Study on Human Interface of In-Vehicle Route Guidance Systems based on Right Hand-side Driver Behaviors

March 2008

JEON, YongWook

Study on Human Interface of In-Vehicle Route Guidance Systems based on Right Hand-side Driver Behaviors

March 2008

JEON, YongWook

Doctoral Dissertation

Study on Human Interface of In-Vehicle Route Guidance Systems based on Right Hand-side Driver Behaviors

（右側走行ドライバの運転行動に基づいた車載経路誘導システムの

ヒューマンインターフェースに関する研究）

March　2008

School of Science for Open and Environmental Systems

Keio University

JEON，　YongWook

Abstract

In recent years, the number of foreigners who visit Japan has been increasing on purpose of sightseeing and business, and their needs for mobility have also become more multifaceted. Although public transportation is the most common form of transportation, there is the possibility that more foreigners will use a car equipped with an in-vehicle route guidance system such as a car navigation system to facilitate mobility during their stay in Japan. However, when foreigners drive in Japan, it is possible that not only the language but also the position of the driver's seat and the side of the road on which cars are driven will be different from traffic environments in their home countries. Therefore it can be presumed that drivers have higher mental workload. On the other hand, past researches reported that inappropriate information provision of car navigation systems affects driver behavior negatively. If the route guidance information is not appropriate for the foreigners, it elicits the problems that mental workload increases and unsafe driving behavior are occurred.

This dissertation studied on human interface of in-vehicle route guidance systems based on characteristics of driver behavior and mental workload of foreign drivers who were accustomed to driving on the right-hand side of road in the case of providing route guidance when they drive on the left-hand side of road.

Chapter 1 mentioned the technological trend of ITS (Intelligent Transport Systems), and discussed the problems when drivers use an in-vehicle route guidance system and foreign drivers adapt for different road environments in Japan. Chapter 2 described evaluating and application tools to analyze and evaluate on driver behavior, and human interface of in-vehicle route guidance systems. Chapter 3 discussed driver behavior, workload and sensibility when foreign drivers drive on the left-hand side of road. The characteristics of driver behavior and mental workload were analyzed on comparison with those of Japanese drivers. Chapter 4 discussed the characteristics of driver behavior when foreign drivers used the route guidance information which consisted of paper map, arrow-type information, map-type information, auditory information. In this research, eye movements, driver behavior and subjective rating were

evaluated when foreign drivers used route guidance information to reach the destination, and clarified the characteristics and affect by providing each route guidance information in relation to foreign driver behavior. Chapter 5 suggested the human interface of in-vehicle route guidance system base on foreign driver behavior. On the base of results relating to visual information of Chapter 4, allocating methods of arrow-type and map-type information were proposed for foreign drivers, in terms of effective provision of visual information. Chapter 6 discussed the relationship among foreign driver behavior, mental workload and factors of route guidance information on the base of results of Chapter 3, 4, 5. Chapter 7 is summary of this dissertation as the conclusions.

要　旨

近年，商業目的や観光目的などで訪日する外国人の数は増加しているとともに，外国人の移動に対するニーズも多様化しつつある．外国人が利用する交通手段としては公共交通機関が一般的だが，移動に関わる外国人の利便性や自由度を向上させる交通手段の一つとして，カーナビゲーションなどの車載経路誘導システムを搭載した自動車の利用が考えられる．しかしながら，外国人が日本の交通環境で運転する場合，言語の違いだけではなく，運転席の位置や走行車線が母国での交通環境と異なることがあり，精神的負荷の高い状態に陥る可能性がある．一方，カーナビゲーションにおける不適切な情報提供がドライバの運転行動に悪影響を及ぼすことが指摘されており，経路誘導情報が外国人に対して不適切であった場合は，精神的負荷の増加や事故に結びつくような運転行動を誘発する可能性があるものと考えられる．

本論文では，右側走行に慣れ親しんだ外国人ドライバを対象とし，左側走行の交通環境において外国人ドライバを経路誘導する場合の車載経路誘導システムのヒューマンインターフェースを，外国人ドライバの運転行動や精神的負荷の特徴に基づいて検討する．

第 1 章では，ITS（高度道路交通システム）に関する技術動向や普及の現状を示すとともに，車載経路誘導システムに関連してドライバに生じる問題点や外国人ドライバが日本の交通環境で運転する場合の問題点を示す．第 2 章では，車載経路誘導システムのヒューマンインターフェース研究やドライバ行動を分析・評価するための方法，評価装置を示す．　第 3 章では，外国人ドライバが左側走行の交通環境で運転する場合の感性や運転行動，精神的負荷を検討する．日本人ドライバと比較した場合の外国人ドライバの運転行動や精神的負荷の特徴を示す．第 4 章では，外国人ドライバが経路誘導情報を利用する際の運転行動の特徴を検討する．経路選択に利用可能な情報として，紙地図，矢印型情報，地図型情報，音声情報から構成される経路誘導情報を設定する．外国人ドライバがこれらの経路誘導情報を利用しながら目的地まで運転する場合の視認行動や運転操作，主観を考察し，各経路誘導情報が外国人ドライバの運転行動に及ぼす影響や特徴を明らかにする．第 5 章では，外国人ドライバの運転行動の特徴に基づいた車載経路誘導システムのヒューマンインターフェースを提案する．第 4 章の視覚情報に関する結果を踏まえ，視覚情報を呈示する際の矢印型情報と地図型情報の配分方法を考案し，外国人ドライバに効果的な配分方法を提案する．第 6 章では，第 3 章，第 4 章，第 5 章の結果を踏まえ，経路誘導情報に含まれる要素と外国人ドライバの運転行動および精神的負荷の関係について議論する．第 7 章は結論であり，本論文の内容を総括している．

Contents

List of Figures

List of Tables

Chapter Ⅰ

INTRODUCTION

1.1. Information Society and Intelligent Transport Systems

1.1.1. ITS and Information

Eliminating traffic congestion, reducing the number of traffic accidents, and improving road conditions are common problems faced by countries all over the world. ITS (Intelligent Transport systems) offers a fundamental solution to various issues concerning transportation, which include traffic accidents, congestion and environmental pollution. ITS deals with these issues through the most advanced communications and control technologies. ITS receives and transmits information on humans, roads and automobiles. ITS is defined as the application of computers, communications, and sensor technology to surface transportation. Used effectively, ITS opens the door to new ways of understanding, operating, expanding, refining, reconfiguring and using the transportation system [National Intelligent Transportation Systems Program Plan].

ITS improves transportation safety and mobility, and enhances global connectivity by means of productivity improvements achieved through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. ITS encompass a broad range of wireless and wire communications-based information and electronics technologies [75]. ITS systems will reduce traffic accidents and congestion while saving energy and protecting the environment by creating ideal traffic conditions. For realizing that, ITS requires not only the roads to be intelligent but variety of transportation, such as railroad, aviation and marine, to cooperate with each other. ITS is aiming to solve road transportation problems, such as traffic accidents and congestion, by networking drivers, roads and vehicles, through cutting-edge information and telecommunication technology. ITS is a national level project that will even change the system of society and it has great potential to create new industries and markets.

ITS market is expected to expand rapidly over the next few decades. Japan, as a major technological power, must work to pioneer new business opportunities by engaging in ITS-related research and development needed for constructing new road transport systems, thereby contributing to the well-being of the world. ITS technologies are expected to be optimal transportation which is to reduce traffic accidents and congestions, promote energy conservation, and enhance sustainability. ITS is a nationwide project will significantly change our society, and have great potential to create the new industries and markets.

1.1.2. Effectiveness of ITS Development

Cars are comfortable vehicles that are necessary for modern life. As we move into the 21 century, there are approximately 700 million cars in the world. However, as the number of cars increases, it causes not only injuries and extensive property damage but also environmental problems.

ITS promotes not only for transportation but also for regions where people enjoy traveling. In addition, ITS can enhance the quality of life by providing much information [41]. In addition, ITS also supports for safer driving for linking vehicles more closely to the road infrastructures through efficient use of ITS [30][75].

(1) Alleviation of Traffic Congestion

Traffic congestion has become serious in urban areas of Japan, due to insufficient road development to accommodate the growing number of vehicles. The annual loss in monetary terms resulting from traffic congestion is estimated to be an enormous 12 trillion yen. ITS will dramatically reduce traffic congestion that causes such a tremendous loss. Annual benefits due to alleviation of traffic congestion by ITS are estimated to be worth 1.2 trillion yen in 2015. VICS (Vehicle Information and Communication System) would reduce the total loss by 6% with a national development rate of 30%. ETC (Electronic Toll Collection System), AHS (Advanced Cruise-Assist System), and other ITS developments could eliminate about 70% of traffic congestion on Japanese expressways.

Other effective methods are the real-time provision of the road traffic information, information on parking availability, and public transport system information; such information encourages the use of public transport through promotion of park and ride systems, and enables efficient road usage through TDM (Traffic Demand Management).

(2) Dramatic Reduction of Traffic Accidents

In Japan, although the number of traffic accident fatalities has been slightly on the decline, more than 8,000 people still die every year in traffic accidents. The number of traffic accidents, on the other hand, is exceeding 930,000 in 2002. Fatalities of elderly drivers over the age of 65 is considerably increasing; this is a serious problem for Japan, since it has now become an aging society and the number of drivers in this age group is expected to increase 3.5 times to about 18 million within 20 years. ITS is expected to greatly traffic accidents.

(3) AHS effective for about 80% of accidents

AHS (Advanced Cruise-Assist Systems), which provides drivers with information, warnings, and operational support, should be effective for about 80% of accidents. The system will considerably reduce the number of traffic accident fatalities and injuries. AHS can provide safe road traffic condition even for elderly drivers, whose reflexes and adaptability to variable conditions are inevitably weaker.

In addition to these effects of AHS automatic detection and report of traffic accidents and disasters will facilitate emergency relief activities and enhance safety in case of such events.

(4) Ensuring Harmony between Traffic Systems and Environment

About 19% of the total CO_2 emissions in Japan comes from automobile traffic, so the reduction of CO_2 emissions from automobiles is indispensable in view of worldwide efforts to prevent global warning. Realization of a road traffic system in harmony with the environment using ITS, in addition to popularization of environment-friendly vehicles, will further reduce CO_2 emissions.

Almost 11% of all automobile fuel consumed in Japan is wasted due to traffic congestion. Reducing congestion through ITS will reduce further CO_2 emissions. Platooning will improve driving efficiency, and reduce CO_2 emissions by about 10% to 15%.

In addition, a road traffic system that is in harmony with the environment will smooth the flow of road traffic reduce CO_2 emissions, such as by improving the efficiency of freight distribution with higher loading ratios of trucks and more efficient vehicle operation, and by promoting the use of public transport systems through park and ride systems and so forth. Traffic control with ITS and car pooling with environmental vehicles are helping to solve the problem of our reliance on cars. The problem of car pollution is being solved in the world to ensure greater comfort and convenience.

(5) ITS Industries to Lead Economic Growth in The 21st Century

The full-scale development of ITS will create an enormous ITS-related market, for the development of infrastructures, distribution of terminal equipment, and diversification of applications. The development of new types of business will also be stimulated. The market size of ITS-related information and telecommunication industries is expected to total about 60 trillion yen for the period between FY 2000 and FY 2015. If its effect upon other industries is also considered, this figure is about 100 trillion yen. ITS may also create employment opportunities in ITS-related information and telecommunication industries for about 1.07 million people in FY 2015.

(6) Economic Benefits of More Efficient Freight Distribution

ITS will shorten distribution travel times by alleviating traffic congestion and enhancing traffic efficiency, and will improve transportation efficiency by assisting the operation of commercial vehicles. As a result, freight distribution cost will be reduced, thus boosting industry and the economy and realizing lower consumer prices through more efficient private enterprises.

(7) Improving The Quality of Life

Greater mobility for elderly people would encourage their participation in social and economic activities, and is an important consideration in view of the aging of society. The issue is especially serious in rural regions where public transport systems are inadequate. AHS is an effective way of increasing driving safety by providing information, warnings, and operational support.

(8) Use of Mobile Multimedia Devices

As indicated by the rapid popularization of mobile phones and mobile phone internet, the need for immediate access to information is greater than ever. If various ITS services are deployed, a seamless interface would become available for users of information and telecommunication devices on roads. In other words, the receiving and transmission of information would be possible even while driving, just as in the office and at home.

(9) Comfortable walking Environment

Pedestrian comfort needs to be improved. Especially, a safe environment for elderly and handicapped pedestrians is essential for assuring participation by people of all walks of life in social and economic activities. ITS will deliver a comfortable walking environment, by providing various services for both drivers and pedestrians.

(10) Invigorating Regional Communities

Through deployment of ITS to suit regional needs and features, it will be possible to solve issues specific to a region, and to form active regional communities. ITS will enable introduction of "demand-responsive bus" that serve people in accordance with their needs to assure mobility. In addition, it will also help develop tourism and indigenous industries in the region, by providing drivers with useful regional information. Incorporation of the Smart Interchange will reduce construction and management of regional areas will revitalize the regional economy, through construction of large-scale projects such as commercial, freight distribution, leisure, and amusement facilities. Regional ties and effective use of national land will also be promoted.

(11) Making Japan a Safer Place to Live

In order to secure the safety of national and the life on it, it is necessary to maintain the safety and reliability of road traffic. Sophisticated and information-oriented road management activities using ITS will prevent damage due to disasters, and enable prompt rescue and recovery in case of a disaster. In addition, ITS will improve roadside conditions, enable programmed and efficient road management and maintenance works, and assure the safety and comfort of users.

(12) Influence on Life and Society

Integration of ITS with computerized systems for livers, houses, and other social stocks will greatly benefit society and domestic life in the information age. An advanced, information-based society will in turn promote effective national land use and appropriate management, as well as better medical, welfare, and educational services, and various other services provided by the private sector. Life in the 21st Century will thus be mad even more convenient, comfortable and safe.

1.2. Research on ITS in the World

1.2.1. ITS in Japan

The Japanese government reviewed the five-year Comprehensive National Development Plans that started in 1962, and the Cabinet approved the new Social Infrastructure Improvement Priority Plan (implementation period runs from 2003 through 2007) based on the Social Infrastructure Improvement Priority Law. As a result, improvement projects in 13 areas, including long-term projects in nine sectors such as roads, ports, and airports undertaken under the previous Comprehensive National Development Plans, were placed under the Social Infrastructure Improvement Priority Plan.

(1) ITS as a National Project

In view of the “Basic Guidelines on the Promotion of an Advanced Information and Telecommunications Society” adopted in February 1995 by the Advanced Information and Telecommunications Society Promotion Headquarters (headed by the Prime Minister) which clearly outlines the principles of promotion ITS in Japan, five governmental bodies of that jointly prepared in July 1996 a “Comprehensive plan for Intelligent Transport Systems in Japan.” That is a master plane on ITS in Japan that incorporates the views of users, clarifies targets for the functions, as well as its long-term visions for development and deployment in order that the construction of ITS is promoted systematically and efficiently. In August 2003, the promotion of ITS was adopted by the IT Strategic Headquarters as a national project entitled “e-Japan Priority Policy Program 2003” [29].

(2) Nine Areas of ITS

In order to clarify the information and functions necessary for ITS services, 21 user services in 9 development areas were divided into 56 specific user services, and then into 172 specific user sub-services, thus comparing a whole system of user services. Each sub-service was defined in detail so that particular services provided will be clear. The main user service system is shown in Table 1.1 [28].

Table 1. 1 Overall structures of User Services that influenced constructing a System Architecture

	Development Area	User Service
1	Advances in navigation systems	1) Provision of route guidance traffic information 2) Provision of destination-related information
2	Electronic toll collection systems	3) Electronic toll collection
3	Assistance for safe driving	4) Provision of driving and road conditions information 5) Danger warning 6) Assistance for driving 7) Automated highway systems
4	Optimization of traffic management	8) Optimization of traffic flow 9) Provision of traffic restriction information in case of incident
5	Increasing efficiency in road management	10) Improvement of maintenance operations 11) Management of specially permitted commercial vehicles 12) Provision of roadway hazard information
6	Support for public transport	13) Provision public transport information 14) Assistance for public transport operations and operations management
7	Increasing efficiency in commercial vehicle operations	15) Assistance for commercial vehicle operations management 16) Automated platooning of commercial vehicles
8	Support for pedestrians	17) Pedestrian route guidance 18) Vehicle-pedestrian accident avoidance
9	Support for emergency vehicle operations	19) Automated emergency notification 20) Route guidance for emergency vehicles and support for relief activities
		21) Utilization of advanced information enabled in the advanced information and telecommunications society

(3) Institutes of ITS

ITS(Intelligent Transport Systems) Japan

ITS Japan is to accelerate the development, deployment, and practical application of ITS toward the enhanced transportation and traffic field [32]. Moreover, ITS Japan promotes more active international exchanges and industrial development, which contribute for the public to realize an energetic society with the comfortable life.

JARI (Japan Automobile Research Institute)

The JARI-ITS Center has been engaged in research activities in the field of Intelligent Transport Systems for many years with the aim of developing new systems for safe, convenient and comfortable mobility by vehicles. This is to be accomplished by extensively incorporating intelligent capabilities and information technologies in both vehicles and the road environment.

As part of activities, JARI has formulated a vision for the creation of a new vehicle-based society amid the rapid advances being made toward a networked world. Specific systems for building that future society, such as the Probe-Car Information Systems, has been proposed and activities are proceeding in collaboration with engineers in wide-ranging fields to research and develop the systems and validate them through public field trials.

Research is also being done on ITS function and human-machine interfaces by conducting various vehicle driving tests and driving simulator experiments. This research is examined ways of presenting information and warnings to drivers, driving-assistance systems and other aspects for ensuring safe vehicle operation. Additionally, traffic flow simulation models and other subjects are being researched for the purpose of evaluating the effects of ITS on improving transport efficiency. In addition, there are many R&D activities such as research on mobility by car in an aging population, field studies related to the development of the Probe-Car Information System, and research concerning high-accuracy location system technologies for vehicles. Experimental research activities are also conducted about vehicle control systems, AVS (Advanced Safety Vehicle), and so on. Moreover, international standardization activities are continually being promoted primarily in concert with the efforts of ISO/TC 204. Surveys of driver behavior patterns and evaluation tests relating to preparation of information infrastructure in connection with ITS implementations are conducted to accumulate data needed for the development of new standards.

UTMS (Universal Traffic Management Systems) Japan

The Universal Traffic Management Society of Japan (UTMS Japan) supports international standardization activities in the ITS field, and aims to foster international understanding of the next-generation traffic management system concept based on infrared beacons.

The UTMS Japan takes part in the ITS Standard Committee, an organization for domestic and international meetings. It sponsors and manages the domestic activities of WG4 (Automatic Vehicle / Freight Identification), WG9 (Integrated Transport Information, Management and Control), and WG 10 (Traveler Information Systems) in TC204. In addition, it sponsors the domestic activity of ISO/IEC JTC1 SC17/WG0 (Motor Vehicle Driver License and Related Documents), and participates in ISO/TC173 (Acoustic Signal Device for Sight-impaired Persons) and CIE (International Commission on Illumination). As a result of the UTMS Japan's proposals based on the outcomes of its research activities, CDRG (Centrally Determined Route Guidance) has been presented in the ITS technical report and PRESTO (Preemption and Prioritization Signal System for Emergency and Public Transport Vehicles) is being considered as a possible ISO standard.

AHSRA (Advanced Cruise-Assist Highway System Research Association)

AHSRA jointly founded in 1996 by 21 private companies for research and development of the Advanced Cruise-Assist Highway System [20]. The AHSRA has been conducting this R&D program in ITS under the auspices of the Ministry of Land, Infrastructure and Transport. The main thrust of program is to improve the safety, efficiency, comfort, and convenience of road transportation by incorporating IT in the road infrastructure that is envisioned for the Advanced Cruise-Assist Highway Systems (AHS).

Research during the three years from 1996 to 1998 was focused mainly on defining a basic conceptual structure for our R&D and formulating the requirements involved. Actual systems intended to support safe driving were developed and prototypes were built on the basis of those research findings. During the year 2000, joint tests of road-vehicle cooperative systems were carried out on the test course of the National Institute for Land and Infrastructure Management of the Ministry of Land, Infrastructure and Transport. In the year 2002, the AHSRA conducted seven locations in Japan that would highlight the effects of systems subjected to new testing and verification. Field Operation Tests of AHS were conducted there over the two years 2002 and 2003. Verification and evaluation were carried out of driver usability in the face of traffic on actual roads, of system safety and reliability, and so on.

HIDO (Highway Industry Development Organization)

HIDO was established to create and enhance the functions of our nation's roads by coordinating the efforts of the government and private sector. In order to contribute to development of roads that respond to the vision of the future, HIDO is tackling the survey, research, development and fostering of new road-related industries [21]. For example, the HIDO conduct various research and development efforts that aim at the development and realization of new road functions such as road information system development, integration of roads and roadside areas, and advanced freight transport systems. Furthermore, HIDO performs a wide range of activities such as assisting in the establishment of enterprises to transform these results into practical business projects.

VICS (Vehicle Information and Communication System) Center

The purpose of VICS center which was founded in 1973 is to make a contribution to the establishment of safe and comfortable traffic environment, to achieve affluent civil life, and to develop social economy. For this aim, VICS center systematically gathers, process, and edits needed road traffic information, managing and operating the traffic information system by using communication and broadcasting media for transmitting to car navigation installed automobiles, sending accurate information to drivers [23].

The road traffic information, or VICS information is edited and processed in VICS center is transmitted to each car navigation equipment via "beacons" or "'FM multiplex broadcasting" devices which is installed on various roads across the country. There are two types of Beacon, one is Radio wave beacon on expressways, and the other is Infrared beacon on major ordinary roads. FM multiplex broadcasting provides wide area information, and Beacons send necessary and detailed information about nearest road condition based on the position where the car is moving.

Besides, there are a number of governmental organizations relating to ITS: the Road Bureau, Ministry of Land, Infrastructure and Transport, National Institute for Land and Infrastructure Management, Ministry of Internal Affairs and Communications, National Police Agency, Ministry of Economy, Trade and Industry, Road Bureau, Ministry of Land, Infrastructure and Transport and so on. And,

1.2.2. ITS in America and Europe

The United States Department of Transportation (USDOT)

The U.S. Department of Transportation's ITS program focuses on intelligent vehicles, intelligent infrastructure and the creation of an intelligent transportation system through integration with and between these two components. The Federal program supports the overall advancement of ITS through investments in major initiatives, exploratory studies and a deployment support program. Federal investments are directed at targets of opportunity -major initiatives- that have the potential for significant payoff in improving safety and mobility and enhancing global connectivity by means of ITS - enabled productivity improvements. These targets of opportunity will both infrastructure and vehicles and focus on the integration between vehicles and infrastructure, between modes of transportation and between jurisdictions. USDOT uses exploratory studies to examine other as yet unexamined or unsolved opportunities for applying ITS technologies to significant transportation problems. USDOT support a deployment support program - architecture, standards, professional capacity building, evaluation, technical assistance, etc. - that fosters the widespread deployment of ITS [75].

The current key activities of the Federal ITS Program

In 2004, the ITS Management reorganized the functions of the ITS program to focus on nine particular high pay-off areas. Each area has decision points at which management evaluates progress. Each major initiative is multimodal, public-private sector involved and aims to improve safety, mobility and/or productivity.

The nine major initiatives are composed of 9 areas; Vehicle Infrastructure Integration (VII), Next Generation 9-1-1, Cooperative Intersection Collision Avoidance Systems, Integrated Vehicle Based Safety Systems, Integrated Corridor Management Systems, Clarus, Emergency Transportation Operations, Mobility Services for All Americans, and Electronic Freight Manifest. Continuing major initiatives within the Federal ITS program are: Commercial Vehicle and Information Systems and Networks Deployment (CVISN), 511 Travel Information, ITS Architecture Implementation, Wireless enhanced 9-1-1.

The Federal ITS Program organization

A corporate-style "board of directors" - the ITS Management Council - develops and directs Federal ITS policy and ensures the effectiveness of the ITS program. The ITS Management Council is chaired by the Administrator of the Research and Innovative Technology Administration.

Advising the ITS Management Council is the ITS Strategic Planning Group. Membership is generally at the Associate Administrator and office director level, and is chaired by the ITS program manager. The

ITS program manager leads the ITS Joint Program Office (JPO), which is comprised of program managers and coordinators of the USDOT's multimodal ITS initiatives. In addition, individual staff members manage crosscutting functions, such as Website development and maintenance, outreach, program evaluation and training. The ITS Joint Program Office is administratively located in FHWA (Federal Highway Administration) and has Department wide-authority in coordinating the ITS program and initiatives among Federal Highway Administration (FHWA), Federal Motor Carrier Safety Administration (FMCSA), Federal Railroad Administration (FRA), Federal Transit Administration (FTA), Maritime Administration (MARAD), National Highway Traffic Safety Administration (NHTSA) and so on.

The Federal ITS Program Establishment

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) established a Federal program to research, develop, and operationally test Intelligent Transportation Systems and to promote their implementation. The program was designed to facilitate deployment of technology to enhance the efficiency, safety, and convenience of surface transportation, resulting in improved access, saved lives and time, and increased productivity.

The program began as a three-pronged effort that fostered the development of ITS through (1) basic research and development, (2) operational tests that served as the bridge between basic research and full deployment, and (3) various deployments support activities that facilitated the implementation of ITS technologies. The ITS program carries out its goals through research and development, operational testing, technology transfer, training and technical guidance in the areas of intelligent vehicles, advanced traffic and transit management, commercial vehicle operations, public safety, traveler information, and intermodal freight.

Early Deployment Planning in the USA

Intelligent Transport Systems really came to the fore in the United States through ISTEA. Among the programs promoted by ISTEA was one to help fund an Early Development Plan (EDP) in each of the nation’s 75 largest cities. Federal aid was available for up to 80% of the cost each deployment planning studies. Guidance was provided from early 1993 on ITS planning and project deployment, although this was not based on a prescribed “model” planning process. As a result, there was wide variation in the approach followed by each EDP project. More recently, the FHWA has commissioned a “Handbook to Integrating ITS within the Planning Process”, whose interim version was issued in April 1997. This already provides a thorough discussion of all the main elements in both ITS planning and deployment; the final version is to be published in 1998 [33].

European Road Transport Telematics Implementation Coordination Committee (ERTICO)

ERTICO was set up in 1991 at the initiative of leading members of European industry, Ministries of Transport and the European Commission. ERTICO is a professional body that represents the interests and combined skills of the European ITS community. Among its membership, ERTICO counts the key players from public Authorities and Industry, as well as Infrastructure Operators and Users. Its activities are financed by annual fees from its partners and through project funding from others, including the European Commission. Founded on the basis that technology can be brought to market through cooperation, ERTICO provides a place for ITS solutions to develop and is the voice of the ITS community among European opinion leaders and decision makers [4][31].

ERTICO project activities typically focus on developing the enabling technology, as well as facilitating the common technical, business and policy framework for deploying Intelligent Transport Systems and Services in Europe. Currently, ERTICO's work is focused on: improving the safety of road users, making transport more efficient and environmentally compatible, enhancing the security of all transport, and strengthening national and international cooperation on ITS.

SERTI project

Trans European Intelligent Transport Systems projects serve to harmonize the deployment of ITS in order to improve the safety, the continuity and the quality of services on the European road network. SERTI is one of seven Euro-Regional projects covering the Trans European Road Network (TERN). Some part of the SERTI project has been researching pictograms which indicate the traffic situation by using clearly identifiable symbols. Pictograms are one of the most interesting solutions to provide traffic information for foreign driver.

CENTRICO project

The main activity of CENTRICO is to be a major cross-border road transport project with 15 partners in North-West Europe. It focuses on proactive deployment of ITS to improve performance on the Trans-European Road Network (TERN). One of CENTRICO projects, Cross-channel information services, aims to provide travel information services to customers crossing the English Channel. These services contribute to efficient long-distance travel through cross-border data exchange and traffic management.

1.2.4. International Standardization

(1) Significance of International Standardization

In recent years, compliance with international standards has become mandatory for equipment and systems subjected to international competitive bidding, according to the Agreement on Technical Barriers to Trade (TBT Agreement) and the Agreement on Government Procurement enacted by the World Trade Organization. Many companies consider international standardization as a corporate strategy for market expansion. Therefore, the standardization in the field of ITS is necessary for every nation and company to compete in accordance with the same rules in order to maintain fair and sound international transactions. As a mechanism in this regard, "international standards" play an important role. It is not too much to say that each member of the international community cannot obtain confidence from companies and other members for its economic activities in the world without engaging in "standardization activities."

There are several reasons why "standardization" is necessary for international economic activities as described below.

WTO's move toward removal of non-tariff barriers: In its efforts for "elimination of trade barriers," the World Trade Organization (WTO) has set up an "agreement on technical barriers of trade (TBT agreement) and obliged its member countries to coordinate their domestic standards with international standards like the International Organizations for Standardization (ISO) on the ground that different standards of each country, and permits and licenses systems may become barriers hampering smooth international logistics.

Effects of international standardization: The role required standardization has been greater than ever before, ranging from guarantee of interest, safety and convenience to environment protection. The earlier establishment of international standards will make it possible to avoid confusion in the market and improve compatibility among systems and machines, which can be enjoyed by everyone in the world. Industry is expected to benefit from effective use of development costs, reduction in manufacturing costs and an increased share.

