Smart

Hey! Sector 25 swap station is low on charged batteries.
Boost the network—keep the power flowing strong.

The map highlights nearby stations currently experiencing high demand and in need of additional batteries.

Stations are prioritized as follows:

1. **High Demand and Revenue:** First, stations with the highest demand and revenue potential
2. **Proximity:** Next, those within a 5 km radius
3. **Dynamic Pricing:** Finally, real-time prices are adjusted based on demand and distance

Since the battery is charged at a partner's station, the partner receives a share of the revenue from the battery's sale displayed here

Technical Requirements

Requirements	Functionality	Impact
Forecasting the number of batteries required	• Use **sensors** and **GPS** data from vehicles to track current battery levels and the driver's location. • Employ **ML** algorithms such as time series forecasting (e.g., ARIMA, SARIMA) or regression models (e.g., linear regression, random forests) to predict future demand.	Provides a forecast of the batteries required at a specific station at a particular time, comparing this with the nearby vehicles and assessing the demand to notify all stations, ensuring they are prepared accordingly.
Real-time formation of Hexagonal Hierarchical Geospatial Indexing System (H3)	• **IoT Sensors:** To track the number of charged and discharged batteries in real time. • **H3 Library:** Divides areas around each swap station into hexagonal grids, representing battery availability. • **Google Maps API** provides route optimization, geocoding, and real-time updates, while Mapbox is open-source and compatible with H3.	Helps make and identify regions with a lower number of charged batteries compared to the number of drivers with low battery levels.
Dynamic Price moderation	• Use **backend logic** to calculate dynamic pricing per battery based on factors like the number of required batteries and the distance between the stations, while also considering real-time demand fluctuations and inventory levels.	Provides estimate of dynamic revenue generated for each battery supplied to different stations, benefiting both the supplier and the receiving station.
Optimization of Battery Logistics	• **Python's OR-Tools by Google** offers various Vehicle Routing Problem (VRP) solvers to optimize the transfer of batteries from one spatial region to another, enabling efficient route planning and minimizing transportation costs for battery redistribution.	This will ensure the smooth and optimized transfer of batteries from regions with an excess of charged batteries and low requirements to regions with fewer charged batteries and high requirements.

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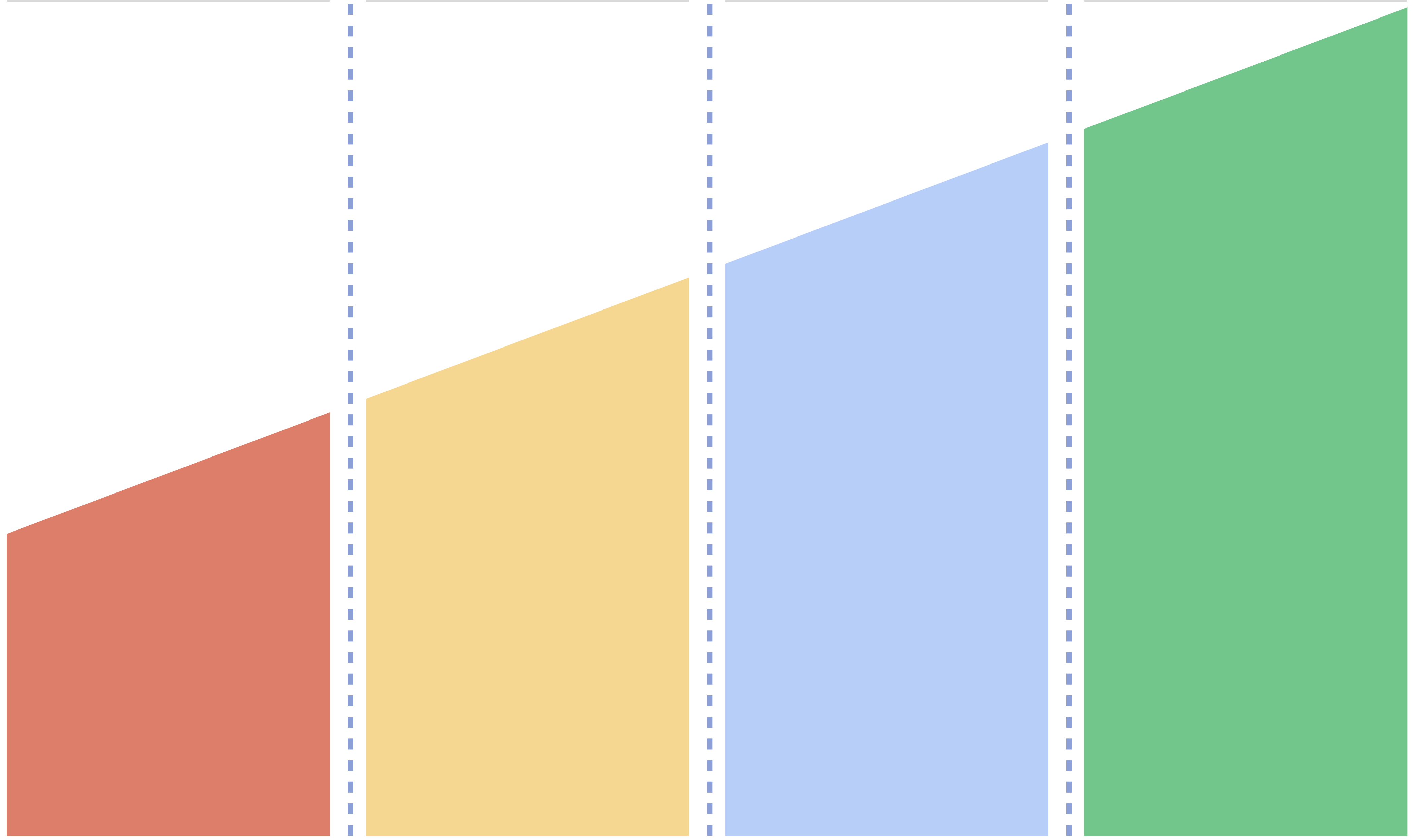
Go to Market Strategy

