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Blockchain Meets Autonomous Electric Taxis: Innovating for Security and Efficiency for Sustainable Future

Ramdhan Nugraha◆, Soo Young Shin°

ABSTRACT

The rapid evolution of autonomous vehicles (AV) and advancements in renewable energy technologies present a unique opportunity to redefine urban transportation. This research explores the integration of autonomous electric taxis (AET) with blockchain technology to address key operational challenges and enhance the efficiency and sustainability of urban mobility. Our research focuses on three critical aspects: the selection of AET, the optimization of charging station locations, and the development of secure, transparent reservation and payment mechanisms through blockchain. The findings suggest that integrating blockchain with AET systems mitigates existing operational inefficiencies and propels the transportation sector toward a more sustainable future. This research contributes to the ongoing discourse on smart cities by demonstrating blockchain's practical applications and benefits in autonomous transportation, potentially influencing global urban transportation policies and practices.

Key Words : Blockchain, Autonomous electric taxi, Charging station, Scheduling, Smart Contract

Ⅰ. Introduction

1.1 Problem Statement

Autonomous cars have advanced significantly in the past few years. Many car companies and tech companies worldwide, like Google, Uber, Tesla, and Toyota, are testing their self-driving cars on real roads[1]. For example, a tech company in Singapore called nuTonomy uses autonomous vehicles (AV) as taxis in 2.5 square miles[2]. These cars were the first driverless vehicles operating on actual streets in Singapore, alongside conventional human-operated vehicles. However, in some countries, AVs are only allowed in certain places and on some public roads. AVs initiate their operation upon receiving commands sent to the internal controller. Drive autonomously, following instructions provided by the controller. Contrary to the efficiency of AVs, traditional taxis also emit harmful pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOCs), and particulate matter, all of which pose health risks and increase societal morbidity and mortality[3].

The AV ecosystem is becoming a crucial focus for companies and car manufacturers as they strive to develop robust solutions that automate driving, refueling, software updates, and data management within vehicles. This area of research is pivotal in demon-

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◆ First Author : Kumoh National Institute of Technology, Department of IT Convergence Engineering; Telkom University, Faculty of Electrical Engineering, ramdhan@kumoh.ac.kr, 학생회원

° Corresponding Author : Kumoh National Institute of Technology, Department of IT Convergence Engineering, wdragon@kumoh.ac.kr, 종신회원

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strating their capability to create stable systems. Evaluating these solutions often prioritizes the safety of passengers and pedestrians, prompting significant investment in research and development to maintain a competitive edge[4].

Customers choose taxis mainly because they have limited time, but heavy traffic often prevents them from reaching their destinations on time. Meanwhile, the current system is unable to meet the entire taxi demand during peak hours. Measures are needed to address this issue fully. The adoption of AV and renewable energy is undergoing a significant transformation in the transportation sector during a time of rapid technological advancement. One of the most promising innovations in this field is using autonomous electric taxis (AET). On the other hand, it is a subset of EVs specifically equipped with autonomous driving technology to operate as taxis without human drivers. These vehicles offer a solution for reducing carbon emissions and enhancing the efficiency and safety of transportation systems. However, implementing AET introduces unique challenges, particularly concerning security, data management, and operational transparency.

Papers[5] and[6] both emphasize enhancing data security and integration within vehicular networks. Paper [5] describes a secure inter-vehicle communication network that uses side channels and a blockchain-based public key infrastructure to safeguard communications. On the other hand, Paper [6] explores a VANET (Vehicular Ad-hoc Network) blockchain implementation to ensure data integrity and security, showcasing blockchain's potential in vehicle-to-vehicle communication. Paper [7] also focuses on data security, integrity, privacy, and availability. It claims to present the first data and information-centric design for autonomous vehicle architecture, incorporating security features, tamper-resilience, and privacy measures to protect vehicular data.

As a distributed ledger technology, blockchain offers great potential to address these challenges[8]. With its inherent capabilities for providing transparency, security, and immutability, blockchain[9] can be pivotal in effectively managing the data generated by AET. This technology enables secure and automatic transaction logging, which is crucial for the operation of AVs that require real-time data exchange with multiple stakeholders. The use of blockchain in AET systems increases user trust through greater transparency and facilitates automatic micropayments between parties, including passengers and service providers. Additionally, this integration helps address data ownership and ethical usage issues, enabling a more responsible and efficient ecosystem.

Therefore, this research aims to explore the practical application and strategic benefits of combining AV technology and blockchain, providing insights into how this integration could redefine the urban transportation landscape in the future.

