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Indonesia's New Capital City Development Strategy from Mobility Optimization Perspective

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Abstract. Based on Indonesia's 2045 vision, Indonesia's new capital city development is expected to accelerate Indonesia's economic transformation. Its development consists of six economic clusters and two supporting clusters, including low carbon-energy targets, smart city, and industry 4.0. This study provides insights into achieving the stated development goals from the mobility optimization perspective. The strategies include optimization and machine learning-based traffic control, real-time and dynamic bus routing, smart waste management, and the use of drones and electric vehicles. This study can guide researchers and practitioners to contribute to Indonesia's new capital city development and accelerate the process.

Keywords: Optimization; mobility; real-time; smart city; machine learning

1. Introduction

Indonesia's government focuses on developing its new capital city. The new capital city development aims to distribute economic improvement in less populated areas of Indonesia. Supporting regulations and key performance indicator for the development have been defined in 2022 and is planned to be completed in 2045 [1]. The new capital city is designed based on six economic clusters and two supporting clusters [2]. Some of the clusters include low-carbon energy and smart city clusters. These clusters were highly related to its mobility system development, with detailed key performance indicators in Ibu Kota Negara [3].

Our study aims to list the essential mobility system characteristics based on the government's requirements. After identifying them, we provide a list of potential topics to be resolved from the mobility optimization perspective. We list the problem's objectives and decision variables for each situation, and we believe that researchers could refer to such a list to conduct detailed studies to resolve the issues.

2. Mobility Optimization in Indonesia's New City Development: Status and Development Strategies

Based on The Indonesia National Artificial Intelligence Strategy (Stranas KA) and the Indonesia government's regulations [3], the development of Indonesia's new national capital city (IKN) in mobility and smart city aspects aims at several targets:

1. Real-time data acquisition, analysis, and decision-making.
2. Integrated and collaborated transportation for resolving congestion and reducing personal vehicle usage. It is highly related to the multimodal transportation network design (which involves transfers between airplanes, trains, buses, ships, etc., ensuring at most two time-transfer rules).
3. At most 10-minutes access to any transportation mode by anyone.
4. Effective and efficient cargo distribution to reduce high logistics costs.

5. Traffic light optimization considering real-time CCTV data.
6. Smart waste management.
7. Early alarm and optimal relief distribution in disaster situations.
8. Low carbon emission transportation (electric and hydrogen-based vehicles) to achieve 100% renewable energy in 2045.

To achieve those goals, mobility and smart city studies for the new IKN from the mobility optimization perspective could be conducted as follows:

1. [City traffic simulation] Optimization and machine learning-embedded city traffic simulation models that use real-time road information (e.g., from Google Maps, Waze, etc.). The analysis should not be time-consuming and have an acceptable solution quality, e.g., in terms of the resulting travel time [4-5]. This study includes the dynamic traffic light scheme setting based on the real-time traffic situation and could incorporate pedestrian movements.
2. [Real-time bus route update] Updates on short/long-term bus routes based on usage data with online change notifications to users through their smartphones. Changes based on real-time information allow us to deal with uncertainties [6].
3. [Multimodal transportation network design] Location, allocation, and routing problems for multimodal transportation network systems could be optimized using mathematical models, heuristics, expert-based rules, and machine learning techniques [7-12]. To ensure the modes support each other, it is possible to simultaneously consider the coopetition (cooperation and competition) aspect.
4. [Bus station location problem] Ensuring good access to stations by bus passengers using the set covering problem for solving the bus routing problem.
5. [Sea toll development] An efficient logistics network design is related to the Indonesia sea toll development project, in which the development of transfer points (e.g., ports) should be scheduled well to increase connectivity [13].
6. [Smart waste truck routing] Smart waste management could be resolved by an online waste truck dispatching and routing that includes predicting the waste level. Such a prediction could be based on historical data using machine learning techniques [14-15].
7. [Drone mapping routing] Drones could be routed to map the disaster area in real-time [16]. Evacuation and logistics distribution routes could be optimized using heuristics and simulation. Such optimization approaches could be combined with data from IoT sensors.
8. [Electric vehicle relocation] Relocation of electric vehicles should be planned appropriately to ensure demand satisfaction [17]. Determining the best location for charging stations (that are reachable by the customers and require a low investment cost) is necessary before using electric or hydrogen-based vehicles. Quantitative analysis should also be conducted to evaluate the effectiveness of the battery recharging and swapping system.