Ensured market share through leadership in standardization: Japan has tended to acquire its market share in the manufacturing stage, while entrusting the establishment of standards to other countries. From now on, Japan is required to promote both technological development and standardization in order to survive market competition efficiently.

(2) ITS and International Organization for Standardization (ISO/TC204)

Among many technical committees of the International Organizations for Standardization (ISO), ISO/TC 204 is in charge of traffic information and control systems in the ITS field. TC 204, a technical committee for standardization for ITS within ISO, was set up in 1992 and went into operation the following year. In ISO, subcommittees (SC) are usually founded under technical committees (TC) and working groups (WG) under subcommittees. Regarding TC 204, working groups are directly under its jurisdiction. Among working groups, some have been suspended or integrated for the ten years since its inception, and now a total of 12 working groups are carrying out its activities. Eight countries serve as lead countries of working groups, and Japan, the U.S. and Germany take charge of two or more working groups.

Working items of TC 204 are total 83 as of February 2005. In October 2002, two international standards were established from WG 14 chaired by Japan, the first of its kind. TC 204 has been actively cooperating with other organizations. Several technical committees have been implementing standardization activities in close contact with each other [6].

In Japan, to keep pace with the activities of ISO/TC204, the ISO/TC204 National Committee was founded in 1993. In order to (a) take with action in response to change in the standardization environment; (b) implement standardization activities in accordance with preset strategies; (c) assist the registration of ITS technologies as JIS (Japanese Industrial Standard); and (d) provide related parties with up-to-date information, the committee has gone through a unique structural reform and changed its name to the ITS Standardization Committee in 2000. And the domestic technical committee was founded. In addition to the existing departments which correspond to the working groups of ISO/TC204, the new committee has created several in-house sections and posts in charge of activities, such as business teams and liaison persons.

Moreover, there are many ministries and organizations involved in standardization of ITS: National Police Agency, Ministry of Economy, Trade and Industry, Japanese Industry Standard Committee, Japan Standards Association, Ministry of Land, Infrastructure and Transport, The Society of Automotive Engineering of Japan, Japan Digital Road Map Association, ITS Standardization Database, and so on.

(3) Standardization relating to Route Guidance and Navigation Systems

The standardization of route guidance and navigation systems is taken charge of WG 11 among 12 working groups. It has thus far worked on “navigation message set: prescription of necessary items for message sets to be handled by on-board navigation systems” “centrally-determined route guidance: prescription of necessary items for interactive CDRG message set exchanged between a center and vehicles” and “message set translator: prescription of reference layer model capable of describing hierarchically the structure of on-board information systems” under the standardization item related to message sets by navigation systems, and “on-board system architecture: simple notation of table forms regarding message sets and supply of convention tools to ASN.1” under the standardization item linked to architecture of on-board system [6].

The standardization of a reference layer model in order to promote standardization work related to on-board systems is under way. The reference layer model is a standardized hierarchical model designed to express various on-board systems such as navigation systems and next-generation on-board systems. It will make it possible to express models incorporating various restrictions on on-board systems-coordination between communication media for access to information sources, coordination between data obtained from information sources and structure of information accumulation to ensure responsiveness to user. Systems proposed individually are expressed after being applied to the reference layer model, highlighting differences in the contents of standardization for each system. This will result in smooth progress in standardization.

1.3. In-Vehicle Driver Assistant Systems

1.3.1. Development of In-Vehicle Systems

Active Safety Systems and Advanced Driver Assistance Systems are hot items in the automotive industry. Low cost, high performance sensors are enabling unprecedented driver assistance applications, including electronic stability control, adaptive cruise control, lane and road departure warnings, blind spot monitoring, adaptive front light control, collision avoidance and smart transmission control. Many of these applications will migrate to full vehicle control as the technology matures. Digital maps such as car navigation systems can dramatically increase sensor and system capabilities and enable new applications like curve warning, early slope adaptation, and speed limit advisories. New systems will incorporate map-provided knowledge of 3D road geometry upcoming turns, and complex intersections. The number of researches has explored the innovative ways that digital maps and real-time sensor data can be integrated for superior safety and driver assistance systems [14].

(1) Driving Safety Support Systems

The Driving Safety Support Systems are expected to reduce traffic accidents, make it easier for the driver to avoid any driver' mistakes, and increase the driver's awareness about safe driving [5]. The motorized society has greatly contributed to economic growth and improvement of people's daily lives. However, traffic accidents have been on the increase and become a social concern. The purpose of the Driving Safety Support Systems is to prevent traffic accidents by issuing visual and audible warnings, thus alerting drivers in advance about possible dangers to ensure driving safety. Various sensors are used to detect cars, motorcycles, and pedestrians that are not in the driver's sight. Based on this information from beacons or radio frequency, the Driving Safety Support Systems alert drivers via message display boards or in-vehicle units. However, this system has also the amount of information, which it will be possible to bundle workload to driver, such as High-accident information system (Alerts based on past statistics), Opposite lane vehicle information system, Speed alert system, Traffic signal violation warning system, Head-on collision warning system, Right-turn collision avoidance system, Left-turn accident warning system, Pedestrian crossing alert system, and Danger zone avoidance control system, etc.

(2) Advanced Mobile Information Systems

The Advanced Mobile Information Systems (AMIS) is to provide traffic information required by each driver via various media including car navigation systems and traffic information display board to disperse traffic flow, alleviate congestion, and reduce stress for drivers. Traffic information collected at the Traffic Control Center is fed directly to in-vehicle car navigation systems by road sensors and CCD cameras via beacons. In addition, traffic information is provided through traffic information display boards, as well as by radio, telephone and fax. The AMIS represents the entire system for proving traffic information through various media, and the Vehicle Information and Communication System (VICS) is one of the AMIS systems. Benefits of the AMIS include traffic flow dispersion, less traffic congestion, reduced travel time, and reduced stress for drivers by encouraging each driver to make decisions based on accurate, real-time traffic information. As a result, a great economic effect is anticipated [5].

(3) Dynamic Route Guidance Systems

Traffic conditions change rapidly. Drivers rely on their experience and traffic information to travel to their destination. The purpose of the Dynamic Route Guidance Systems (DRGS) is to assist drivers in avoiding traffic congestion and reaching their destinations as fast as possible by guiding drivers to the most time-efficient route dividing traffic into multiple routes, and reducing the confusion in choosing routes. Beacons transmit information about the optimum routes for the driver's destination, which are calculated based on link travel time at the Traffic Control Center, through infrared beacons and in-vehicle units which utilize the map display function of car navigation systems to indicate an optimum route for each driver's destination. In addition, estimated travel time to the destination is provided for the driver's convenience. The systems offer various benefits, including reduced travel time, fuel saving, reduced exhaust emissions, and more efficient traffic flow [5].

(4) Car Navigation System

Car navigation systems started to be installed only 10 years ago. In Japan, the first car navigation system was produced in 1981. In 1990, car navigation systems equipped with a digital road map were first introduced. Initially, the media consisted of only one CD-ROM. Then the number of CD-ROM increased, which need to be replaced by the driver. In 1997, DVD navigation system was developed. In 2001, HDD navigation system with a huge capacity was put on the market. The increase in the capacity of media have enabled advanced navigation services to be provided such as clear voice announcements, three-dimensional displays, and fast retrieval. Car navigation systems have become increasingly popular, recording a total shipment volume of 26 million systems in 2007 and are widely becoming a standard feature of automobiles [60]

Car navigation systems may be offered as standard equipment, a purchase option, or as an after-market system. Most of in-vehicle navigation systems have similar functions. The initial driver task is to enter a required destination. This is usually achieved using a remote control or touch screen to enter an address, telephone number, or building name. Systems will usually allow a driver to enter specific destinations. Once a destination is entered, the navigation system will calculate a route based on pre-set criteria such as shortest time, shortest distance, and maximum use of motorways or even avoiding motorways.

Rapidly widespread car navigation systems As ITS technologies have become more advanced, car navigation systems are becoming more widespread. Various systems for assisting driving through car navigation system have been developed such as detection of zigzag driving, navigation-assisted shift control, notifying curves ahead and lane guide. Recently, full-scale telematic services are enabling various kinds of mobile communication to be performed. As a result, car navigation system is not only a more comfortable and convenient driving experience made possible but social effects such as congestion reduction are becoming more pronounced.. Today, car navigation units come with many functions other than car navigation and have evolved into a mobile information tool. Figure 1.1 indicates as of the end of March 2007 there were 26.1 million car navigation systems in operation.

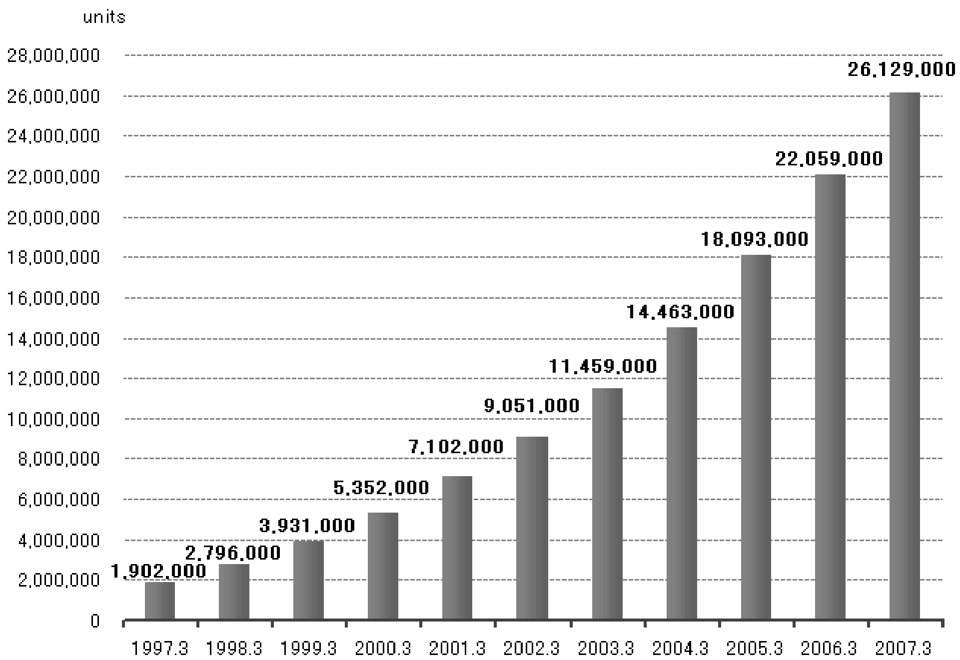
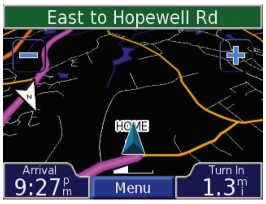


Figure 1. 1 Shipment volume of car navigation (25% annual increase)

[Road Bureau, Ministry of Land, Infrastructure and Transport][60]

Advanced car navigation function Car navigation units can display the fastest routes by using VICS information, various kinds of accumulated data, and highly accurate congestion prediction. As shown in Figure 1.2, maps can be displayed in various ways, such as in two dimensions, in customized formats, and three-dimensional computer graphic animations. The units can also display lines dividing parking lots. Units that link with ETC on-board units are increasing, and their functions are being integrated, such as displaying ETC lanes, tolls, and tolls in the past on the display and giving the information by voice.

(a) Three-dimensional computer graphic animation of major intersections



(b) Nighttime mode

(c) Highlighting congestion

Figure 1. 2 Various functions of car navigation systems

Most systems will then provide voice instructions and visual information to the driver: for each turn or maneuver the driver is required to make, the navigation system will present a symbol to indicate and direction of turn that is required. A visual indication of the distance to the next maneuver may be given via a countdown distance. Turn information is usually provided in the following stage: on completion of a maneuver, a preview of the next maneuver (distance and direction) is given; preparatory instructions will then be given at several points preceding a maneuver; and a final turn instruction is given just before the driver needs to take a particular turning. Navigation systems may also provide a stylized 2D or 3D “map view” of the route and /or particular maneuvers. The system may switch between turn-by-turn and map overview modes, depending on the proximity to a maneuver [60].

As well as visual instruction, most navigation systems will provide simultaneous auditory information to the driver that emphasizes some form of distance representation, e.g. “turn left in 200 m” or “Just ahead and turn left”. Auditory information consists of either pre-recorded voice instructions, or text-to-speech translations. If a driver makes a navigational error (e.g. does not turn when recommended or takes an incorrect turning), the system can dynamically recalculate the route.

By car navigation systems, services to provide the amount of information including have been deployed, such as displaying maps of road sections where accidents are frequent, giving warnings by voice and display when the vehicle approaches such a section, and warning drivers of sharp curves and merges ahead by voice and display, road condition, and today weather. There are also car navigation units that display the image of the rear of the vehicle, which is difficult to see by the driver, and announce the information from a rear camera. And there are also units that display the images of both the front right and front left of the vehicle.

(5) VICS

Road users always want to know that the information on traffic congestion and restriction. VICS (Vehicle Information and Communication System) aims at cutting costs by shortening the time required for transportation, improving road safety by providing accurate information, and protecting the environment by streamlining traffic. In other words, VICS enables drivers to select the shortest, most convenient routes available, and ensures that traffic is distributed smoothly, further improving on-road safety and the flow of traffic. The VICS displays in characters, graphics or superimposed on a map shown on a car navigation system monitor, real-time information on traffic congestion and restriction relayed from road beacons or FM multiplex broadcasting. VICS is the world's first real-time road traffic information system debuted on April in 1996, the information is broadcast to on-board equipment such as car navigation systems in the form of text and graphics. Since then, accumulated shipment volume of on-board equipment systems with VICS has reached over 18 million units in 2007 and is widely recognized as standardized equipment of car navigation systems.

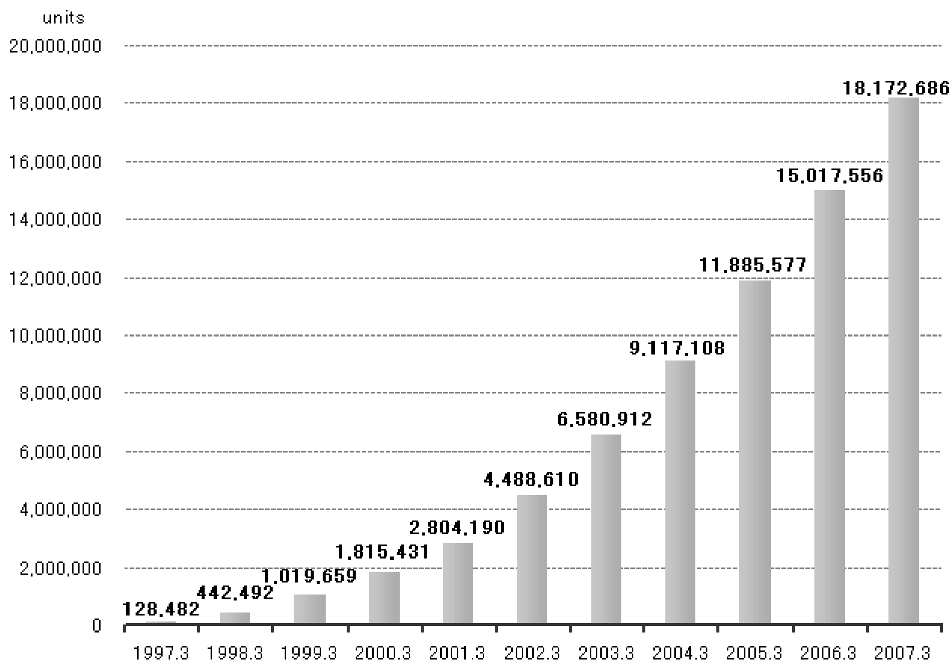


Figure 1. 3 Shipment volume of VICS (25% annual increase)

[Road Bureau, Ministry of Land, Infrastructure and Transport][60]

Figure 1.3 indicates as of the end of March 2007 there were 18.1 million VICS units. The proportion of VICS compatible car navigation equipment shipped came to approximately 80%.

In the context of the communication and spread of these ITS system, to create an ITS market and promote further the spread of the car navigation systems and VICS systems, government and private sectors are collaborating on programs aimed at achieving multiple services employing the DSRC (Dedicated Short Range Communication, 5.8 GHz) used in them.

1.3.2. Increasing In-Vehicle Information to Driver

The increasing availability of in-vehicle navigation system and traffic information is giving drivers unprecedented sophisticated tools for managing journeys. In-vehicle information systems (IVIS) try to improve safety, improve driver's situational awareness and reduce anxiety, but they may also increase mental workload and distraction. This issue is particularly important as a secondary task in driving because they sometimes create extremely dangerous driving conditions by driving distraction from the road. Driver distraction is recognized as a significant cause of road traffic incidents.

The effect of in-vehicle information systems on traffic safety is currently under debate and suitable methods for measuring and comparing the impact of such devices on driver behavior are urgently required. There are numbers of in-vehicle information (advisor or caution or warning) and technologies such as Collision Avoidance/Warning System, Adaptive (Intelligent, Smart) Cruise Control, Lane Tracking or Lane Departure Warning, Advanced Collision Warning System, and so on. A number of systems are developed rapidly, and provided amount of information for drivers. Drivers may feel much workload while driving, if those are not considered the advent of human factor or interfaces.

In the in-vehicle systems, car navigation system offers a state-of-the-art technological solution to driver navigation in an unfamiliar area. It typically presents real-time navigation information to the driver based on a series of map overviews and/or any instructions via visual and auditory forms such as graphic, text, and voice information. However, there are lots of information, drivers have to pay attention to internal (e.g. radio set, air-conditioner, vehicle controllers) and external (e.g. traffic signals, signboards, Variable Message Sing) vehicle environment while driving. Navigation systems and other advanced display and control systems associated with ITS can present a wide range of driver related information. Since these visual displays have associated controls (e.g., to select a zoom level or menu option), the associated hand-controlled activities also visually guided and become part of the visual demand associated with a display application. For this reason, it is important to consider not only the visual behavior in relation to information display, but also the duration and frequency of glances associated with driver control actions.

It is true that some additional in-vehicle systems are designed to reduce overloading driver resources: car navigation removes anxiety and the need for looking at a paper map, adaptive cruise control reduces the need for skill-based longitudinal vehicle control. However, these systems may also introduce additional demands in terms of information uptake and driver action. Therefore, it is necessary to research to determine the optimum human-machine interface for each vehicle environment.

1.4. Japan as a Tourist Attraction Country in the World

The number of foreign nationals visiting Japan exceeds 15,000 a day. Presently foreign nationals from all corners of the globe are living in Japan. From the viewpoint of international mutual understanding it is of great benefit when foreign nationals from many industrial parts of the world come and live in Japan, and it is becoming increasingly more important for Japan, which occupies a key position in the tourist industry and the international community, to welcome them openly into Japanese society. On the other hand, when accepting foreign nationals Japanese society needs to reinforcement of a system under which the safety and interests of society are protected and the tourist of Japan can improve the mobility.

1.4.1. The Number of Foreign Nationals Entering Japan

The number of foreign nationals entering Japan topped 1 million in 1978, 2 million in 1984, 3 million in 1990, 4 million in 1996, and 5 million in 2000. In 2004, the number reached a new record high of 6,756,830, an increase of 1,029,590 (up 18.0%) from 5,727,240 in 2003 [24].

In 2003, the US and coalition war on Iraq and the outbreak of SARS (Severe Acute Respiratory Syndrome) in Asia temporarily brought down the number of foreign visitors to Japan. However, in 2004 the US military attacks on Iraq and the rampant SARS epidemic both returned to stability, and Japan also made further efforts to increase the number of foreign visitors to Japan, aiming at encouraging tourism in Japan. These factors contributed to the significant increase in foreign nationals entering Japan in 2004.

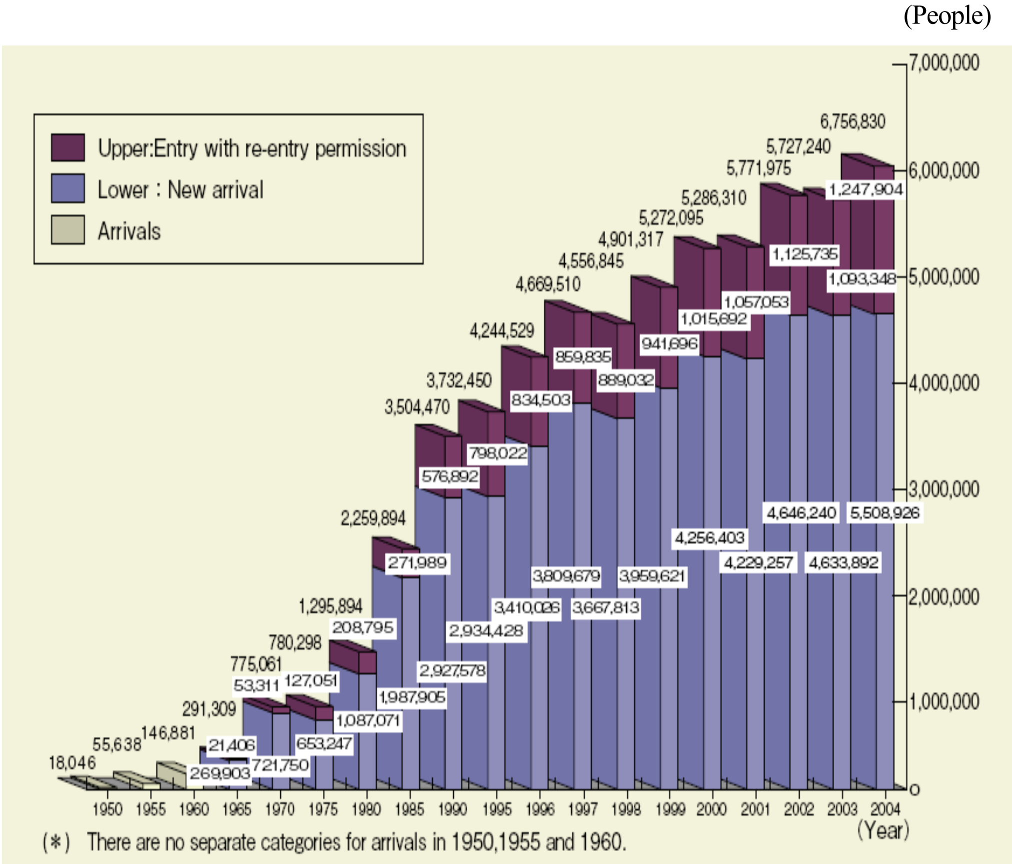


Figure 1. 4 Changes in the number of foreign nationals entering Japan [24]

The number of foreign nationals entering Japan was about 18,000 in 1950 when the government began to compile immigration control statistics. However, the number topped one million in 1978 and has maintained an upward trend ever since. In 2004, the number exceeded an earlier record by some one million to reach about 6.76 million as shown in Figure 1.4. Owing to the government promoting measures to increase foreign tourists visiting Japan, it is expected that these measures will contribute to the number maintaining its upward trend.

1.4.2. Entering Japan by Purpose of Entry (Status of Residence)

The changes in the number of newly entering foreign nationals by status of residence show the number of foreign nationals entering Japan by purpose of entry in recent years. As the tourists who permitted a short period of time in Japan are accounting for almost 93% of the overall number of visitors to Japan in 2004.

(1) Temporary Visitors

The status of residence of “Temporary Visitor” is for a foreign national whose purpose is sightseeing, recreation, sports, visiting relatives, participation in an observation tour, educational course or meeting, or any other activity that requires the foreign national to stay in Japan for only a short period of time. The permitted length of stay is 15 days, 30 days, or 90 days. Any foreign national who enters Japan for a short stay is not required to obtain a visa in advance if he / she is a US or European national for instance, whose country has agreed on mutual visa exemption [24].

In principle, any foreign national who has entered Japan with the status of residence of “Temporary Visitor” is not allowed to change his/her status to any other status because work in Japan is not permitted and the permission for entry has been obtained through relatively simple procedures according to the Immigration Control and Refugee Recognition Act. The number of foreign nationals newly entering Japan with the status of residence of “Temporary Visitor” was 5,136,943 in 2004, accounting for 93.2% of the total number of new arrivals. The number had increased by 876,969 (up 20.6%) from the year 2003 as shown in Figure 1.5.

A further examination of the number of foreign nationals newly entering Japan with the status of residence of “Temporary Visitor” in 2004 shows that the number of foreign nationals visiting Japan for sightseeing was 3,110,413, accounting for 60.5% of the total number of new arrivals. 1,297,309 foreign nationals came to Japan for business, forming the second largest group of new arrivals and accounting for 25.3% of the total. According to the statistics on new arrivals for the purpose of sightseeing by nationality (place of origin), China (Taiwan) occupied the largest number at 931,707, an increase of 273,443 (up 41.5%) from 2003 and replacing R.O. Korea. Chinese (Taiwanese) tourists to Japan had increased by 273,443 (up 41.5%) from 2003, accounting for 30.0% of the total number of foreign nationals who entered Japan for the purpose of sightseeing.

In addition to Taiwan, more than 100,000 temporary visitors came to Japan from the following three countries: R.O. Korea, the US, China (Hong Kong), which were 875,847 (accounting for 28.2% of the total), 294,597 (9.5%), and 201,186 (6.5%), respectively. Moreover, the tourist come from the North and South America occupied the number over 800 thousands, account for 16% of the total number of the temporary visa receivers.

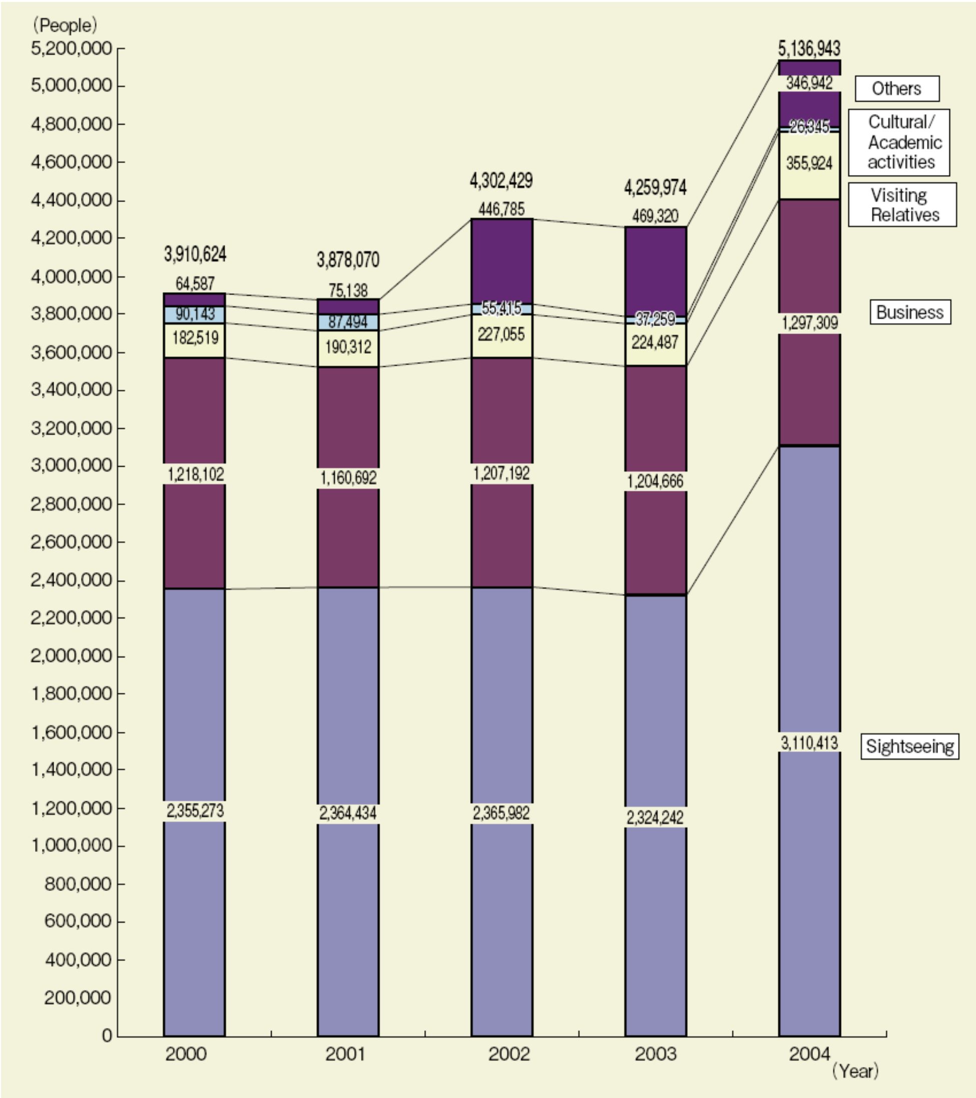


Figure 1. 5 Changes in the number of new arrivals with the status of residence of "Temporary Visitor" by purpose of entry [24]

(2) The Number of Foreign Nationals Entering Japan by Age

More foreign males came to Japan than females. The numbers of foreign males and females entering Japan in 2004 were 3,628,809 and 3,128,021 respectively. The percentages of males and females were 53.7% and 46.3% respectively. According to the statistics by age as indicated in Table 1.2, foreign nationals in their twenties and thirties represented the largest age group, accounting for 46.2% of the total number of foreign nationals entering Japan.

