Improving the Readiness of Roads for the Era of Automated Vehicles: Focusing on Road Design and Planning

Kwangho Kim

This article is intended to get roads ready for the commercialization of automated vehicles. In this regard, a novel approach is established to construct plausible scenarios by considering major affecting factors for the operation of automated vehicles. This scenario-based approach is applied to two use cases. One case concerns the situation where automated vehicles are sold to individual consumers for personal mobility, and the other case pertains to the application of automated vehicles to shared-use mobility such as carsharing or ridesharing. Finally, near-term projects on road design and planning were derived in consideration of the road improvements needed for operating automated vehicles.
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- A Study on Enhancing Equity of Advanced Transportation Services: Focusing on the Shared-use Mobility, 2019, KRIHS
- Safety Features of Freeway Weaving Segments with a Buffer-Separated High-Occupancy-Vehicle (HOV) Lane, 2018, International Journal of Injury Control and Safety Promotion
- A Preliminary Study to Make the Road Sector Ready for the Commercialization of Automated Vehicles: Focusing on Road Design and Planning, 2018, KRIHS
- Research to Improve the Accessibility of a Metropolitan Area by Utilizing Shared-Use Mobility, 2017, KRHS
- A Study to Improve Highway Management Evaluation, 2017, Ministry of Land, Infrastructure, and Transport
- A Multi-level Analysis of the Relationship Between Urban Built Environment and Severe Injury Traffic Crashes, 2017, KSCE Journal Civil Engineering

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Summary

This article was motivated to help the road sectors prepare for the commercialization of automated vehicles. In this regard, relevant concepts and technologies were reviewed, and then plausible scenarios on the operation of automated vehicles were investigated in detail. Furthermore, near-term projects related to road design and planning were derived in consideration of the road improvements required to accommodate automated vehicles under highly plausible scenarios.

Notably, this article contributes to establishing a scenario-based approach by employing three key factors that are likely to influence the ways automated vehicles will be introduced. The first factor is associated with the evolution of the mobility markets related to automated vehicles. The second factor concerns the technology options for automated cognition and judgement. The third factor is related to the purpose of the communication systems between an automated vehicle and its surrounding road infrastructure. These three factors were comprehensively examined to construct the scenarios for two use cases. One of these is the situation where automated vehicles are sold to individual consumers for personal mobility. The other case pertains to the application of automated vehicles to shared-use mobility services.

The results presented in this article, however, include the following limitations. First of all, the examined scenarios related to the commercialization of automated vehicles are not comprehensive largely due to simplifications regarding the affecting factors and their available options. In addition, the projects derived in this article are not specified in sufficient detail.

Apart from these limitations, this article is meaningful as an initial attempt to help road sectors respond properly to the era of automated vehicles. Hopefully, there will be follow-up studies to further develop the results of this article. To this end, more thorough reviews of the technology options and additional market research would be worthwhile. In particular, pilot studies to revise the manuals or standards on road design and planning need to be launched as soon as possible.

Automated vehicles capable of self-driving are expected to operate on public roads in the near future. In light of this, there are two opposing opinions about the role roads play in response to the commercialization of automated vehicles. One group of experts argues that roads should be given the intelligence to directly influence the controls of automated vehicles. Others disagree with such active involvement by roads in automated driving, expressing concerns about both infrastructure costs and liability issues.

Apart from the specific roles of roads, most experts agree that roads should accommodate automated vehicles in both safe and efficient ways. In this vein, this article is intended to derive key projects to improve the readiness of roads, specifically by improving their design and planning. In deriving these projects, plausible scenarios are constructed by anticipating the way how automated vehicles will be introduced in the near future.