Characteristics of each mobility optimization problem are addressed in Table 1.

Table 1
Characteristics of mobility optimization problems in Indonesia‘s new capital city.

Mobility problem type	Objective	Decision variables	Main characteristics	Related references
City traffic simulation	Minimizing congestion	Traffic light schedule, vehicle flow (direction)	Real-time data analysis, dynamic update	[18]
Real-time bus route update	Minimizing total travel times of passengers or buses	Updated bus routes	Real-time transportation card tag recording and analysis	[19]
Multimodal transportation network design	Maximizing transportation demand satisfaction by all modes	Location of transfer stations	Reducing effects of competition between modes and increasing connectivity	[20]
Bus station location problem	Minimizing total distances between stations and passenger points	Location of bus stations	Determining appropriate time and location to update bus stations	[21]
Sea toll development	Maximizing (domestic and international) profit increase of the ports	Amount of yearly investment for each port	Appropriate prediction of (domestic and international) market share change due to the investment	[13]

Smart waste truck routing	Maximizing waste truck utilization	Real-time truck routes	Regional waste level prediction-based route determination	[22]
Drone mapping routing	Minimizing total drone observation times	Drone routes and altitudes	Image processing and data transfer techniques	[10]
Electric vehicle relocation	Minimizing total relocation times	Relocation time and destination for each electric vehicle	Real-time electric vehicle usage data obtained from smartphone and online systems	[14]

Each problem above must be described and formulated mathematically to mimic the natural systems, and appropriate solution methods (e.g., rules, algorithms, metaheuristics) must be developed. The proposed models should be tested through implementations in biological systems, e.g., using actual data and applied to government-developed systems, or at least tested on accurate condition-like simulations [15]. The implementations on natural systems are highly related to data extraction using IoT sensors and big data analysis techniques (using machine learning techniques), which might highly depend on multidiscipline and Penta helix collaborations.

2.1 City traffic simulation

One method to optimize city traffic is reinforcement learning (RL), a machine learning technique. By using RL, we could assess real-time traffic situations, make real-time decisions, and measure the effect of making such decisions to be considered when making the following decisions. The basic concept for RL is illustrated in Figure 1 [23], and an example of values used for each component is shown in Figure 2 [24]. Every time we observe the state and based on that, we take action. Each action would provide a particular reward that we use to give some scores to the state-action candidates (to be considered in the subsequent decision-making). For instance, given a specific traffic condition, when we set a particular light duration sequence, and it allows us to reduce the number of waiting for cars at the intersection, we give a higher score for that condition and sequence setting pair, so in the future, we will likely to make similar decisions. Some latest review papers discussing using RL for city traffic optimization are [23,25].

Figure 1
Reinforcement learning framework

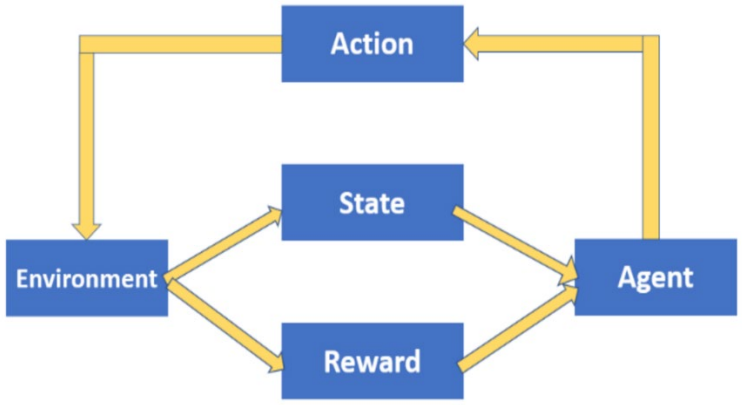
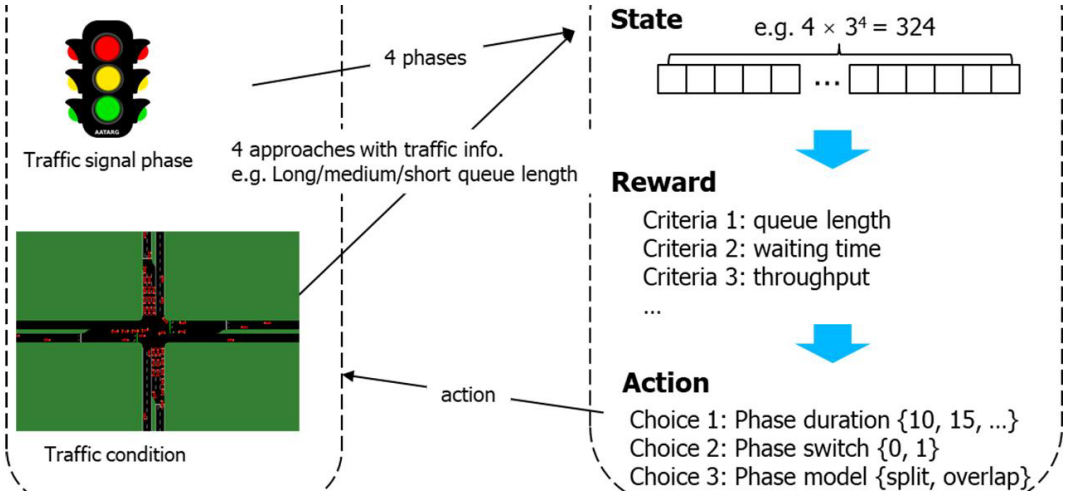


