Smart Highway: Near Future System in Jakarta

今や東南アジア有数の大都市となったジャカルタ。その深刻な交通渋滞を解消するための「スマート・ハイウェイ」実現に向けた課題を検証する。

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Abstract The growing number of vehicles on the road and the resulting traffic jams are deemed to increase severe accidents. This is due to the fact that the current transportation infrastructure and current mass technology applied to vehicles are unable to cope with the influx of vehicles on the road. Traffic management poses many critical challenges in most modern cities. To alleviate the aforementioned problems, the smart highway car control system concept was submitted. With the implementation of the smart highway control concept, traffic jam and vehicular accident can be avoided and the car users are more comfortable with a hassle-free autopilot system on their vehicles. This system provides both practically important traffic data collection and control information and can trace criminal or illegal vehicles such as stolen cars or vehicles that evade toll tax. The basic system architecture will be consisted of ACC sensor, RFID reader, and GPS navigation. Based on the latest technology, the system collects and calculates average speed and traffic information on every highway in the world. Then, it shares and synchronizes live traffic data by upstreaming transmission of messages about the current traffic situation and adjusts the speed of a specific car via communication program to the cars around it. Through a flooding algorithm, each server in a distinct center exchanges and updates information with all neighboring servers in other distinct centers so that the servers in various distinct centers can get all the latest traffic data in a highway. In this paper, we analyze and compare the latest developments of several different intelligent transportation systems' fundamental components. We elaborate some proposed suggestions to those components and analyze the potency and challenges of its implementation in Jakarta transportation.

Keywords smart highway system, intelligent transportation system, traffic jam

Introduction

In 2013, there were 104,118,969 registered vehicles in Indonesia, compared to the year 1999 when there were only 18,224,149 vehicles, a roughly 571% increase in a span of 16 years [1]. Referring to the aforesaid statistics provided by Statistics Indonesia (BPS) [1], the current transportation infrastructure and car technology are deemed insufficient in sustaining the influx of vehicles that can make problems such as traffic congestion and vehicular accidents. About 100,106 cases of highway accidents were reported by BPS on 2013 [2]. Various measures have been taken in the attempt to overcome the traffic problems. On the other side, transport accounts for 26% of global CO_2 emissions and car use is one of the principal contributors to greenhouse gas emissions. Traffic congestion is one of many causes of increased emissions [3]. Although

the problem can be addressed via many methods, this paper focuses on the smart highway car management system.

Jakarta City, as other metropolitan cities in the world, faces problems such as traffic jam, complicated urban development issues, crime, etc. [4]–[6]. This study will explain and elaborate the concept of intelligent transportation management technology and analyze its feasibility to be implemented in Jakarta City.

Related Works

Some of recent relevant studies on intelligent transportation have been proposed in related literatures. Table 1 shows some of those relevant researches.

Our review of those relevant studies reveals one important gap in them; there is no comprehensive study that can explain the future transportation system.

Theoretical Background

Smart highway system is a system specifically made for cars that are on a highway system. This system helps make them more sustainable transportation and helps alleviate the traffic congestion especially on highways.

The smart highway system can be implemented on cars, especially in Indonesia where Jakarta is one of the most jammed cities in the world [6]. With its deployment in the field of car technology, it is hoped that it would solve the aforementioned problems faced by the government within the highway.

A. Transportation system in Jakarta

Metropolitan cities like Jakarta have population more than 20 million and keep rising on. Jakarta is also known as one of the most crowded cities in the world [11]. District developments in Jakarta are quite rapid, especially in areas around its central business district, *Golden Triangle,* such as Jalan Sudirman-Thamrin and Sudirman main lane. Mature areas such as Cikini, Menteng, Kuningan, and Kebayoran Baru grow flourishingly into developed resident area. Most of the time, district development is also correlated with the development of transportation's infrastructure. For example, the development of outer ring roads around Jakarta and new highways that connect suburban areas, Bekasi, Bogor and Tangerang. Unanimously with resident and main street developments, business districts such as shopping center, hotel, and office complexes also grow rapidly [11].