Until fully automated driving is realized, the safety of automated vehicles will largely depend on ‘interactions between an automated vehicle and its human operator’ and ‘interactions between an automated vehicle and the road’ as illustrated in Figure 1 below. The former interaction occurs whenever driving responsibility is transferred between an automated vehicle and its human operator — i.e., the person in the driver’s seat. In this regard, many empirical studies have already been conducted to understand human factors such as the reaction time involved in changing driving modes. On the other hand, the latter interaction concerns either ‘cognition or judgement by individual automated vehicles’ or ‘road infrastructure that can accommodate the operations of automated vehicles.’ Note that these interactions are the main concerns of this article.
Chapter II. Automated Vehicle Concepts and Technologies

1. Automated Vehicle Concepts

Automated vehicles are intended to perform self-driving without the involvement of human drivers either temporarily or throughout the entire trip. For self-driving, three functions called cognition, judgement, and control are required as summarized in Figure 2. First, cognition is necessary to monitor its position and to detect changes in its surroundings such as oncoming obstacles and lane-changing vehicles. Such monitoring and detection are performed by sensors (e.g. Cameras and Radars) as well as positioning systems such as the Global Positioning System (GPS). In addition, automated vehicles are required to make judgements such as choosing driving routes or avoiding crashes. Such decision-making procedures are incorporated into the algorithms devised for calculation, data fusion, etc. Eventually, control systems will be able to operate by themselves based on information from both cognition and judgement. Control maneuvers such as executions and stops are carried out through electronic or mechanical systems. Note that multiple sensors, as shown in Figure 3, are required to perform these three functions of automated driving.

Given the above background, this article’s primary goal is to figure out what is necessary to improve the design and planning of roads, particularly in the near future until 2025. This near-term horizon was chosen because of the consideration that there will be much uncertainty with technology options and the mobility market in relation to automated vehicles produced beyond 2025.

The contents of this article are as follows. The second chapter discusses automated vehicle concepts and technologies. Here, technological trends in both driving automation and road digital infrastructure are examined. The third chapter identifies likely scenarios on the introduction of automated vehicles in consideration of major affecting factors. The fourth chapter presents road infrastructure requirements to accommodate automated vehicles under highly plausible scenarios. And finally, the last chapter discusses the key findings of this study and its implications.
An automated vehicle can operate either independently or cooperatively with nearby vehicles or road infrastructure as shown in Figure 4. The former is often called an Autonomous Vehicle (AV). In this article, AV is used as an abbreviation of autonomous vehicles or road infrastructure as shown in Figure 4. The latter is called Connected Automated Vehicle (CAV). In this regard, the Society of Automotive Engineers (SAE) defined five distinct levels of driving automation as shown in Figure 5 below. According to this categorization, automated driving systems up to level 2 are considered driver support features. On the other hand, the person in the driver’s seat does not take any responsibility under normal conditions with automated driving at levels higher than 2. Note, however, that automated driving at level 3 implies that the human operator should take the role of driver whenever the vehicle systems require human involvement.

In comparing AV with CAV, it is hard to concede the existence of purely independent self-driving. The reason is that even an independently operated AV may refer to High Definition maps, which are occasionally considered as part of road digital infrastructure. Thus, it is more meaningful to figure out how much intelligence from the exterior of a vehicle should influence its automated control.

The level of driving automation is largely determined by the responsibility of the person in the driver’s seat of an automated vehicle. In this regard, the Society of Automotive Engineers (SAE) defined five distinct levels of driving automation as shown in Figure 5 below. According to this categorization, automated driving systems up to level 2 are considered driver support features. On the other hand, the person in the driver’s seat does not take any responsibility under normal conditions with automated driving at levels higher than 2. Note, however, that automated driving at level 3 implies that the human operator should take the role of driver whenever the vehicle systems require human involvement.

<table>
<thead>
<tr>
<th>SAE LEVEL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE LEVEL 0</td>
<td>The driver’s seat has full control over the vehicle.</td>
</tr>
<tr>
<td>SAE LEVEL 1</td>
<td>The vehicle has limited intelligent sensing and limited automated driving features.</td>
</tr>
<tr>
<td>SAE LEVEL 2</td>
<td>The vehicle has increased automated driving features and can take control of the vehicle under certain conditions.</td>
</tr>
<tr>
<td>SAE LEVEL 3</td>
<td>The vehicle has increased automated driving features and can take control of the vehicle under a wide range of conditions.</td>
</tr>
<tr>
<td>SAE LEVEL 4</td>
<td>The vehicle has increased automated driving features and can take control of the vehicle under all conditions.</td>
</tr>
<tr>
<td>SAE LEVEL 5</td>
<td>The vehicle has fully automated driving features and can take control of the vehicle under all conditions.</td>
</tr>
</tbody>
</table>