Table 1. 2 Changes in the number of foreign nationals entering Japan by gender and age bracket [24]

(people)

Age bracket \ Year		2000	2001	2002	2003	2004
Total	Total	5,272,095	5,286,310	5,771,975	5,727,240	6,756,830
	Male	2,954,947	2,920,787	3,170,553	3,134,669	3,628,809
		56.0%	55.3%	54.9%	54.7%	53.7%
	Female	2,317,148	2,365,523	2,601,422	2,592,571	3,128,021
		44.0%	44.7%	45.1%	45.3%	46.3%
Under 20	Total	482,116	479,820	517,075	521,980	638,487
	Male	239,561	235,105	252,115	253,394	306,663
	Female	242,555	244,715	264,960	268,586	331,824
20s	Total	1,061,285	1,091,919	1,170,797	1,187,927	1,372,607
	Male	467,522	470,331	500,573	497,958	565,985
	Female	593,763	621,588	670,224	689,969	806,622
30s	Total	1,454,831	1,453,928	1,554,298	1,513,595	1,751,671
	Male	876,376	862,166	916,459	886,872	1,008,432
	Female	578,455	591,762	637,839	626,723	743,239
40s	Total	1,090,843	1,086,173	1,204,598	1,214,438	1,439,559
	Male	697,304	690,321	763,673	772,150	895,562
	Female	393,539	395,852	440,925	442,288	543,997
50s	Total	666,853	659,169	745,297	745,494	895,113
	Male	400,352	391,229	436,015	438,403	512,139
	Female	266,501	267,940	309,282	307,091	382,974
Over 60	Total	516,167	515,301	579,910	543,806	659,393
	Male	273,832	271,635	301,718	285,892	340,028
	Female	242,335	243,666	278,192	257,914	319,365

1.5. Necessity of Research

1.5.1. Problems of In-Vehicle Route Guidance Information

As show in Figure 1.6, drivers have to pay attention to a lot of exterior information such as signboards, traffic signals, VMS (Various Message Sign), traffic signs to perceive the traffic and road situations. Moreover, drivers have to obtain the vehicle information through gauges and speedometer installed on the dashboard. As new systems are introduced into the vehicle, drivers may also need to refer to a dashboard display, and any number of audio signals that could be activated. The result is likely to be a high physical and mental workload, potentially resulting in one or more of the following: (a) inappropriate lateral or longitudinal vehicle control, (b) incorrect route selection, (c) reduction in safety margins in relation to other traffic and road infrastructure, (d) feelings of anxiety and discomfort, (e) failure to assimilate the information being presented to them (e.g. not hearing the traffic), (f) ineffective use of in-vehicle systems. Therefore, many researches have been focused on how to minimize driver's physical and mental workloads to in-vehicle information because of the enormous increase in the volume of in-vehicle systems [25][45][69][70].

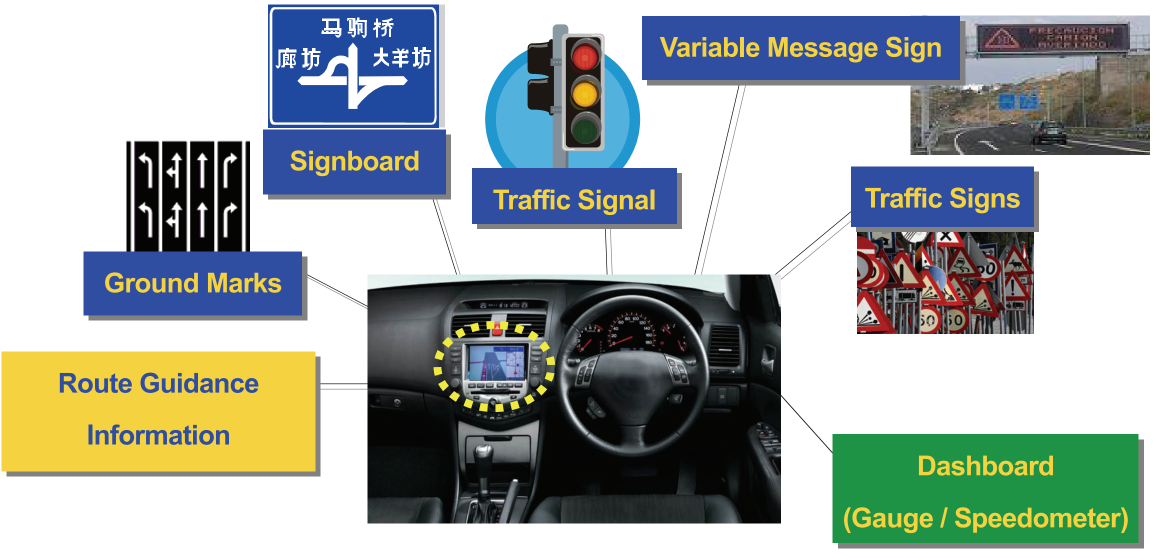


Figure 1. 6 Increasing information to driver through interior and exterior environments

Car navigation systems reduce the burden on the driver, while mobile terminals make life easier for pedestrians. On the other hand, traffic accidents resulting in using the car navigation have tended to on the incline. According to the report [1], 75% of the traffic accidents caused by the use of car navigation systems are due to fixation of gaze on the display. These problems were identified: reduction in concentration level caused by operating or obtaining information from the car navigation system, confusion caused by inappropriate provision of information, and mismatches of purpose between the user and the system. Potential methods for solving these problems include improving the car navigation system, investigating the interface between the car navigation system and the driver, and implementing measures based on the personal characteristics of the user. These have led to various researches being carried out. Some research centers studied on the quantitative evaluation of in-vehicle equipment and recently published updated design guidelines for industry to use. For the safety to the drivers, the improvement of system is implemented by taking into account not only quantitative aspects but the qualitative aspects.

The more in-vehicle information has progressed toward the developing ITS technologies, the more drivers have felt the increasing loads on information processes, especially concerning the mental workload of driving [10]. The provision of information to drivers and the increasing availability of driver support systems such as intelligent cruise control highlight the importance of understanding the human factors aspects of in-vehicle equipment. Use of the car navigation systems is secondary to the potentially demanding task of driving. Indeed, the purpose of a navigation system to provide guidance at route decision points means that it frequently will provide information at points of high attentional demand. Therefore, the design and evaluation of the interface should be prerequisite [59].

1.5.2. Two Types of Driving Directions in the World

The traffic system relating to driving direction in the world is generally divided into two main groups determined by which side of the road one drives on. As shown in Figure 1.7, the driving direction in the world is divided into two, the right-hand side of the road and the left-hand side of the road. In countries such as Japan, the United Kingdom, and Australia, the driver's seat is normally positioned on the right-hand side of the vehicle. However, in some European countries, America, and some Asian countries including Korea where the driver's seat is normally positioned on the left-hand side of the vehicle, the common driving style in these countries are called left-hand side driving.

In this research, a "Left-lane driver" is defined as a person who is accustomed to driving on the left-hand side of the road. Accordingly, a "Right-lane driver" is defined as a person who is accustomed to driving on the right-hand side of the road.

Although public transportation is the most common form of transportation, there is the possibility that more foreigners will use a car equipped with an in-vehicle route guidance system such as a car navigation system to facilitate mobility during their stay in Japan. If tourists who are accustomed to drive on right-hand side of road come to Japan and drive on the left-hand side of the road by using a rental car, they potentially make many mistakes due to failing to adapt from driving on the right-hand side of the road to the left-hand side [15].

According to the statistics on new arrivals for the purpose of sightseeing by nationality, as indicated in Table 1.3, the country which accepted traffic system as right-hand side driving occupied over than 5.8 million tourists. It is accounting for over than 85% of the total number of tourists who entered Japan for the purpose of sightseeing. Another report by Immigration Bureau of Japan was reviewed that Japan should maintain its efforts to attract tourists from these countries [24].

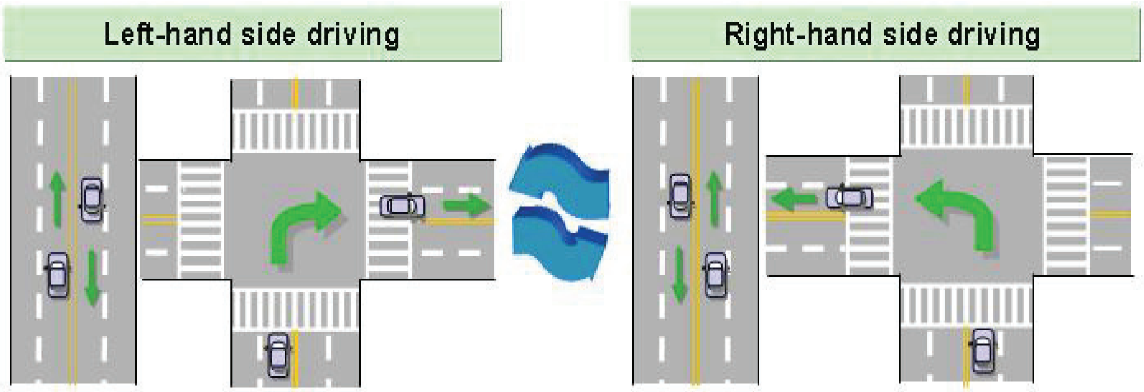


Figure 1. 7 Two types of driving directions divided by conventions

Table 1. 3 Changes in the number of foreign nationals entering Japan by major nationality (place of origin) [24]

(People)

Year / Nationality (Place of Origin)	1985	1988	1991	1994	1997	2000	2001	2002	2003	2004
Total	2,259,894	2,414,447	3,855,952	3,831,367	4,669,514	5,272,095	5,286,310	5,771,975	5,727,240	6,756,830
R.O.Korea	296,708	515,807	1,097,601	1,140,372	1,236,597	1,286,583	1,342,987	1,472,096	1,621,903	1,774,872
China(Taiwan)	356,934	392,723	686,076	681,183	857,877	944,019	838,001	909,654	816,692	1,117,950
United States of America	487,713	457,620	554,147	548,265	642,933	749,343	715,036	755,196	678,935	785,916
China	100,972	112,389	142,150	210,476	283,467	385,296	444,441	527,796	537,700	741,659
Philippines	65,529	86,567	125,329	126,739	124,856	169,755	186,262	197,136	209,525	236,291
China(Hong Kong)	Counted separately from the United Kingdom since 1991		37,483	31,535	30,806	49,423	74,704	136,482	163,254	226,321
Untied Kingdom	183,863	149,954	105,535	123,638	170,251	198,675	203,551	225,074	206,331	222,284
Australia	53,553	40,568	52,058	63,323	79,548	150,046	152,480	167,868	175,315	197,940
Canada	61,270	58,583	63,120	75,560	96,516	122,260	128,707	134,845	129,460	146,109
Thailand	44,123	41,994	105,666	63,812	67,015	73,472	77,521	86,683	95,018	121,963
Others	560,076	529,115	886,787	766,464	1,079,648	1,143,223	1,122,620	1,159,145	1,093,107	1,185,525

1.5.3. Researches of Human Factors on In-Vehicle Route Guidance Systems

There has been considerable human factors research on navigation systems over the past 15 to 20 years [3][7][18][46][56][66]. Additionally, as listed in Table 1.4, several sets of safety and usability guideline for in-vehicle navigation systems have been developed. A well-designed navigation system can prevent wrong turns, reduce travel times, and hopefully, alleviate some of the driver's workload. However, as Nowakowski indicated, poor usability can misdirect drivers, increase driving workload, and lead drivers to make unsafe maneuvers [50].

Table 1. 4 Relevant human factors in-vehicle route guidance system guidelines

Organization / Publisher	Reference of Guideline / Practice / Standard	Comments
TRL (Transport Research Laboratory) A Stevens, et al.	TRL Limited (2004) Design Guidelines for Safety of In-Vehicle Information Systems	The guidelines in this document are intended to alert designers of IVIS to some legal and ergonomic issues relevant to safety.
AAM (Alliance of Automobile Manufacturers) (2003 June 17; Version 3)	Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems	Voluntary industry guidelines and best practices for future telematics devices including cell phones, navigation systems, and internet links.
Battelle DOT, Federal Highway Administration. Campbell, J.L., Carney, C., and Kantowitz, B.H. (1997)	Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) (Technical Report FHWA-RD-98- 057)	Voluminous document with references to interface design. User interface has been said to have a windows flavor, includes physical ergonomics information (e.g., legibility, control sizes)
Commission of the European Communities (1999)	Statement of Principles on Human Machine Interface (HMI) for In-Vehicle Information and Communication Systems ("EU Principles)	Mostly motherhood statements, some minor revisions are expected soon.

Ross, T., et al. (1996)	HARDIE Design Guidelines Handbook: Human Factors Guidelines for Information Presentation by ATT Systems	Early set of European guidelines, less data than UMTRI or Battelle.
JAMA (Japan Automobile Manufacturers Association)	JAMA Guideline for In-Vehicle Display Systems - version 3.0.	Set of detailed design guidelines for interfaces. These guidelines are voluntary in Japan but followed by all OEMs and sometimes by aftermarket suppliers, but some aspects are particular to Japan.
Society of Automotive Engineers	SAE Recommended Practice Navigation and Route Guidance Function Accessibility While Driving (SAE J2364)	"15-Second Total Task Rule," specifies maximum allowable task time for navigation system tasks performed while driving when using visual displays and manual controls.
	SAE Recommended Practice Calculation of the Time to Complete In-Vehicle Navigation and Route Guidance Tasks (SAE J2365)	Calculation procedure used to estimate total task time (and compliance with SAE J2364).
TRL (Transport Research Laboratory) Stevens, A., Board, P.,A., and Quimby, A. (1999)	A Safety Checklist for the Assessment of in-Vehicle Information Systems: Scoring Performance (Project Report PA3536-A/99)	Simple check list.
UMTRI (The University of Michigan Transportation Research Institute) Green, P., Levison, W., Paelke, G., and Serafin, C.	Preliminary Human Factors Guidelines for Driver Information Systems (Technical Report UMTRI-93-21), Ann Arbor, MI:	First set of comprehensive design guidelines, including principles, general guidelines, and specific design criteria, with an emphasis on navigation interfaces.

A potential safety concern with in-vehicle navigation systems is their use of relatively complex visual displays [48]. Furthermore, the complex information will be associated with high attentional demand to the drivers. According to the statistics of traffic accidents in 2003, investigated by the National police agency in Japan, there were 1,307 accidents caused by using car- navigation systems out of a total of 936,721 traffic accident. Although this number is not more than approximately 0.15% of the total, the number is increasing as the car navigation is popularized.

As indicated in Table 1.5, the researches of such in-vehicle route guidance information were conducted in various fields, for example, such as an examination of the best font size on the in-vehicle display in regard to the driver's sight ability [80], and the design of next of next generation for old drivers [48]. Most previous studies investigated the effects or the comparisons of route guidance systems in terms of driving performance and workload [49][54][76], and studied the visual attention on the road or the object [8][45][47][72][74]. In addition, many researches have been focused on how to minimize driver's physical and mental loads to in-vehicle information because of the enormous increase in the volume of in-vehicle systems [59][69][70]. Additionally, several sets of safety and usability guidelines for in-vehicle navigation systems have been developed as well as researches of human factors [35][61][62][74][78].

Although there has been considerable research on in-vehicle navigation systems, many safety and usability problems reoccur in system after system, even in system that have been subjected to some sort of safety or human factors evaluation.

Table 1. 5 Research contents of in-vehicle route guidance system guideline

	Contents	**Description**	**Operating method**	**Display**
Visual Info.	Color of Node	Font size	Menu layout	Position
	Components	Font color	Control layout	Luminous intensity
	Kind of Landmark	Readability	Order of destination entry	Contrast
Auditory Info.	Content of voice guidance	Providing timing	Method of presentation	
	Number of character	Audibility		

1.6. Objectives of The Thesis

This research deals with the characteristics and behavior of drivers who accustomed to left-hand side driving drive on the right-hand side. Further complicating the task of driving on different side of the road is the difference of the driver's seat position in a car. When foreign tourists drive in Japan, it is possible that not only the language but also the position of the driver's seat and the side of the road on which cars are driven will be different from those in their home countries. Therefore it can be presumed that drivers from overseas have a higher mental workload. The position of the driver's seat in Japan is on the right side of the car, and traffic drives on the left of the road. Therefore, if a right-lane driver drives on the left-hand side of a road, there is a large margin for error. In order to achieve comfortable and safe driving, route guidance information provided to drivers from overseas should aim to reduce the driving workload as much as possible.

The main aim of this research was to facilitate the mobility of foreign drivers driving temporary in Japan by examining driver behavior during the use of in-vehicle route guidance information. The approach and needs of this thesis are to investigate the current design of car navigation and determine whether or not the amount of information provided is appropriate for the driver. As the in-vehicle route guidance system, these researches ensure driving safety and alleviate driving workload, and enhance the mobility for foreign tourists through research on various driver behaviors and characteristics.

This investigation is to identify differences in the behavior of left-lane driver and right-lane driver who have driven on opposite lane. This research conducted to clarify whether there are differences of driver's sensibility and behavior between left-lane drivers and right-lane drivers. The sensibility differences are compared them with foreigner who lived in European or American country. The workloads and the driving behavior were compared between the Japanese who have driving experiences and the Koreans who have no driving experiences in Japan. Also, this research tries to figure out the cause why the differences might be.

Most previous studies investigated the effects or the comparisons of route guidance systems in terms of driving performance and workload, and studied the visual attention on the road or the object. In addition, many researches have been focused on how to minimize driver's physical and metal workload to in-vehicle information in terms of supporting new developed in-vehicle systems. However, these studies researched little had been reported on the evaluation of information types with various providing methods. Moreover, there are a lack of studies in the published literature that provide a direct evaluation of the providing method of in-vehicle information, especially for foreign drivers who drive in changed environments. This thesis presents an overview of evaluation methods used to measure driver behaviors, mental workloads with relation to in-vehicle route guidance information. The objectives of this thesis are to develop a route guidance information system to improve the mobility of foreign drivers through evaluating on various types of in-vehicle route guidance for foreign drivers considering human interface.

1.7. Thesis Organization

This research was investigated the types of information and several types of supporting methods relating to route guidance information systems, and evaluate the usability of the systems in order to improve driving safety and mobility of foreign drivers who drive in Japan temporarily. Also, this research is conducted to increase traffic safety by reducing the number of the glance times and the duration time to the in-vehicle route guidance information. In order to achieve these objectives, this research intends to develop various types of in-vehicle route guidance information and suggests in-vehicle route guidance systems to support the way to select information. The flow of this thesis is shown in Figure 1.8.

Chapter 1 mentioned Intelligent Transport Systems in our dairy life and the information society, and discussed the trend of in-vehicle information research in various fields of view. This chapter suggested that the reason to have to do research on in-vehicle information owing to increasing information to drivers, and enhance a mobility for attracting foreign tourists.

Chapter 2 described the implemental devices, evaluating tools and applications to evaluate the in-vehicle route guidance information for appropriate supporting method. This chapter introduced human information evaluating approaches, and suggested the driver behavior and workload models in changed road environments.

Chapter 3 described a comparison in sensibility using Semantic Differential method and driver behavior between two types of drivers, the left-lane driver and the right-lane drivers distinguished by road convention.

Chapter 4 discussed that evaluations on six types of in-vehicle route guidance information, a paper map, an arrow indicator, two arrow indicators with voice information, two map-type navigations with voice information. In this Chapter, a new method to evaluate the visual attention was used. The scene available to the driver was divided into the 10 areas of the roadway which are more detail than any other researches.

Chapter 5 evaluated driver and visual behavior with relation to developed four types of driver in-vehicle route guidance systems for foreign drivers and evaluate the most suitable system, which will improve driver safety and navigation, to be used for the design of future navigation systems.

Chapter 6 discussed a number of evaluating methods and analyses including the visual and driver behavior, mental workloads, and questionnaires relating to results of those researches. Limitations of these researches were described, and suggested the future researches.

Chapter 7 concluded that this these has the validation and effect in field of research on the in-vehicle route guidance information, and suggests the recommendation to design the navigation systems for foreign drivers.

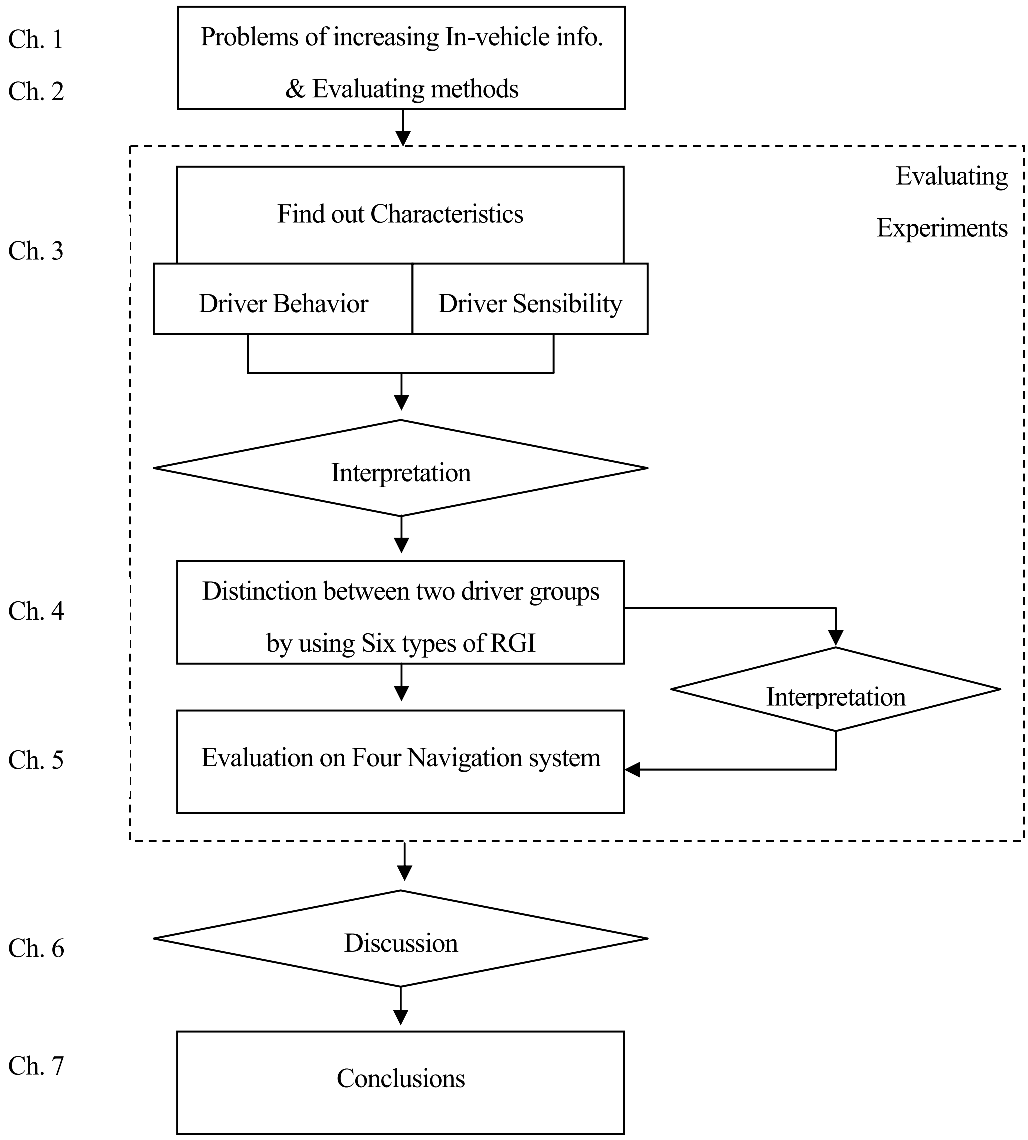


Figure 1. 8 Research flow and organization of thesis

Chapter Ⅱ
EVALUATING METHODS for DRIVER BEHAVIOR and WORKLOAD

2.1. Apparatus and Devices

2.1.1. Driving Simulator

Driving simulator is often used for evaluating of driver behavior, workload to adapt the in-vehicle route guidance systems, testing warning information, etc., depending on the driver's status while driving and individual differences [80]. NADS (National Advanced Driving Simulator) in the University of Iowa and a world class driving simulator in VTI (Swedish National Road and Transport Research Institute) are major examples [67]. Various fields of researches were conducted in the laboratory using those driving simulators, and evaluated on human factors with regard to functionality and driver acceptance of in-vehicle route guidance systems. A driving simulator is able to realize the dangerous situations and set up the situation in accordance with the purpose of an experiment.

There are many advantages for using a driving simulator rather than on-road testing [51], for example, 1) Driving safety: It can exclude the traffic accident which may occur in real road driving. Especially, multiple-vehicle scenarios are more safely studied in a simulator. 2) Equipment cost: Simulator allows study of driver responses to changes in the vehicle without having to construct a vehicle with those features or performance characteristics without occupying large space. 3) Experimental control: A wider variety of test conditions can be prescribed and consistently applied in a driving simulator, same situation is repeatable. 4) Circumstantial limitation: Depending on research, useless units are able to eliminated and extended experimental conditions by programming software [58].

The simulator in this research is high-fidelity simulators. A relatively large number of dependent variables can be used to assess driving performance in the context of an experimental design reflecting subject attributes and trial randomization.

(1) Configurations

In order to achieve a more realistic situation and obtain data on driver behavior and maneuver while driving, a motion-based driving simulator of 360 degrees of sight and mirror projections was used as shown in Figure 2.1. A middle class wagon (Impreza, Subaru Co. LTD.) with automatic transmission was equipped with a full body including a rearview mirror and two door mirrors, and screen of 360 degrees that was composed of 8 screens of 150 inches respectively. A six-DOF motion system was controlled electrically and generated the driving motion and vibration. Figure 2.2 shows the exterior aspect of driving simulator.

The car navigation system (CN-HD9000D, Panasonic™) was installed on the top of the center console to the left of the driver as shown in Figure 2.3. The system was connected with the coordinate network of the simulator and could provide the route guidance information to drivers. A video system captured driver's face, brake and accelerate pedal, steering wheel, in-vehicle route guidance information, etc. An eye-moving device (eye-camera) was installed to evaluate the driver's eye movement relating to the provision of the in-vehicle information and its response time. Speed information was presented on a 7-inch screen set up in the instrument panel of the car.

Figure 2.4 shows the recording device of experiment by using 4 channel controller and video set, which is used to obtain data on driver visual behavior, the eye movements of each subject was monitored by an eye camera and recorded by a digital video recorder as image data. In addition, driver operations and data related to vehicle motion were collected at 60 Hz by the host PC of the driving simulator in real time.