Those rapid developments also have negative effect on transportation, such as traffic congestion,

Table 1. Related relevant works

Authors	Literature	Result
Martinez et al., (2010)	Emergency services in future intelligent transportation systems based on vehicular communication networks	By combining V2V and V2I communication, new intelligent transportation system will improve the response time and efficient resource usage of roadside emergency services [7]
Taniguchi & Shimamoto (2004)	Intelligent transportation system based dynamic vehicle routing and scheduling with variable travel times	Dynamic vehicle routing and scheduling model (VRPTW-D) shows that it can alleviate congestion problems as well as reduce total costs [8].
Zhang et al., (2011)	Data-driven intelligent transportation systems: A survey	Data driven intelligent transport systems is a very promising field that can provide more functions and services to further improve our transportation system [9].
Zhao, (2000)	Mobile phone location determination and its impact in intelligent transportation systems	TOA, TDOA, and assisted- GPS solutions are the leading contenders for current communications used in intelligent transportation systems [10].

especially in Golden Triangle area. These problems lead on other problems like air pollution and noise pollution. Several main road projects are expected to solve these problems [11].

Urban structure in Jakarta has two faces; one is located near the main roads and the other is located behind the urban space. Those transportations are bus, train, *angkot/angkutan kota*, *bajaj,* bike taxi, and bicycle *ojek* [12].

Road development to provide enough space for private vehicle mobility has triggered high rate of vehicle ownership drastically, making roads on Jakarta often heavily congested and make inefficiency of the fuel consumption, of course the air pollution is high and road safety is compromised. To deal with transportation problems above, the government has made some new initiative like Bus Rapid Trans System Project, also known as Trans Jakarta, and Jakarta Monorail Project or also known as Mono Rail Train (MRT), but this Monorail project is still undeveloped. Trans Jakarta has been formed since 2004, it serves the 1st corridor route running from Jakarta Kota to Blok M. The 2nd and 3rd routes have been operated since 2006 and serving route from Pulogadung to Kalideres. The monorail train was planned and being built in two lines, the green line will serve from Semanggi-Casablanca-Kuningan-Semanggi, and the blue line serve from Kampung Melayu-Casablanca-Tanah Abang-Roxy. But this project is dogged by financial problem [12]. Another kind of train in Jakarta is Light Rail Train (LRT), this project is the same as the MRT one, undeveloped. LRT has been planned based on Jakarta 2005 Transportation Plan, and total investment on this project is estimated at 1.3 billion dollars. The first LRT will be built to connect the new town of Bumi Serpong Damai, Bintaro Jaya, and other large scale of residential area of southwestern area of Jakarta. The LRT will be built on the second level of triple decker structure, since it has toll road at first level and arterial road underneath [13].

B. Advantages of smart highway system implementation in Jakarta

The smart highway system is considered beneficial for car drivers and highway police as well as in ecological conservation. For the drivers, the all-in- one integrated system could help them feel more comfortable with autopilot system that can simply drive them reach their destinations. And information gathered via the implementation of the smart highway system can be obtained to predict the traffic pattern and the time needed to reach a destination. These are very useful for drivers too. In terms of ecological conservation, the level of pollution can be reduced by decreasing vehicle emission. The smart highway system uses Adaptive Cruise Control (ACC) that automatically accelerates or decelerates a vehicle to a desired velocity and prevents collision between vehicles [14]. This can be showed by the fact that vehicle travel and time-on-road are reduced. As fuel consumption is directly related to vehicle kilometers travelled, it will reduce as well. With the information provided,drivers are able to avoid.

Government is also able to take benefit from smart highway system implementation as it can help reduce traffic congestion on the highway and exploit drivers' data, e.g., Global Positioning System (GPS), fuel consumption, travel distance, etc., as the cars always connected to a global control network that unify the smart highway system via Wireless Local Area Network (WLAN).

C. Categories of smart highway system

The smart highway system can be divided into three categories: smart toll payment, smart drive, and smart geo. Further discussion on the implementation of each category with examples of its implementation will also be provided.