Figure 2
Berkeley's DeepDrive traffic light control using RL

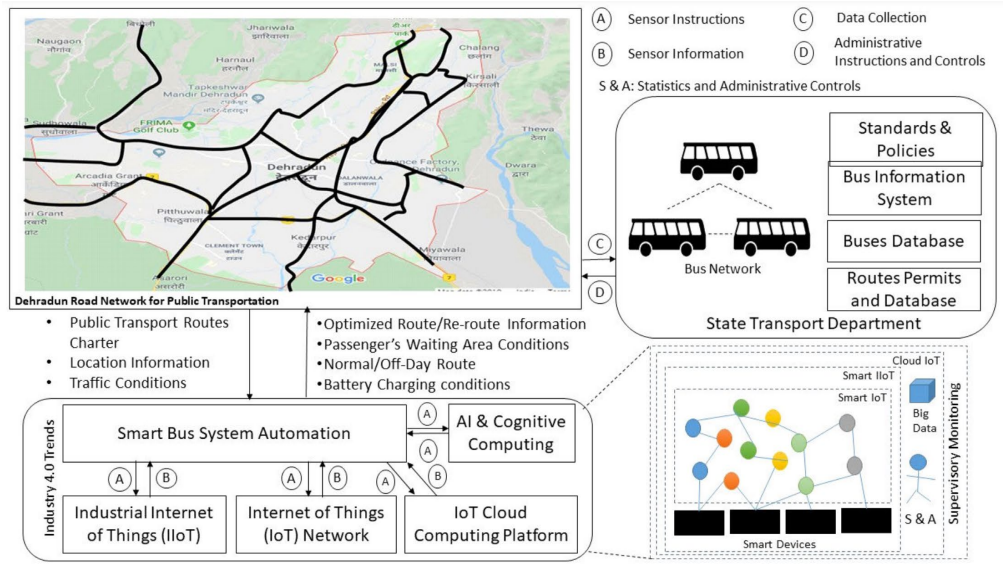


2.2 Real-time bus route update

It is common to have fixed bus routes to ensure passengers' convenience. It might be possible to update the routes after a certain long period. In this case, the regulator usually places some information on the route change and informs passengers so they can adapt to the new bus route or schedule. Because of the development of communication technologies, many personal cars use navigation systems to travel from their current point to their destinations. Considering the same trend of technology use by bus drivers and users, it will become possible for the regulator to apply more dynamic bus routes in the future.

Dynamic bus routes could allow higher utilization of the buses, shorter passenger travel times, and less heavy traffic. To generate such ways, it is necessary to capture and predict passengers' mobility behavior, e.g., by observing the bus and taxi travel demands [26-27]. To satisfy the requirement of 10-minute access to main facilities in Indonesia's new capital city, it is necessary to minimize the total user ride time (e.g., [19]). To reduce the traffic in the mobility network, it is required to route the bus(es) while considering other buses in the system. Considering the density of the passengers' travels, it would be necessary to appropriately design overlapping subroutes to satisfy the passenger demands [28]. More complex bus routing problems could incorporate the bus arrival prediction [29], necessary bus waiting times at stations to reduce passengers' waiting time [27], and the usage of electric buses with battery charging requirements [30] (Figure 3).