Figure 4. Concept of Autonomous Vehicles and Connected Automated Vehicles

The level of driving automation is largely determined by the responsibility of the person in the driver’s seat of an automated vehicle. In this regard, the Society of Automotive Engineers (SAE) defined five distinct levels of driving automation as shown in Figure 5 below. According to this categorization, automated driving systems up to level 2 are considered driver support features. On the other hand, the person in the driver’s seat does not take any responsibility under normal conditions with automated driving at levels higher than 2. Note, however, that automated driving at level 3 implies that the human operator should take the role of driver whenever the vehicle systems require human involvement.

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In comparing AV with CAV, it is hard to concede the existence of purely independent self-driving. The reason is that even an independently operated AV may refer to High Definition maps, which are occasionally considered as part of road digital infrastructure. Thus, it is more meaningful to figure out how much intelligence from the exterior of a vehicle should influence its automated control.
2. Technology Options for Driving Automation

There are two technology options available for an autonomous vehicle to recognize and judge either oncoming obstacles or other dangerous traffic situations. One option named AV1 is to obtain information from relatively inexpensive sensors (e.g. cameras and radars) and to interpret such collected information by means of Artificial Intelligence (AI). In contrast, the other option (AV2) is to trace the information scanned from high-resolution sensors such as LiDAR with respect to HD maps in real-time basis.

The above two options for driving automation differ from each other as summarized in Table 1 below. In the case of AV1, an object is defined as moving if it has both directional vectors and speeds. Under this option, an automated vehicle determines its moving direction by monitoring landmark points on the relevant digital map. On the other hand, AV2 recognizes a moving object by identifying static components of HD maps. The latter AV option can improve the positioning of an automated vehicle with the aid of HD maps.

### Table 1. Technology options for automated cognition and judgement

<table>
<thead>
<tr>
<th>Features</th>
<th>Option</th>
<th>AV1</th>
<th>AV2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Technology</td>
<td>Interpreting the information of radars and cameras by means of AI</td>
<td>Tracking the information scanned from LiDAR with respect to HD maps</td>
<td></td>
</tr>
<tr>
<td>Determination of moving objects</td>
<td>Considering both directional vectors and speeds</td>
<td>Identifying static components of HD maps</td>
<td></td>
</tr>
<tr>
<td>Criteria for direction to proceed</td>
<td>Directional vectors and speeds</td>
<td>Trip purpose and vehicle positioning</td>
<td></td>
</tr>
</tbody>
</table>

3. Key Components of Road Digital Infrastructure

3.1 High-Definition (HD) maps

Maps built for self-driving purposes are usually called High-Definition (HD) maps. These maps require spatial data with a high precision, having margins of error in the range of centimeters, to provide both static and dynamic information related to roads and traffic conditions. A key role of HD maps in this regard is to complement the limitations of sensors. Moreover, HD maps help automated vehicles focus computational resources on critical changes that directly affect driving safety.

HD maps are composed of both static and dynamic information as shown in Figure 6 below. Static information such as a bridge’s location rarely changes. Most static information has been already reflected in current navigation maps. On the other hand, dynamic information (e.g. road climate and signal phases) may require real-time data acquisition.

3.2 Communications between a vehicle and its surrounding objects

Technologies used for communications between a vehicle and something are usually...
called as V2X. For example, V2V (Vehicle-to-Vehicle) communications can be used to warn of imminent crashes between vehicles at intersections. In addition, V2I (Vehicle-to-Infrastructure) communications can improve driving safety by means of timely information sharing between a vehicle and the nearby roadside infrastructure.

There are several technology options available for V2X. One of them is called Dedicated Short-Range Communication (DSRC). This technology option has the advantage of providing accurate and immediate transmission of safety-sensitive messages. However, DSRC has limitations with its frequency spectrum and data storage. In contrast, cellular communications can be used for broader transmission of messages, but this option may lack the timeliness in responding to oncoming dangers. In this regard, 5G cellular technologies are considered a promising option for HD maps, owing to the improvements in both transmission speed and data storage.