Smart drive

The smart drive is implemented on car in the effort to overcome the traffic congestion problems by equipping interconnected auto pilot system. Auto pilot system is a system that drive car automatically in

self- drive mode. This system will be synchronized with every car in that highway system to decide route and cruising speed, assisted by ACC sensor [14]. When a car passes through highway ingress, smart drive will send information to the control system and the egress, so the synchronization will be established. When the car is nearing to the egress, the system will inform the driver to switch to manual drive mode. If the system is unresponsive, it will stop the car in the roadside near the egress. By using this method we can minimize traffic jam in highway that was caused by congestion shock wave [8]. Information exchange is also important in implementing smart highway system. In those days, data fusion has been applied in diverse fields in civilian and military applications. Several methodologies have been proposed in the literature to function multi-sensor fusion and aggregation under heterogenous data configurations. With the modern deployment of smart transportation system and needs of real-time and accurate data, several technologies have been developed such as Floating Car Data, that this data will be uploaded to Traffic Management Center (TMC). One of the advantages we could find is this smart geo feature. This technology can help the user to find out the traffic conditions that prevail on urban road using new measurement device such as cameras, GPS and cell phone tracking [15].

By using this kind of wireless sensor that deployed in the roads, we could drastically improve the collection of traffic information and enhance traffic control. With the increasing number of vehicles on the roads, it becomes important to monitor and manage the roads for abnormal behavior that can cause delay or congestion. This sensor is also power efficient, as an example, by integrating low-power RF chips, high speed/low power design and ultra-low power wireless sensor networking protocols in vehicle can be installed in less than 20 minutes and have 10-year battery life [16].

Not only helping driver to avoid congestion, this wireless network can also be used to control traffic light effectively. Research conducted by Tubaishat *et al.* (2009) shows that real-time adaptive sensor used on traffic lights that use simple algorithm and sensor can increase 30-50% improvement on average trip waiting time [17].

Smart toll payment

The smart toll payment system is implemented to overcome the limitation of the conventional toll payment method electronically. This is because the conventional method causes delay and inconvenience for the highway driver as they have to deal with cash. The smart highway system will use Radio Frequency Identification (RFID). This tool will be placed on car door, so when the car passed in front of the gate, it will automatically detect and pays the toll tax. The main concern hindering the implementation is the privacy and security issues. This is due to fact that confidential data of the drivers are being dealt with threats such as spoofing, replay attack, and sniffing [18]. There is also another alternative using the Dedicated Short Range Communication (DSRC) founded by Bera *et al.* (2006). He said in his paper that this new technology can be applied as a media for road to car communication. This technology can make a communication up to 200 meter geographically between a mobile user and a fixed base station. DSRC using wireless frequency near 5.8GHz. The problems of this method is there will be an interference between DSRC devices. But this interference only happened at some frequencies. Based on experiments conducted by Bera *et al.*, the optimum frequency to operate DSRC is between 5.76-5.84GHz [19].

Smart geo

The smart geo system is implemented to overcome the limitation of the driver navigation. It connects to GPS system around the world via satellites. This system can find driver's destination easily and can track the car when it's stolen. This system also can help the government as alternative to improve navigation and maps development that uses the driver or citizen as a volunteered geography. Sites such as Wikima-

pia and OpenStreetMap are empowering citizen to create a global patchwork of geographic information [16]. Feng & Law (2002) says in their paper that positioning plays an essential role in smart transportation system [20]. The global positioning system (GPS) is reliable to be used in difficult environments such as urban canyons, inside building, etc. But GPS alone can't provide enough positioning accuracy. Usually GPS is assisted alongside other technologies like mobile phone. The assisted GPS (A-GPS) has a lot of advantages in smart transportation system. It uses various devices to make a typical positioning system for vehicle. There is a distance sensor, either an odometer that provides distance directly, or an accelerometer that provides distance indirectly [20].

The reason why the typical positioning system uses many sensors is that no single sensor can provide adequate information for navigation. So the best solution is to combine them all. The comparison of those methods are shown in Table 2.