1.2 Research Objectives

This research offers an innovative approach to developing smarter and more sustainable autonomous transportation infrastructure by focusing on three key aspects:

1. AET Selection: Optimal selection criteria for AET are identified based on performance, reliability, and battery life.
2. Charging Station Selection: Utilizing real-time blockchain data, a smart charging station selection strategy.
3. Reservation and Payment Mechanisms: Develop a smart contract to handle reservations and payments in the blockchain to enhance trust between the customer and the AET operator.

By combining these elements, the research addresses the operational challenges faced by AET and sets new standards for sustainable and efficient transportation practices. The outcomes are expected to significantly contribute to the literature and practice, influencing the long-term development of smart transportation systems in urban settings. Figure 1 illustrates the system model implemented in this research.

The rest of this paper is organized as follows: Chapter II describes the Literature Review. Chapter III explains the Proposed Framework. Chapter IV discusses Result: justification of blockchain applicability

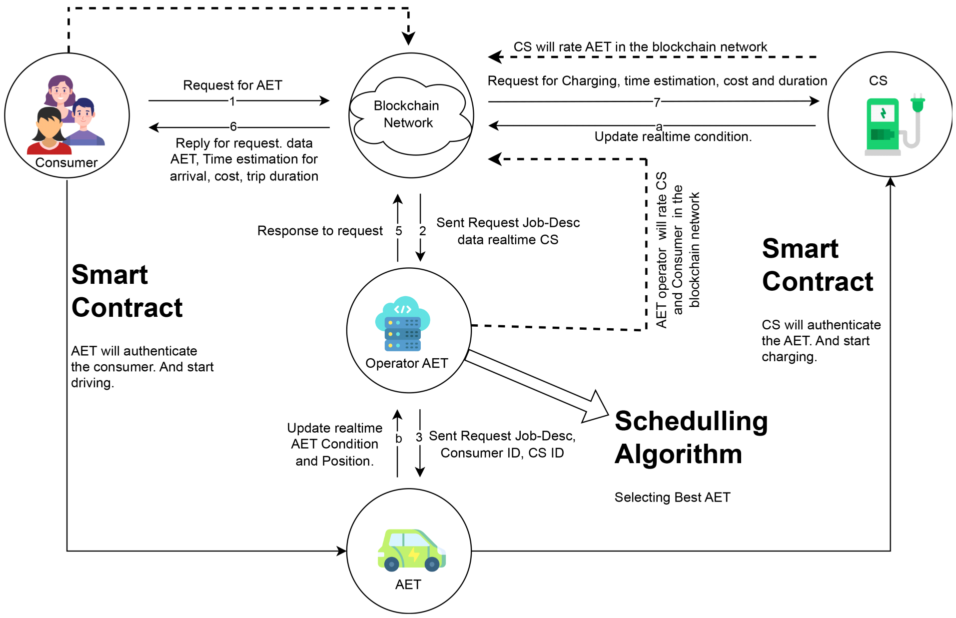

Fig. 1. System Model

smart AET. Lastly, Chapter V Conclusion and Recommendations.

Ⅱ. Literature Review

Several academic studies have explored the application and development of blockchain and smart contracts across various domains. A systematic mapping study[10] reviewed peer-reviewed research papers on smart contracts, categorizing them based on security, privacy, software engineering applications, performance, scalability, and other related topics while also tracking the evolution of smart contract research annually. Another study[11] highlighted the growing popularity and usage patterns of smart contracts within a blockchain, detailing the costs associated with deploying these contracts. Research[12] delved into blockchain-empowered software systems, discussing the development of decentralized applications (DApps), including historical context, synchronization and double spending issues, proof of work, and a comprehensive definition of blockchain. A proposal[13] for a decentralized IoT solution for vehicle communication using Ethereum demonstrated blockchain's potential to enhance the security and autonomy of transport systems, suggesting effective utilization of crowd-sourcing technology for future transportation needs. Lastly, an examination[14] of blockchain in IoT applications addressed the basic taxonomy of the technology, including consensus mechanisms and smart contracts, and the challenges of security and privacy when integrating blockchain with physical assets represented as tokens.