Level

Test Launch in a Local Area	Iterate and Enhance	Full-Scale Launch and Promotion	Ongoing Monitoring and Optimization



Stage 1	Stage 2	Stage 3	Stage 4
Launch the feature in a targeted area, like Gurgaon, with a high concentration of EV users and battery swapping stations, while gathering feedback and monitoring KPIs	Review collected feedback and data to identify key issues, feature requests, and areas for improvement. Make adjustments based on user input	Expand the rollout to other high-EV adoption cities, such as Delhi, Bangalore, and Mumbai, before moving to full-scale coverage. Develop a comprehensive marketing plan	Regularly track the feature's performance across all active markets and create a roadmap for updates based on user feedback and new technological improvements

Success Metrics

North Star Metric:

- %Reduction in average waiting period
  (final goal was to reduce long waiting period in peak hours)
  Other overall metrics to see success:
- Average difference in traffic distribution in a day
- % Increase in driver's income

Feature specific Metrics

Traffic visualisation	• # Drivers navigating traffic • % shift in traffic from previously swamped stations • Effectiveness of estimated waiting time
Slot booking system	• # Daily slot booking • % swaps from slot booking • Average waiting time of unbooked battery swaps
Proactive Battery Swapping	• % Daily proactive battery swaps • % Decrease in battery lifecycle efficiency • % Increase in driver's work shift
Redistribution of charged batteries	• % increase in battery swaps/ station • # Inter station battery exchanges

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Real-time traffic visualisation at stations

Risks	Mitigation
A sudden shift of a station from **low to high** traffic can disrupt drivers already en route to that station	Real-time classification of EVs as **'In-ride' or 'Idle'.** An Idle EV within a 0.5 km range of a station will be counted as part of that station's traffic
Requirements for GPS, real-time tracking, and predictive models may take considerable time to become **accurate and optimized**	Solution initiation by collecting **data from stations** with vehicle sensors at entry and exit gates, and validating GPS, real-time tracking and predictive models to optimize the developed models

Introduction to slot booking system

Risks	Mitigation
Possibility of drivers **skipping** their pre-booked slots could cause issues for other drivers in need of slots or instant battery swaps	**Penalty** for drivers who do not show up on time or at all for their slots, involving restrictions on future slot booking opportunities or a monetary penalty
Drivers arriving **without a reserved slot** may experience delays	Proper **allocation** of pre-booked slots should be implemented while also accommodating drivers arriving without a reservation, based on **predictive analysis**

Proactive battery swapping

Risks	Mitigation
Recharging batteries at a high frequency can adversely **affect their lifespan**	Incentivizing the **20%-80%[1] rule** for plugging and unplugging batteries would rather increase their lifecycle. Moreover, offering incentives for optimal battery percentages during swaps
All drivers will swap their batteries **early in the day** to benefit from discounts and ensure uninterrupted travel, creating **peak demand and synchronizing** battery levels	Discounts offered at **specific times of the day** that doesn't add up to the waiting times for drivers, avoiding synchronization of battery percentages based on records of battery swaps

Distribution of charged batteries based on station demand

Risks	Mitigation
Station managers would prefer **not to sell** charged batteries to another station at a lower cost instead of swapping them with drivers	Overall analytics should ensure that the **benefits** from selling charged batteries to other stations **exceed** those from waiting for drivers to arrive
This incurs **additional logistics** costs for transferring charged batteries between stations	**Partnerships** with companies like **Yulu** can provide logistics support in exchange for subsidized batteries

[1]: 20%-80% rule for plugging and unplugging batteries

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