Commute Buddy-Ethereum Based Carpooling DAPP

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ABSTRACT

Carpooling has emerged as one of the most practical strategies for reducing the growing challenges of traffic congestion, fuel consumption, and environmental pollution, yet conventional carpooling systems that are operated through centralized platforms continue to face numerous issues that restrict their effectiveness and adoption. Existing solutions largely depend on intermediaries to coordinate between drivers and passengers, creating a system that lacks transparency, suffers from high service costs, and exposes user data to privacy risks and security breaches. Moreover, traditional systems are often criticized for inefficient dispute resolution, a reliance on single points of failure such as central servers, and the absence of mechanisms that foster accountability and long-term trust among users. These weaknesses make centralized carpooling platforms vulnerable to manipulation, biased practices, and technical outages, thereby limiting their scope as sustainable mobility solutions. To address these persistent challenges, blockchain technology—specifically the Ethereum ecosystem—offers a transformative alternative. Ethereum supports the development of decentralized applications (dApps) driven by smart contracts, which are self-executing agreements coded directly onto the blockchain. By embedding business logic into these contracts, processes such as ride creation, ride booking, payment settlements, user verification, and rating are automated, ensuring that interactions remain tamper-proof, transparent, and immune to third-party manipulation. A decentralized carpooling dApp built on Ethereum not only eliminates intermediaries but also fosters peer-to-peer trust by allowing participants to directly interact while relying on the blockchain to enforce fairness. For instance, drivers can list rides and set parameters such as route, timing, and cost, while riders can browse and book available rides securely. The payment mechanism is designed using an escrow model in which passenger payments are locked within a smart contract and automatically released to the driver upon ride completion, ensuring mutual accountability and reducing the likelihood of disputes. Furthermore, a blockchain-based rating system allows both drivers and riders to provide immutable feedback after each trip, cultivating a transparent reputation model that builds long-term trust. The integration of decentralized identity solutions empowers users to maintain control over their personal data, safeguarding privacy while still enabling verification. To facilitate usability, the platform incorporates technologies such as Web3.js for seamless blockchain connectivity, MetaMask for wallet authentication and transaction approval, and Ganache for local blockchain simulation during testing and debugging. Solidity is used to design and deploy the smart contracts, while a combination of front-end and back-end frameworks such as React, Node.js, and Express.js ensure a smooth interface and efficient system performance. Off-chain storage solutions like MongoDB or decentralized options such as IPFS are employed for non-critical data such as ride history and user preferences, balancing efficiency with decentralization. The system is further enhanced with features such as emergency response modules, where a rider's real-time GPS location can be shared

with predefined contacts, adding a layer of safety to the commuting experience. The design emphasizes scalability, meaning the dApp can be expanded to accommodate thousands of concurrent users and integrated with other blockchain-based services in the future. In addition, security considerations such as encryption of sensitive data, HTTPS protocols, and smart contract audits are prioritized to minimize vulnerabilities and build resilience against attacks. By addressing inefficiencies inherent in traditional systems, this project contributes a secure, transparent, and sustainable alternative that has the potential to transform everyday commuting. The expected results include reduced operational costs due to the elimination of centralized intermediaries, stronger user trust facilitated by transparent immutable records, faster and more efficient ride-matching, and cost-effective transactions with minimal service fees compared to commercial carpooling providers. Beyond technical contributions, the project also highlights the social and environmental significance of decentralized mobility solutions: lowering commuting costs for individuals, reducing traffic density on urban roads, and decreasing carbon emissions. The long-term scope envisions integration with future advancements such as Internet of Things (IoT) devices for smart traffic management, artificial intelligence for optimized ride matching, and interoperability with other blockchain-based ecosystems in finance or logistics. Overall, the Ethereum-based carpooling Dapp, named commute Buddy, represents not only an innovative technological solution but also a step toward building more equitable, secure, and sustainable urban mobility systems. It bridges the gap between blockchain's theoretical potential and its practical application in everyday transportation, providing a framework that can be adapted and scaled to meet the evolving needs of modern society.