D. Smartness transportation index of Jakarta

The followings are modified indicators of the smartness transportation level in Jakarta. There are total 60 indicators and the data source was taken from our previous study. The smartness index is assessed by the following formula. If the smartness capabilities are existed, then give a value of 1, and if there are no or not yet developed or there is no proof, then give a value of 0 [21].

Table 2. Comparison of the three methods

Method	Advantages	Disadvantages
Smart drive	With the help of Traffic Management Center, could drastically improve the collection of traffic information and enhance traffic control.	Need big resources that are not cheap Data fusion and TMC still need to be tested
Smart geo	Can help to find driver's destination easily and can track the car when it's stolen.	Single sensor is not accurate enough to determine the position.
Smart toll payment	Makes the toll payment easier	There may be still an interference happened when using the DSRC technology.

There are 6 major category of the scoring, (1) sense; (2) process and control; (3) communicate; (4) predict; (5) heal; and (6) prevent; and 3 subcategories for each: private, public, and commercial and emergency.

For the sense category, in private section, Jakarta has 1 point on en-route detection, detect at parking facilities, detect at intersections and detect for enforcement. In public section, it has 1 point en-route detection, detect at terminal/depot, detect at stations/stops, passenger detection and detect for enforcement. In commercial and emergency section it has 1 point on en-route detection, detect at terminal/depot, detect at checkpoints, container/cargo detection and detect for enforcement.

Look into the process and control category. In private section, it has 1 point on each, control signal, automated parking systems, in-vehicle safety management, infrastructure safety and security, toll/parking charge payment. In public section, it has 1 point on each, signal priority driver-less transit vehicle, infrastructure safety and security, inter-modal and e-fare payment, but in-vehicle safety management gets 0 point. In commercial and emergency it also has 1 point on each of signal priority, dynamic route guidance, in- vehicle safety management, infrastructure safety and security, payments at port interface.

In the communicate category, in private section, it also has 1 point on vehicle-driver, driver- infrastructure, and vehicle-vehicle, but infrastructure- vehicle gets 0 point. In public section, it has 1 point on, operator-user, user-authority, and operator-operator, but authority-vehicle gets 0 point. In commercial and emergency section, it has 1 point on authority-operator, operator-driver, but driver-authority, vehicle-vehicle gets 0 point.

The predict category almost the same, private section with traffic flow prediction, but responsive supply and early disaster warning has no point. Pub-

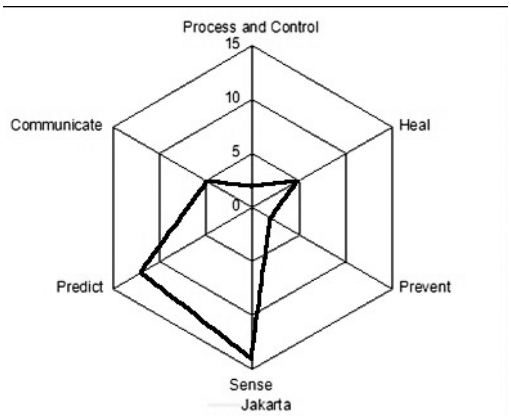

Fig 1. Performance Analysis of Jakarta Transportation [21]

lic section with demand prediction has 1 point, but responsive supply and early service failure warning has no point. Commercial and emergency section with demand prediction, responsive supply and early disaster warning, all that three items get 0 point.

In the heal category, the private section consisted of tunnel recovery and incident recovery, and both have 1 point each. In the public section, track/service recovery and incident recovery has the same point. In commercial and emergency section, incident recovery has 1 point, but asset item get 0 point.

Lastly, the prevent category. In the private section, integrated land use planning gets 1 point. Public section consisted of special event planning and public transport planning get 1 point too. In commercial and emergency section, commercial transport planning and special event planning gets 0 point.

The final calculation of smartness index (IS) for Jakarta is 63.49% [19]. One point that Jakarta needed to improve its smartness is special event planning on public prevention.