Ⅲ. The Proposed Framework

3.1 Scheduling AET and Charging Station Selection

This section addresses the scheduling of AET and the optimal selection of charging stations to ensure uninterrupted operations. Fig. 2 illustrates a sophisticated system managing AETs utilizing real-time data and advanced routing algorithms to optimize navigation and scheduling. Each AET, from AET 1 to AET n, is equipped with various sensors (Sensor 1 to Sensor n), collecting different types of real-time data. This data is integrated into a scheduling algorithm, specifically a genetic algorithm, which works with a traffic model to effectively route and schedule the AETs. The system coordinates with navigation

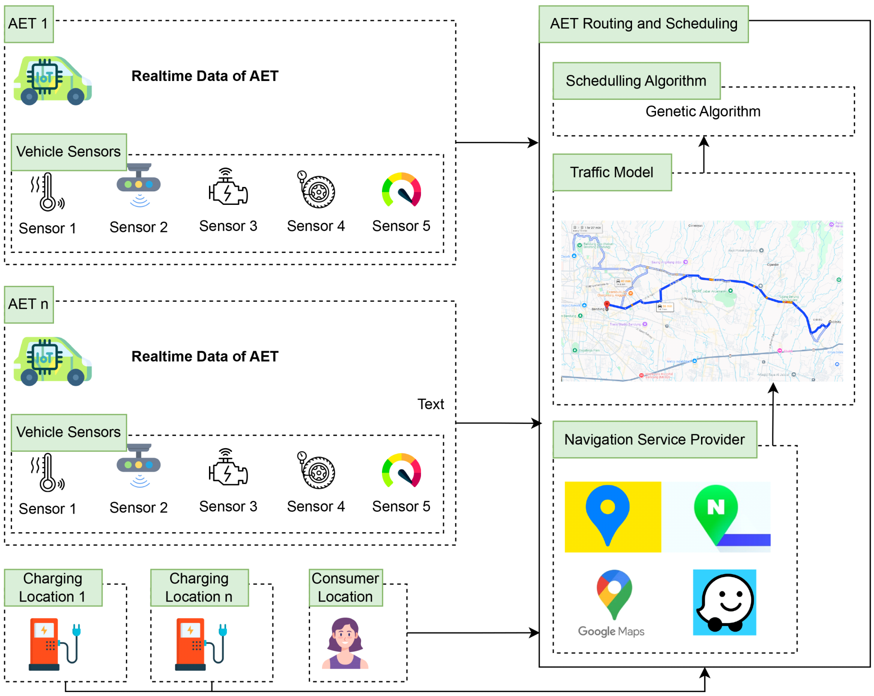

Fig. 2. AET Routing and Scheduling

service providers, such as Google Maps, for precise and updated mapping information. This complete set-up makes sure that scheduling and routing work well by looking at real-time traffic conditions and finding the best travel routes. This could cut down on travel times and improve fuel efficiency for many AETs in different places, such as charging stations and consumer locations, showing how the network is fully integrated for operational logistics.

In this paragraph, the variables used will be described. Where (i) is the index of the AET, (P_i) pickup location for AET i, (D_i) destination location of the customer for AET i, (C_i) location of the nearest charging station after dropping off the customer for AET i, (B_i) remaining battery of AET i, (E_{P_i, D_i}) Energy required for the journey from pickup to customer's destination for AET i, (E_{D_i, C_i}) energy re-quired for the journey from the customer's destination to the nearest charging station for AET i, ($B_{req,i}$) minimum required battery for AET i to complete its task (going to pickup location, to destination, and to charging station). ($Cost_i$) operational cost for using AET i. (j) index of the charging station. (A_j) availability of charging station j when the AET arrives. $A_j = 1$ if available, $A_j = 0$ if not available. (T_j) waiting time at charging station j if not available. (D_{C_j}) Distance from the customer's destination to the charging station j, ($Cost_{C_j}$) cost of using charging station j, including travel cost and waiting time. ($y_{i,j}$) binary variable indicating whether AET i uses charging station j.

Objective Function and Constraints: Selecting AET i to ensure it satisfies all constraints and offers the lowest operational cost. The mathematical formulation of this problem is as follows:

$$B_i \geq E_{P_i,D_i} + E_{D_i,C_i} \quad \forall i \tag{1}$$

$$\min \sum_i Cost_i \cdot x_i \tag{2}$$

subject to:

$$\sum_i x_i = 1, x_i \in \{0,1\} \quad \forall i \tag{3}$$

$$B_i \geq E_{P_i, D_i} + E_{D_i, C_i} \cdot x_i \quad \forall i \tag{4}$$

The above formulation ensures that one AET is selected that meets the battery requirement and has the lowest operational cost. The constraint $B_i \geq E_{P_i, D_i} + E_{D_i, C_i} \cdot x_i$ ensures that only the selected AET needs to satisfy the battery requirement.