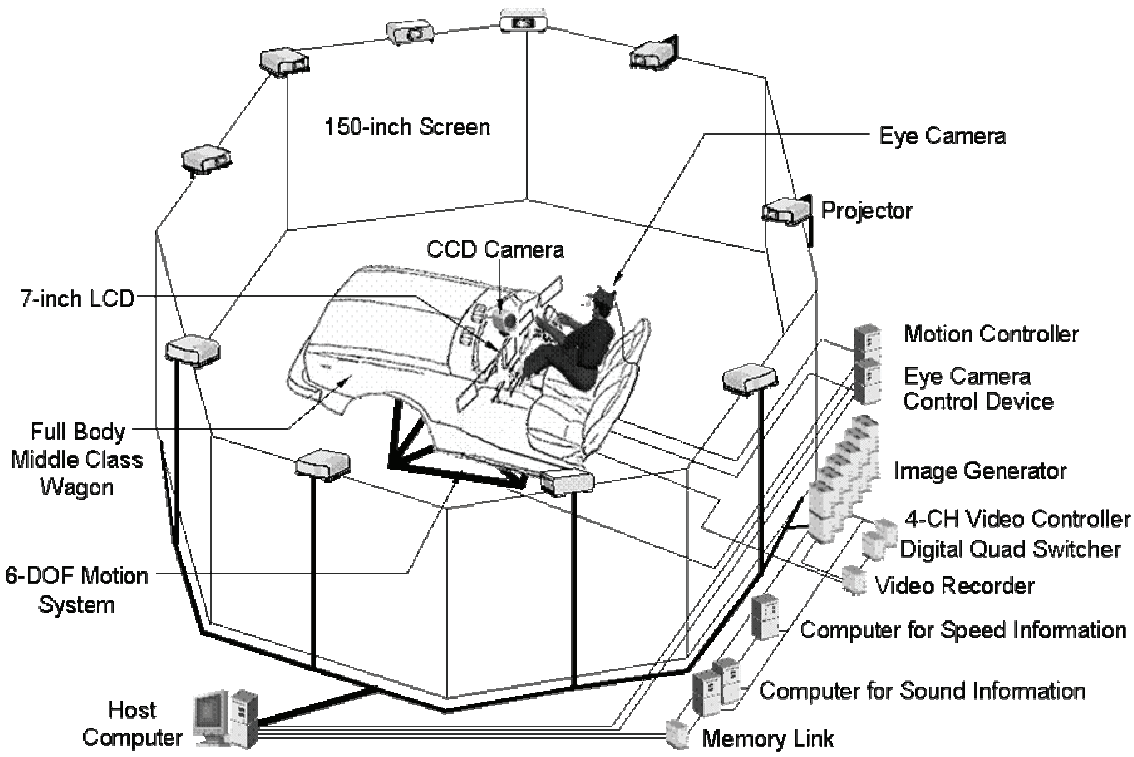


Figure 2. 1 Configurations of driving simulator

Figure 2. 2 Exterior aspects of driving simulator

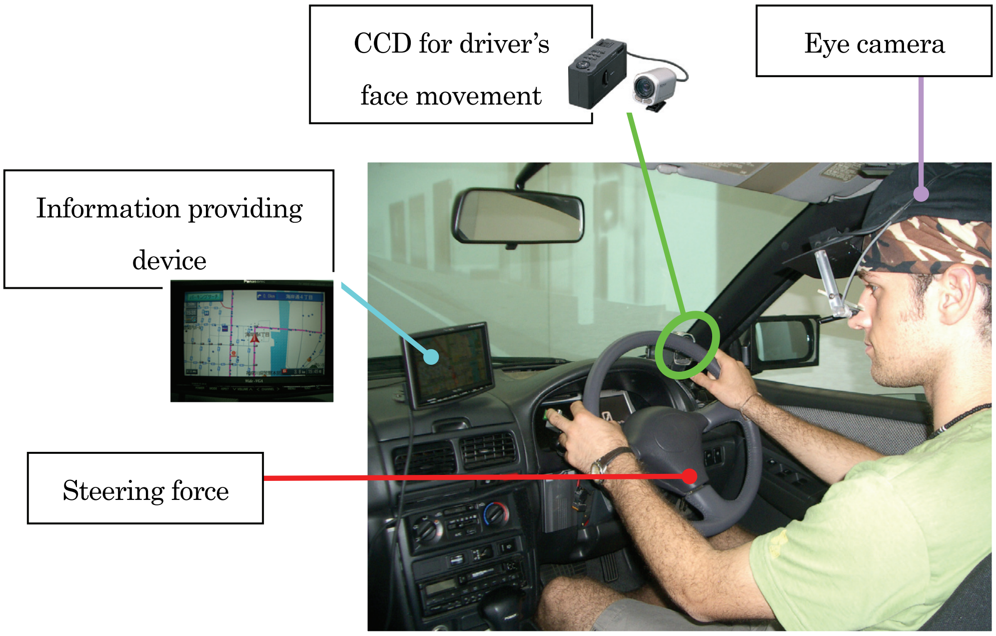


Figure 2. 3 Interior configuration of driving simulator

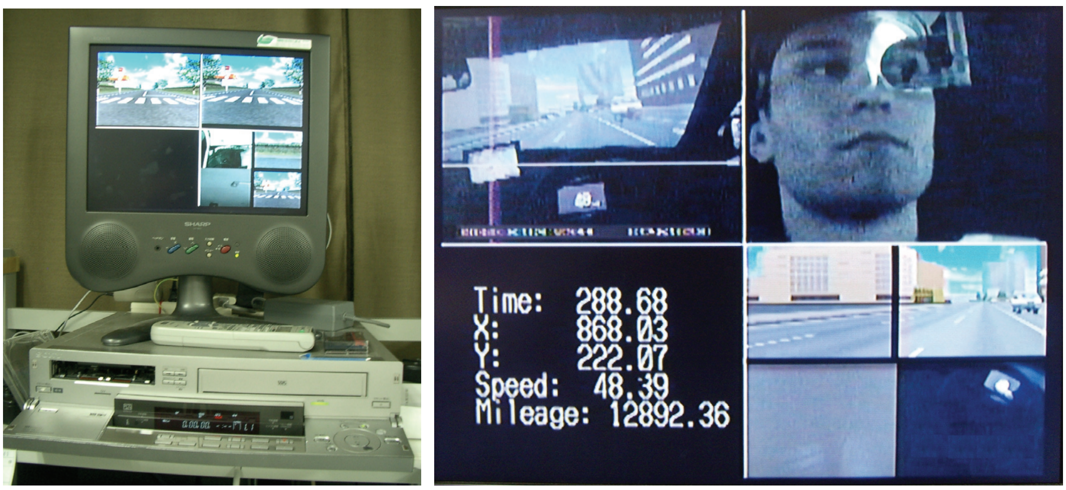


Figure 2. 4 Seven scenes by using 4 channel controller and video set

(2) Specifications

For enhancing the reality felt from driving on the simulator, considering issues such as the scenery in the simulator, the route, time, the traffic conditions, the practical way, the driving environment scenes were generated driving routes based on the roads of Minato Mirai 21 District, which is a typical commuting road. Figure 2.5 shows the map of the driving simulator, and the driving areas of referring map of Minato Mirai 21 district in driving simulator is shown in Figure 2.6. Traffic density was controlled by programming Microsoft ™ Visual C++. Road conditions were dry at day time, and the screen was generated with a 60Hz refresh rate.

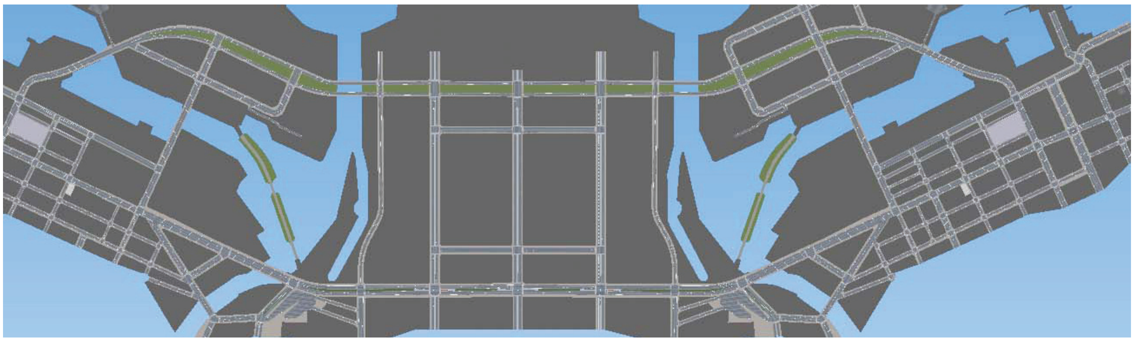


Figure 2. 5 Road configuration of driving simulator

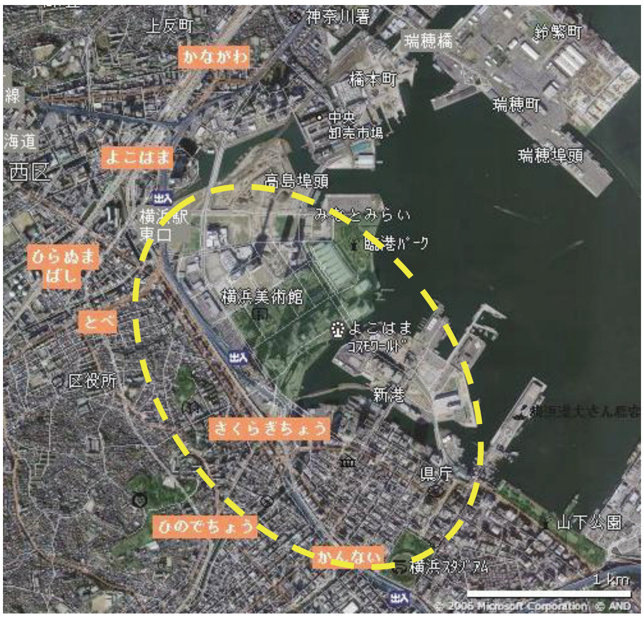


Figure 2. 6 Referring map of Minato Mirai 21 district to driving simulator (Live Search map by Microsoft™)

The driving route roughly divided in three types of roads:

(a) Six-lane divided lanes

As shown in Figure 2.7, these roads have a length of 2 to 2.5 km long with parkways and shoulders, a 50km/h speed limit, one or two right turns and left turns, and that take between 3 to 4 minutes to complete. However, for the experiment using the car navigation system, the length of the roads was reduced to 1 to 1.5 km, which takes between 1 to 2 minutes to complete. This is because a portion of road network was not covered by the car navigation systems.

Figure 2. 7 A sample scene of dual carriageway

(b) Four lane roads (no the median strip):

These roads have a length of 2.5 to 3 km long four-lane divided roads with a 40km/h speed limit, two or three right-turns and left-turns, and took between 4 to 5 minutes to complete as shown in Figure 2.8.

Figure 2. 8 A sample scene of four-lane divided road

(c) One-way road:

These roads have a length of 0.5 to 1 km long one-way roads with a 30km/h speed limit, one right turn and left turn, and take between 1 to 2 minutes to complete. Figure 2.9 shows a simple of a one-way road scene.

Figure 2. 9 A sample scene of one-way road

During the experiment, the state of all driver control (braking, accelerating, etc) and part of the vehicle dynamics (speed, degree of steering wheel control, driving trace, etc) were recorded; this made it possible to produce a time/speed trace of each maneuver to check for any hesitation, erratic steering, etc. Thus, the drivers' activities such as steering angle, driving speed, pedal activity were measured. The data of the drivers' behavior were sent to the host PC of the driving simulator in real time.

2.1.2. Eye Camera for Evaluating Eye Movement

The collection of accurate eye movement and other physiological data is an intrinsically challenging task for the researcher. A various researches have been used eye camera or EOG (Electrooculography) for evaluating driver's eye movement to stimuli objects [9][74].

In this research, the head mounted eye camera (ISCAN^{TM}) was used to evaluate driver's visual attention to route guidance information. The ISCAN can be adjusted for any subject by using the computer keyboard, the eye tracking instrumentation. Incoming eye movement and auxiliary data can be seen graphically in real-time, calibrated, and recorded in the computer's memory. Calibrated or raw eye movement and auxiliary data can also be output in real-time. In the head mounted eye camera, optics and IR (Infrared Radiation) illuminator are all mounted either on a hat assembly which is placed on the subject's head. This configuration allows for eye movement recording while the subject is performing some tasks in which head movements cannot be constrained in space [26]. For detailed configuration on the head mounted eye camera components show in Figure 2.10, refer to the operating instructions for these instruments.

The output from the eye-camera consisted of a video-recording of the scene as viewed by each driver, together with a marker on the scene that indicated the location of the current visual fixation. These recordings were the subject of a frame-by-frame analysis to identify the target of the driver's visual attention.

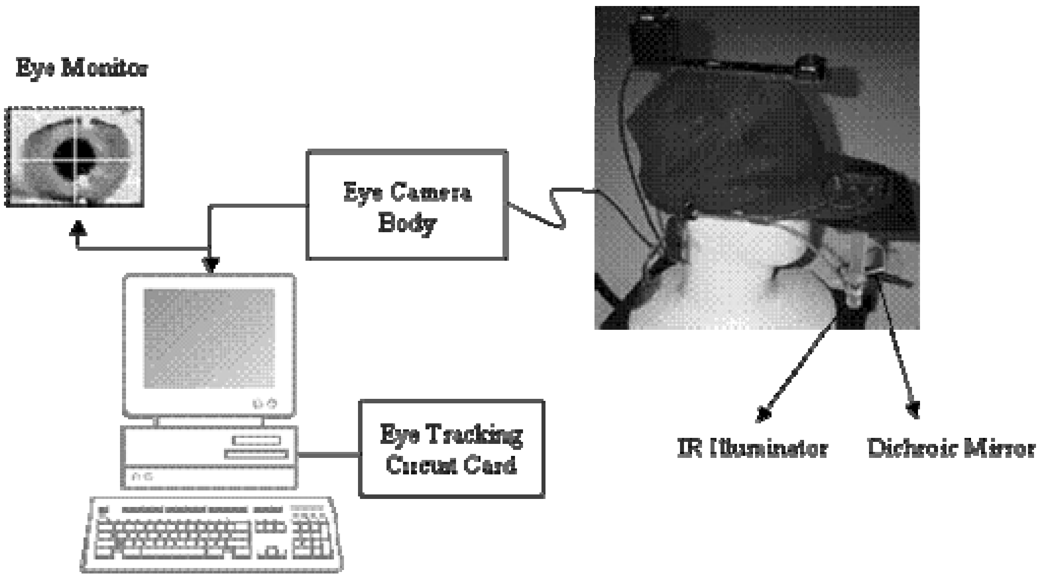


Figure 2. 10 Configuration of eye tracking system

2.2. Objective Evaluations

2.2.1. Eye Movements

Different aspects of eye activity have been assessed, including eye-blink latency, eye-blink duration, eye-blink rate, and eye-movements to stimuli. A relationship between blink rate and visual workload has been demonstrated in the flight environment, and blink rate typically decrease with increase in such demand. Likewise, blink duration shows the tendency to decrease with increase in visual demand. Results of many researches have been interpreted by some investigators as suggesting that eye-blink measures may be principally sensitive to visual as opposed to auditory or cognitive demands and those measures represent somewhat diagnostic indexes of visual workload.

Eye movement data consisted primarily of the individual fixation times on each of several general “targets” within the driver’s field of view, and the percentage of total fixation times on those targets. The following definitions adapted from SAE, 2000 [61] are used with the glance behavior data:

- **Target**: The forward road scene, the navigation system display, or other stimuli.
- **Fixation time**: The duration of a fixation at 1 target. It does not include the transition time to or from the target.
- **Glance duration**: The time from the moment at which the direction of gaze moves toward a target to the moment it moves away from it; Fixation time plus the transition to the target, the glance time.
- **Glance Frequency**: The number of glances to a target within a predefined sample time period, or during a pre-defined task, where each glance is separated by at least on glance to a different target.
- **Total fixation time**: The sum of the individual fixation times on 1 target for a destination entry.
- **Total glance time**: The sum of the individual glance time on 1 target.
- **Total task time**: The elapsed time between when a driver first looks away from the road until he or she finally looks back after the last fixation for 1 destination entry.
- **Transition**: A change in eye fixation location from 1 target to another.

2.2.2. Driver Performance

Driving simulator and observational techniques allowed a wide range of objective measures to be taken. Those reported are as follows:

- **Journey time**: Total time taken by drivers to reach their destination minus nonvoluntary stoppage time (i.e., due to traffic incidents but not voluntary stoppages to look at a map or notes).
- **Navigational errors**: Errors were occurred when a subject strayed from the designated route.
- **Vehicle performance parameters**: Vehicle speed, steering wheel variability, indicator use, lane-changing behavior, and so on.

In this research, the movements of the simulator’s brake pedal, accelerator pedal and steering wheel were recorded; this made it possible to produce a time/speed trace of each maneuver to check for any hesitation, erratic steering, etc. Thus, the drivers' activities such as steering angle, driving speed, pedal activity were measured. The data of the drivers' behavior were sent to the host PC of the driving simulator in real time. Navigational errors were classified according to the type of maneuver at which the error occurred and the action taken by the subject. An error rate value was calculated accounting for the variation in the numbers of the different maneuver types within the routes, and the differences in subject numbers across the types of navigation systems conditions. Therefore, these values represent the likelihood (in percentage form) of a maneuver of a particular type resulting in a navigational error within this study. This analysis was speculative somewhat, and was conducted to allow examination of gross differences between the different error types. Therefore, it was only considered appropriate to carry out statistical testing for the overall error rate.

Steering wheel variability was analyzed in this study. The purpose of this analysis was to examine whether subjects mad compensatory adjustments to the steering to correct any path deviations caused by looking away from the road ahead.

Vehicle speed relating to the visual attention places the emphasis on the likelihood of long glance durations at high speeds.

2.2.3. GSR as a Physiological Assessment

Galvanic skin response (GSR), also known as electrodermal response (EDR), psychogalvanic reflex (PGR), or skin conductance response (SCR), is a method of measuring the electrical resistance of the skin. There are many electrodermal activity research, most of it dealing with spontaneous fluctuations. There is a relationship between sympathetic activity and emotional arousal, although one cannot identify the specific emotion being elicited. The GSR is highly sensitive to emotions in some people. Fear, anger, startle response, orienting response and sexual feelings are all among the emotions which may produce similar GSR responses. One branch of GSR explanation interprets GSR as an image of activity in certain parts of the body. The mapping of skin areas to internal organs is usually based on acupuncture point.

GSR is conducted by attaching two leads to the skin, and acquiring a base measure. Then, as the activity being studied is performed, recordings are made from the leads. There are two ways to perform a GSR - in active GSR, current is passed through the body, with the resistance measured. In passive GSR, current generated by the body itself is measured. GSR is widely used to evaluate on workload as a tool of measurements in the field of various researches [9].

2.3. Subjective Evaluations

2.3.1. Semantic Differential Method

SD (Semantic Differential) method is used to manufacturing product but little does in field of ITS (Intelligent Transport Systems). This thesis applied the SD method as a part of Kansei Engineering for identifying driver's sensibility. The participants performed a detailed adjective evaluation about the general impression of the driving on Japanese roads at the end of driving. The evaluation checklist is made of 5-point scales from 1 to 5, for example, simple is 1 and complex is 5. The checklist was composed of 70 adjectives those were selected from papers, dictionary, and magazine relating to spatial and kinetic adjectives of vehicles. For a comparison among the group of participants, a factor analysis (a varimax of orthogonal rotation method) was performed on 70 adjectives [37].

2.3.2. Mental Workload

A large number of reports have presented workload studies, theoretical discussions, and review of past research. A many number of different approaches and techniques for measuring workload have been discussed, developed, and used.

Subjective techniques have proliferated in particular. The increasing number of techniques for measuring workload creates both an opportunity and a problem for human factors practitioners and researchers. On one hand, tools have been developed for a wide variety of situations. On the other hand, human factors specialists faced with choosing the most appropriate from these tools. In various subjective assessments, Cooper and Harper rating scale and NASA-TLX are widely used for evaluating subjective workload. Those assessment methods were used in this research by modified.

(1) Cooper and Harper Rating Scale

Cooper and Harper (1969) developed a rating scale to measure the mental workload involved in piloting aircraft with various handling characteristics [11]. The scale has since been modified by many researchers to be applicable to a variety of settings. The Modified Cooper and Harper rating scale was developed for workload assessment in systems in which the task is primarily cognitive, rather than motor or psychomotor, and in which the original Cooper and Harper rating scale may not be appropriate [19].

As shown in *Appendix B*, the Cooper and Harper rating scale was modified for adjusting this research. the Modified Cooper-Harper rating scale is a 10-point unidimensional rating scale that the scale involves traversal of a decision tree, yielding a rating between 1 (lowest workload) and 10 (highest workload). These numbers are conceived as ordinal indicators of the degree of mental workload. The rating scale uses a decision tree to assist the rater in determining the most appropriate rating to assign.

(2) NASA Task Load Index

The NASA Task Load Index uses six dimensions to assess workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Twenty-step bipolar scales are used to obtain ratings for these dimensions. A score from 0 to 100 (assigned to the nearest 5) is obtained on each scale. A weighting procedure is used to combine the six individual scale ratings into a global score; this procedure requires a paired comparison task to be performed prior to the workload assessments. Paired comparisons require the operator to choose which dimension is more relevant to workload for a particular task across all pairs of the six dimensions. The number of times a dimension is chosen as more relevant is the weighting of that dimension scale for a given task for that operator. A workload score from 0 to 100 is obtained for each rated task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by the total weights (i.e., for the 15 paired comparisons) [17][19]. Table 2.1 indicates the content of NASA-TLX.

As shown in *Appendix C*, this evaluating technology is also used in this research through modifying the origin. Because the major objective of the NASA-TLX was to examine workload in a broad army context, which has been conducted in relatively narrow aviation environments. This has different from those of studies in driving environment, hence the NASA-TLX was modified for adjust the purpose of this research. The modified version includes a scale to measure perceived driver distraction.

Operator ratings are among the least intrusive of all techniques because they can be administered after the task or mission is completed without disturbing the operator during task performance. Further, the techniques are flexible and portable; no equipment or special data collection devices are needed. These techniques can be quick and inexpensive to administer and analyze. These substantial advantages recommended their application in most operator workload investigations.

Table 2. 1 NASA-TLX rating scale definitions

Title	End points	Description
Mental demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Low/High	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How much did you have to work (mentally and physically) to accomplish your level of performance?
Frustration level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

2.3.3. Questionnaires

It is difficult to investigate all of evaluating aspects by testing objective and workload methods. Moreover, the many aspects of usability issues are not limited to difficulties during operations, but may include complaints about poor functions or slow response. In typical usability test, data usually include task-completion time, the error rate, the log of the user's operations, subjective responses to the questionnaire, and so on. However, it is also necessary to identify the sources of the problems and to understand what users think and feel while they use a product [43]. During the past decade, a great deal of research has been undertaken in the development and application of subjective questionnaires as a assessment techniques, e.g., "thinking-aloud protocol method", "question-asking protocols", and "VPA

(Verbal Protocol Analysis)" [40][44].

Subjective questionnaires can encourage the evaluator to treat each part of the system as separate and therefore not to take account of the implications for the design as a whole. Increasingly, navigation systems are becoming part of an "integrated" console that includes other in-vehicle functions such as heating and ventilation system, and mobile telephone, etc. In these cases it is important to consider the implications of the interaction between the different sub-systems.

2.4. Models of Driver Assistance System

Driver assistance systems should be based on a driver behavior model. It links information about required and actual behavior with information about the driver and driving situation. Driver assistance functions that counteract driving errors are developed using an analysis of driver's behavior in given driving situations. A number of models of the navigation task and the driver's cognition exist [57][63][68].

Figure 2.11 presents a driver assistance system model based on the three-stage (perception, judgment, operation) and AHS (Advanced Cruise-Assist Highway System) model.

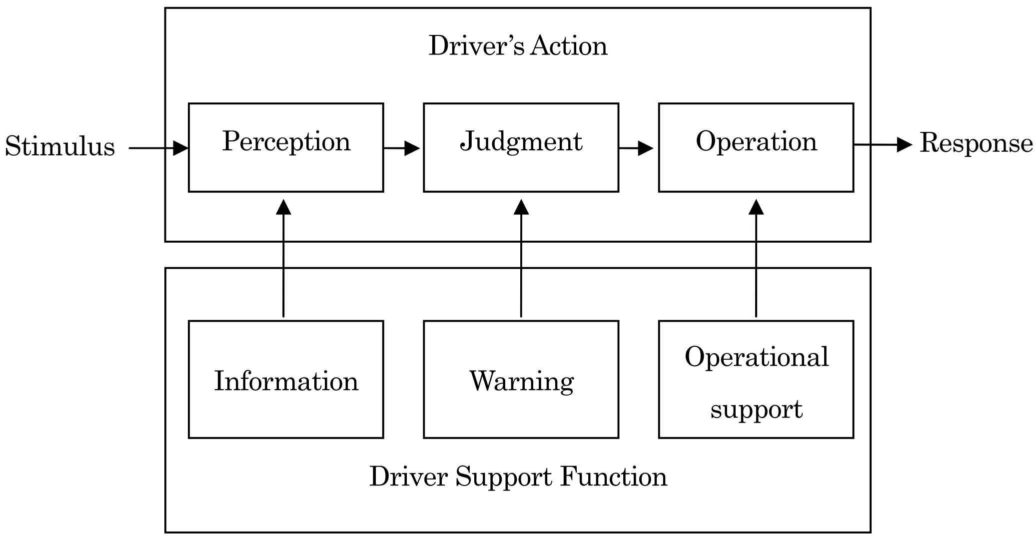


Figure 2. 11　Model of driving assistance system

The three stages intervene between the presentation of a stimulus and the execution of a subsequent response. Early processes associated with perception and stimulus can be classified as the perceptual stage. Following this stage are intermediate processes involved with decision making and thought, classified as the judgmental stage. Information from this judgmental stage is used in the final action stage to select, prepare, and control the movements necessary to affect a response.

On the other hand, AHS provide drivers with information, warning, and operational support to eliminate 1) delays in recognition, 2) errors in judgment, and 3) errors in operation, which are the three major causes of accidents. The systems consist of 1) roadside sensors, which detect obstacles such as standing vehicles, slow vehicles, and rear-end congestion, and transmit the information to vehicles, and 2) on-vehicle systems that transmit the information to drivers by voice and head-up displays (image projected on the front glass) depending on the speed of the vehicle. AHS effectively prevent accidents through cooperation between the roadside and in-vehicle units and providing information to drivers in real time [28].

Besides, a cognitive driver model differentiates several processing stages within the driver. Input from the traffic environment and the vehicle is perceived by the driver. A number of stages are distinguished in perception. In a second step, stimuli are processed with regard to the question whether an action is necessary and kind of action should be executed. Finally, a vehicle reaction is planned and executed. These stages of processing are influenced by traits (e.g., age, driving experience, personality) and stages (e.g., fatigue, stress) of the driver and his current aims (e.g., reaching the destination as fast as possible).

As one of hierarchical model developed by Rasmussen (1990), described that the driver task splits into three levels: strategic, maneuvering and control [57]. This model links easily with the mode of cognitive behavior. He introduced a paradigm for describing three levels of human behavior: skill-based behavior, rule-based behavior, and finally knowledge-based behavior. During navigation, the driver is performing at all three levels: at the strategic level is the use of the information for overall route planning; at the maneuvering level, the driver is maintaining his position in relation to other traffic and the road geometry; at the control level is the automatic vehicle control actions. Such a model is useful to indicate the metrics that should be used to indicate effect on driver behavior, e.g. route completion time (strategic), lateral lane position (maneuvering) and rate of deceleration into a turn (control) [59].

Only when they conform to the drivers needs will driver assistance systems contribute to an increase in driving safety. Possible actions of assistance systems (inform-warn-act-take control) take place at different levels of the human information processing, action chain and hence knowledge about the fundamentals of the cognitive process is required. In this research area strategies for assistance systems based on this concept are developed and their effect and acceptance by the driver is evaluated.

Objective and subjective assessment techniques evaluate performance and workload through the use of the operator's judgment. However, the operator should consider the concept of model sufficiently in advance.

Chapter Ⅲ

COMPARISON in SENSIBILITY and BEHAVIOR between TWO TYPES of DRIVERS by ROAD CONVENTION

3.1. Different Kansei and Driver Behavior between Two Types of Hand-side Drivers

3.1.1. Introduction

Since the car has become a necessity in our life, research into the sensibility has become a focus of international interest. Therefore, it is becoming an important task for car design to accommodate drivers' habitual driving behavior and the sensibility for higher safety.

Although the Japanese car is favorably commented upon by the world car user, there are little concerns about the sensibility difference for foreigner living in Japan, even if they are a few. Also, there are differences in driving characteristics regardless of having the same skill due to different custom or using converse driving lanes. For example, the Japanese and the Koreans may have similarity of human characteristic and living environment. However there are lots of differences in their sensibility caused by the customs and the habit such as living and traffic environments between two countries.

In the previous study [13], the cognitive map between Swedish and immigrated Japanese-Swedish people is examined. The results of research show that the types of elements in a cognitive map and the cognitive process using those elements in route selection are different between Swedish and Japanese drivers. A. Bianchi et al. reported that parent's self-reported driving behavior explains their children's respective self-reported behavior, even when exposure and demographic and life-style factors controlled by surveying data about driving exposure, life style, accidents, and traffic-tickets [2].

Even though these studies are not research on the sensibility in relation to different style driving, this research is supposed that the road convention or infrastructures affect their driving behavior and the sensibility.

3.2.2. Objectives of Research

The aim of this investigation is to identify differences in the behavior of left-lane driver and right-lane driver who have driven on opposite lane. This research conducted to clarify whether there are differences of driver's sensibility and behavior between left-lane drivers and right-lane drivers. The sensibility differences are compared them with foreigner who lived in European or American country. The workloads and the driving behavior were compared between the Japanese who have driving experiences and the Koreans who have no driving experiences in Japan. Finally, this research is tried to figure out the cause why the differences might be.

3.2. Method

3.2.1. Evaluating Method on Sensibility Differences between Two Types of Drivers *(Experiment I)*

(1) Participants

Forty-five participants took part in the evaluation of Semantic Differential Method. The participants consisted of three groups; 26 Japanese drivers (mean age: 24.1 years, mean driving experience: 59.6 months), 12 Korean drivers (mean age: 30.0 years, mean driving experience in their country: 74.5 months), and 7 European and American drivers (mean age: 22.6 years, mean driving experience in their country: 48.9 months, mean of living period in Japan: 10.3 months). All of the participants were male. Korean, European and American drivers had no experience of driving a car in Japan or other countries accepted the left-hand side driving.

(2) Semantic Differential Method

The participants performed a detailed adjective evaluation about the general impression of the driving on Japanese roads at the end of driving. The evaluation checklist is made of 5-point scales from 1 to 5, for example, simple is 1 and complex is 5. The checklist was composed of 70 adjectives those were selected from papers, dictionary, and magazine relating to spatial and kinetic adjectives of vehicles [37] [53]. For a comparison among the group of participants, a factor analysis (a varimax of orthogonal rotation method) was performed on 70 adjectives.

3.2.2. Evaluating Method on Differences of Driver Behavior between Two Types of Drivers *(Experiment Ⅱ)*

(1) Participants

Moreover, in the participants, the data of 5 Japanese (mean age: 23.2 years, mean driving experience: 38.8 months) and 5 Korean drivers (mean age: 29.6 years, mean driving experience: 69.8 months) were collected by driving on a driving simulator to compare driving behavior between left-lane drivers and right-lane drivers. Five Koreans had no experience of driving a car in Japan although they had lived in Japan (mean of living period: 24.6 months), and other countries accepted the left-hand side driving.

(2) Measurement

Subjective evaluation

MNASA-TLX (Modified of NASA-TLX) was used as the driver’s mental workload evaluation with modifying NASA-TLX for comparing needs of mental efforts, driving uncomfortableness, timing stress, difficulty of searching for devices, difficulty of operating devices, and difficulty of perceiving the outside environment between left-lane drivers and right-lane drivers.