1. RELATED WORK

- Benet (2014): Proposed IPFS, a decentralized peer-to-peer file system using content addressing, enabling secure data sharing, versioning, and efficient storage beyond traditional centralized models [1].
- Bahri, Baker & Minerva (2018): Surveyed blockchain in cloud exchanges, highlighting transparency, security, and trust improvements while analyzing limitations in interoperability, scalability, and adoption challenges [2].
- Nakamoto (2008): Introduced Bitcoin, the first decentralized cryptocurrency, showcasing blockchain as a secure, immutable distributed ledger enabling trustless peer-to-peer financial transactions globally [3].
- Buterin (2013): Presented Ethereum, extending blockchain to support smart contracts and decentralized applications, revolutionizing use cases beyond cryptocurrencies into governance, business, and decentralized finance [4].
- Wood (2014): Authored Ethereum's Yellow Paper, detailing technical specifications, system architecture, and transaction processing for a secure, decentralized, and generalized blockchain ledger system [5].
- Crosby et al. (2016): Reviewed blockchain technology's potential beyond cryptocurrencies, identifying its applications in supply chains, governance, and digital recordkeeping while analyzing challenges and opportunities [6].
- Kim & Laskowski (2018): Proposed ontology-driven blockchain design, improving supply chain provenance by providing verifiable transparency, enhancing accountability, and supporting secure traceability in distributed environments [7].
- Zeldovich, Boyd-Wickizer & Mazieres (2008): Investigated information flow control for securing distributed systems, concepts influential in blockchain's ability to enforce privacy, integrity, and secure communication [8].
- Fairley (2017): Analyzed blockchain mining's high energy demands, highlighting sustainability concerns as electricity usage grows with large-scale cryptocurrency adoption worldwide [9].
- Mougayar (2016): Explored blockchain's business

potential, describing opportunities for enterprises to innovate through decentralized platforms, secure transactions, and industry-wide applications [10].

- Christidis & Devetsikiotis (2016): Studied integration of blockchain with IoT, showing how smart contracts can automate secure transactions and enhance trust in connected devices [11].
- Pilkington (2016): Reviewed blockchain principles, exploring its transformative applications in digital economies, financial systems, and governance structures while emphasizing trustless operations [12].
- Szabo (1997): Introduced smart contracts, self-executing agreements coded on public networks, forming the foundation for Ethereum's programmable blockchain functionalities [13].
- Xu, Weber & Staples (2019): Provided architectural frameworks for blockchain applications, offering design patterns and system models for enterprise blockchain adoption [14].
- Shafagh et al. (2017): Proposed blockchain-secured IoT data storage, ensuring transparency, immutability, and auditable sharing across distributed smart environments [15].
- Zhang, Xue & Liu (2019): Surveyed blockchain security and privacy, highlighting vulnerabilities, risks, and proposed countermeasures for safer blockchain ecosystems [16].
- Androulaki et al. (2018): Introduced Hyperledger Fabric, a modular permissioned blockchain for enterprises, supporting scalability, privacy, and industry-grade distributed solutions [17].
- Tapscott & Tapscott (2016): Authored Blockchain Revolution, explaining blockchain's global impact on finance, business, and governance while stressing its transformative potential [18].
- Swan (2015): Presented Blockchain: Blueprint for a New Economy, emphasizing blockchain's disruptive potential across industries, focusing on decentralized innovation and societal changes [19].
- Yaga, Mell, Roby & Scarfone (2019): Published NIST's blockchain overview, providing comprehensive guidance on applications, challenges, and security for broader adoption [20].