Cost Function for Charging Station: The cost for using charging station j by AET i is calculated as follows:

$$Cost_{C_j} = \text{TravelCost}_{C_j} + T_j \cdot (1 - A_j) \cdot \text{WaitCostPerUnit}$$

where TravelCost Cj is the travel cost to charging station j based on distance, and WaitCostPerUnit is the cost per unit time of waiting.

Mathematical Model with Charging Station Constraints: The updated mathematical model with constraints and objective function for choosing the charging station. Minimize the total cost of travel and charging:

$$\min\left(\sum_i \sum_j Cost_i \cdot x_i + Cost_{C_j} \cdot y_{ij}\right) \tag{5}$$

Constraints: Choose only one AET and one charging station: $\sum_i x_i = 1$, $\sum_j y_{ij} = 1 \ \forall i$. The AET must have enough batteries: $B_i \geq E_{P_i, D_i} + E_{D_i, C_j} \cdot x_i \ \forall i$, $\forall j$. AET can only select a charging station if it is chosen: $x_i \leq y_{ij} \ \forall i$, $\forall j$. Minimize waiting time at charging stations: $y_{ij} \leq A_j \ \forall i$, $\forall j$, or in conditions where all charging stations are unavailable:

$$\min\left(Cost_{C_j}\right) \quad \text{when} \quad A_j = 0 \quad \forall j \tag{6}$$

This model efficiently selects the most optimal AET and charging station to minimize waiting times and overall costs.

Optimizing autonomous taxi scheduling in our system uses a genetic algorithm (GA), a sophisticated method that iteratively searches for the best solutions by mimicking natural evolutionary processes. Here's a more relatable breakdown of GA in our model:

Algorithm 1 GA for Taxi Scheduling

```
Input: i, j, P_i, D_i, B_i, C_i, A_j
Output: Path
initialize_population(size)
evaluate_fitness(population)
while not termination_condition() do
    parents ← select_parents(population)
    offspring ← crossover(parents)
    mutate(offspring)
    evaluate_fitness(offspring)
    population ← select_survivors(population, offspring)
end while
best_solution ← find_best_solution(population)
return best_solution
```

Chromosome Representation: In this system, each chromosome represents a potential solution where each gene within the chromosome corresponds to an assigned taxi for a customer request. Essentially, the chromosome is a vector, with each element indicating which taxi is assigned to fulfill a particular customer request.

Assessing the quality of solutions (Fitness Function): The fitness of each chromosome is assessed based on the total distance traveled by all taxis encapsulated in the chromosome. This evaluation is adjusted to consider whether the current battery levels of the taxis suffice to cover the designated routes, ensuring that the system adheres to operational constraints while optimizing travel distance.

Choosing the best features (Selection): The genetic algorithm selects chromosomes for reproduction using tournament or roulette wheel selection methods. These methods preferentially select individuals with higher fitness scores, promoting the population's retention and combination of beneficial traits.

Mixing best solutions to create even better Ones (Crossover): During the crossover phase, two parent chromosomes are combined to produce offspring. Techniques such as one-point or two-point crossover allow for mixing parent genomes, potentially creating more effective solutions by combining optimal routes from each parent.

Introducing small changes for diversity (Mutation):

Mutation introduces random changes to a chromosome, which helps maintain genetic diversity within the population and prevents the algorithm from stagnating at local optima. This could involve altering the taxi assigned to a specific request, thus exploring new possibilities that may yield a shorter total distance or better battery utilization.

Knowing when to stop (Termination Condition): The algorithm repeats its process of selection, crossover, and mutation until a stopping criterion is when successive iterations no longer produce significant improvements.

Implementation Details (Alg. 1) :

- ***Initialization***: The initial population is randomly generated, with each chromosome representing a feasible assignment of taxis that meet both the distance and battery requirements.
- ***Fitness Evaluation***: Each chromosome's fitness is calculated by summing the total distances traveled by the taxis it represents, penalizing those that do not meet battery constraints.
- ***Crossover and Mutation***: These genetic operations are applied to produce new offspring, which are then mutated to explore new areas of the solution space.
- ***Termination***:The algorithm continues to evolve the population until predefined conditions are met, ensuring that the best possible solutions are thoroughly explored.

The Genetic Algorithm (Alg. 1) is utilized to tackle the path planning problem for AET. This algorithm determines the optimal route from the current position of the AET to the customer's location, the customer's desired destination, and the selected charging station. Variables derived from the preceding formula have an impact on the decision-making process. The algorithm starts by creating an initial population of genes. Subsequently, it systematically employs crossover and mutation operators to generate new chromosomes. Following each iteration, it evaluates the fitness of these updated chromosomes using a designated objective function (referred to Equation 5 and 6). The best-performing chromosomes are chosen to create the subsequent generation. The procedure runs until specific termination requirements are achieved, hence concluding the algorithm.