As described in Figure 7 below, the applications of V2X depends largely on whether it is used to inform the human operator or the vehicle system itself. For the sake of convenience, applications targeted to the former shall be deemed ‘V2X information’ in this article. This application is already being used to improve the safety and mobility of human-driven vehicles. On the other hand, V2X can also play a role in controlling an automated vehicle. This is called ‘V2X control’, and will require more accurate and timely information in comparison with V2X information.

### I. Prospect of Introducing Automated Vehicles

Partially automated driving is already available to auto consumers, and automated driving at an even higher level is likely to be commercialized in less than 10 years. For example, the Boston Consulting Group estimated that automated vehicles will occupy around 13% of the global auto market in 2025. According to this estimate, one may frequently experience mixed traffic composed of automated vehicles and human-driven vehicles in the near future.

### Figure 8. Expected growth of global market for automated vehicles

- **Partially autonomous:** 15.0%
- **Fully autonomous:** 9.8%
- **Partially autonomous:** 12.4%
- **Fully autonomous:** 0.5%

Automated vehicles will be introduced in different ways depending on both ‘level of driving automation’ and ‘spatial scope of deployment.’ One of likely approaches in this regard is to confine the deployment of automated vehicles while applying a higher level of automation to them. This so-called ‘Everything Somewhere’ (ES) approach can be applied to well-managed urban roads that are usually designed for lower operating speeds as compared to expressways. The other approach of ‘Something Everywhere’ (SE) is to deploy partially automated vehicles with few restrictions on their areas of operation or routes. This approach will involve mixed traffic conditions where automated vehicles and human-driven vehicles travel on the same roads.

As shown in Figure 9 below, these two approaches would correspond to different mobility markets, particularly at the initial stages of introducing automated vehicles. The ES approach is likely to go well with shared-use automated vehicles (e.g. carsharing and ridesharing) as opposed to their non-shared counterparts. The reason is that higher-level automated vehicles will be expensive to purchase due to the cost of sensors in the near future. On the other hand, the SE approach has been already applied to the so-called Advanced Driving Assistance Systems (ADAS) that are sold as part of optional packages to individual auto consumers for their personal mobility. Ultimately, the mobility markets for the ES and the SE approaches are expected to merge as automation technologies improve and become cheaper.

2. Scenarios on the Commercialization of Automated Vehicles

2.1 Overall Scenario Settings

The uncertainty related to the commercialization of automated vehicles can be addressed by employing the following three key factors. One of them is associated with ‘level of driving automation’ and ‘spatial scope of deployment.’ In this regard, the aforementioned ES and SE approaches are feasible options. The second factor corresponds to ‘technology options for cognition and judgement.’ In this regard, recall that AV1 complements relatively low-resolution sensors with AI, and that AV2 monitors information from higher-resolution sensors such as LiDAR while referring to HD maps. The third factor is determined by the purpose of the communications between a vehicle and its surrounding objects (i.e. V2X). For this factor, ‘V2I information’ and ‘V2I control’ would be feasible in the near future. Note that V2V communications would rarely be available in situations where the market penetration of automated vehicles is not high enough.

The scenarios can be constructed by enumerating all feasible combinations of three options, each of which corresponds to one of the affecting factors mentioned above. For example, (ES, AV1, V2 control) is one such feasible combination. Here, the total number of scenarios amounts to 8 (=2^3) in all. Among these scenarios, the most plausible scenario will be selected for each of two use cases as described in the following.

2.2 Selection of Highly Likely Scenarios for the Near Future

In the case of automated vehicles sold to individual consumers for their personal mobility, (SE, AV1, V2I Information) is identified as the most likely scenario for the near-term horizon ranging from 2020 to 2025; note the path highlighted by the bold red line in Figure 9(a). The reason is that individual auto consumers would prefer using automated vehicles for their personal mobility without spatial restrictions. In addition, such unrestricted automated driving would be compatible with lower-level automation that is usually performed by inexpensive sensors in combination of AI. For lower-level driving automation, it is more desirable to use V2I communications to inform human drivers rather than directly control vehicles.