Figure 3
Electric bus system design in Dehradun Smart City

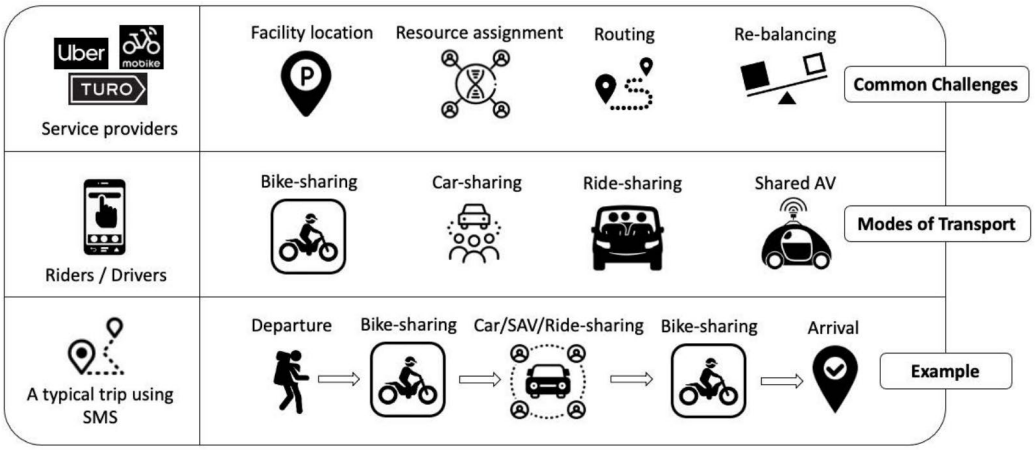


2.3 Multimodal transportation network design

Each transportation mode has its advantages, which highly depend on each unit's capacity, speed limit, operation scheme, etc. [31]. Designing an efficient multimodal transportation network design in Indonesia's new capital city is necessary to ensure good access between each pair of points in the town while effectively using each mode as a single mode of transportation. The multimodal transportation network design topic starts from the system installation until the functional design of the transportation modes. The management of the same or different transportation modes could be conducted by more than one institution, e.g., government or private companies. Such separated control could potentially cause competition between the services [32]. However, to ensure an overall sound transport system connectivity and utilization, it is necessary to incorporate cooperation between different service providers and transportation modes. Such combined competition and cooperation aspects fit into the competition framework. Although the coopetition's economic benefit was still limited [33], there are various potential advantages, e.g., carbon emission reduction when incorporating environment-friendly-transportation modes into the transportation network [34].

The multimodal transportation location problem (Table 1) discusses the installation of a new transportation mode network, given some existing networks of transportation modes. An example of a recently discussed transportation mode is the rapid transit Hyperloop [35]. Latest studies on other multimodal transportation network design issues considered: the transportation mode center's centrality consideration (in China; [36]), the robustness of the network when facing accidents and disasters (in Lisbon; [37]), multimodal traffic management during emergency evacuation [38], real-time matching for demand request fulfillment when using different modes [34] (Figure 4), urban multimodal transportation road network design and allocation [39]. Some review studies on multimodal transportation emphasized the importance of (1) environment-related analysis [40], which is suitable for the targets made for Indonesia's new capital city development, and (2) accurate data collection when using multimodal transportation for disaster evacuation purposes [41].

Figure 4
Coordinated transportation modes in a shared mobility system



2.4 Bus station location problem

The development of Indonesia's new capital city must ensure 10-minute access by passengers to any station of any transportation mode, including the bus. It is necessary to design bus station locations close to passengers' pickup points. We need to determine (1) when we need to update the bus station locations and (2) how the locations need to be updated.

A set covering approach has been used for designing bus station locations [42]. The latest reviews on bus station location problems or set covering issues stated the importance of considering travel time uncertainty [43-44]. The necessity for capturing and dealing with more dynamics in the travel demands could be covered through the recent developments and usages of IoT sensors, e.g., using GPS, GIS [45], and smart card data [46] (Figure 5).