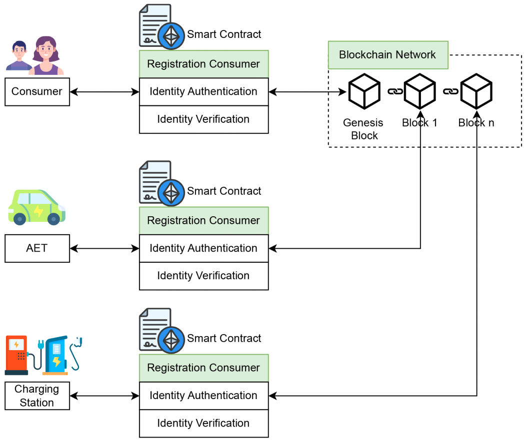

Fig. 3. Node registration

3.2 Regsitration on blockchain technology

Smart transportation systems, encompassing applications like real-time parking management, electronic toll collection, and collision avoidance, face significant privacy and security challenges due to insecure communications over public channels. Singh et al. (2020)[15] review these issues within the context of blockchain and AI in smart cities, highlighting how their integration could foster a sustainable, intelligent society and improve the security of intelligent transport systems. In response to these challenges, Sakthi et al. (2022)[16] advocate for a decentralized, scalable, and robust fog computing framework to manage vehicular networks efficiently through blockchain technology, enhancing secure data sharing and vehicular communication. Further, Fu and Zhu (2021)[17] explore blockchain's role as a trust infrastructure in smart cities, detailing the use of private, consortium, and public blockchains to ensure secure, authorized access across systems, alongside mechanisms for selecting blockchain authentication nodes and ensuring interoperability among diverse blockchain architectures. This suggests a move towards a lightweight, efficient security framework essential for protecting data in smart transportation systems.

Fig. 3 illustrates a consumer registration process within a blockchain network for different entities, including consumers, autonomous electric transport (AET), and charging stations. Each entity engages in a series of steps, starting with a smart contract that manages its registration, identity authentication, and identity verification. These steps ensure that each participant' s identity is securely verified before they are allowed to interact with the blockchain network, which is depicted as a series of blocks starting from a Genesis Block to Block n. This process helps maintain the integrity and security of transactions within the network.

Fig. 4 presents a connectivity framework where an AET vehicle integrates with a blockchain network through various onboard sensors. The AET communicates with the blockchain, consisting of a sequence of blocks from the Genesis Block to Block n, ensuring secure and tamper-proof data handling. Vehicle sensors, labeled from Sensor 1 to Sensor n, each possibly measuring different parameters such as temperature, speed, proximity, etc., collect data and feed it directly to the AET. This system enables real-time data collection and processing, enhancing the vehicle's performance and safety features by leveraging blockchain's decentralized and secure nature to manage and record this data effectively.

Fig. 5 outlines the structure of a consumer's digital wallet, illustrating how personal and transactional data are organized within it. The 'Wallet Consumer' includes the user's profile, the user's historical booking, and the user's historical payment. The user's profile contains personal details such as the user's name, photo, address, contact number, and payment method. These components collectively facilitate user identification and transaction processing, providing a comprehensive overview of user activity and preferences within the wallet, thus enabling personalized and secure user interactions and financial transactions.

In the blockchain-based consumer application, each consumer possesses a wallet address and a corresponding cryptocurrency token linking to the tourism blockchain via a cryptocurrency exchange server. The system utilizes various smart contracts to facilitate interoperability among users and service providers.