Methodology

In this research, we conducted the following procedure, as shown in Figure 2: literature review, resume analysis, synthesis, proposed idea, and conclusion. In literature review, several researches related to

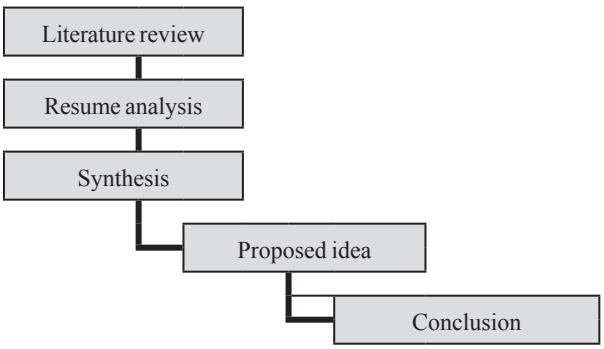

Fig.2 Procedure of Work

transportation system and vehicle management were collected and reviewed. The result of the review was used to make resume analysis and to formulate synthesis. After synthesizing suggestions, proposed idea was produced. The final step was to generate conclusion of this research.

A. Literature review

Over the next few years, drivers will become more informed with the advent and deployment of the intelligent transportation system. This technology can help the driver to save the trip cost by showing the most efficient path to reach a destination and help to prevent being congested in roads. Kennedy *et al.* (2005) said that process of becoming sustainable transportation needs four essential components: (1) establishment of effective bodies for land use planning; (2) the creation of fair, efficient and stable funding mechanisms; (3) strategic investments in major infrastructure; and (4) the support of investments through local design. The development of the sustainable transportation is a challenge to human technology development [22]. Besides that, the organizational capacity also has important site to form urban governance for successful regional land use and transportation planning.

According to a research conducted by Levinson (2003), uninformed driver capacity is reduced by 33-50% for the percentage of time saved peaks for incidents on the road [23]. This research shows that by using smart transportation, we can save our time

on the road by following the shortest path informed by smart highway system to reach our destination [23].

B. Resume

Based on our literature review, we formulate 6 categories of Intelligent Transport System (Fig.3). The analysis of each category is described in Table 3.

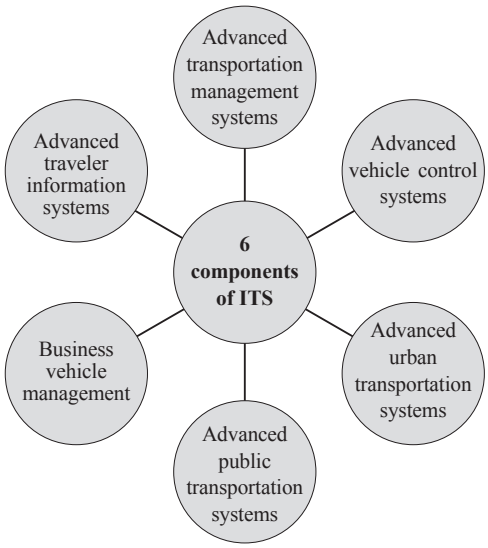

Fig.3 Mindmap of the six fundamental components of Intelligent Transportation Systems [9]