Objective evaluation

During experiment, the maneuvers of the simulator's brake, accelerator pedal and steering wheel were recorded; this made it possible to produce a time / speed trace of each maneuver to check for any hesitation, erratic steering, etc. Therefore, the drivers' behaviors such as steering angle, driving speed, pedal operation (number of stepping the brake and accelerator pedal) were measured.

GSR (Galvanic Skin Response) as drivers' physiological signal was also observed for measuring drivers' tenseness during the urban driving generated by the driving simulator.

3.2.3. Apparatus and Experimental Conditions

In order to obtain driver's behavior and maneuvering data while driving, a motion-based driving simulator was used as described in *Chapter Ⅱ*. The experiment was carried out in the laboratory of 24 degree centigrade for providing comfortable circumstances for subjects as much as possible. The scene of driving environment was realized by referring the roads of Minato Mirai 21 District which is a typical commuting road. The determined route consisted of two types of roads: (a) six-lane divided roads with shoulders, 50km/h speed limit, and 2.5 to 3 km long, had a right-turn and a left-turn, and took between 5 to 6 minutes; (b) four-lane divided roads with 40km/h speed limit and 1.5 to 2 km long, had a right-turn, and took between 2 to 3 minutes. Traffic density was kept low. Road condition was dry at daylight time and the screen was generated by 60Hz refresh rate.

3.2.4. Experimental Design

Driving experimental procedure is presented as Figure 3.1. In this research, all participants were accustomed to driving the driving simulator for 15 to 20 minutes-along a pre- determined course. However, various papers had reported that Visually-Induced Motion Sickness (VIMS) is induced by driving computer simulators [42][52]. Therefore, if the symptom of VIMS developed to a subject, the subject did not take part in the next experiment. Twenty-six Japanese, 12 Korean, 5 European and American drivers evaluated 70 adjectives by SD method. And, 5 Japanese and 5 Korean drivers evaluated the questionnaires about metal workloads at the end of experiment.

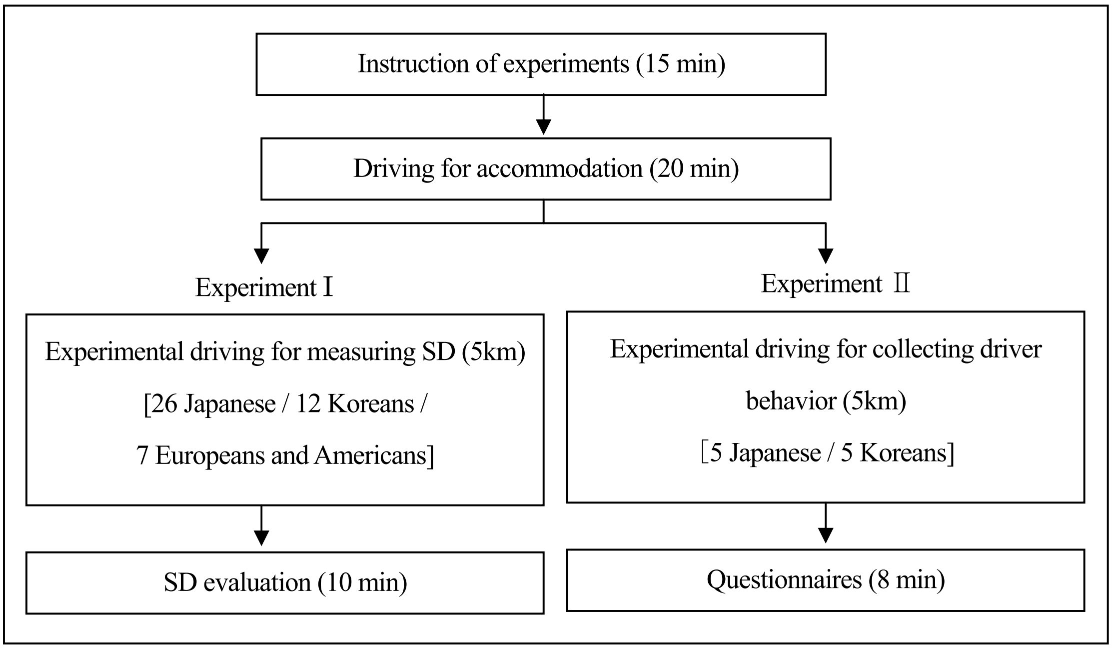


Figure 3. 1 Experimental procedures

3.3. Results

3.3.1. Semantic Differential Method

The result of factor analysis of Japanese, Korean, and European and American driver is respectively shown in *Appendix A*.

In case of the Japanese drivers, factor loading were determined for 12 factors. The 12 factors together explained 69.99% of the total amount of variance. The first factor explained 17.50% of the total variance and consisted of 12 adjectives. This factor was named "a feeling of driving simulator"; felt by driving on the simulator such as 'firm' and 'uneasy'. The second factor explained 12.27% of the total variance; this factor included 11 adjectives of the impression by driving the simulator; therefore this factor was named "new experience by driving on simulator", presented by 'fantastic' and 'exotic'. The third factor explained 8.99% of the total variance. This factor was named "a feeling of the experiment", included 6 adjectives such as 'irritating' and 'blunt'.

In terms of Korean drivers, four factors were divided and explained 69.99% of the total amount of variance. The first factor explained 24.62% of the total variance. The first factor was labeled the "new experience of driving on Japanese roads", pertained to the preference for driving as consisting of 'unusual' and 'impressive'. The second factor was labeled "impression of driving on simulator", pertained to driving on simulator as like 'exhilarant' and 'embarrassed': This factor explained 20.03% of the total variance. The third factor explained 14.50% and consisted of 8 adjectives like 'clean' and 'peculiar' that drivers felt on driving in Japan.

As the result in factor analysis of European and American drivers, adjectives are divided into 2 factors. Two factors together accounted for 68.98% of total amount of variance. The first factor accounted for 46.01%. This factor was named the "a feeling of new experience", pertained to the preference for general driving as consisting of 'tense' and 'exciting'. The second factor accounted for 22.99% and was named "impression of driving on Japanese road"; pertained to the driving on abroad road such as 'impressive' and 'embarrassed'.

3.3.2. MNASA-TLX

Figure 3.2 shows the total mental workload of two groups about driving all section of experimental road. Result indicates that the subjective weighted workload (WWL) of right-lane drivers required more than twice comparing with that of left-lane drivers' (F (1, 10) =12.03, p<0.01).

Right-lane drivers felt timing stress relating to using of driving devices (F (1, 8) =7.12, p<0.05) and difficulty of searching for devices such as turn signal (F (1, 8) =6.98, p<0.05) more than left-lane drivers. Although there is not difference in the statistics in terms of the total, as shown in Figure 3.3, right-lane drivers had much more workloads than left-lane drivers except driving uncomfortableness.

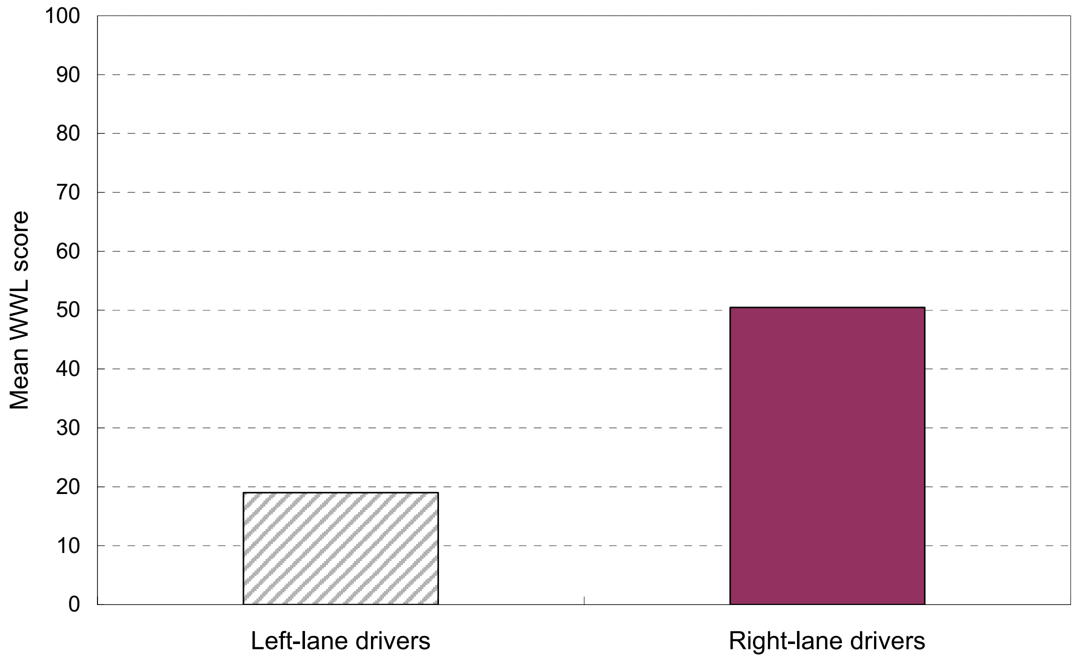


Figure 3. 2 Total Mental Workload by MNASA-TLX

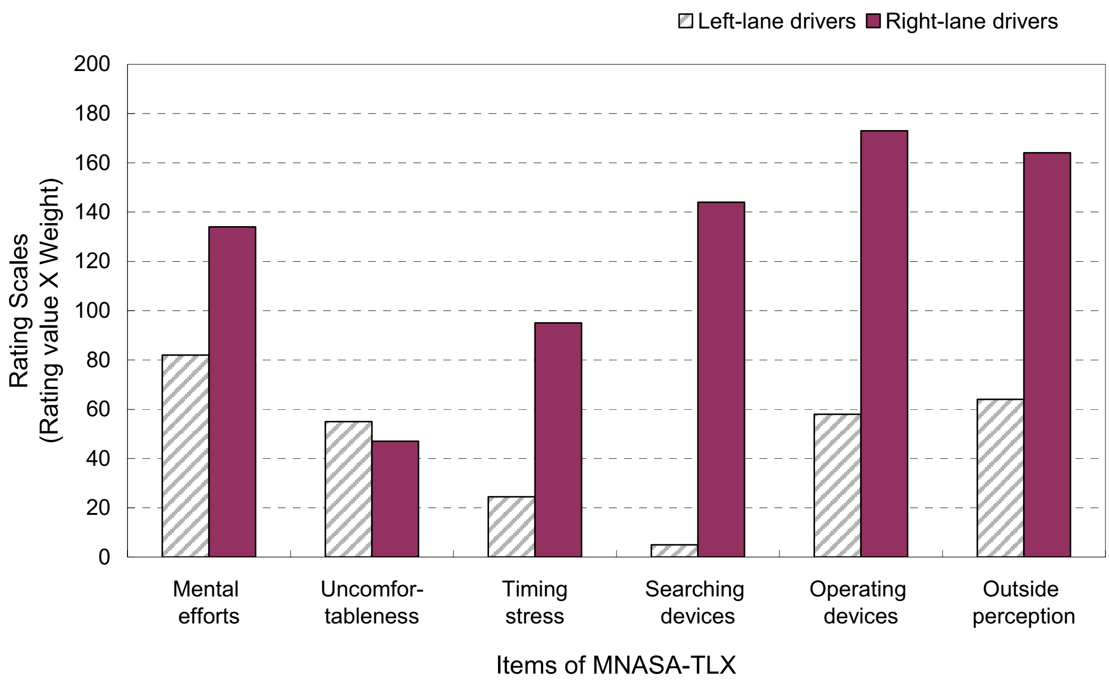


Figure 3. 3 Mental Workload of Each Item by MNASA-TLX

3.3.3. Galvanic Skin Response

Figure 3.4 shows that right-lane drivers were tense at right-turn in comparison with the case of driving straight road. There is little difference in the case of left-lane drivers; right-lane drivers have lots of difference between right-turn and straight driving, however. It is not significant for comparing the averages because GSR is related to the moisture situation of subjects' skin. (Right turn: $F(1, 8) = 0.59$, $p > 0.05$, Straight: $F(1, 8) = 0.98$, $p > 0.05$).

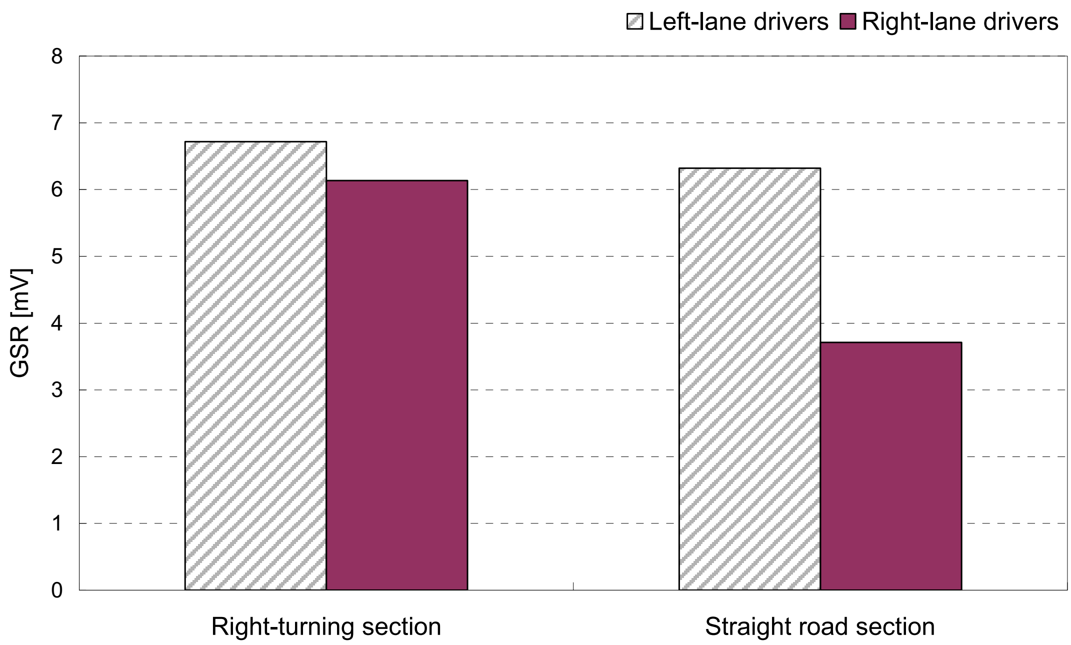


Figure 3. 4　Average of GSR

3.3.4. Driver Behavior

There are no significant in relation to average speed and steering wheel between two groups (p>0.5). However, as shown in Figure 3.5 and Figure 3.6, right-lane drivers steered larger angle and higher speed than left-lane drivers when they make right-turns at the intersection.

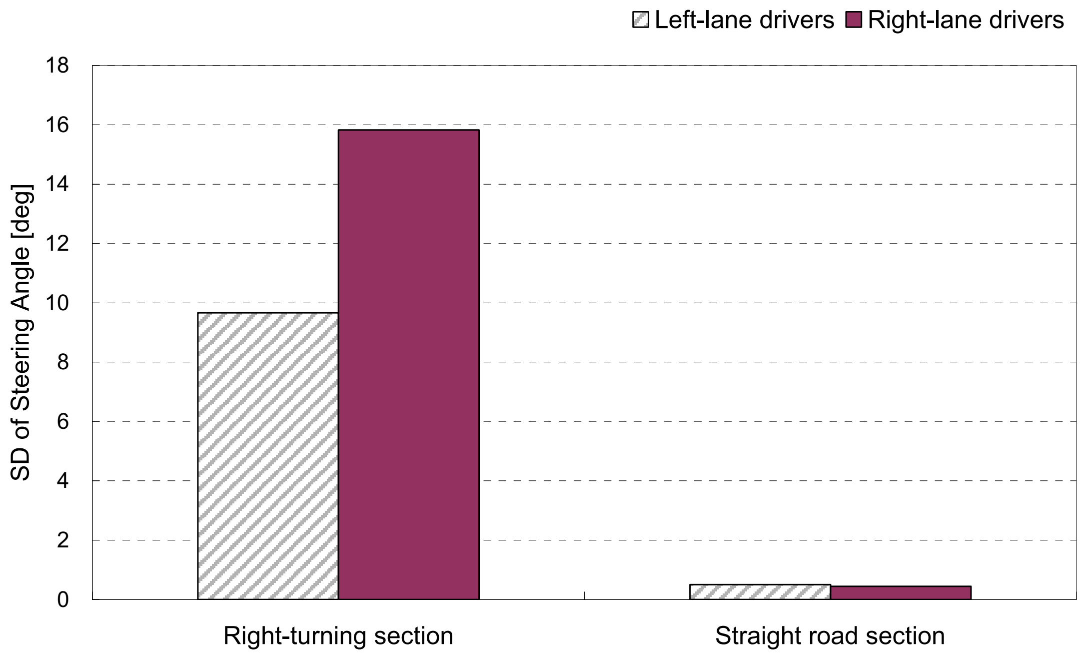


Figure 3. 5 Standard Deviation of Angle of Steering Wheel

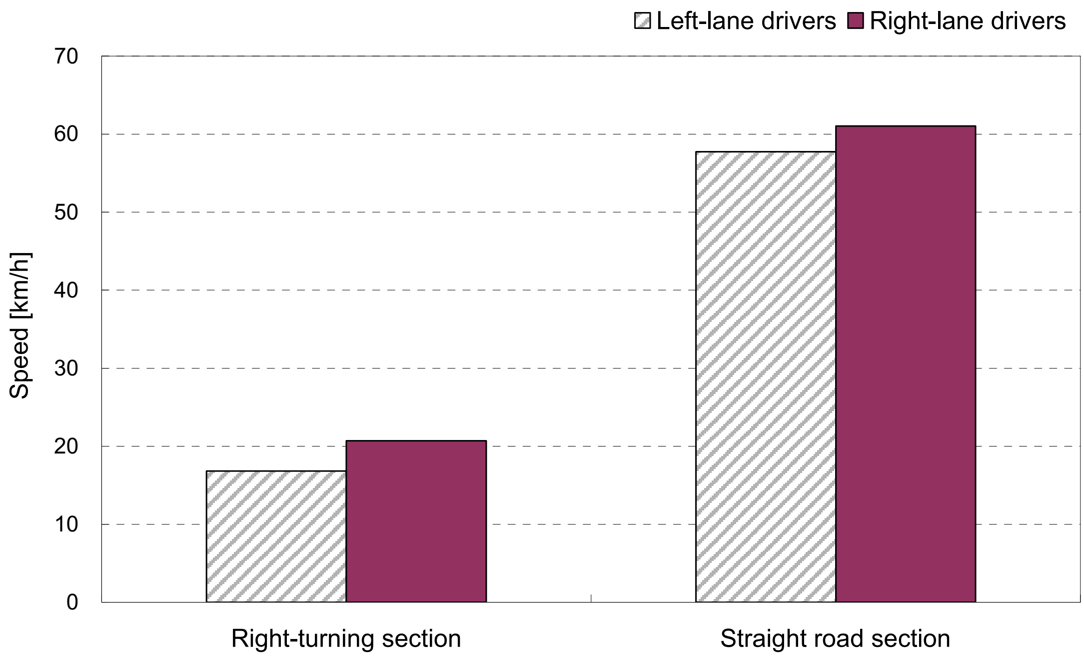


Figure 3. 6 Average Speed in the Straight section and Right-turn

3.4. Discussion

The main objective of this study was to investigate the comparison in driver behavior and the sensibility between left-lane drivers and right-lane drivers, and to explore issues of drivers' acceptance of the road convention.

This research was tried to compare the sensibility differences between left-lane drivers and right-lane drivers by analyzing the results of SD method. Although human sensibility may concern about physical and psychological condition, the environment of growth, etc., there are many significant different things as supporting the results such as mental workload, and ability of driving operation between them. At the results of SD method, right-lane drivers presented their new experience from driving on Japanese road at first while left-lane drivers pertained to driving on general road by driving on simulator.

From the comparisons of the MNASA-TLX, the right-lane drivers who had the greatest experiences were needed higher workload such as time stress when they operated devices in new circumstance. In terms of the right-lane drivers' behavior, their steering skill was worse, and they failed to see the traffic sign, regardless of taking much effort. Depending on driver's confidence, some drivers felt that driving on the Japanese road was not difficult. However, they took a few mistakes when they make a turn with operating turn signal or get into the wrong lane approaching a junction.

The right-lane drivers operated unsafe driving through the video analysis as they steered the steering wheel many times to adjust their car to driving lanes, and conducted a few operating mistake by confusing the position of turn signal and windshield wiper. Left-lane drivers were accustomed to right-turns and they saw much information such as the traffic signal and opposite vehicles, and so on, however right-lane drivers mostly see the lane to drive along.

In this study, the English translation of the 70 adjectives and questionnaires was checked by a native speaker, who was fluent in both Japanese and English. Even so, some items might be ambiguous and interpreted slightly differently. Actually, problems in translation procedure are not only the reason for lack of equivalence but different traffic cultures between the original questionnaire and the translation. The use of a procedure such as back translation by an independent translator might be necessary.

In the factor analysis, the number of samples was not greater than number of variables, based on a fairly small driver sample. It might be cause the result that the factors were divided into only two groups in part of European and American drivers. However the result indicates that there are dedicate shapes of different sensibility in three driver groups, respectively.

3.5. Conclusions

The results of this research could not reach the conclusion that there is the confirming evidence to support that the different driving behavior comes from the different sensibility. The result in the present study, however, indicates that driving habit affect their sensibility and impose higher mental workload at the same driving tasks. It seems that the drivers' sensibility has affected according to the driving environments by the driving lane. In the previous study, P. Ulleberg et al. indicated that personality traits have indirect effects on risk-taking behavior [73].

SD (Semantic Differential) method as an evaluating method of human sensibility is used to manufacturing product but little does in field of ITS (Intelligent Transport Systems). This study was researched on field of ITS applying to human sensibility using their habit. This data are to be applied to quantifying the ITS requirements and evaluation of the accident evasion effects using computer simulations. Further research is needed concerning the usability, the sensibility difference, and effectiveness of different types of in-vehicle route guidance systems. For example, providing more cues prior to the turn intersection such as changing display color, flashing the vehicle icon in the map and using flashing arrows could affect driving performance to adjust a car for human sensibility.

3.6. Summary

This paper deals with the sensibility difference, the characteristics and behavior of driver's who are accustomed to drive on the right-hand side of the road, drive on the left-hand side, and comparison with left-lane drivers. SD (Semantic Differential) method was used for comparing the driving sensibilities of the two types of drivers. Moreover, GSR (Galvanic Skin Response) was measured to obtain changes in the physiological signal in terms of objective evaluation while driving on simulated driving. Driving metal workload was also evaluated based on MNASA-TLX as a subjective evaluation. Results indicate that the sensibility and characteristics of the right-lane drivers' were shown differently in comparison with those of the left-lane drivers when driving on the opposite lane due to their habit and traits. The result of SD method is that right-lane drivers presented a feeling of incompatibility by the road convention.

However, left-lane drivers presented a feeling from driving simulator as the first factor. In the result of metal workload, the right-lane drivers were in higher stress condition than left-lane driver due to driving on opposite lane that they were not used to. The results implied that driving habit has influence on driver's sensibility and mental workload.

Chapter Ⅳ

EVALUATION on VARIOUS TYPES of ROUTE GUIDANCE SYSTEMS

4.1. Evaluation on In-vehicle Route Guidance Information

4.1.1. Introduction

Car navigation system as an in-vehicle route guidance system offers a state-of-the-art technological solution to driver navigation in an unfamiliar area. It typically presents real-time navigation information to the driver based on a series of map overviews and/or any instructions via visual and auditory forms such as graphic, text, and voice information. The car navigation consists of two important pieces of visual information: landmarks and distances. Landmarks are key elements in instructing a driver to an unfamiliar destination and are typically supported by a vehicle navigation system [34]. By providing external reference points, which are easily remembered and recognized, they can potentially reduce the need to refer to a display in order to locate the necessary direction at turns. Distance information helps the driver actually locate the turning at the intersection at which to turn.

In addition, the number of foreigners who entered Japan in 2005 was over the 6 million people, according to an investigation by the Immigration Bureau of Japan. It is increased in 18.0% compared with the previous year and is the highest ever. If the drivers who were used to driving on the right-hand side of the road drives on the left-hand side of the road by using a rental car, they could make any mistakes due to failing to adapt from driving on the right-hand side of the road to the left-hand side [15]. Moreover, the complex information will be associated with a high amount of attention, and therefore cause them to incur potentially fatal injuries.

The main objective of this research was to investigate the effects of selected in-vehicle route guidance systems on the visual and mental demands of driving especially subjected to two types of drivers according to road trauma; Japanese young driver and foreigners who were used to driving on the right-hand side of the road.

Most previous studies investigated the effects or the comparisons of route guidance systems in terms of driving performance and workload [1][64][72], and studied the visual attention on the road or the object [8][15][74]. There are few researches available of the visual attention in relation to route guidance systems, and comparing them between the right-lane driver and the left-lane driver.

4.1.2. Objectives of Research

The approach and needs of this study was to investigate the current design of car navigation and determine whether or not the amount of information provided is appropriate for the driver. This research collected data on how different route guidance systems affect visual attention and driving performance.

The specific aims of this research were to determine the following:

(a) whether or not the currently used and wide-spread car navigation systems lead to the best level of visual attention and driving performance compared with other systems,

(b) whether or not reducing the information leads to improving driving performance and lower mental workload compared with the current car navigation system.

(c) whether or not English voice information leads to better driving performance and lower mental workload compared with Japanese voice information for foreign drivers in the case of a road in Japan,

(d) finally, what factors and contents of information lead to better driving performance and less mental workload for drivers.

4.2. Evaluating Methods

4.2.1. In-Vehicle Route Guidance Information

The information was presented on 7-inch LCD (liquid crystal display) installed on the top of the center console to the left of the driver. Participants were asked to operate a driving simulator while using six different types of the route guidance system.

(1) Paper Map (P)

The paper map is generally used to outline a route in an unfamiliar area without offering a technology device such as a car navigation system. The paper map in this experiment contained symbols indicating locations of traffic signals, landmarks, such as banks, convenience stores, famous fast food restaurants, etc., a start and a destination point, and two way points. The size of the map was 297 x 420 mm. Each participant was instructed to reach the destination through the shortest route via two waypoints using the paper map. The paper map is abbreviated to "P" in the below descriptions. Figure 4.1 shows an example of the paper map.

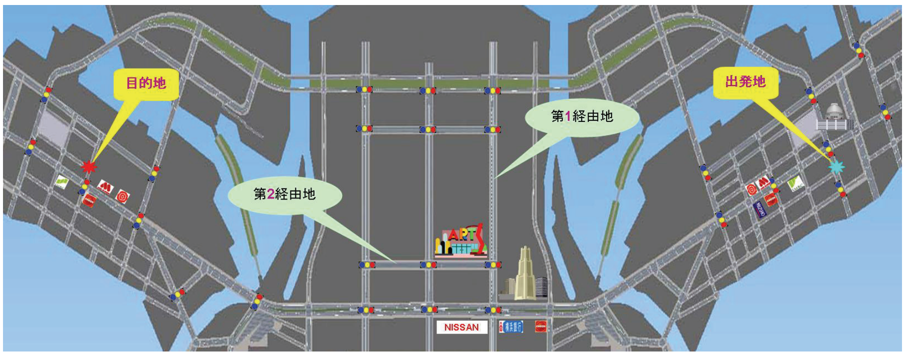


Figure 4. 1 Paper map

(2) Arrow Indicator (A)

Figure 4.2 shows an example of arrow displays. In the experiment, these displays were accompanied by tonal signals. The visual information on each arrow display consisted of simple directional arrows that showed the driving route at any time, landmarks, and distance information. The distance information was changed from 300 m to 100 m, and then removed from the display, corresponding to the distance to the target intersection. Moreover, when the distance information was updated, a tonal signal was provided. The orientation of the map was always heading up the display. The timing of the update of distance information was similar to that of a car navigation system. The arrow displays with tonal signals are abbreviated to “A” in the below descriptions.

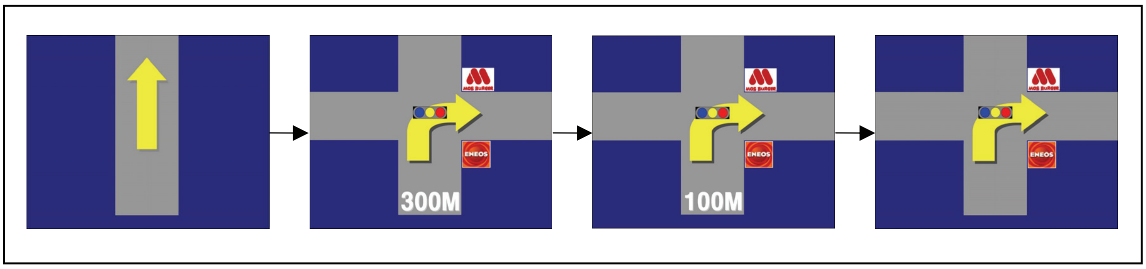


Figure 4. 2 Examples of Arrow displays

(3) Arrow with Japanese Voice Information (AJ)

The visual information of the arrow displays with Japanese voice information was the same or a little much as that for the arrow indicator. The obvious difference with the arrow system (A) was that the driver was provided with Japanese voice information made by LaLa Voice program (Toshiba Co. LTD.). The voice information is similar to that of a car navigation system. When the vehicle is heading to the turn, the voice information system announced the distance remaining to the turn. The arrow displays with Japanese voice information are abbreviated to “AJ” in the below descriptions.