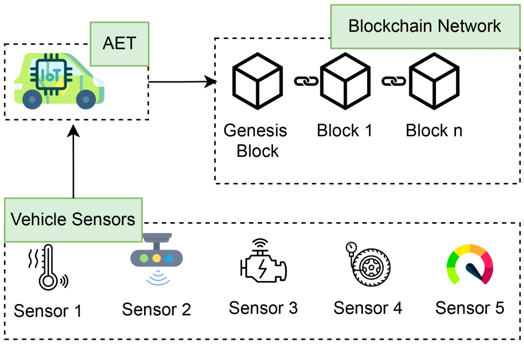

Fig. 4. IoT of AET registration

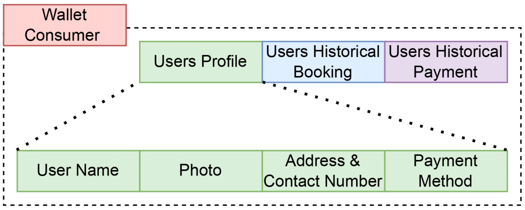

Fig. 5. Consumer Wallet registration

Relationship Contracts: maintain associations between consumers and service providers using specific wallet addresses. **Service Level Contracts**: track the status (ACTIVE or INACTIVE) of these relationships and differentiate multiple associations based on the Ethereum address of the executing nodes, allowing consumers access to data and transaction logs. **Permission Contracts**: regulate data access on the blockchain, assigning permissions at the time of record creation. These permissions include read (query specific node details), write (modify node data), transfer (move data between nodes), and administrator (full rights to alter node data).

These contracts collectively ensure secure, controlled interaction and data access within the tourism blockchain ecosystem.

Fig. 6 depicts two scenarios in a blockchain network involving transactions between consumers, an autonomous AET company, and a charging station company facilitated by smart contracts. On the left, a consumer interacts with the AET company via a smart contract, leading to a recorded transaction from the Genesis Block to subsequent blocks in the blockchain. On the right, a similar interaction occurs between the consumer and the charging station com-

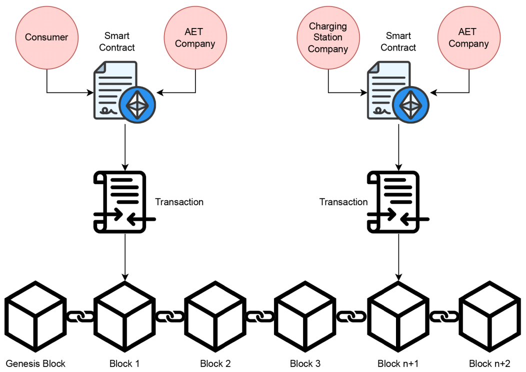

Fig. 6. Smart Contract

pany, with the transaction recorded in the blockchain from Block n+1 onwards. This blockchain setup ensures secure and transparent recording of transactions, preventing tampering and ensuring data integrity throughout the process.

3.3 Intelligent Charging Station

This study proposes a smart electric vehicle (EV) charging station energy management system utilizing blockchain technology to protect EV user privacy, assure equitable power transactions, and accommodate the charging needs of numerous EVs.

Fig. 7 illustrates the communication and transaction process between an AET and a charging station facilitated by a blockchain network. Initially, the AET sends a charging request to the charging station (step 1), which then responds with scheduling information (steps 2 and 3). After the AET confirms the schedule (steps 4 and 5), the charging station provides transaction details (steps 6 and 7). Subsequently, a new transaction is created and logged in the blockchain network, starting from the Genesis Block to Block n (step 8). Finally, the blockchain verifies the transaction (step 9), ensuring secure and tamper-proof processing. This process also includes mutual authentications between the AET and the charging station, confirming the identity and authorization of both parties involved in the transaction.

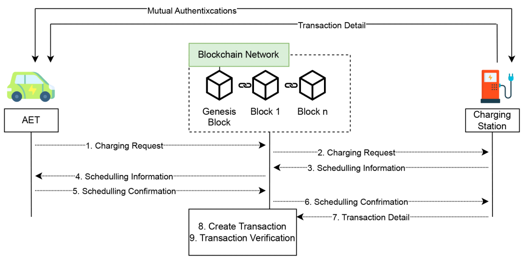

Fig. 7. Consumer registration

3.4 Reservation and Payment Mechanisms

In this paper, a smart contract is used to enhance trust between user interaction, charging stations, and AET operators. The smart contract is built based on the following features:

- ***Registration***: To register the customer address in the smart contract, if the user has not yet registered, they cannot access the smart contract feature
- ***Request Order:*** Add a new order along with the customer location information while also acting as a reservation process.
- ***Response Order:*** In this part, the operator calculates $Cost_{C_j}$ off-chain, updates the result to the smart contract (including reservations on the charging station), and notifies the customer.
- ***Accept Order:*** In the event that the customer accepts the order, they will store their money temporarily in the smart contract to secure the payment process between the customer and the AET operator.
- ***Finish Trip:*** After the trip has finished successfully, the money stored temporarily in the smart contract is transferred to the AET operator.

3.5 Feedback from the service

In the evolving landscape of urban mobility, the interdependence of taxis, charging stations, and consumers has given rise to a dynamic feedback ecosystem, enhancing service quality and trust. This intricate web of feedback mechanisms is pivotal in shaping the future of transport services, as detailed below.