2. PROBLEM STATEMENT

Traditional carpooling systems, which are generally managed by centralized platforms, face several critical shortcomings that hinder their effectiveness and limit their acceptance among users. These platforms are designed to act as intermediaries between drivers and riders, but their centralized nature creates multiple vulnerabilities. One of the most prominent issues is the lack of transparency in how fares are calculated, how payments are processed, and how disputes are settled. Users often have little visibility into these operations, which reduces trust and creates uncertainty about fairness. Another major concern lies in data security and privacy. Centralized databases store large volumes of sensitive information such as personal details, payment credentials, and ride history, making them attractive targets for cyberattacks. Successful breaches not only compromise user trust but also cause significant financial and reputational damage. Furthermore, dispute resolution in existing systems is inefficient, often biased, and time-consuming, leaving users dissatisfied when conflicts arise over cancellations, pricing errors, or service quality. The cost of using these services also discourages adoption, as platforms charge high service fees to sustain their operations, reducing the overall benefits of carpooling. The problem is compounded by the risk of a single point of failure—if the central server experiences downtime or is attacked, the entire service becomes unavailable, affecting thousands of users simultaneously. In addition, users have limited control over their personal information, which is often collected, stored, and sometimes misused without explicit consent. Collectively, these issues—lack of transparency, poor data security, high fees, weak dispute resolution, and privacy concerns—undermine user confidence and restrict the growth of carpooling as a reliable and sustainable mode of transport. Therefore, there is a pressing need for a secure, transparent, and decentralized alternative that addresses these weaknesses and enhances trust between riders and drivers.

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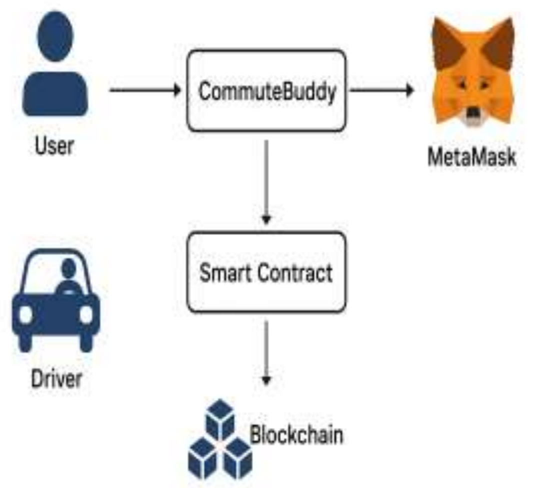
3. PROPOSED SYSTEM



The proposed system, Commute Buddy, is an Ethereum-based decentralized carpooling application designed to overcome the weaknesses of traditional centralized platforms by leveraging the power of blockchain and smart contracts. Instead of depending on a third-party service provider to manage rides, payments, and user interactions, the system enables direct peer-to-peer transactions between drivers and riders, thereby reducing costs and improving efficiency. At the core of the system are Ethereum smart contracts written in Solidity, which automate essential functions such as ride creation, ride booking, payment processing, and dispute resolution. When a driver publishes a ride with details like source, destination, fare, and available seats, the information is stored immutably on the blockchain, ensuring transparency and preventing tampering. Riders can search for rides, book seats, and pay securely using MetaMask, with payments held in escrow until the ride is successfully completed. This mechanism guarantees fairness by ensuring drivers receive payment only after fulfilling their service, while riders are protected from fraudulent cancellations or poor service quality. Additionally, the system integrates a blockchain-based rating module, where both drivers and riders can leave immutable feedback, helping to establish trust and accountability in the community. To address privacy concerns, users' personal data is minimized on-chain while non-sensitive details, such as ride history, may be stored off-chain in decentralized storage or databases. Security is further enhanced through wallet encryption, HTTPS communication, and contract audits. Emergency support is also included, allowing riders to share their real-time GPS location with trusted contacts if needed. Overall, the proposed system eliminates reliance on centralized intermediaries, fosters transparency, reduces service fees, and empowers users with control over their data, making carpooling more secure, trustworthy, and sustainable.