(4) Arrow with English Voice Information (AE)

The visual information of the arrow displays with English voice information was the same as that for the arrow with Japanese voice information. The obvious difference with Japanese voice information was that the driver was provided with English voice information made by a TTS (Text-To-Speech: TTS is the creation of auditable speech from computer readable text) program supported by AT&T. The voice information is similar to that of a car navigation system. The content of voice information was the same that of the arrow with Japanese voice information. When the vehicle is heading to the turn, after the tonal signal, distance and direction information for the target intersection was provided vocally in English. The arrow displays with English voice information are abbreviated to “AE” in the below descriptions.

(5) Car Navigation with Japanese Voice Information (CJ)

Figure 4.3 shows examples of the display of the car navigation system with Japanese voice information. A commercial car navigation system (CN-HD9000WD, Panasonic™) was modified for connection with the driving simulator. The visual information provided by the car navigation system consisted of landmarks such as banks, gas stations, etc. A simplified map with a reduced scale was displayed 300 m before the target intersection. After a tonal signal, distance and direction information for the target intersection was provided vocally in Japanese. When the vehicle made a turn, the expansion map was presented on half of the display. The car navigation system with Japanese voice information is abbreviated as "CJ" in the below descriptions.

(6) Car Navigation with English Voice Information (CE)

The contents of visual information of the car navigation system with English voice information was the same as that of the car navigation system with Japanese voice information. The car navigation system was supported in Japanese only, so that the TTS program was also used by translating Japanese to English. After the tonal signal, distance and direction information to the target intersection was provided vocally in English. The car navigation system with English voice information is abbreviated as "CE" in the below descriptions.

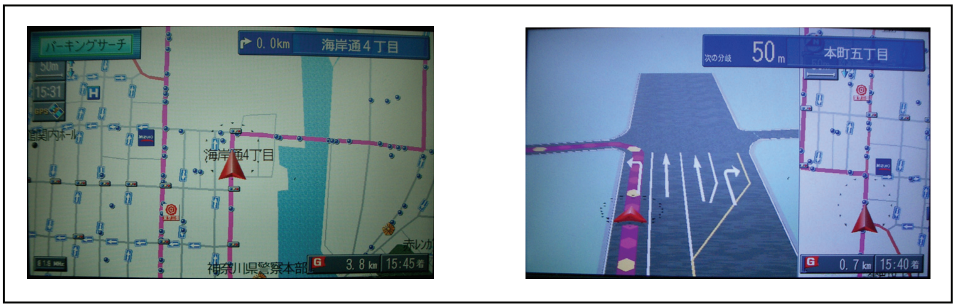


Figure 4. 3 Examples of Car navigation Display

4.2.2. Participants

Participants consisted of two groups; left-lane drivers and right-lane drivers. As the left-lane drivers, eight young Japanese drivers (mean age: 24.1 years) between the age of 20 and 36 took part in this experiment. All of whom held Japanese driving license (mean driving experience: 64.3 months). Their proficiency in English was not high enough to understand the voice information provided by the route guidance systems. As the right-lane drivers, seven young European and American drivers between the ages of 20 and 25 (mean age: 22.6 years): three Americans, three Canadians, and one German. None had the Japanese proficiency to understand the voice information provided by the route guidance systems. The participants of this group had no experience of driving a car in Japan although they had lived in Japan (mean of living period in Japan: 10.3 months) or other countries accepted the left-hand side driving as the traffic rule using a car navigation system. They possessed a driving license in their country (mean driving experience: 48.9 months). The participants drove a car more than once a week, and had normal vision ability. All of the participants were male. Participants signed a consent form before participating in the study.

4.2.3. Apparatus and Devices

In order to measure data on driver behavior and maneuver while driving, a motion-based driving simulator was used as described in *Chapter Ⅱ*. Figure 4.4 shows the interior equipments in the cockpit of driving simulator. Speed information was presented on a 7-inch screen set up in the instrument panel of the car. Route guidance information was presented on 7-inch LCD installed on the top of the center console to the left of the driver.

Figure 4.4 Interior equipments of driving simulator

In order to obtain data on driver visual behavior, the eye movements of each subject was monitored by an eye camera and recorded by a digital video recorder as image data. In addition, driver operations and data related to vehicle motion were collected at 60 Hz by the host PC of the driving simulator. A six-DOF motion system was controlled electrically and generated the driving motion and vibration.

4.2.4. Experimental Conditions and Environments

The experiment was carried out in a laboratory with a temperature of 24 degree centigrade in order to provide the subjects with as comfortable an environment as possible. The driving environment scenes were based on the roads of Minato Mirai 21 District, which is a typical commuting road. Traffic density was kept low. Road conditions were dry at day time, and the screen was generated with a 60Hz refresh rate. The determined route consisted of three types of roads: (a) 2 to 2.5 km long six-lane divided roads with parkways and shoulders, a 50km/h speed limit, one or two right-turns and left-turns, and that took between 3 to 4 minutes to complete (in the case of car navigation system, the roads were 1 to 1.5 km long, had a right-turn and a left-turn, and took between 1 to 2 minutes to complete because some parts of the roads were not connected with the coordinate network of the simulator) (b) 2.5 to 3 km long four-lane divided roads with a 40km/h speed limit, two or three right-turns and left-turns, and took between 4 to 5 minutes to complete (c) 0.5 to 1 km long one-way roads with a 30km/h speed limit, a right-turn and a left-turn, and took between 1 to 2 minutes to complete. During the experiment, the movements of the simulator’s brake pedal, accelerator pedal and steering wheel were recorded; this made it possible to produce a time/speed trace of each maneuver to check for any hesitation, erratic steering, etc. Thus, the drivers’ activities such as steering angle, driving speed, pedal activity were measured. The data of the drivers’ behavior were sent to the host PC of the driving simulator in real time.

4.2.5. Experimental Design

Driving experiment procedure is presented as Figure 4.5. In order to get the participants accustomed to the driving simulator, training was conducted for 15 to 20 minutes-along a pre-determined course. Once they were comfortable driving, they were asked to drive naturally. This exercise was repeated depending on whether or not the participant was getting used to the simulator. If participants exhibited any of the symptoms of simulator sickness during this training stage, they were excused from the rest of the experiment [42]. After training on the simulator, the drivers were fitted with the eye-camera (ISCAN^{TM} 4200/C). And then the drivers were asked to drive in six scenarios that included all the types of route guidance systems used for data collection. The output from the eye-camera was stored on video (WV-DR5, Sony Co. LTD.). The order of the route guidance system was selected randomly. Finally, participants were asked to evaluate the questionnaires at the end of each scenario.

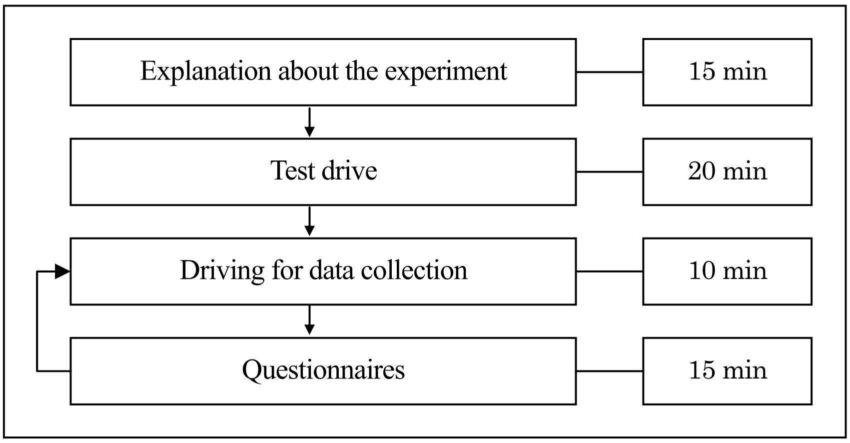


Figure 4. 5 Experimental procedures

4.2.6. Measurement

The following items were measured to analyze and evaluate driver behavior while using route guidance information.

(1) Visual Behavior

Visual behavior was analyzed while the vehicle was moving. Visual behavior in response to the route guidance information was calculated in terms of the average glance duration and average number of glances. In addition, the total glance time to the route guidance information during a 30-second sampling section was calculated. This 30-second period was set during a straight section of the four-lane divided roads.

(2) Driver Behavior

Average speed was calculated during the 30-second sampling section, and a sampling period of right and left turns was recorded by the host PC. The 30-second period was set during a straight section of the four-lane divided roads.

(3) Subjective Evaluation

Mental workload was evaluated during use of the route guidance information based on MNASA-TLX (Modified NASA-TLX) [42]. MNASA-TLX was used to evaluate the driver's mental workload while driving from the viewpoints of mental effort, driving discomfort, time-based stress, difficulty of searching for devices, difficulty of operating devices, and difficulty of perceiving the outside environment. The mental workload was calculated as a WWL score.

4.3. Results

4.3.1. Visual Behavior

The output from the eye-camera consisted of a video-recording of the scene as viewed by each driver, together with a marker on the scene that indicated the location of the current visual fixation. These recordings were the subject of a frame-by-frame analysis to identify the target of the driver's visual attention.

(1) Glance Duration to The Route Guidance Systems

As shown in Figure 4.6, the average glance duration to the route guidance system were inspected in the all driving sections while the vehicle was moving. A three-way ANOVA (two levels of arrow display or car navigation systems, two levels of English voice or Japanese voice, two levels of left-lane driver or right-lane driver) was carried out for the average glance duration. There was no effect due to the types of drivers, however there was a significant effect of information ($F (1, 5) = 17.40$, $p<0.001$) between the left-lane drivers and the right-lane drivers. In addition, there were significant differences in the types of drivers between the six different types of route guidance systems (left-lane drivers: $F (5, 42) = 9.25$,

$p<0.001$, right-lane drivers: F (5, 36) =8.10, $p<0.001$). It was also found that there were differences in average glance duration between the AJ (arrow with Japanese voice prompt) and the CJ (car navigation with Japanese voice information) (left-lane driver: F (1, 14) =40.51, $p<0.001$, right-lane driver: F (1, 12) =25.30, $p<0.001$), as well as between the AE (arrow with English voice prompt) and the CE (car navigation with English voice information) (left-lane drivers: F (1, 14) =69.49, $p<0.001$, right-lane drivers: F (1, 12) =29.12, $p<0.001$). However, the difference in average glance duration between the AJ (arrow with Japanese voice prompt) and the AE (arrow with English voice prompt) (left-lane drivers: F (1, 14) =1.62, $p>0.05$, right-lane drivers: F (1, 12) =0.04, $p>0.05$) was not statistically significant, and neither was that between the CJ (car navigation with Japanese voice information) and the CE (car navigation with English voice information) (left-lane drivers: F (1, 14) =0.009, $p>0.05$, right-lane drivers: F (1, 12) =0.10, $p>0.05$).

The ANOVA showed a significant difference between the English voice and Japanese voice information and it was clarified that average glance duration of the right-lane drivers (non-Japanese drivers) was shorter than that of the left-lane drivers (Japanese drivers). In addition, the glance duration of the right-lane drivers to the paper map was longer than that for the other route guidance information.

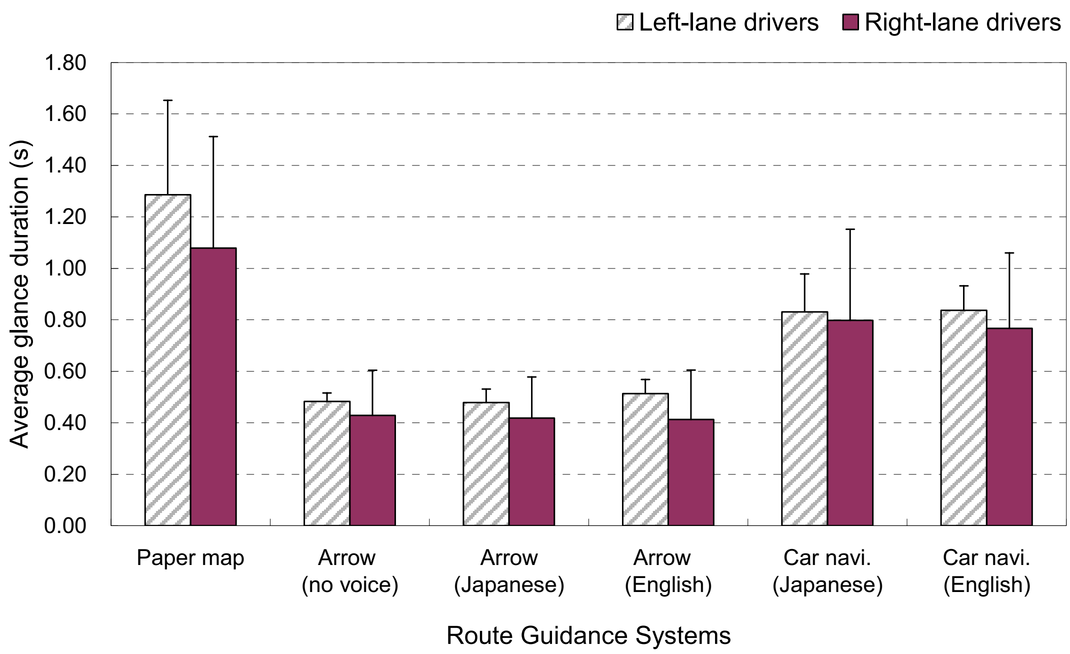


Figure 4. 6 The average glance duration of glance duration to the route guidance information on driving in the all sections

Table 4.1 indicates the average number of glances per minute, and percentage of total glance time to the route guidance information while the vehicle was moving. As drivers mainly checked the paper map after stopping on the road shoulder, it is excluded from the following discussion.

Table 4. 1 The average number of glances per minute and percentage to total driving time on moving of each of the six types of route guidance systems

	Average number of glances / min		Percentage of total glance time to driving time	
	Left-lane drivers	Right-lane drivers	Left-lane drivers	Right-lane drivers
Paper map	1.34	1.98	3.13%	4.33%
Arrow (no voice)	7.55	9.13	5.53%	6.49%
Arrow (Japanese)	6.72	8.48	4.63%	5.98%
Arrow (English)	6.84	6.87	5.31%	4.73%
Car navi. (Japanese)	9.35	11.15	12.91%	15.47%
Car navi. (English)	10.10	9.29	14.27%	12.41%

As indicated in Table 4.1, the left-lane drivers responded the greatest average number of glances and visual attentions when they used the CJ (car navigation with Japanese voice information), while the CE (car navigation with English voice information) had the greatest percentage to total driving time. However, the AJ (arrow with Japanese voice prompt) produced fewer the average number of glances and percentage of total glance time than other route guidance systems.

In terms of right-lance drivers, the AJ (arrow with Japanese voice prompt) produced the greatest average number of glances, and the CJ (car navigation with Japanese voice information) was the greatest percentage of total glance time. It was the AE (arrow with English voice prompt) that the right-lane drivers responded fewer the average number of glances and percentage of total glance time. In the case of the right-lane drivers (non-Japanese drivers) using the car navigation system, the percentage of glance duration to the route guidance information was higher than that for the arrow display. In particular, the percentage of glance duration was much higher than for any other methods when the right-lane drivers used the car navigation system with Japanese voice information (CJ).

This result indicates that the CE (in the case of left-lane drivers) or the CJ (in the case of right-lane drivers) gets the driver's attention off the road.

Figure 4.7 shows the total glance duration to the route guidance information during the 30-second sampling straight road section. The results show a longer total glance duration when drivers were using the car navigation system than the types of arrow information, regardless of the driver group. In addition, the total glance duration of the right-lane drivers was longer when they used the car navigation with Japanese voice information (CJ).

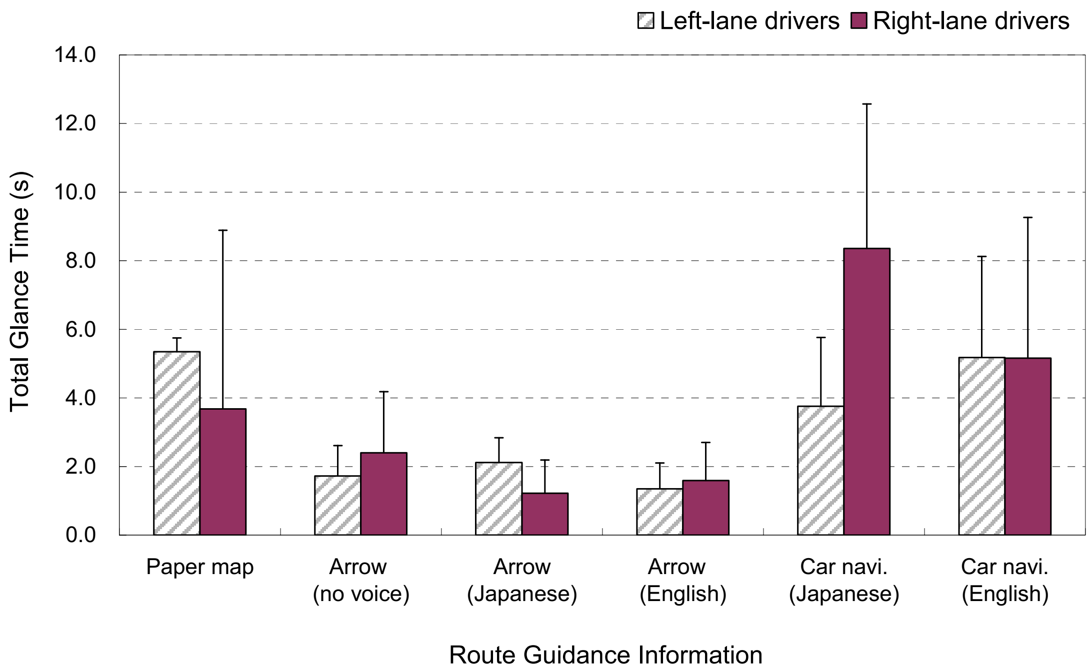


Figure 4. 7 Total glance time to each route guidance information during 30-second sampling section

(2) Visual Attention while Driving

The 30-second straight road sections were analyzed in order to determine the duration of fixating objects in the driver's scene. Figure 4.8 shows that 10 areas of the scene were composed of the middle ahead (MA), middle left (ML), middle right (MR), near ahead (NA), upper ahead (UA), route guidance information (RGI), right side mirror (RM), left side mirror (LM), rearview mirror (RvM) and speedometer (SM). Table 4.2 indicates the average of fixations within each of the 10 areas of the scene that was divided by driver's view during the sampling period of straight road.

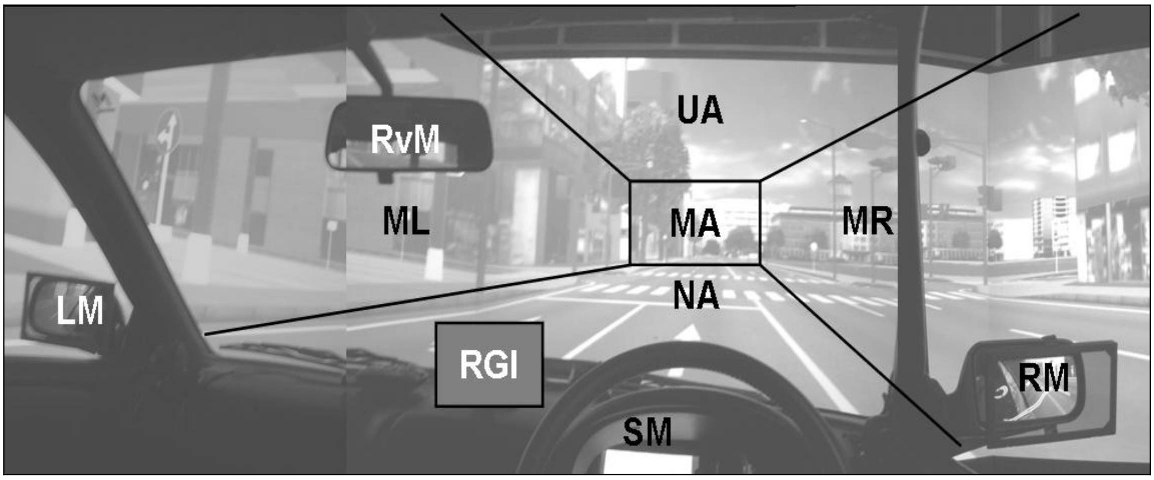


Figure 4. 8 Visual classification of driver's view on straight road

There were three effects of areas due to the types of information between the left-lane drivers and the right-lane drivers; the RGI (F (1, 5) =9.19, p<0.001) and the MR (F (1, 5) =4.82, p<0.001). In addition, there were significant effects of the types of drivers in the case of the MA (F (1, 5) =43.21, p<0.001), the NA (F (1, 5) =13.50, p<0.001), the RM (F (1, 5) =6.74, p<0.05) and the SM (F (1, 5) =5.41, p<0.05).

In the each type of drivers, there was no difference found that was attributable to the six types of route guidance systems for both the left-lane and the right-lane drivers. However, the differences among the 10 parts of the scene were statistically significant (left-lane drivers: F (9, 50) =240.33, p<0.001, right-lane drivers: F (9, 45) =75.36, p<0.001), especially in RGI (route guidance system) (left-lane drivers: F (5, 42) =4.70, p<0.001, right-lane drivers: F (5, 36) =5.83, p<0.001), which had the same result as the average glance duration. In the case of the RGI, both of the drivers attracted fewer fixations in the A (arrow indicator), the AE (arrow with English voice information) and the AJ (arrow with Japanese voice information) compared to the P (paper map), the CJ (car navigation with Japanese voice information) and the CE (car navigation with English voice information), so that the eye fixations were separated to the other scene.

Table 4. 2 The average of fixations in each of the 10 parts of the scene on each of the six types of route guidance systems during 30 seconds of sampling for each driver. [Standard deviations of average are in brackets]

	Left-lane drivers						**Right-lane drivers**					
	P	**A**	**AJ**	**AE**	**CJ**	**CE**	**P**	**A**	**AJ**	**AE**	**CJ**	**CE**
MA	20.01 [3.14]	23.89 [1.38]	20.90 [3.49]	22.13 [2.71]	21.06 [3.08]	19.88 [4.37]	17.38 [3.08]	17.29 [3.58]	16.15 [2.39]	17.22 [4.73]	13.49 [6.01]	16.08 [3.87]
ML	1.41 [0.55]	1.04 [0.89]	0.78 [0.68]	1.52 [1.53]	1.11 [1.06]	0.59 [0.35]	0.76 [0.13]	0.95 [0.86]	1.51 [0.94]	0.93 [0.50]	0.76 [0.51]	0.72 [0.39]
MR	3.37 [2.43]	0.98 [0.93]	1.35 [1.49]	1.53 [0.75]	1.52 [1.07]	1.03 [0.82]	4.47 [2.86]	2.44 [1.95]	1.57 [0.98]	2.72 [2.13]	1.23 [0.99]	0.96 [0.45]
NA	0.00 [0.00]	0.35 [0.00]	1.40 [0.00]	1.05 [0.95]	0.63 [0.48]	0.00 [0.00]	2.13 [1.51]	5.57 [8.18]	2.57 [1.18]	6.22 [6.15]	3.29 [5.28]	4.15 [5.61]
UA	1.47 [1.34]	0.50 [0.16]	0.64 [0.26]	1.80 [0.78]	0.80 [0.33]	0.00 [0.00]	1.12 [0.08]	0.36 [0.14]	2.17 [1.05]	0.80 [0.60]	0.00 [0.00]	0.25 [0.00]
RGI	5.35 [0.40]	1.72 [0.89]	2.12 [0.72]	1.35 [0.75]	3.76 [2.00]	5.18 [2.94]	3.68 [5.21]	2.40 [1.78]	1.22 [0.97]	1.59 [1.11]	8.36 [4.21]	5.16 [4.10]
RM	1.87 [2.07]	0.51 [0.20]	3.14 [0.00]	0.70 [0.28]	0.97 [0.35]	0.65 [0.13]	2.01 [0.67]	1.39 [1.71]	1.67 [1.11]	0.95 [0.59]	2.11 [1.60]	1.42 [0.40]
LM	0.00 [0.00]	0.00 [0.00]	1.47 [0.00]	0.00 [0.00]	0.00 [0.00]	1.26 [0.34]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]	0.00 [0.00]	0.52 [0.57]
RvM	1.32 [0.44]	0.00 [0.00]	3.00 [0.00]	0.57 [0.00]	0.52 [0.00]	1.64 [1.63]	1.24 [0.46]	0.89 [0.78]	3.20 [1.06]	0.96 [0.32]	0.95 [0.18]	1.70 [1.76]
SM	2.34 [2.53]	2.14 [1.22]	3.69 [2.27]	2.58 [1.09]	2.55 [0.56]	3.04 [3.44]	4.09 [2.63]	3.66 [2.79]	4.68 [2.25]	4.01 [2.49]	3.48 [2.54]	2.79 [1.65]

Duncan comparisons as a post-hoc comparison were used to analyze the main effect of inspection parts. The MA had more fixations compared to any of the other parts on both of the left-lane and the right-lane drivers.

For the left-lane drivers in the case of the paper map (P), a group of three parts did not differ from each other: MR, SM and RGI. These three parts had fewer differences of average among each other. A second group of parts did not differ from each other: SM, RGI, ML, RM, UA and RvM. A third group of parts did not differ from each other: RGI, ML, RM, UA, RvM, LM and NA. These seven parts received fewer fixations than other zones.

For the right-lane drivers in the paper map (P), a group of two parts did not differ from each other: SM and MR. These two parts had fewer fixations than MA, and did not differ from each other. A second group of parts did not differ from each other: MR, RGI, NA, and RM. A third group of parts did not differ from each other: RGI, NA, RM, ML, RvM, UA and LM. These seven parts received fewer fixations than other zones. The overall type of differences of fixation on divided parts of the scene is as follows. Grouping parts that are joined by an underline were not significantly different in the fixation. The part attracting the greatest number of fixations is listed on the left.

Left-lane drivers;

MA MR SM RGI ML RM UA RvM LM NA

Right-lane drivers;

MA SM MR RGI NA RM ML RvM UA LM

The different types for using Arrow indicator (A) were as follows:

Left-lane drivers;

MA SM RGI MR ML UA RM NA LM RvM

Right-lane drivers;

MA SM NA RGI MR RM ML RvM UA LM

The different types for using Arrow with Japanese voice information (AJ) were as follows:

Left-lane drivers;

MA SM RGI MR ML UA RM RvM LM NA

Right-lane drivers;

MA SM NA RGI RvM ML MR RM LM UA

The different types for using Arrow with English voice information (AE) were as follows:

Left-lane drivers;

MA SM MR RGI ML UA NA RM RvM LM

Right-lane drivers;

MA SM NA RGI MR RM ML UA RvM LM

The different types for using Car navigation with Japanese voice information (CJ) were as follows:

Left-lane drivers;

MA RGI SM MR ML RM NA UA RvM LM

Right-lane drivers;

MA RGI SM NA RM MR ML RvM LM UA

The different types for using Car navigation with English voice information (CE) were as follows:

Left-lane drivers;

MA RGI SM MR RvM ML LM RM NA UA

Right-lane drivers;

MA RGI NA SM RvM RM MR ML LM UA

4.3.2. Average Speed of Each Section by Using Route Guidance System

Figure 4.9 and Figure 4.10 show that the average speed of the left-lane and the right-lane drivers during the sampling 30-seconds straight road sections, and the sampling period of right and left turns while using the six types of route guidance systems, respectively. The portion of turns at intersection in this study, a vehicle was analyzed from the point when it proceeds into an intersection until the point when it completely leaves the intersection by turning onto another road.

For the right turns in the left-lane drivers and the right-lane drivers according to the different types of route guidance systems, there was statistical significant ($F(1, 5) = 8.98$, $p < 0.001$), while there was no different in straight road and left-turns. In addition, there were significant differences between the six types of route guidance systems in a right-turn at an intersection (left-lane drivers: $F(5, 42) = 5.16$, $p < 0.01$, right-lane drivers: $F(5, 36) = 4.58$, $p < 0.05$). However, there were no differences attributable to different types of systems on straight roads (left-lane drivers: $F(5, 42) = 0.82$, $p > 0.5$, right-lane drivers: $F(5, 36)$

=0.28, *p*>0.05) and a left-turn at an intersection (left-lane drivers: F (5, 42) =0.60, *p*>0.5, right-lane drivers: F (5, 36) =0.81, *p*>0.05). In the average speed on a straight road, the results showed that the A (arrow indicator) was associated with the highest speed followed by the AE (arrow with English voice information) in the case of left-lane drivers, and the CE (car navigation with English voice information) was associated with the highest speed followed by the AJ (arrow with Japanese voice information) in the case of right-lane drivers. However, the right-lane drivers mad errors of route selection several times when using the car navigation system with both Japanese (CJ) and English voice information (CE). In addition, the right-lane drivers made a few operating errors due to the different positions of the turn signal and the windshield wiper switches when using the car navigation system.

In the case of the left-lane drivers, the drivers drove slower with the P (paper map) compared to any other route guidance system on the straight road. On the other hand, the CJ (car navigation with Japanese voice information) and CE (car navigation with English voice information) produced slower speeds compared to other information systems in right and left turns.

In terms of the right-lane drivers, the drivers drove slower with the AE (arrow with English voice information) compared to any other route guidance system on the straight road. It was closer to the speed limit on the straight road section.