Firstly, consumers who utilize taxi services are provided the opportunity to rate their experience based on several criteria, including the ride's comfort, speed, and internal conditions of the vehicle such as the cabin temperature and aroma. This feedback helps taxi companies improve their service quality by addressing any discomforts or preferences the passengers may express.

Additionally, taxis reciprocate by evaluating consumers. They provide ratings based on the passengers' behavior during the ride, such as adherence to vehicle integrity (no damage or misconduct) and the efficiency of their payment mechanisms. This mutual rating system fosters a respectful and accountable service environment.

Secondly, taxis play a crucial role in assessing the infrastructure supporting their operation, specifically charging stations. After each charging session, taxi drivers rate the charging stations on aspects such as the duration and quality of the charging process. This feedback is essential for charging stations to optimize their services, ensuring that taxis can maintain maximum efficiency with minimal downtime.

Furthermore, charging stations reciprocate by rating the taxis that utilize their services. This rating system covers several aspects, including the punctuality of the taxi's arrival at the charging station, the condition of the taxi both before and after charging, and the promptness of payment post-service. This evaluation helps maintain a standard of operation, encouraging taxis to adhere to best practices in maintenance and financial transactions.

Each rating given within this interconnected system is meticulously recorded and stored on a blockchain. This ensures the data's integrity, transparency, and permanence, making it immutable and secure from tampering. The blockchain storage method significantly enhances the trust and reliability of the feedback, as all stakeholders can be assured that the records are accurate and unaltered.

The aggregated data from these ratings serves as critical reference points for all stakeholders involved, ensuring that each party is accountable and strives to uphold the highest standards of service. This feedback loop enhances operational efficiency and contributes significantly to the overall sustainability and user satisfaction in urban transport ecosystems. This model, presented in an international journal article, exemplifies a forward-thinking approach to managing and improving the interrelations within smart transportation networks, providing a reliable and consumer-friendly environment.

Ⅳ. Simulation and Result: justification of blockchain applicability smart AET

Simulation setup: The code was written using the Python programming language, and the experiments were conducted on a system equipped with an Intel Core i5 processor and operating at a frequency of 3.0 GHz with 16 GB of RAM. The blockchain simulation is conducted using *Geth* (*Go Ethereum*) Version 1.10.26 to simulate both *Proof-of-Work* and *Proof-of-Authority* consensus mechanisms. For both consensus types, mining nodes are simulated on the same device. The smart contract is developed in Solidity, with the Ethereum coin used for transactions, covering both gas costs and payments between the customer and the AET operator.

The graph in Fig. 8 illustrates the progression of fitness values in a genetic algorithm over 200 generations. Initially, the minimum fitness value starts at approximately 525 and experiences a sharp decline, reaching around 450 by generation 50. This rapid improvement in the early generations indicates an effective search and optimization by the algorithm. By generation 100, the minimum fitness stabilizes to about 425, and minor fluctuations are observed as the generations proceed, settling near 420 by generation 200. Conversely, the maximum fitness starts at a higher point of about 735 and also shows a significant initial decline, stabilizing to around 520 by generation 50. This trend continues more gradually, reaching about 510 by generation 100 and then slowly tapering off to approximately 505 by the end of 200 generations. Overall, the data indicates that while both the minimum and maximum fitness improve significantly in

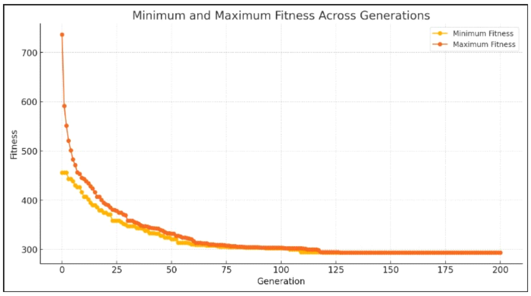

Fig. 8. Evolution of Minimum and Maximum Fitness Values in a Genetic Algorithm Over Generations.

the early stages, the rate of improvement slows down as the algorithm converges toward optimal solutions. The ending fitness values reflect a nar-range between the best and worst solutions, highlighting the algorithm' s efficiency in enhancing overall population fitness over time.

The result of our smart contract cost is shown in Fig. 9. In our smart contract, the cost of *Registration*, *Accept Order*, and *Finish Trip* features is shown to be at a lower gas cost. The registration process cost is low because the state in the updated smart contract has only one variable. As for the *Accept Order* and *Finish Trip* features, these functions are only handling the transaction, where the *Accept Order* is to store the temporary money in the smart contract, and when the trip is finished, the stored temporary money will be sent from the smart contract to the AET operator. The *Request Order* and *Response Order* update the state of various variables, resulting in a higher gas cost than other features. Although some of the gas costs is quite high, achieving a gas cost lower than 100,000 is possible.