On the other hand, automated vehicles serving shared-use mobility would conform well to the scenario (ES, AV2, V2I information) in the near future as shown in Figure 9(b). Shared use mobility, which is justified for relatively expensive sensors, would be introduced to limited urban areas or routes in consideration of both service safety and reliability. Note that, in this regard, it is inevitable
for the human operator to take a role of a driver at least partially. Such human involvement may be particularly required unless separate roads or lanes are reserved for shared-use automated vehicles. In addition, V2-information is considered more feasible than V2-control for this application.

Figure 10. Highly plausible scenarios for operating automated vehicles (near-term horizon)

CHAPTER IV.
Projects Required to Get Roads Ready for Automated Vehicles

1. Road Improvements Required to Accommodate Automated Vehicles

1.1 Road Improvements Required for All Automated Vehicles

Road infrastructure must be improved, regardless of whether or not automated vehicles are applied to shared-use mobility. In the near-term horizon, the general requirements are ‘communication infrastructure to warn the human operator’, ‘safe areas for stopping or rest’, and ‘facilities for automated valet parking’.

First, there are occasions where either V2V or V2I is supposed to send a warning message to automated vehicles about unexpected or complicated hazards. Such V2X warnings may not be indispensable for driving automation lower than level-3. The reason is that the human operator is supposed to take the responsibility of driving at any time. Even in that case, however, V2X warnings would be useful in enhancing road safety by informing the human operator of imminent hazards.

In addition, safe areas for stopping or rest are required for automated vehicles to address situations where the human operator requires time to recover from unconsciousness or fatigue. Safe areas are also required when an automated vehicle needs repairs due to a malfunction or crash. When an automated vehicle is in a safe area, the condition of its occupant(s), if necessary, should be reported to either a traffic management center or a police agency.
Furthermore, parking facilities require improvements in consideration of automated vehicles. First of all, parking facility designs need to be revised to allow vehicle users to be dropped off or picked-up at the entrance of a parking facility, thereby creating more parking spaces as shown in Figure 12 below. In addition, automated valet parking would require surveillance systems to remotely control individual vehicles, in addition to security systems to prevent hacking.

**Figure 12. Potential design revisions in consideration of automated valet parking**

In addition, some facilities need to be customized to ease the transfer of travelers from or into shared-use automated vehicles at transit stations. For example, ridesharing pick-up/drop-off places need to be improved or newly installed to meet the needs of shared-use automated vehicles. Such transfer facilities for automated vehicles need to be designed by considering the safety of general travelers as well as the users of shared-use automated vehicles. To this end, the movements of automated vehicles, if necessary, should be separated from those of other road users. In addition, communication facilities can also be installed to help pedestrians or bicyclists be aware of imminent self-driving near pick-up/drop-off areas.

**1.2 Road Improvements Customized for Shared-use Automated Vehicle**

Automated vehicles, if used for shared-use mobility, would require HD maps comparable to those for higher-level driving automation. Road management authorities should take the responsibility of performing timely updates to such HD maps with regard to highway information in the relevant area and/or the routes designated for automated driving. In this regard, road management authorities, map providers, and mobility service providers must establish cooperative relationships among one another to have HD maps reflect changes in the driving environment, such as changes regarding safety signs and road works, in a timely manner.

In addition, some facilities need to be customized to ease the transfer of travelers from or into shared-use automated vehicles at transit stations. For example, ridesharing pick-up/drop-off places need to be improved or newly installed to meet the needs of shared-use automated vehicles. Such transfer facilities for automated vehicles need to be designed by considering the safety of general travelers as well as the users of shared-use automated vehicles. To this end, the movements of automated vehicles, if necessary, should be separated from those of other road users. In addition, communication facilities can also be installed to help pedestrians or bicyclists be aware of imminent self-driving near pick-up/drop-off areas.

**2. Near-term Research Projects to Enhance Road Design and Planning**

**2.1 Overview of Deriving Near-term Research Projects**

Near-term research projects related to road design and planning can be derived by considering the road improvements required to operate automated vehicles both safely and efficiently. These projects can be categorized into 4 types depending on the ‘application of automated vehicles’ and ‘research area’ as presented in Table 2 below. The first type is intended to enhance manuals and standards on road design and planning to accommodate all automated vehicles, regardless of whether or not such vehicles are applied to shared-use mobility. The second type is concerned about enhancing methods to analyze road capacity or travel demand in situations where automated vehicles operate on public roads. The third type is required to revise the manuals and standards on designing and planning road facilities customized for shared-use automated vehicles.
Finally, the fourth type is intended to improve the methodologies used to analyze the operations of shared-use automated vehicles or to evaluate their impact.