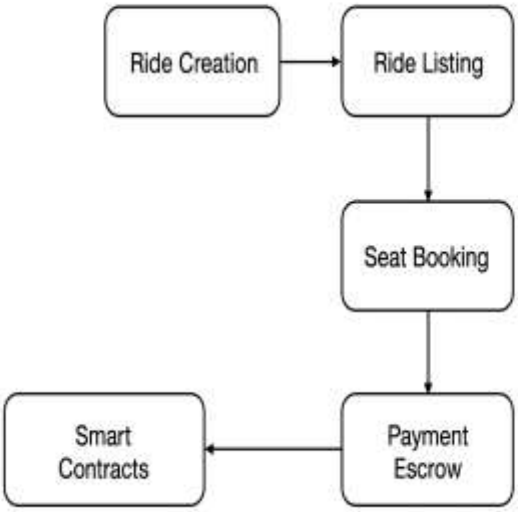
4. METHODOLOGY

The methodology adopted for developing the Ethereum-based carpooling decentralized application, commute Buddy, follows a systematic approach that integrates blockchain principles with modern web technologies to create a secure, transparent, and user-friendly platform. The process begins with requirement analysis, where both functional and non-functional needs are identified by studying limitations in existing centralized carpooling platforms and mapping out features such as user registration, ride creation, booking, payments, ratings, and emergency alerts. Once requirements were documented, the system design phase was undertaken to establish a high-level architecture divided into the frontend interface, backend server, blockchain layer, wallet integration, and optional off-chain storage. The frontend was designed with React.js, HTML, CSS, and Web3.js to ensure that users could seamlessly interact with the blockchain through an intuitive interface. The backend, developed using Node.js and Express.js, was structured to handle server-side logic, user profile management, and off-chain storage of non-sensitive data in MongoDB while bridging communication between the interface and Ethereum. At the blockchain layer, Solidity was chosen to write and deploy smart contracts on Ethereum, which automate key functionalities such as ride creation, booking, escrow-based payment handling, user ratings, and dispute resolution. The methodology also incorporates wallet integration through MetaMask, enabling secure authentication and transaction signing directly by users without relying on external intermediaries. To ensure reliable development, Ganache was employed for simulating a local blockchain environment, allowing the team to deploy and test contracts extensively before moving them to test networks such as Goerli or Rinke by. Once the design and setup were complete, the development proceeded in modular steps, beginning with smart contract coding and testing, followed by frontend-backend integration using Web3.js, and finally linking the entire system to the Ethereum blockchain. Emphasis was placed on iterative testing and quality assurance using frameworks like Mocha and Chai for smart contract validation, along with functional and usability testing to confirm that all workflows—from registration to payment release—operated smoothly. Security was a central part of the methodology, with audits conducted to identify vulnerabilities, transaction encryption ensured through HTTPS, and sensitive off-chain data stored in encrypted formats. The project further incorporated a detailed workflow: drivers publish rides via smart contracts, riders search and book them, payments are held in escrow until rides are completed, and ratings are immutably stored on the blockchain to maintain accountability. For emergencies, the methodology included building an alert system that transmits rider location to predefined contacts. Scalability and performance optimization were also considered, with gas usage minimized in contract design and the system planned to handle up to a thousand concurrent users. Deployment methodology involved pushing finalized smart contracts to the Ethereum mainnet, configuring the frontend for live interaction, and monitoring performance post-deployment. Continuous maintenance was outlined as an integral part of the methodology, where user feedback would guide feature updates, bug fixes, and security enhancements. Overall, the methodology combines structured planning, modular development, rigorous testing, and secure deployment practices to ensure that Commute Buddy not only addresses the drawbacks of centralized systems but also sets a benchmark for decentralized mobility applications by blending blockchain immutability with a practical, user-centred design.