Fig 10 shows how latency changes with the number of transactions and compares the performance of two consensus mechanisms, Proof of Work (PoW) and Proof of Authority (PoA), each with a different number of mining nodes (1, 2, and 3). As the number of transactions increases, the latency trends vary significantly across different setups. For PoW, increasing the number of mining nodes generally stabilizes latency, though with fluctuations. Notably, PoW with

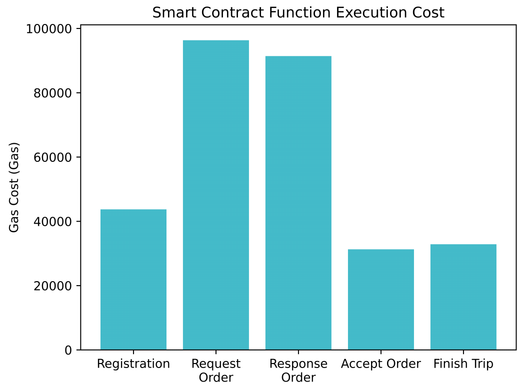

Fig. 9. Smart contract transaction cost.

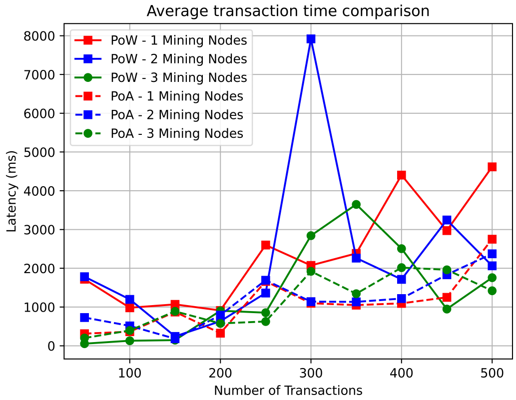

Fig. 10. Latency

one mining node experiences a dramatic spike in latency at around 300 transactions, which then reduces. For PoA, latency generally remains lower and more stable compared to PoW, indicating more efficient handling of transactions with fewer spikes and less variance. PoA with three mining nodes exhibits the most stable latency across the transaction count, highlighting its potential efficiency in processing a higher number of transactions with lower delay.

V. Conclusion and Future Work

This study discusses the impact of integrating AET with blockchain on autonomous electric taxis' cost efficiency, operating system security, and customer service. By optimizing the selection of AETs to serve customers while considering battery charging locations, optimal results are achieved for determining which AETs will serve customers and the best routes. Simultaneously, blockchain can enhance service and customer trust in data and transaction security. The results show that the system can operate effectively and is capable of handling issues with AET routing and scheduling. In addition, the reservation and payment mechanisms are successfully simulated in a blockchain environment using smart contracts. Furthermore, selecting AET models for various customers and developing our blockchain private network will be considered for future research.

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Ramdhan Nugraha

2009 : B.Eng. degree, Indonesia University of Education

2013 : M.Eng. degree, Bandung Institute of Technology

2014-Current : Lecturer, Telkom University

2021-Current : Ph.D. student, Kumoh National Institute of Technology

<Research Interest> artificial intelligence, internet of things, vehicle routing problem, blockchain, quantum cryptography

[ORCID:0000-0002-3252-1615]

Soo Young Shin

2006 : Ph.D., Seoul National University, School of Electrical Engineering and Computer Science, Seoul, South Korea.

2006.03-2007.06 : Seoul National University, ERC-ACI (Researcher)

2006.07-2007.06 : University of Washington, Seattle, USA, School of Electrical Engineering (Post Doc. Researcher)

2007.07-2007.08 : Seoul National University, ERCACI (Researcher)

2007.09-2010.08 : Samsung Electronics, Telecommunication System Division, System Design Lab. (Senior Researcher)

2010.09-Present : Kumoh National Institute of Technology, School of Electronic Engineering (Assistant/Associate/Full Professor)

2014.12-202017.01 : Dean of International Program and Language Education Center, Kumoh National Institute of Technology

2017.02-2018.01 : University of British Columbia, Vancouver, Canada (Visiting Scholar)

2017.08-Present : IEEE Senior Member

<Research Interests> Future Wireless Communications, Signal Processing, Unmanned Mobility, Quantum Computing, Internet of Things, AI/Deep Learning, etc.

[ORCID:0000-0002-2526-239]