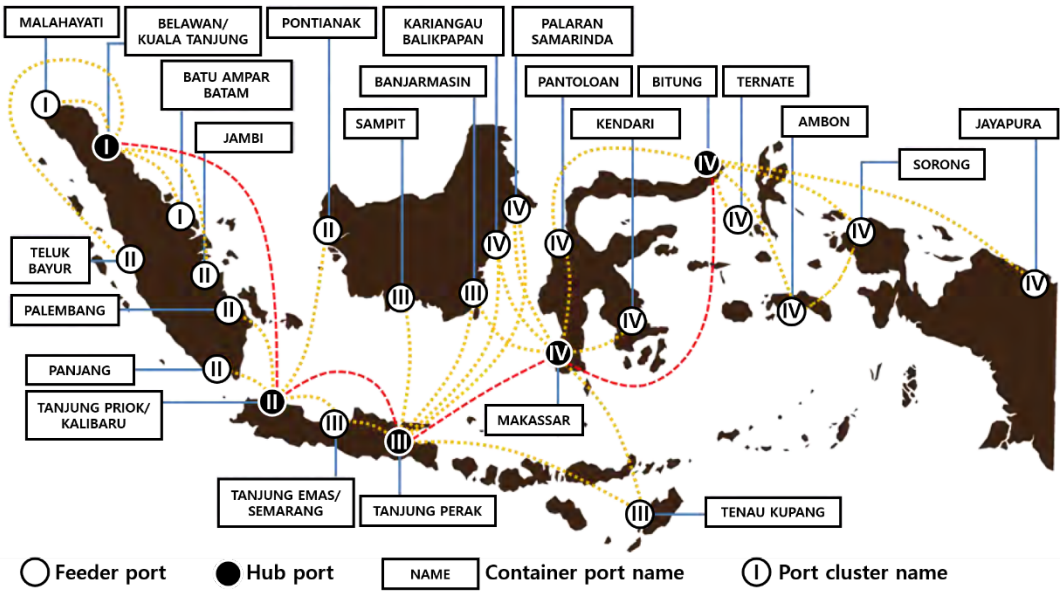
Figure 5
Passengers' origin-destination travel density based on smart card data.

2.5 Sea toll development

Indonesia's sea toll project was planned to be executed between 2019 and 2024 [13]. It aims to increase connectivity between central (hub) and support (feeder) ports, dispersedly located in Indonesia. The port network is presented in Figure 6. Given the planned budget for the five years, it is necessary to allocate several investment funds to specific ports or port clusters in which specific year, which has been studied by [13]. The goal was to prioritize investments in port pairs with a more significant number of container flows.

To support the development of Indonesia's new capital city, it is necessary to further assess the port development around the new capital city at Kalimantan island. To increase Indonesia's port competitiveness, we must also consider potential international cargo flows aside from domestic ones. Another requirement is to simultaneously observe the development in the hinterland area and identify bottleneck segments within the whole multimodal transportation network in the new capital city area [47-48].

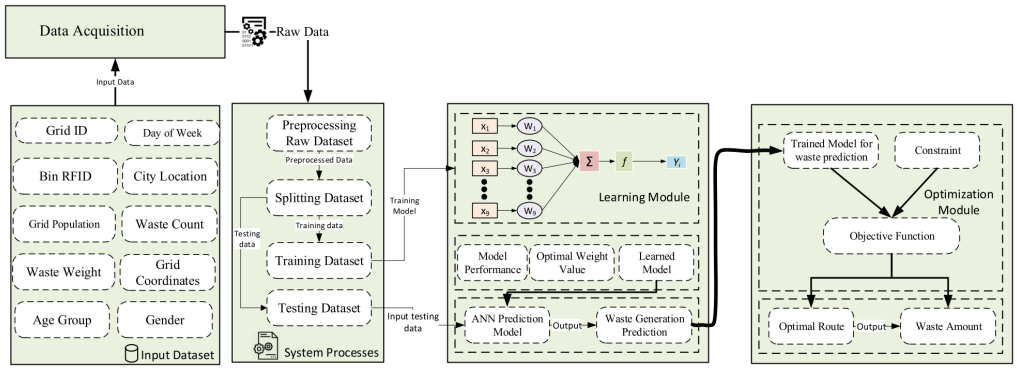
Figure 6
Port network in Indonesia



2.6 Smart waste truck routing

Along with the development of information technology and extensive data collection in smart cities, it becomes possible to schedule waste-collecting trucks better. One way is to predict waste levels in target pickup areas using the data provided by the sensors, then deploy the truck on dynamic routes constructed in real-time [49]. A detailed data structure, collection, and processing scheme was presented in [50], as shown in Figure 7. A recent study on intelligent waste collection considered route workload balance and dealt with real-sized problem instances [22]. To develop an intelligent waste transportation network in Indonesia's new capital city, we might optimize the system starting from its design before optimizing its operation.