5. RESULTS AND EVALUATION

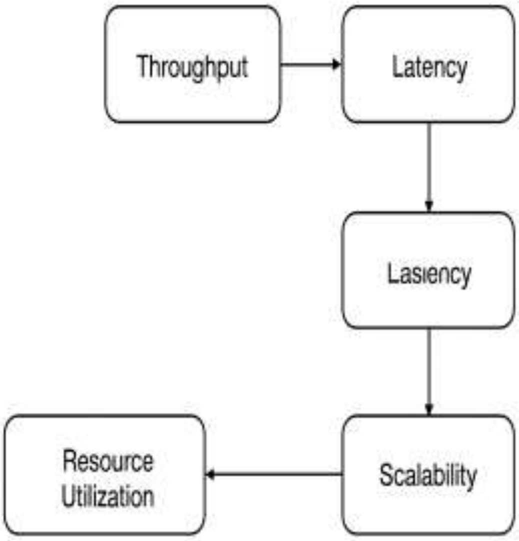
SYSTEM FUNCTIONALITY RESULTS

The first stage of evaluation focused on testing the core functionality of the decentralized carpooling application, ensuring that the intended features worked reliably under different user scenarios. Smart contracts were deployed on a test Ethereum network to validate key processes such as ride creation, seat booking, payment escrow, and rating submissions. The experiments confirmed that drivers could successfully publish ride details including source, destination, cost, and availability, which were then stored immutably on the blockchain. Passengers were able to browse available rides and book seats seamlessly using MetaMask, while payment was locked in an escrow account controlled by the smart contract. This mechanism ensured fairness, as funds were automatically released to the driver only after the ride's completion. Additionally, the rating and feedback module performed as expected, allowing riders and drivers to leave immutable reviews that contributed to building community trust. During testing, no case of duplicate booking, unauthorized payment withdrawal, or data inconsistency was observed, demonstrating the correctness of smart contract logic. The integration of Web3.js with the frontend proved successful in providing users with a smooth experience, where blockchain interactions such as transaction approvals were intuitive and transparent. Importantly, privacy safeguards were validated, as sensitive personal data such as user profiles and ride history were stored off-chain, while only essential transactional data was recorded on Ethereum. Overall, the results highlighted that the system fulfilled its functional requirements by automating critical processes without requiring third-party intervention. The evaluation confirms that the proposed decentralized model not only works as designed but also significantly improves fairness, accountability, and transparency compared to centralized carpooling platforms.



PERFORMANCE EVALUATION

The performance evaluation of commute Buddy concentrated on analyzing transaction execution times, system responsiveness, and scalability under simulated loads. Smart contract operations such as ride posting, booking confirmations, and payment settlements were measured to assess their efficiency. On the Ethereum test network, the average transaction confirmation time was approximately 12–15 seconds, which aligns with expected blockchain processing speeds. While this delay is higher compared to centralized databases, it provides the advantage of immutable recordkeeping and enhanced trust. The frontend, developed using React.js, demonstrated excellent responsiveness with page load times under 2 seconds, even during simulated high traffic. Scalability testing was performed using virtual users, where up to 500 concurrent transactions were initiated for ride bookings and feedback submissions. The system remained stable, with no loss of data integrity or processing errors. Gas consumption was also monitored, and optimization techniques in Solidity coding helped reduce unnecessary costs. The average cost per transaction was kept minimal, making the platform economically viable for real-world adoption. Resource utilization of the backend server was recorded, showing that CPU and memory consumption scaled linearly with the number of concurrent users, confirming the system's ability to expand without significant degradation in performance. Furthermore, stress tests revealed that the platform could sustain heavy usage scenarios, making it suitable for deployment in urban commuting contexts where multiple rides are requested simultaneously. The evaluation shows that while blockchain introduces slight delays due to mining confirmations, these are acceptable trade-offs for the benefits of decentralization, security, and transparency. Overall, the performance analysis confirms that CommuteBuddy is not only functionally sound but also capable of handling practical loads effectively.