### 2.2 Research Projects on Road Improvements for All Automated Vehicles (Manuals and Standards)

- **Revising standards on road structures and facilities**
  
  These projects are intended to revise standards on road structures and facilities by considering the commercialization of automated vehicles. Revised elements should include road classifications, design speed, separation of lanes, etc.

- **Revising road capacity manuals**
  
  These projects aim at revising road capacity manuals to analyze mixed traffic composed of automated vehicles and human driven vehicles. Specifically, road capacity needs to be assessed in consideration of the ‘car-following behaviors of automated vehicles’, ‘ratio of automated vehicles in mixed traffic’, etc.

- **Revising road design standards**
  
  The purpose of these projects is to revise elements of road design standards in consideration of the driving performance of automated vehicles. To this end, the ‘level of service’ for a road needs to be newly defined. In addition, road geometry (e.g. curvature) and safety facilities (e.g. guardrails) need to be designed with a consideration of the vision and control systems of individual automated vehicles and their human-driven counterparts.

- **Establishing standards on V2I facilities**
  
  These projects aim to develop standards on designing or installing V2I facilities that provide timely warning messages to human operators so that they can immediately take over driving responsibilities in response to imminent dangers. In this regard, experiments involving diverse situations are needed to figure out a person’s reaction time required for a driving mode change.

- **Establishing design standards on road facilities for safe stopping**
  
  These projects are required to establish the criteria for designing or installing safe stopping facilities for automated vehicles. To this end, either simulations or field studies are required to evaluate the diverse alternatives on safe stopping facilities for automated vehicles.

- **Establishing design standards on automated valet parking facilities**
  
  These projects are intended to establish design standards for facilities planned for safe and efficient automated valet parking. For these projects, either simulations or field studies are required to evaluate the design alternatives for self-driving vehicle parking facilities. The infrastructure subject to such revision or improvement in this regard includes parking structures, information systems, etc.

### Table 2. Categories of research projects on road design and planning for automated vehicles

<table>
<thead>
<tr>
<th>Application</th>
<th>Research Area</th>
<th>Manuals and Standards</th>
<th>Analytical Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road improvement for all automated vehicles</td>
<td>• Revising standards on road structures and facilities</td>
<td>• Developing methods to assess capacity and delays for mixed traffic composed of human driven vehicles and automated vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Revising road capacity manual</td>
<td>• Developing models to estimate travel demand by considering the operations of automated vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Revising road design standards</td>
<td>• Establishing standards on road facilities for safe stopping</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Establishing design standards on road facilities for shared-use automated vehicles</td>
<td>• Establishing design standards on facilities for automated valet parking</td>
<td></td>
</tr>
<tr>
<td>Road improvements customized for shared-use automated vehicles</td>
<td>• Establishing guidelines on HD maps for shared-use automated vehicles</td>
<td>• Developing methods to determine road segments suitable for the operations of shared-use automated vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Establishing design standards on pick-up/drop-off facilities for shared-use automated vehicles</td>
<td>• Developing methods to evaluate the impact of mobility services based on shared-use automated vehicles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Establishing guidelines on HD maps for shared-use automated vehicles</td>
<td>• Establishing design standards on road facilities for safe stopping</td>
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</tr>
<tr>
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<td>• Establishing design standards on road facilities for safe stopping</td>
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</tbody>
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Chapter IV. Projects Required to Get Roads Ready for Automated Vehicles
2.3 Research Projects on Road Improvement for All Automated Vehicles (Analytical Methods)

- Developing methods to assess capacity and delays by considering mixed traffic

These projects are intended to develop methods to determine the capacity of a road serving mixed traffic composed of both human-driven vehicles and automated vehicles. In this regard, potential road capacity increment must be quantified by varying the ratio of automated vehicles in the mixed traffic. In addition, road management authorities may need to evaluate the impact of automated vehicles on traffic delays. To this end, analytical tools need to be developed to estimate potential reductions to delays due to the introduction of automated vehicles.