Table 3. Comparison of Recent Development State of Six Fundamental Components

No	Category	Paper	Advantages	Disadvantages
1	Advanced transportation management systems	Towards the intelligent transportation systems (Figueiredo, 2001)	With this still-in-development technology, we can decrease congestions on roads and highways and improve road system productivity [24]	Requiring complex task that uses high economical resources and a large variety of technologies [24]
2	Advanced vehicle control systems	Review of the State of Development of Advanced Vehicle Control Systems (AVCS) (Shladover, 1995)	Advanced vehicle control system (AVCS) in terms of overall system capacity (vehicles per hour), fault tolerance, and total system cost outweigh that concern. [25]	There are still limits to the performance that can be achieved at each level of feedback information, and higher levels of performance generally require more information [25]
3	Advanced urban transportation systems	Urban public transportation systems (Vuchic, 2007)	In small cities the role of transit is predominantly social, in medium-sized cities, transit becomes an important factor in providing an efficient alternative to driving. In mega cities, represents the most efficient transportation system for large volumes of passenger travel [26]	Trolleybuses system require higher investment in lines as well as in vehicles. Lines cannot be rerouted if this is needed for temporary changes [26].
4	Advanced public transportation systems	Review of the Applications of Agent Technology in Traffic and Transportation Systems (Chen, 2010)	The integration of new technologies, such as mobile agent technology, should enhance the flexibility of systems and the ability to deal with uncertainty in dynamic environments [27]	The design implementation, and application of agent based approaches in the area of traffic and transportation are still immature and need to be further studied [27]
5	Business vehicle management	Smart card data use in public transit: A literature review (Pelletier et al., 2010)	Smart card systems can be useful for providing data to both planners and researchers so that we can enhance the strategic, tactical, and operational performance of transit authorities [28].	The research and development cost is high. The cost of implementation is high. Social acceptance is slow [28]
6	Advanced traveler information systems	Travel information as an instrument to change drivers' travel choices: a literature review (Chorus et al., 2006)	Modal shifts towards transit and adaptations of departure time and route choices would reduce passenger transport externalities such as congestion, fossil fuel exhaustion, noise, etc. [29]	The variation in behavioral response to information, a substantial part of this variation will always remain unexplained: traveler behavior, and particular travelers' response to knowledge limitations and information provision [29]

C. Synthesis

Based on the resume analysis, we synthesize suggestions for each component of Intelligent Transportation System (Table 4.).

D. Proposed idea

This paper set out to provide literature review show that smart highway system should give benefits to users and society overall. The amount of time saved under recurring congestion in metropolitan cities. After analyzing the literature, the concrete idea to make this happen is developing and implementing the most needed components above, the advanced traveler system, because it is the main point that awareness of each individual can reach. Like the aforementioned sentences above, the uninformed road users have their capacity reduced by 33-50% without the help of that technology. The development of the smart transportation system involves a large number of areas, the first one we maximize, refine, and implement its technology and its usage, the smart geo. After that, the second direction is mass production and implementation of smart highway system, the all-in integrated smart driving system. And the third possibility consists of development and refinement of model of roads, vehicles, and humans, so the last thing, we can plan out the future of smart highway transportation system. In the future, there will be no more congestion, no more inefficient fuel consumption, and no more wasted time on roads to reach a destination. All of these technologies will make sustainability in the bright future.

E. Consideration

Among the six suggestions, we consider the advanced traveler information systems is the fundamental of the intelligent transportation system, because the individual driver have unique variation in behavioral response to the information, and because of the limitation of the knowledge among the drivers.

Table 4. Proposed Suggestions for Six Fundamental Components

No	Category	Paper	Suggestion
1	Advanced transportation management systems	Towards the intelligent transportation systems (Figueiredo, 2001)	Continuous development of road-vehicle system (navigation system, board computers, real time traffic transmission) and public fully automated individual cars for public use [7]
2	Advanced vehicle control systems	Review of the State of Development of Advanced Vehicle Control Systems (AVCS) (Shladover, 1995)	The highest layer of the fully automated control system is the network layer. Earlier communication technology considered obsolete because of the dramatic change in computer hardware and software and communication technologies that have occurred since then [25].
3	Advanced urban transportation systems	Urban public transportation systems (Vuchic, 2007)	Transit must be planned at the same time as streets and highways, and given the necessary priorities to achieve a desirable balanced use of transit, cars, bicycles, pedestrian and other modes of transportation [26].
4	Advanced public transportation systems	Review of the Applications of Agent Technology in Traffic and Transportation Systems (Chen, 2010)	Make an integrated cross sectors (transportation, land use, energy, etc) and scale (urban, regional and global policies). Must be advanced through integrated studies of environmental conditions within these cities [27].
5	Business vehicle management	Smart card data use in public transit: A literature review (Pelletier et al., 2010)	Developing smart card data for strategic, tactical, and operational purposes will help to improve the public transportation system and increase its role in sustainable transportation [28].
6	Advanced traveler information systems	Travel information as an instrument to change cardrivers' travel choices: a literature review (Chorus et al., 2006)	A useful and less costly alternative data-collection method is to construct a multimodal travel simulator-experiment. Considering the provision of travel information as a travel demand tool among car-drivers [29].