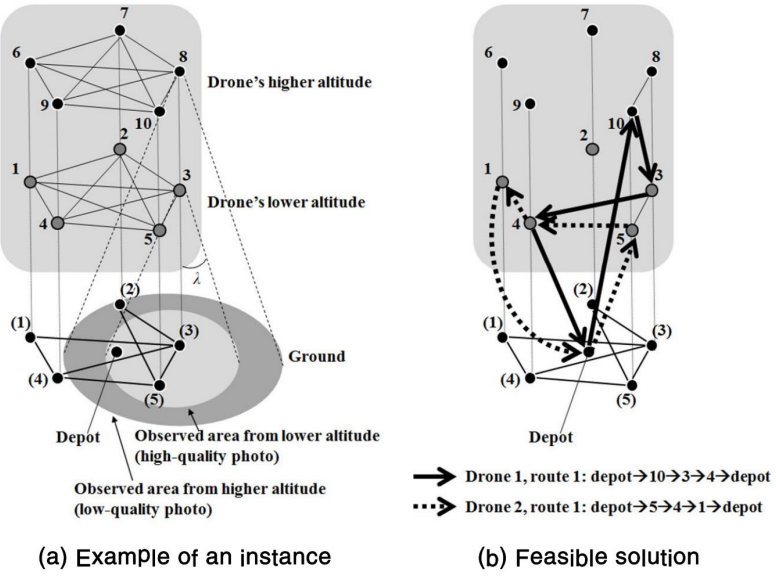
Figure 7
Data collection, analysis, and processing for intelligent waste truck routing.



2.7 Drone mapping routing

Routing drones with observation or monitoring purposes on a three-dimensional area would be an emerging technology in Indonesia's new capital city. Drones could observe areas that cost more when followed directly by a human. In their studies, Singgih et al. [10] and Zhen et al. [51] studied a three-dimensional drone routing problem to minimize the total drone travel times. The observable area from different flight altitudes and an example of feasible drone routes are illustrated in [10] (Figure 8). The study needs to be further improved by specifically applying image processing techniques on the flying drones and designing an efficient data transfer scheme to allow fast reporting on real-time traffic situations observed by the drones.

Figure 8
An instance and solution for the three-dimensional drone routing problem



2.8 Electric vehicle relocation

Indonesia's government targets to operate a transportation system with low carbon emissions, which will be achieved using electric vehicles and hydrogen-based ones. Related to the electric vehicle relocation, Singgih et al. [14] showed how the battery charging requirements could be satisfied through appropriate vehicle-station allocations and relocation schedules. To utilize the big data appropriately, we must consider electric vehicle reservation data from users' smartphones or booking systems.

Other than the relocation process itself, there are more issues to resolve regarding the electric vehicle systems for Indonesia's new capital city, e.g., general electric vehicle routing that considers the battery limitation during travel [52] and electric vehicle routing with energy usage prediction and partial recharging scheme [53]. With more data availability and digitalized systems, it is necessary to conduct more data-driven studies, e.g., using electric vehicle charging data [54-55].

3. Conclusions

This study listed the main characteristics required for mobility system development for smart cities in Indonesia's new capital city. Various potential optimization issues to be resolved are listed with their problem descriptions and updates on some latest related studies on the topics. This study provides insights into what kinds of problems to consider.

We must conduct a more detailed problem description, in-depth requirement analysis, and appropriate solution method design for future research topics. The problem definition and research should be conducted collaboratively with planners in Indonesia's new capital city to ensure accurate identification of requirements and deliverability of the outcomes (how we could implement the results effectively to resolve actual issues). Instead of only conducting studies on the computational aspect, incorporating the data collection scheme using IoT sensors would be an essential research direction.

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