- Developing models to estimate travel demand by considering the operations of automated vehicles

These projects are necessary to improve the analytical methods that estimate overall travel demand by considering automated vehicles. To this end, the traditional 4-step travel demand estimation may be combined with activity-based models to incorporate diverse features (e.g., land-use patterns, road networks) related to choosing an automated vehicle as the preferred option among available transportation modes.

2.4 Research Projects on Road Improvements Customized for Shared-use Automated Vehicles (Manuals or Standards)

- Establishing guidelines on HD maps for shared-use automated vehicles

The purpose of these projects is to establish guidelines on constructing and maintaining HD maps to aid the operation of shared-use automated vehicles. In the near future, such HD maps are likely to be used primarily for specific areas or routes designated for higher-level driving automation. The contents of such guidelines on HD maps should include data protocols, relationships among stakeholders, update intervals, security systems, etc.

- Establishing design standards on pick-up/drop-off facilities for shared-use automated vehicles

These projects are intended to establish design standards on the facilities required for a traveler to transfer from or onto a shared-use automated vehicle at transit stations. Such transfer facilities need to be designed with a consideration towards safety as well as the convenience of travelers at the station in question. The facilities addressed in this regard should include ‘stopping areas for either pick-up or drop-off’, ‘information systems to warn pedestrians or bicyclists’, etc.

2.5 Research Projects on Road Improvements Customized for Shared-use Automated Vehicles (Analytical Methods)

- Developing methods to determine the road segments suitable for the operations of shared-use automated vehicles

These projects are motivated to develop methods to select road segments suitable for the operation of shared-use automated vehicles in both safe and efficient ways. Detailed criteria need to be set in consideration of various features including road geometry, communications infrastructure, crash frequency, etc.

- Developing methods to evaluate the impact of mobility services based on shared-use automated vehicles

These projects are intended to evaluate the impact of introducing automated vehicles for shared-use mobility services. In particular, most transportation management authorities would be concerned about the impact of using shared-use automated vehicles as feeder services to transit stations. The impact analysis may require integrated simulation models by combining activity-based travel demand estimation and transit assignment.
Chapter V. Conclusions

This article was motivated by a desire to help the road sectors prepare for the commercialization of automated vehicles. As background, this article reviewed relevant automated vehicle concepts and technologies. In addition, a scenario-based approach was established to anticipate the way automated vehicles will operate in the near future. Then, near-term research projects related to road design and planning were derived in consideration of the road improvements required to meet the needs of automated vehicles.

This scenario-based approach employed three key factors to address the uncertainty surrounding the technologies and mobility market relating to automated vehicles. First, ‘level of automated driving’ and ‘spatial scope of deployment’ will affect the mobility market of automated vehicles. The second factor concerns the technology options used for automated cognition and judgement. The third factor is determined by the purpose of the communications systems between an automated vehicle and its surrounding road infrastructure. These three factors were considered comprehensively to construct highly plausible scenarios for two distinct use cases. One of these cases involves automated vehicles being sold to individual consumers for their personal mobility. The other case pertains to the application of automated vehicles to shared-use mobility services such as carsharing and ridesharing.

The scenario-based approach of this article, however, has room for improvement in terms of both comprehensiveness and detail. First, this article considered just three influencing factors on the operation of automated vehicles. In addition, each of the factors was assumed to have binary options. Another limitation of this article is that the derived projects were not sufficiently detailed. In this regard, there should be follow-up studies to refine or to modify the conclusions of this article by conducting a more thorough review of both the technology options and market research related to automated vehicles.

Apart from these limitations, this article is meaningful as an initial attempt to improve the readiness of roads for the era of automated vehicles. Hopefully, pilot studies based on this article’s findings should be launched as soon as possible through partnerships between the public and private sectors. It would be particularly worthwhile to identify what to revise in existing manuals or standards on road design and planning by conducting both relevant field studies and simulations.
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Improving the Readiness of Roads for the Era of Automated Vehicles: Focusing on Road Design and Planning

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