Result and Discussion

A. Potency of Smart Highway system in Jakarta

Congestion is a cause of increased emissions and there is a strategy to increase road capacity, but it is not the answer. Active traffic management system can significantly reduce congestion. The smart highway concept appears on the rationale to resolve traffic congestion problem in Jakarta. This literature research shows clearly the potential of using smart highway system to improve the performance of traffic and transportation system. In general, the design, implementation and application of smart highway system in the area of traffic and transportation are still immature and need to be further studied. The integration with other technologies, such as mobile agent technology, should be considered to enhance the flexibility and the ability to deal with uncertain conditions in environment. One day this system may become the future of transport system on sustainable development in general. In this case, a broader range of sustainability indicators may be considered. Changes in the transport sector may induce changes in various other sectors, which in turn may affect sustainable development. For example, it may induce macro- economic changes (e.g. lower production costs, and higher production values in trade and industry), resulting in changes in Gross Domestic Product (GDP) and employment levels.

B. Challenges of Smart Highway system in Jakarta

A number of challenges can be identified, such as demand, costs, effort and continuing research for smart highway system. The first challenge is the funding to do a research to make a prototype of this system, and the continuing research to make better system. Costs will not be cheap. But if the demand for the system is high, the production costs will automatically be reduced. So, a help from government to make an adoption of this system to every car in Jakarta is necessary.

This means there is an opportunity to cooperate with policy makers, and the implementation will become incremental at best. There needs to be a collective rediscovery of confidence in strategic and long term planning for traffic congestion in Jakarta and ecological conservation. A consistent progress should be made toward this system as one of many solutions for aforementioned problems, and of course an increase in funding levels. This can be best attained by the form of strategic planning system proposed by the government at Jakarta City and then this system can be implemented broadly at the national level.

To reach a sustainable transport system, drivers may have to drive less and enhance accessibility. However, from an individual point of view it may be more attractive to continue driving because of many advantages of individual car use. The car is especially attractive because of its convenience, independence, flexibility, comfort, speed, perceived safety, and privacy. The car also provides more status and pleasure than other modes of transportation.

Conclusion and Future Works

In this study, the various types of smart highway system have been presented. From the various examples of the implementation of such systems being presented, we can say that it is efficient in alleviating the traffic problems that arise especially in jammed cities like Jakarta. There may be some disadvantages in the implementation of such systems, but the advantages far outweigh its disadvantages. Without new technologies, such traffic congestion and emission reduction may be considered impossible to meet if not adopted. Unfortunately, although technologies could theoretically provide the traffic congestion solution, ~~but in~~ CO_2 reduction would be difficult, expensive and long term solutions. There are other combined measures which would provide a quicker and easier solution over a shorter time span.

- *Car use and ownership.* On the urban city like Jakarta, transport system has great inertia and take years to change. As a result, without a strict policy, there will be many more cars in Jakarta. Instead of promoting education to peo-

ple, the government should offer substantial tax incentives on smaller cars to limit the buy of new cars per year. Although seen as more long-term solution, land use planning could be the one solution in Jakarta.

- *Road freight.* There is a need to increase the public awareness of using mass transportation. This system has been applied in Jakarta as 3-in-1 road. This can encourage regional production in a timescales and can reduce empty running.

We have performed the analysis and comparison among the recent development of six fundamental components of intelligent transportation system. We also have elaborated some alternatives to those components and analyzed its feasibility to be implemented in Jakarta transportation system. From the discussion above, we found that the most feasible technology that can be applied to the smart highway system is the smart geo, because the A-GPS technology is provided globally via satellites and can be used in various difficult environments such as urban canyons, inside buildings, etc.

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