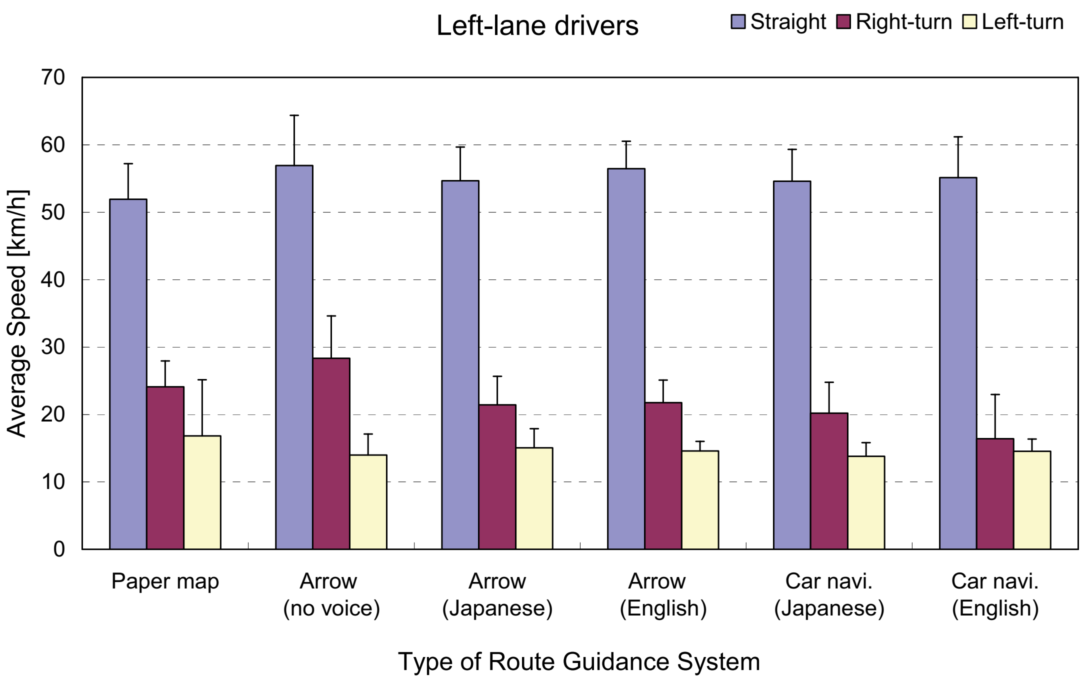


Figure 4. 9 Average speed of left-lane drivers

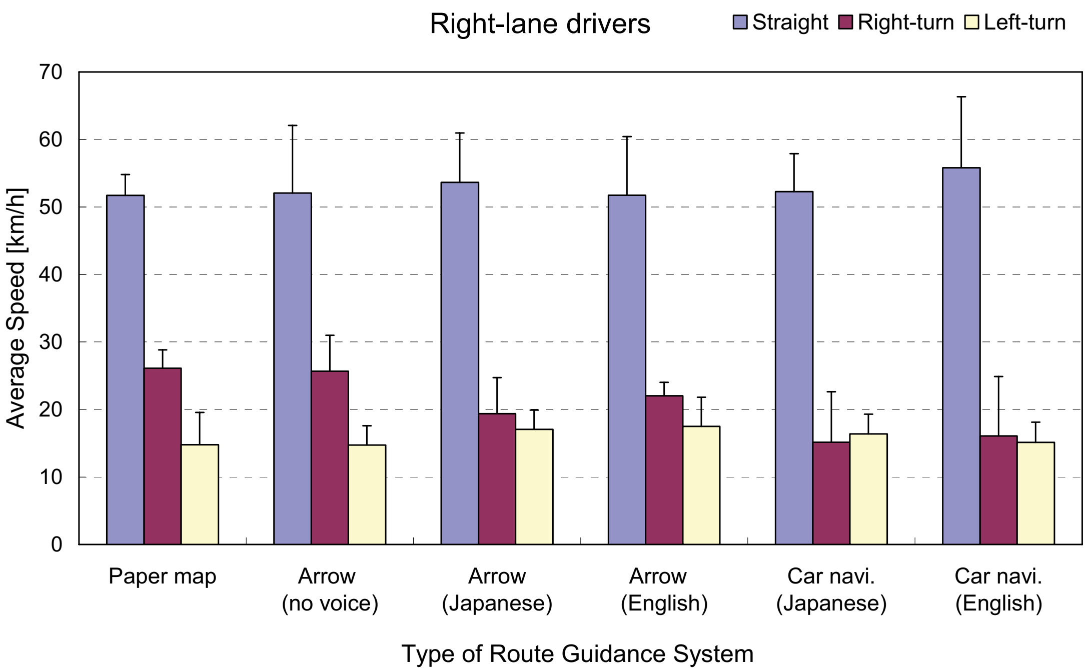


Figure 4. 10 Average speed of the right-lane drivers

4.3.3. Subjective evaluation

Drivers' mental workload was evaluated for each of the six route guidance systems based on the MNASA-TLX (Modified of NASA-TLX). MNASA-TLX was used as the drivers' mental workload evaluation with modifying NASA-TLX (National Aeronautics and Space Administration-Task Load Index) for comparing needs of mental efforts, driving uncomfortableless, timing stress, difficulty of searching for devices, difficulty of operating devices, and difficulty of perceiving the outside environment between left-lane drivers and right-lane drivers [17][38].

Figure 4.11 shows that the weighted workload was obtained for each of the six types of route guidance systems based of the MNASA-TLX procedure. The results for perceived driver workload failed to detect any significant differences between the six types of route guidance systems on either group of drivers, neither was that between the left-lane drivers and the right-lane drivers.

However, in the case of left-lane drivers, the AJ (arrow with Japanese voice information) had the lowest mean workload, and the P (paper map) had the highest mean workload. For the right-lane drivers, the arrow indicator (A) had the lowest mean workload, and the P (paper map) had the highest mean workload, in agreement with the results of the previous study [64]. The AE (arrow with English voice information) had slightly lower workload compared to the CE (car navigation with English voice information). The right-lane drivers had a much lower workload with the English voice information than the Japanese voice information.

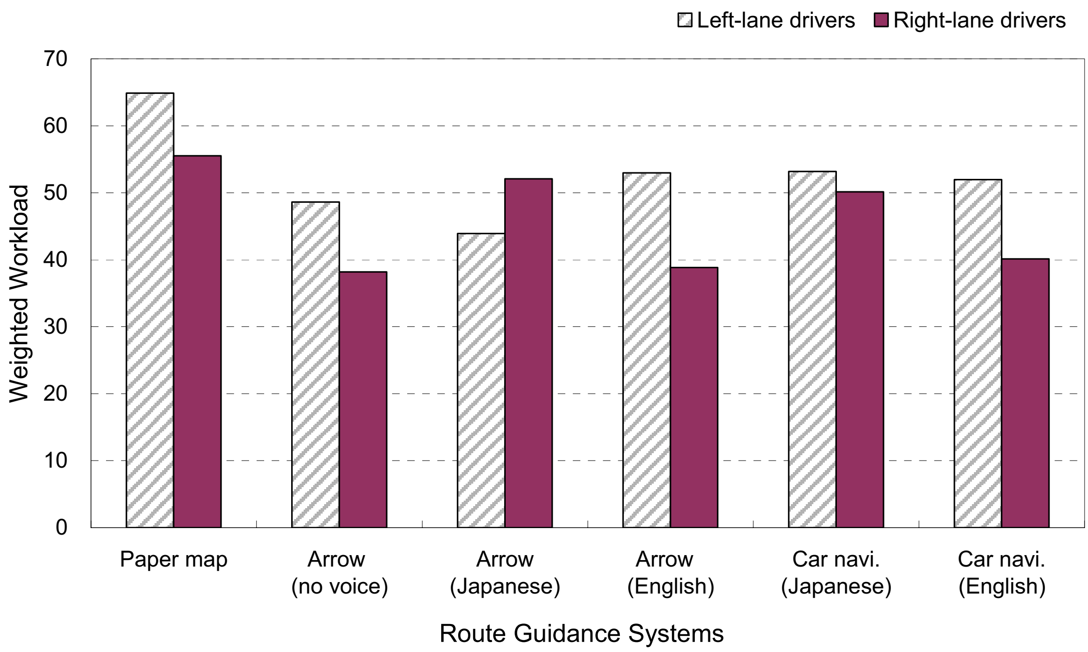


Figure 4. 11 Result of MNASA-TLX of each type of route guidance system

4.4. Discussion

The main objective of this research was to identify what characteristics of route guidance systems affect the attentional demand and efficiency of the driving performance, and which route guidance system lead to better visual attention and driving performance. In addition, this study aims to find what factors and contents of route guidance information system are effective for foreign drivers who were not accustomed to drive on left-hand side of the road.

The results of the average glance duration to the route guidance system showed that the AJ (arrow with Japanese voice information) has not only fewer fixations but also fewer glances when compared with the other systems in the case of the left-lane drivers. In terms of the right-lane drivers, the AE (arrow with English voice information) has not only fewer fixations but also fewer glance duration when compared with the other systems.

The scene available to the driver was divided into the 10 areas of the roadway including the rear-view mirror, two side mirrors and the speedometer. A comparison of the eye fixations made on 10 parts of the scene and on the six types of route guidance systems did not appear to show any statistical differences on both drivers. Drivers' visual attention was attracted to the various parts of the scene depending on the supporting type of route guidance information. In the case of the left-lane drivers, the middle ahead (MA) and route guidance information (RGI) attracted more fixations compared to the other parts of the scene, and the left side mirror (LM) tended to attract fewer fixations compared to other parts of the scene.

In the case of the right-lane drivers, the middle ahead (MA) attracted the greatest fixations and the near ahead (NA) attracted more fixations, followed by the speedometer (SM) or the route guidance information (RGI) compared to the other parts of the scene. This tendency appears to have been caused by effort to adapt the lane of the road from driving on the left-hand side of the road due to driving habit that they were accustomed to driving on right-hand side of the road in their country. In addition, the right-side parts of the driver's view such as the middle right (MR) and the right side mirror (RM) attracted more fixations compared to the left-side parts such as the middle left (ML) and the left side mirror (LM). It showed a clearly different tendency from previous research [74]. It is an interesting result that the predicted eye fixations for the right-side are slightly lower compared with the left-side. In general, drivers usually obtain the information on the left-side of the road that contains more road-related information (i.e., traffic signs). In Japan, the left side does contain more road-related information. However, the results of this research was not support this tendency. The reason are probably that drivers' fixations were attracted to oncoming vehicles on the opposite side of the road or other peripheral objects, and the driving habit that was learnt at an early age affected their driving behavior because the drivers who were accustomed to drive on right-hand side of the road drove on left-hand side of the road. It may be difficult to change.

The result of the eye fixation showed an increase in mirror use and the separation of the middle right (MR) and the middle left (ML) on the AJ (arrow with Japanese voice information) for the left-lane drivers and the AE (arrow with English voice information) for the right-lane drivers compared to other route guidance systems. This is the same tendency as that of the experienced drivers in previous study that was shown [74].

Considering the driving performance by analyzing the average driving speed indicated that drivers perform better in the driving task with the AJ (arrow with Japanese voice information) for the left-lane drivers and the AE (arrow with English voice information) for the right-lane drivers, driving closer to the speed limit than when using the other systems. The A (arrow indicator) as well as the AE (arrow with English voice information) lead the driver to better performance. However, it forces driver to look at the information frequently due to without voice information.

The results of the subjective analysis (MNASA-TLX) for both the two types of drivers indicate that the P (paper map) had the highest workload. It seems that the paper map forced the drivers to imagine the current location because of its complexity and the absence of real-time information on the location of the driver on the road. Compared with the voice information, drivers had obviously lower workload with Japanese voice information compared to English voice information in the case of Japanese drivers, however, the right-lane drivers had lower workload with English voice information compared to Japanese voice information. In the case of right-lane drivers, the AJ (arrow with Japanese voice information) was higher workload and greater number of glances than the arrow alone option (A). At the end of experiment, the participants indicated that the Japanese voice information was sounded like an alarm to pay attention to look at the information. As the similar result, for the left-lane drivers, the AE (arrow with English voice information) had slightly higher workload compared to the A (arrow indicator).

As this result indicated that the Japanese voice information could not play a role as an indicator to the foreign driver was occurred higher workloads and worse performances. Moreover, the results indicate that the right-lane drivers performed better in the driving task with the AE (arrow with English voice information) compared to not only the A (arrow indicator) and the AJ (arrow with Japanese voice information) but also the P (paper map) and two car navigation systems with Japanese (CJ) or English voice information (CE). It shows that drivers' driving behavior was concerned about the visual information better than voice information. This also indicates the present car navigation system gets drivers' eyes off the road, and increases the drivers' workload because there is too much information. These tendencies may result from visual narrowing under high cognitive load.

For the left-lane drivers, drivers performed better in the driving task with the AJ (arrow with Japanese voice information) compared to not only the P (paper map) but also the other two car navigation systems (CJ) (CE). These results were different from those of a previous study [1]; the obviously different experimental factor compared with the previous study was that the driver was provided with landmarks on the arrow information in this research.

4.5. Conclusions

The results of this research included several effects:

(a) The present car navigation system leads to more visual attention and worse driving performance compared with the arrow with voice information system

(b) The arrow with voice information system by reduced the amount of information leads to better driving performance and alleviated mental workload compared to the current car navigation system

(c) The results implied the necessity of a redesign of the current car navigation system to alleviate drivers' workload by reducing the amount of information, because the in-vehicle information is increasing.

(d) Finally, considering that especially subjected to the foreign drivers who were not accustomed to drive on the left-hand side of the road, the present car navigation system by supporting with translating Japanese to English voice information was not appropriate for instructing the foreign driver to an unfamiliar destination.

In-vehicle route guidance systems which the amount of information are reduced or simplified would be as useful for foreign drivers, and received as positively, if they meet a perceived need and are designed effectively. However, due to the tendency of foreign drivers to make longer glances when assimilating information presented visually in a vehicle, auditory information presentation offers alleviating workload.

In this study, the results showed that the foreign drivers had longer average glance duration and higher values of percentage of total glance time to the map-type navigation (car navigation) system than for the arrow-type navigation system. In addition, they tended to see the right-side parts of the road during driving on straight section due to the habit of driving on the right-hand side of the road in their home countries. It is inappropriate driving behavior while driving on the road of Japan because they are more likely to fail to notice road-related information on the left-side of the road. The results also implied that too simple information produces higher values of total glance time, and increases glance frequencies as results from A (simple arrow). Moreover, the arrow-type information system was not able to indicate the driver's current position on the road network, which glance frequencies were increased. However, the amount of visual information provided on map-type navigation system was too much for foreign drivers driving temporarily in Japan. According to these results, the appropriate distribution and combination between arrow-type and map-type information is expect to be helpful in-vehicle route guidance information for foreign drivers. Therefore, the next study should be evaluated these providing methods.

4.6. Summary

The amount of complex information will be associated with high attentional demand to the drivers according to in-vehicle information is increasing. The aim of this study was to investigate the effects of different types of in-vehicle route guidance information on the visual and mental demands of driving. Fifteen drivers who participated in this study consisted of two groups; eight Japanese and seven European and American drivers took part in this study. They were asked to operate a driving simulator while using six different types of route guidance information (a paper map, an arrow indicator, an arrow indicator with either Japanese or English voice informations, and car navigation systems with either Japanese or English voice information). During the course of the experiment, a driver's eye movements were recorded in order to identify differences of the amount of time that related the driver's view points. A range of driver behavior was measured, including average number of glances, eye fixation to road, driving speed and mental workload. Results indicated that drivers responded the most appropriate value with appropriate speed, lower workload and the least average number of glances when using the arrow indicator with voice information. However, the car navigation system currently available in most cars today forced drivers' attention off the road in order to concentrate on the car navigation display due to the plethora of information displayed.

Chapter V

DEVELOPMENT on DEVICES considering HUMAN INTERFACE

5.1. Evaluation to Development of In-Vehicle RGI System considering Human Interface for Foreign Drivers

5.1.1. Introduction

In recent years, with the improvement of GPS (Global Position Systems) and communication technology, various types of automobile interior communication systems are widely used by automobile manufactures in the world. Each communication system can benefit drivers by providing them with relative information immediately (e.g. navigation information). However, it also puts a load on driver behavior at the same time. More recently, new in-vehicle devices have been introduced such as VICS (Vehicle Information and Communication System), collision warning system, etc., more complex entertainment systems and other devices aimed at assisting the driver. While these devices are all useful in one or more important ways, they raise the issue of possible driver distraction and whether the secondary workload can become so high that it begins to affect primary task performance [10]. A number of researches mentioned that these in-vehicle information systems can provide convenience and immediate information on one hand. On the other hand, they are very likely to overwork the load of driver's visual attention [47][79].

Early study in Wierwille et al. (1988), the map-based system was associated with significant visual distraction (on average 33% of journey time was spent glancing towards the in-vehicle display, compared with none for a memorized route and 7% for a paper map) [78]. However, despite these levels of visual demand, drivers preferred the map-based system to traditional methods such as a paper map. Srinvisan (1997) preformed a driving simulator study to evaluate driver performance with three types of system: an in-vehicle electronic map only, a head-up symbol display plus the map, and voice instructions plus the head-up display. The map-based component of the various interfaces was consistently rated favorably by drivers even though this generally had a negative impact on performance [64]. However, the previous researches and guidelines conducted a large range of fields, these could not adapt for the drivers who drive on changed traffic environments. And there had not been reported on the researches of improving the mobility for foreign drivers.

5.1.2. Objectives of Research

Over 8 million foreigners entered Japan in 2006, an increase of 9% from the previous year, and the highest number to date. The residency status of "Temporary Visitor" is for a foreign national whose purpose is sightseeing, recreation, sports, visiting relatives, participation in an observation tour, educational course or meeting, or any other activity that requires the foreign national to stay in Japan for only a short period of time. The permitted length of stay is up to 90 days. A further examination of the number of foreign nationals newly entering Japan with the as a "Temporary Visitor" in 2006 shows that those who came to Japan for sightseeing was 6.7 million, accounting for 80% of the total number of new arrivals [22]. According to the statistics by nationality for new arrivals that came for sightseeing, over than 85 % came from a country where "right-hand side driving" is the norm.

Moreover, there is little mobility which is able foreign tourists to adapt for changed road environments while the government encourages them to attract [39][71]. In addition, much cognitive activity is demanded at the task of navigating in unfamiliar road environments, and elicits the problems that drivers have in planning and searching efficient routes to destinations [59].

This research was conducted based on the results of *Chapter Ⅳ*. The preliminary study was evaluated the driving behavior of foreign drivers based on six types of route guidance information including a paper map, arrow displays with tonal signals and Japanese and English voice information, and car navigation systems with Japanese and English voice information. The results showed that the foreign drivers had larger values for average glance duration and percentage of total glance time to the route guidance information for the map-type navigation system than for the arrow-type navigation system. The amount of visual information provided on map-type navigation system was too much for foreign drivers driving temporarily in Japan. Arrow-type navigation system was considered to be more effective glance behavior. However, some of the limitation of the arrow-type navigation system is also exist. It could not support a driver's current position on the road network, which glance frequencies were increased. Therefore, it is necessary to research on the providing methods considering not only the suitable distribution, but also the compatible combination between arrow-type and map-type information in terms of visual attention.

For this research, four types of route guidance systems were developed by combining arrow-type and map-type route guidance information to supplement faults of each visual information, and evaluated with several focuses on;

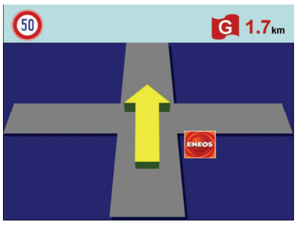
(a) what method is able to alleviate mental workload and reduce driver's visual attention to the in-vehicle route guidance information.
(b) which method of in-vehicle systems is appropriate to improve the driver's safety efficiently.
(c) what the differences among four types of route guidance systems exist in terms of visual attention and driving behavior.
(d) finally, what contents and providing methods of in-vehicle route guidance information are more effective for foreign drivers as well as the future navigation system.

5.2. Methods

5.2.1. Configuration of Route Guidance Information

Developed route guidance information systems consisted of two types of information. Table 5.1 shows example of arrow-type and map-type information.

Table 5. 1 Features of Arrow-type and Map-type route guidance information

	Arrow-type	**Map-type**
Schematic of visual information		
Description of visual information	❒ Simple graphical representation of the junction	❒ Road network with the route to be taken highlighted ❒ Names of district and current road
Components	❒ Path / Node / Landmark	❒ Path / Node / Landmark / District / Edge
Language Support	❒ Arabic numeral	❒ Characters ❒ Arabic numeral
Characteristics	Explicit directions	Overall view
	Easy to understand at a glance	Plan for upcoming maneuvers

Arrow-type navigation system:

The information on the arrow-type navigation systems was composed of directional arrows, landmarks, the distance to the turn, the remaining distance to destination and speed limit as a traffic regulation, so that the driver is able to reach the destination safely, with no confusion. The TTS (Text-To-Speech: TTS is the creation of auditable speech from computer readable text) program supported by AT&T was used by translating Japanese to English, and by LaLa Voice program (Toshiba Co. LTD.) in the case of Japanese voice information. The produced voice was almost like a human voice. When the vehicle is heading to the turn, the voice information system announced the remaining distance to the turn. A new screen of visual information was presented at 100m and 300m before turning, synchronously.

Map-type navigation system:

A car navigation system (CN-HD9000WD, Panasonic ™) was used to provide route guidance information with Japanese and English voice information for Japanese drivers and European and American drivers each other.

5.2.2. Four Types of In-Vehicle Route Guidance Information Systems

In relation to the concept of route guidance by in-vehicle navigation systems, while route guidance information based on conventional route maps is provided to drivers in Japan, route guidance information based on direction arrows and remaining distance is sequentially provided in the US, which is called the turn-by-turn concept [13]. Such a difference in the route guidance concepts is considered to be characterized by differences in environmental and cultural factors between the two countries. In this study, four types of in-vehicle route guidance information systems were developed by combining two navigation concepts. They were evaluated on the comparison of each driver's favorite information type and efficiencies of those systems.

(1) Established Information by setting up

Change Arrow-type information to Map-type information (AM):

Main information is the arrow-type route guidance information, which changes to map-type route guidance information for a while if a driver pushes a switch installed on the windshield wiper controller. It will be changed back automatically. The driver can control the switch, whenever he wants, with their finger without moving their hand.

Change Map-type information to Arrow-type information (MA):

Main information is the map-type route guidance information, and it is changed to arrow-type route guidance information for a while if a driver pushes the switch. It will then change back automatically. The driver also can control the switch with their finger without moving their hand.

(2) Information selected by Driver's Intention

Selectable Map-type information or Arrow-type information (SI):

A driver can select one of information types between arrow-type and map-type route guidance information. If a driver pushes the switch, the information is changed from the arrow-type route guidance information to the map-type information or vice versa. This system is only changed manually according to the driver's selection.

Separated Display of proving Route Guidance Information (SD):

Two types of route guidance information are separated and supported on two display units, arrow-type navigation and map-type navigation. The map-type navigation is installed on the top of the center console to the left of the driver, and the arrow-type navigation is installed on the dashboard beside the speedometer.

As shown in Figure 5.1, the types of information are controllable with a driver's finger of left-hand by pushing the switch posited on left-hand side of the steering wheel. Figure 5.2 shows the position of route guidance information while using SD (Separated Display of proving route guidance information).

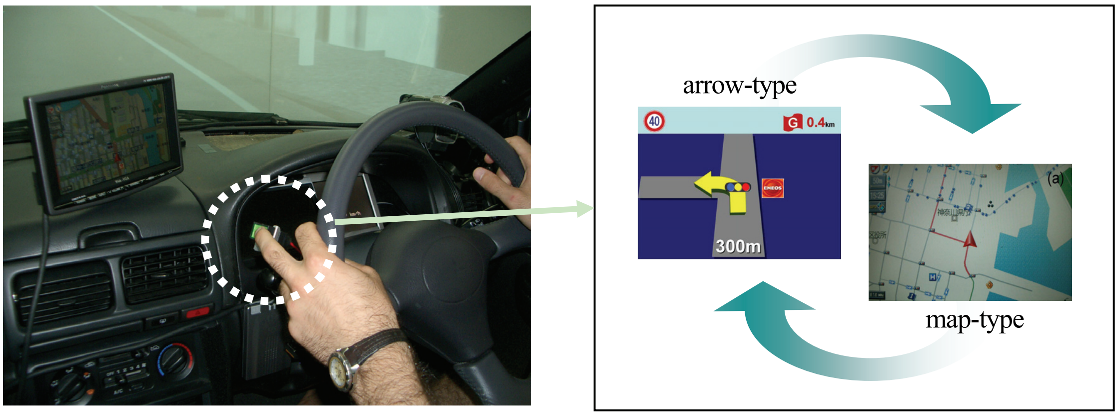


Figure 5. 1 Providing and controlling method of route guidance information

Figure 5. 2 Position of route guidance information of SD providing method (map-type information on the top of the center console, arrow-type information at the place of the dashboard)

5.2.3. Participants

Participants were divided into two groups; left-lane drivers and right-lane drivers. As the left-lane drivers, twelve young Japanese drivers aged between 21 and 35 (mean age: 24.1 years, SD: 4.3) took part in this experiment. They were currently licensed driver (mean driving experience: 69.8 months). Their proficiency in English was not enough to understand the voice information provided by the route guidance systems. As the right-lane drivers, twelve young European and American drivers between the ages of 21 and 32 (mean age: 24.8 years, SD: 3.5). None had the Japanese proficiency to understand the voice information provided by the route guidance systems, and had experienced left-hand side driving on the road although their average length of stay in Japan was almost 1 year (mean of living period in Japan: 11.3 months). The right-lane drivers possessed a driving license in their country (mean driving experience: 77.2 months). All participants had driven a car more than once a week before coming to Japan, and had normal or corrected vision ability. All of the participants were male. Participants signed a consent form before participating in the study.

5.2.4. Apparatus and Experimental Conditions

In order to achieve a more realistic situation and obtain data about each driver's behavior and maneuvers while driving, a motion-based driving simulator was used as described in *Chapter II*. The route guidance information was presented on 7-inch LCD (Liquid Crystal Display) installed on the top of the center console to the left of the driver [27][79].

The experiment was carried out in a laboratory with a temperature of 24 degree centigrade in order to provide the subjects with as comfortable an environment as possible. The driving environment scenes were based on the roads of Minato Mirai 21 District, which is a typical commuting road. Traffic density was kept low. Road conditions were dry at day time, and the screen was generated with a 60Hz refresh rate. The determined route consisted of three types of roads: (a) 1 to 1.5 km long six-lane divided roads with parkways and shoulders, a 50km/h speed limit, had a right-turn and a left-turn, and that took between 1 to 2 minutes to complete (b) 2.5 to 3 km long four-lane divided roads with a 40km/h speed limit, two or three right-turns and left-turns, and took between 3 to 3.5 minutes to complete (c) 0.5 to 1 km long one-way roads with a 30km/h speed limit, a right-turn and a left-turn, and took between 1 to 2 minutes to complete.

5.2.5. Procedure

For the first step, participants received operating instructions for operating the driving simulator and reviewed the route guidance systems. They were asked that their primary task was to arrive at the pre-determined destination, keep the speed limit, maintain a safe following distance and keep the vehicle in the lane. Figure 5.3 presents the driving experimental procedure.

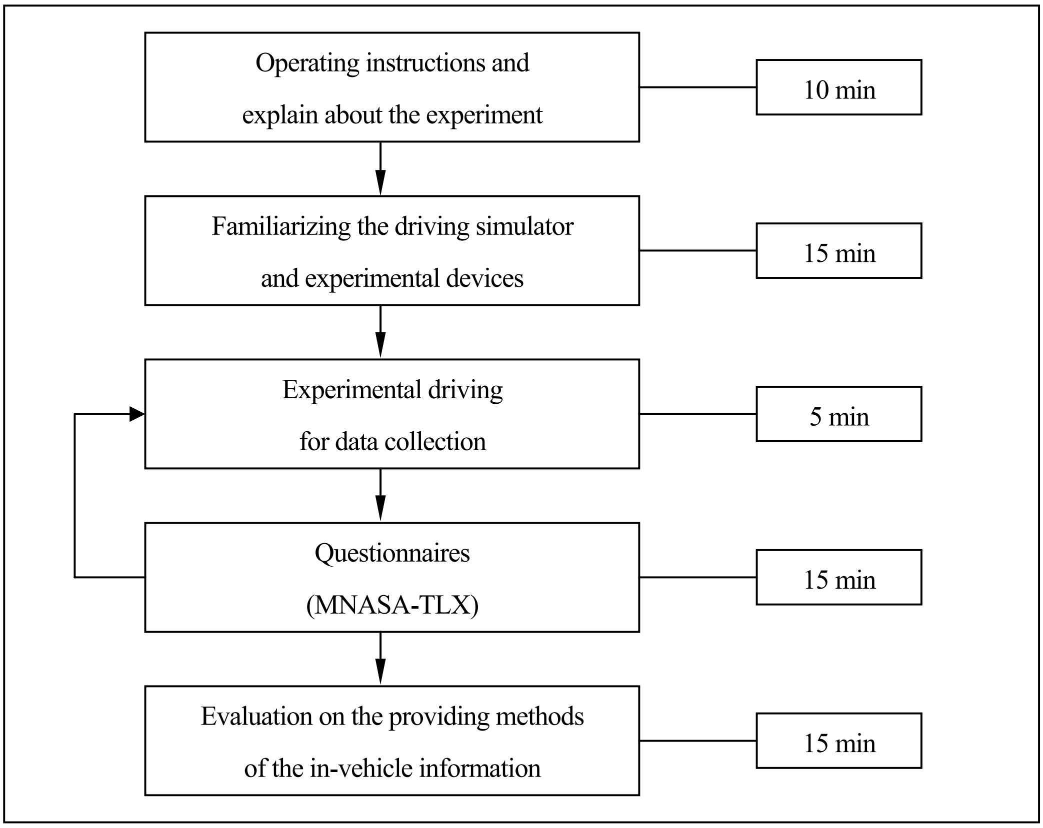


Figure 5. 3 Experimental procedures

In order to get the participants accustomed to the driving simulator, training was conducted approximately 15 minutes along a pre-determined course. This exercise was repeated depending on whether or not the participant was getting used to the driving simulator and the route guidance systems. If participants exhibited any of the symptoms of simulator sickness during this training stage, they were excused from the rest of the experiment, which rarely occurred. Most of them became generally familiar with the experimental instruments. Once they were comfortable driving, they were asked to drive naturally. After familiarizing on the simulator, the drivers were fitted with an eye-camera (ISCAN^{TM} 4200/C). And then, the drivers were asked to drive in different four scenarios. Each scenario was supported by different types of route guidance systems. The output from the eye-camera was stored on video set (WV-DR5, Sony Co. LTD.). In order to eliminate any possibility of ordering effects, the order of the route guidance system was selected randomly. After completing each experiment, the driver stopped the vehicle and filled out subjective questionnaires. At the end of experiments, participants were asked to personal impression relating to merits and demerits of the four types of route guidance systems.