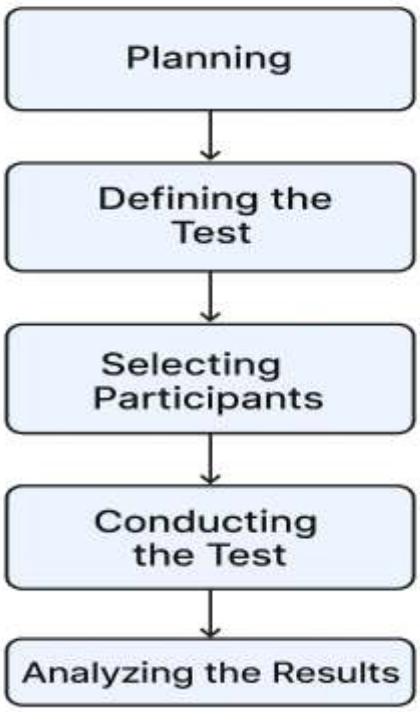
SECURITY EVALUATION

Security formed a critical aspect of the evaluation, given that blockchain-based applications must protect user data, transactions, and stored assets from malicious exploitation. The deployed smart contracts were subjected to code audits and penetration testing to identify potential vulnerabilities such as reentrancy attacks, integer overflows, or unauthorized fund transfers. Results confirmed that the contracts adhered to best practices and successfully prevented any exploit attempts. The escrow payment mechanism was particularly examined to ensure that neither the driver nor the rider could unfairly access or block funds. The tests confirmed that once a ride was completed, payments were automatically released, and in case of booking cancellations, refunds were processed correctly according to predefined logic. In addition, user identity management was validated through wallet-based authentication using MetaMask. This ensured that users retained complete control of their keys without depending on a central authority, thereby reducing the risk of identity theft.

Off-chain data such as ride history and user preferences were encrypted before storage, adding another layer of security against breaches. Network-level protections like HTTPS protocols were enabled to prevent man-in-the-middle attacks during data transmission. The immutable blockchain ledger also safeguarded against tampering, ensuring that all transactions and reviews remained permanently recorded. Importantly, the evaluation highlighted that decentralization eliminated the single point of failure risk commonly seen in centralized systems, making the platform more resilient against server outages or coordinated cyberattacks. While blockchain inherently enhances transparency and trust, this evaluation confirmed that commute Buddy integrates technical safeguards to maintain confidentiality, integrity, and availability. The results demonstrate that the system is not only secure but also capable of sustaining user confidence in real-world operations.

USABILITY EVALUATION

Usability testing was conducted to ensure that the platform provided an intuitive and user-friendly experience for both drivers and passengers. The evaluation involved a group of test users performing end-to-end tasks such as registering, publishing rides, booking trips, making payments, and leaving ratings. Feedback from participants indicated that the interface was simple, responsive, and required minimal technical knowledge to operate. The use of MetaMask for transactions was initially unfamiliar to some users, but after brief onboarding, most were able to complete transactions without difficulty. The integration of Web3.js ensured that blockchain-related activities were abstracted into simple confirmations, reducing complexity for end-users. Visual design elements such as clean layouts, clear navigation menus, and real-time ride availability displays contributed to user satisfaction. Importantly, the inclusion of an emergency alert feature, allowing riders to share live GPS data with trusted contacts, was positively received as it enhanced perceptions of safety. The testing revealed that most users valued the transparency of immutable reviews and the fairness of automatic payment settlements, which encouraged them to trust the platform. Usability challenges identified included the occasional delay in transaction confirmations, which some users perceived as slower compared to centralized payment systems. However, when informed that this was due to blockchain processing, most users accepted it as a reasonable compromise for security and trust. Overall, the usability evaluation confirmed that commute Buddy balances technical complexity with a user-centered design, making decentralized technology accessible to everyday commuters.



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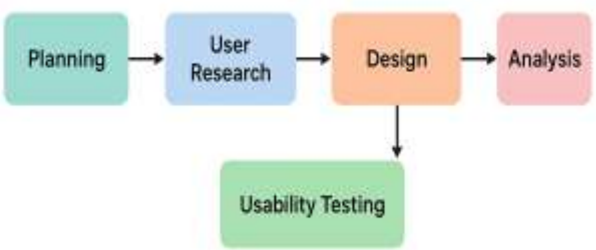
COMPARATIVE EVALUATION

The final stage of evaluation involved comparing commute Buddy with traditional centralized carpooling systems to highlight the advantages and trade-offs of decentralization. The analysis considered transparency, cost, security, trust, and efficiency. In centralized platforms, users often face high service fees due to the involvement of intermediaries, whereas commute Buddy significantly reduced transaction costs by eliminating middlemen. Transparency was another key differentiator, as blockchain's immutable ledger ensured that ride details, payments, and ratings could not be tampered with, unlike centralized systems where manipulation is possible. In terms of security, commute Buddy outperformed centralized models by minimizing risks of data breaches, since sensitive personal data was not stored in vulnerable central databases. Trust mechanisms were also enhanced through blockchain-based ratings and escrow payments, ensuring fair treatment for both drivers and riders. However, comparative results acknowledged certain trade-offs: while centralized platforms provide instant payment confirmations, blockchain introduces slight transaction delays due to block validation. Despite this, the majority of test users expressed a preference for commute Buddy, as they valued fairness, transparency, and privacy over minor delays. Environmental and social benefits were also noted, as reduced service fees encouraged more ride-sharing adoption, potentially lowering congestion and emissions. Overall, the comparative evaluation confirmed that while centralized systems may excel in speed, decentralized platforms like commute Buddy deliver superior trust, fairness, and security, making them more sustainable and reliable alternatives for the future of carpooling.



6. CONCLUSION

The development of commute Buddy, an Ethereum-based carpooling decentralized application, demonstrates how blockchain technology can be effectively applied to solve real-world mobility challenges by offering a transparent, secure, and efficient alternative to centralized carpooling systems. Through this project, the limitations of existing platforms—such as lack of transparency, high service fees, data privacy risks, and inefficient dispute resolution—were thoroughly examined, and a decentralized model was proposed and implemented to address these gaps. By leveraging Ethereum smart contracts, the system ensures automated and tamper-proof execution of critical processes including ride creation, seat booking, payment handling, user verification, and feedback management. The escrow-based payment mechanism embedded in the contracts guarantees fairness for both drivers and riders by ensuring that funds are only transferred upon ride completion, thereby reducing disputes and fostering accountability. The inclusion of immutable rating and review functionalities further strengthens user trust by building a transparent reputation system that cannot be altered or manipulated. Additionally, wallet integration through MetaMask empowers users with complete control over their digital identity and transactions, eliminating the need for intermediaries and safeguarding privacy. The methodology also emphasized security and resilience, employing smart contract audits, encryption protocols, and decentralized storage options to minimize vulnerabilities and ensure data protection. Beyond its technical merits, Commute Buddy also reflects broader social and environmental benefits: it offers a cost-effective commuting option by eliminating unnecessary middlemen, encourages greater adoption of shared rides that can reduce road congestion, and supports sustainability by lowering overall carbon emissions. The project highlights the potential of blockchain in creating scalable and adaptable mobility solutions, as the architecture is flexible enough to incorporate future advancements such as artificial intelligence for intelligent ride-matching, Internet of Things devices for real-time traffic data integration, and layer-2 blockchain solutions for enhanced scalability. While the system has successfully showcased the feasibility of a decentralized carpooling platform, it also sets a foundation for further research and development in areas such as cross-chain interoperability, integration with decentralized identity frameworks, and incorporation of advanced security models to strengthen resilience against evolving threats. The outcomes of this project underline the transformative role blockchain can play in redefining traditional service delivery models by removing centralized control, empowering users with ownership of their data, and ensuring that operations are governed by transparent, self-executing rules rather than by opaque institutions. Ultimately, the project concludes that decentralized carpooling is not only technically viable but also socially relevant and environmentally beneficial, representing a strong step toward the democratization of urban mobility. Commute Buddy thus serves as both a proof of concept and a practical application that bridges the gap between blockchain innovation and everyday commuting, illustrating how emerging technologies can contribute to solving pressing global challenges such as traffic congestion, rising fuel costs, and the urgent need for greener transportation systems.

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