5.3. Results

The data from the eye-camera were analyzed to identify the glance behavior to the in-vehicle route guidance information.

The following definitions are used to analyze the glance behavior modified with SAE Recommended Practice [61]:

- Fixation time (FT); the duration of a fixation at navigation display. It does not include the transition time to or from road scene.
- Total fixation time (TFT); the sum of the individual fixation times on navigation display.
- Journey time (JT); the time that the vehicle is on moving, excluding stopping time.
- Percentage of total fixation time to journey time (PTJ); the percentage value of the sum of the individual fixation times to overall journey time.
- Glance frequency (GF); the sum of the number of times that driver's eye is focused on navigation display.

5.3.1. Glance Behavior

The visual attention to the navigation display was evaluated in the all driving sections while the vehicle was in motion. The data of glance behavior consisted primarily of the individual fixation time on the navigation display within the driver's field of view.

Table 5.2 summarizes the average values for glance behavior, journey time, and percentage of total fixation time to journey time for each driver while the vehicle was in motion. The first column of values, below each driver group, shows the average fixation to navigation display (FT). The next column is the average total fixation time which integrates each fixation time (TFT). This time is excluded the stoppage time because drivers tend to see the navigation display for a long time when vehicle was stopped standing by traffic sign. The third column indicates the average journey time from the start point to the destination (JT). This time is also excluded the stoppage time because of a case which the vehicle did not stop to wait on the traffic signal at an intersection according to driving speed. The last column is the percentage of the total fixation time to the journey time on driving in the all sections (PTJ).

Table 5. 2 Average value for glance behavior, journey time, and percentage of total fixation time to journey time [standard deviations are in brackets]

Devices	Right-lane driver				Left-lane driver			
	FT (s)	TFT (s)	JT (s)	PTJ (%)	FT (s)	TFT (s)	JT (s)	PTJ (%)
Change Arrow to Map	0.66 [0.33]	29.1 [11.6]	245.2 [29.4]	12.1	0.69	34.8 [11.9]	262.6 [40.5]	13.4
Change Map to Arrow	0.78 [0.31]	35.9 [14.5]	258.0 [28.2]	14.2	0.80	34.4 [10.6]	263.6 [37.7]	13.3
Selectable Information	0.75 [0.34]	34.00 [14.7]	247.3 [19.9]	13.7	0.79	37.7 [9.8]	273.1 [37.9]	13.9
Separated Display	0.75 [0.36]	35.2 [14.0]	257.4 [26.8]	14.0	0.82	37.8 [10.6]	257.9 [32.8]	14.6

The average fixation time was significant difference in the types of drivers between the four different types of route guidance systems (right-lane drivers: $F(3, 44) = 2.95$, left-lane drivers: $F(3, 44) = 2.91$, all $p<0.05$). However, there was not found any difference between driver groups.

The average journey time over all drivers was about 258.1s and had a high standard deviation. This was due to the interlocking signal; once a vehicle was stopped at the intersection, the vehicle should be waited for the signal at the next intersection, which was depend on each scenario. However, the journey time was not significantly different within the four types of devices. In the case of analysis of glance behavior, therefore, the percentage of the total fixation time to the journey time is more important value than that of the journey time. The AM (Change Arrow-type information to Map-type information) had the lowest value, followed by the SI (Selectable Map-type information or Arrow-type information).

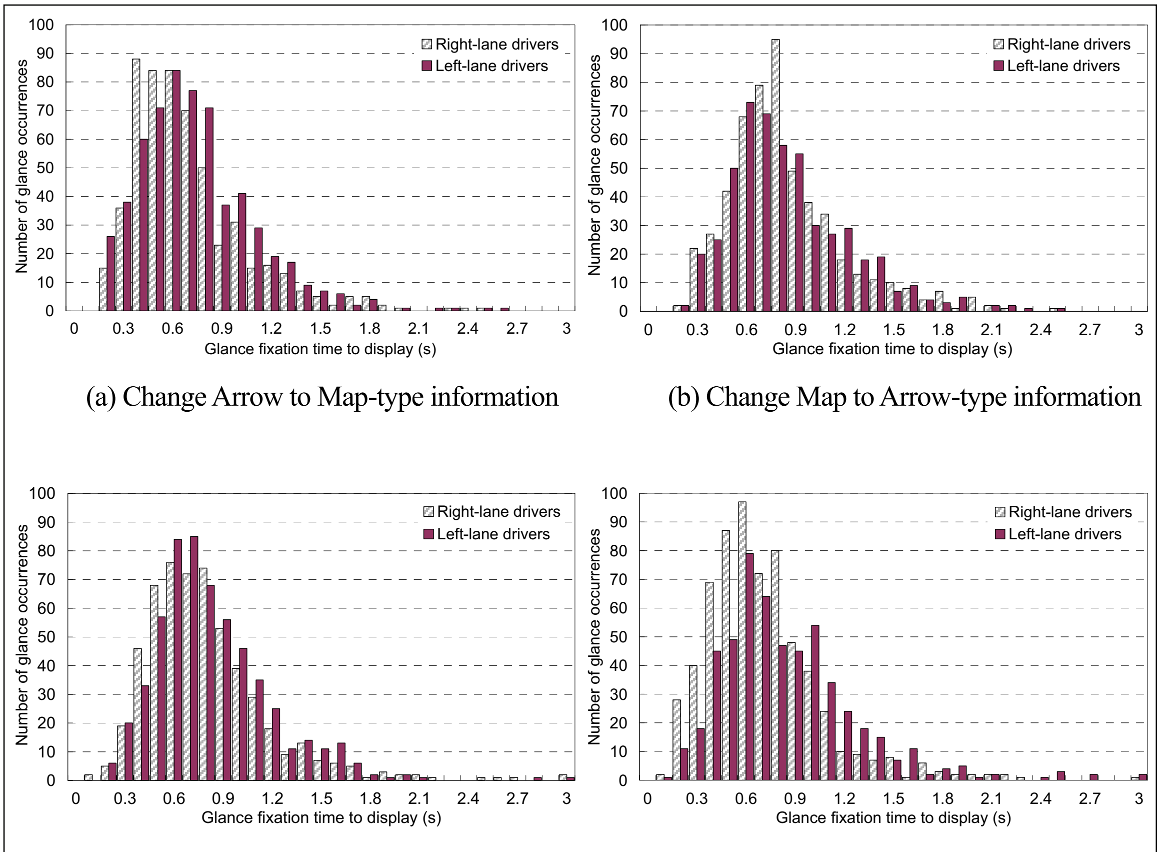
In the results of the total fixation time of the right-lane driver, MA (Change Map-type information to Arrow-type information) produced the greatest the average value, and the percentage of the total fixation time to the journey time, while AM (Change Arrow-type information to Map-type information) produced the least in terms of the same values; average fixation time is 0.66s, and individual averages ranged from 0.48s to 0.99s . However, in the case of the left-lane drivers, MA (Change Map-type information to Arrow-type information) produced the least values. These results suggest that MA (Change Map-type information to Arrow-type information) supported mainly map-type navigation is not appropriate for the foreign drivers who could not be accustomed to driving on the left-hand side of the road, and is associated with the most visual distraction towards the in-vehicle display.

Figure 5.4 shows distributions of the fixation time to the display in those cases for the four types of devices of each group. Table 5.3 shows percentile value of glance frequency of two types of drivers while using four types of navigation displays. While average values for glance behavior are shown in Table 5.2, higher percentile values have been suggested for use in possible design guidelines or as behavior criteria. Those corresponding 80 to 90 percentile values for these data are also shown in Table 5.3.

The average display fixation time of AM (Change Arrow-type information to Map-type information) had a tendency to concentrate on lower fixation time from 0.4s to 0.7s in comparison with other devices, and values of 80 percentile are lower than 1 second (average of right-lane drivers: 0.66s, and average of the left-lane drivers: 0.69s). However, MA (Change Map-type information to Arrow-type information) and SD (Separated Display of proving route guidance information) had the greatest values in the four navigation displays. In the case of the right-lane drivers, the noticeable difference was the distribution for MA (Change Map-type information to Arrow-type information), and this was due to whether driver could read the character presented on navigation display.

The frequency of SI (Selectable Map-type information or Arrow-type information) which driver could select information was distributed evenly until 1.5 seconds. It means that drivers saw the display at an opportune moment if they needed information. Moreover, in the case of MA (Change Map-type information to Arrow-type information), the right-lane drivers paid attention to the display during 0.8s.

When drivers used the SD (Separated Display of proving route guidance information) navigation display, there are values over 2 seconds, occasionally. To see the navigation display over 2 seconds while driving, reported well, it is very dangerous time and likely to become a traffic accident.



(a) Change Arrow to Map-type information

(b) Change Map to Arrow-type information

(c) Selectable Information

(d) Separated Display

Figure 5. 4 Glance frequency to navigation display of two types of drivers

Table 5. 3 Percentile value of glance frequency (s)

	Right-lane driver		Left-lane driver	
Systems	80th	90th	80th	90th
Change Arrow to Map	0.88	1.13	0.95	1.15
Change Map to Arrow	1.03	1.29	1.1	1.32
Selectable Information	0.98	1.20	1.03	1.24
Separated Display	1.00	1.31	1.05	1.31

Figure 5.5 shows that total fixation time of each information type to the four types of systems, and explains the total fixation time (TFT) in the Table 5.2 in more detail. Each bar in Figure 5.6 shows the average total number of glance frequency (GF) to the navigation display including the average number of arrow-type and map-type navigation of each driver group while the vehicle was in motion. As shown in Figure 5.6, both of two driver groups responded the greatest number of glances frequency when they used the SD (Separated Display of proving route guidance information). In addition, the SD had the greatest value of the percentage of total fixation time to journey time; as indicated in table 5.2. Moreover, Figure 5.6 shows that the right-lane drivers had lower glance frequency in comparison with the left-lane drivers except MA (Change Map-type information to Arrow-type information). In the case of the right-lane drivers, MA (Change Map-type information to Arrow-type information) produced the greatest values of average fixation time, total fixation time, and journey time. However, in the case of the left-lane drivers, MA (Change Map-type information to Arrow-type information) produced almost same value with AM (Change Arrow-type information to Map-type information) in total fixation time and journey time.

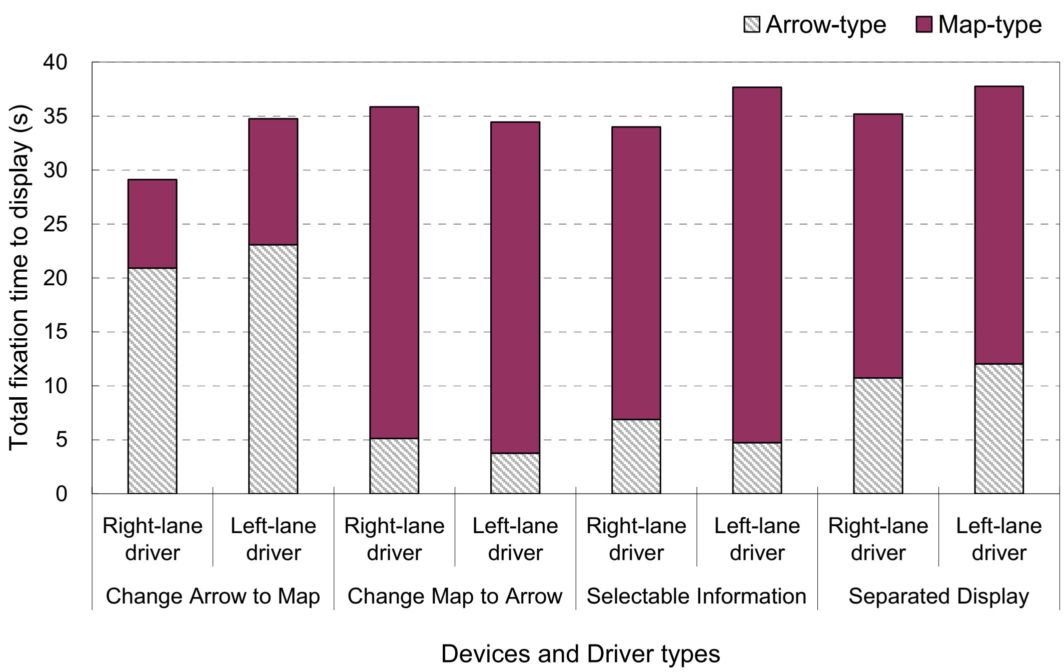


Figure 5. 5 Total fixation time to display while using each device of two types of drivers

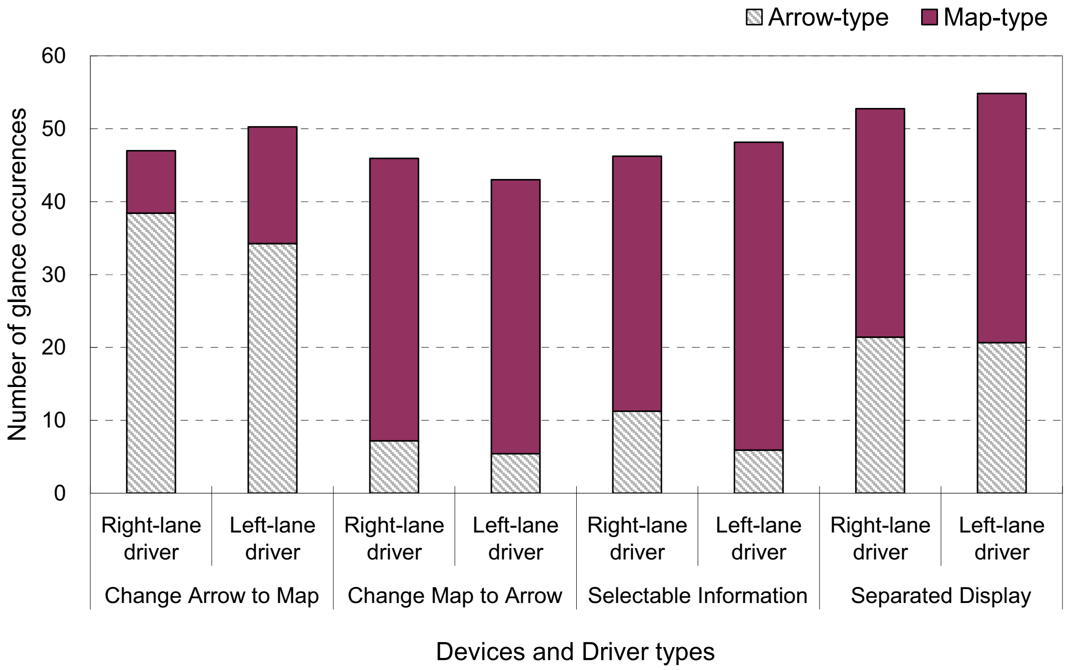


Figure 5. 6 Total number of glance frequency while using each device of two types of drivers

Comparing with the map-type information in the MA (Change Map-type information to Arrow-type information) between Figure 5.5 and Figure 5.6 in the case of the right-lane drivers, there are considerably differences. The total fixation time of the MA (Change Map-type information to Arrow-type information) was the most value in Figure 5.5 but the number of glance occurrences was the least value in Figure 5.6. The MA (Change Map-type information to Arrow-type information) attracted lower glance occurrences than the others, whereas the fixation time was the longest. In the case of the proportion between Figure 5.5 and Figure 5.6, the arrow-type information of the number of glance occurrences had much value than that of the fixation time, in the all of systems.

In comparison with SI (Selectable Map-type information or Arrow-type information) between two types of driving groups in Figure 5.5 and Figure 5.6, the right-lane drivers selected the arrow-type navigation in 23.3% of total fixation frequency, and the left-lane drivers were 12.3 %. Moreover, the right-lane driver spent much time on giving glances to the arrow navigation comparing with the left-lane drivers in terms of overall values of the fixation frequency. In those cases of SI (Selectable Map-type information or Arrow-type information) and SD (Separated Display of proving route guidance information), there were significant differences in each devices (p<0.001).

For the SI (Selectable Map-type information or Arrow-type information), which drivers could select the information type, the map-type information attracted more visual attention than that of the arrow-type information. The map-type information provided much larger information than the arrow-type information. Of course, this means it takes longer period for a driver to understand the information at a glance. As the same tendency in the SD (Separated Display of proving route guidance information) in Figure 5.6, the number of glance occurrences to the map-type information was much percentage to the arrow-type information (69.5% in Figure 5.5, and 59.4% in Figure 5.6). Drivers spent much time on giving glances to the map-type information comparing with the arrow-type in the all values of glance behavior except the AM (Change Arrow-type information to Map-type information) (all, $p<0.001$).

5.3.2. Driving Performance

Navigation errors were inspected for each driver over all driving courses in relation to four navigation systems. Drivers did not have any errors from using the AM (Change Arrow-type information to Map-type information) and the SI (Selectable Map-type information or Arrow-type information). However, a driver committed an error to locate turn while using the MA (Change Map-type information to Arrow-type information) owing to his misunderstanding the route guidance information. Three drivers disregarded a traffic signal when they used the SD (Separated Display of proving route guidance information). They could not recognize the changed signal because visual attention was distracted by two displays. The SD (Separated Display of proving route guidance information) system supported two types of information, the arrow-type navigation installed on the dashboard and the map-type navigation installed on the top of the center console, so that drivers had a tendency to reconfirm the route selection by glancing two types of information alternately.

5.3.3. Driver Workload

MNASA-TLX (Modified of National Aeronautics and Space Administration-Task Load Index) was used for comparing 6 items of mental workload among the four types of systems: needs of mental efforts (NM), driving uncomfortableness (DU), timing stress (TS), difficulty of searching for devices (DS), difficulty of operating devices (DO), and difficulty of perceiving the outside environment (DP) [52].

Weighted workload (WWL) of each item was obtained for each of the four navigation devices based on the MASA-TLX procedure as shown in Figure 5.7 and Figure 5.8. The results for perceived total WWL failed to detect any significant differences between the four types of navigation devices in two driver groups, neither was there any between the left-lane drivers and the right-lane drivers.

However, in the case of the right-lane drivers, they had increased workloads on the difficulty of perceiving the outside environment (DP) from driving on different traffic environments, and the timing stress (TS) relating to the mental press of information cognition more than the operation of devices (DO). Overall workload, when they used SD (Separated Display of proving route guidance information) for navigation display, they had the lowest mean workload (value: 20.8), and had the highest mean workload for using AM (Change Arrow-type information to Map-type information, value: 30.2), followed by MA (Change Map-type information to Arrow-type information, value: 27.1).

For the left-lane drivers, they also had increased workload on the difficulty of perceiving the outside environment (DP) more than the operation of devices (DO). However, they stressed on mental effort and driving uncomfortableness result probably from driving simulator or driving experience lower than the

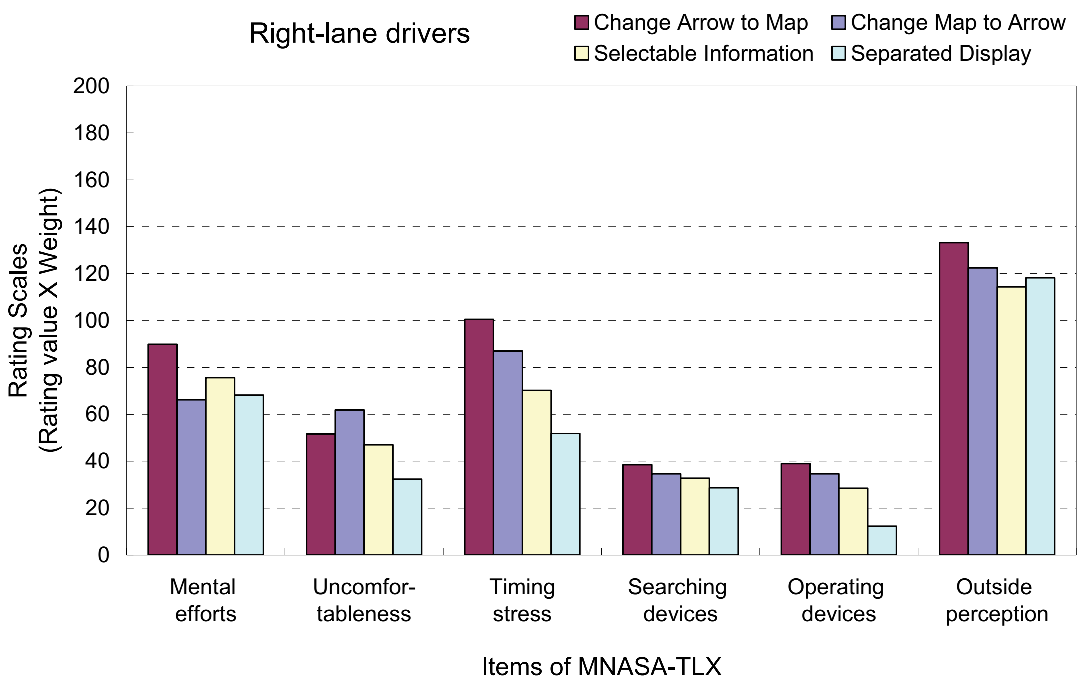


Figure 5. 7 Result of MNASA-TLX items of Right-lane drivers

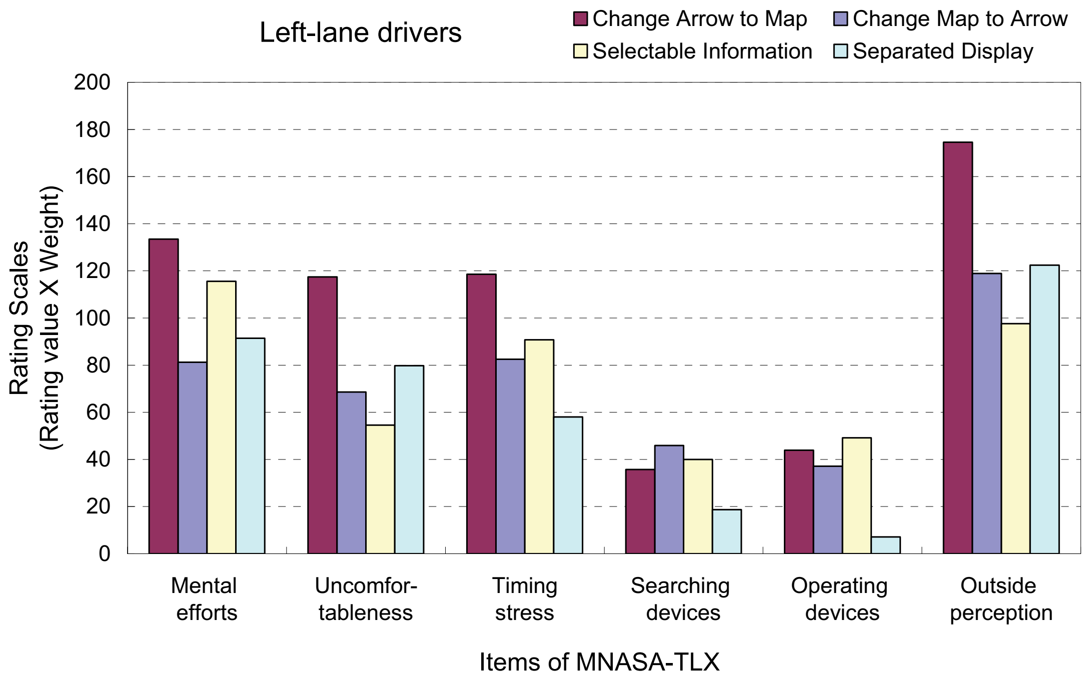


Figure 5. 8 Result of MNASA-TLX items of Left-lane drivers

right-lane drivers. They had the highest workload when they used AM (Change Arrow-type information to Map-type information, value: 41.0). This is remarkably different comparing to that of right-lane drivers. The SD (Separated Display of proving route guidance information) produced the least workload (value: 25.3), followed by MA (Change Map-type information to Arrow-type information, value: 28.96). The SI (Selectable Map-type information or Arrow-type information) had slightly higher workload compared to MA (Change Map-type information to Arrow-type information, value: 29.9).

5.3.4. Subjective Evaluation

Figure 5.9 shows that drivers' evaluation on the four types of navigation systems in relation to their usability. There was significant difference between the four different types of route guidance systems (F (3, 44) =6.75, p<0.01).

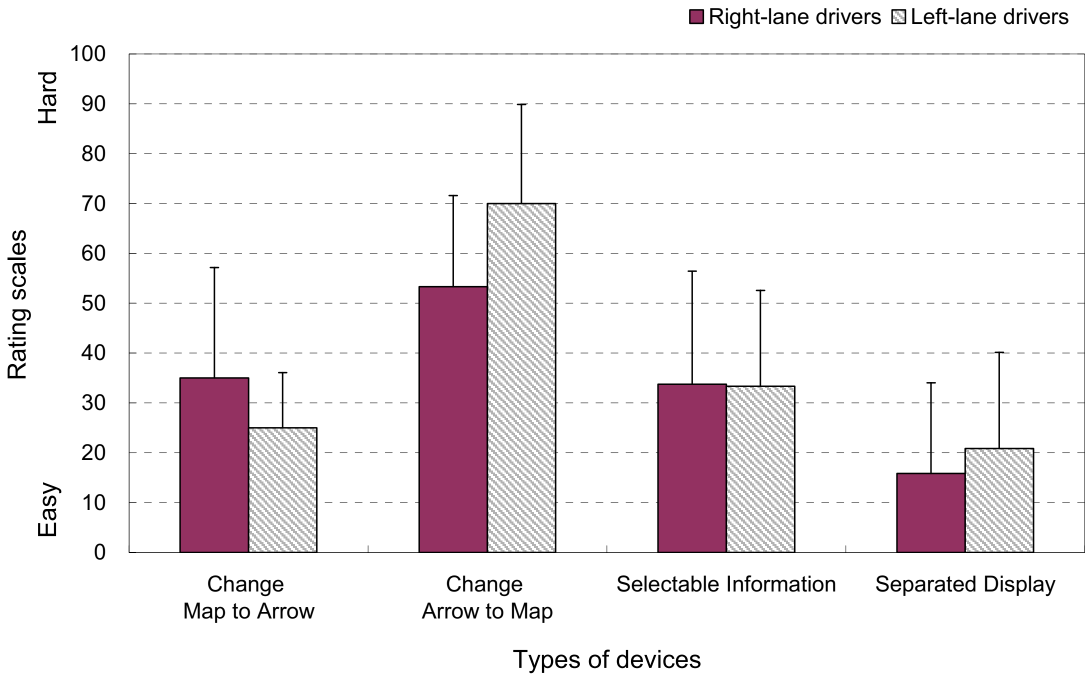


Figure 5. 9 Subjective evaluation on each navigation devices

As shown in Figure 5.9, drivers felt that the SD (Separated Display of proving route guidance information) was the easiest system to use than the others. In this study, the questionnaire revealed a wide range of more positive opinions toward the SD (Separated Display of proving route guidance information) than other systems. There were several reasons for preferring the SD (Separated Display of proving route guidance information) to other systems, e.g., the AM (Change Arrow-type information to Map-type information) provided simple design of the road network (only main streets were presented) made drivers difficult to cognitive or perceive them effectively. Drivers were difficult to interpret on the approach to maneuver where two close turns, and too little changeable information to give the driver a clear impression of relative distance changes. Besides, the SD (Separated Display of proving route guidance information) provided simultaneously two types of route guidance information without controlling the switch.

Overall evaluation on four navigation systems based on participants' comments is presented in Table 5.4.

Table 5. 4 Summarization of evaluating on the each systems based on participates' comments

Established information by Setting up	**AM** (Change Arrow-type information to Map-type information)	
	Merit	▪ able to notice quickly when driver has to turn if there were a lot of turns for a long route. ▪ Very precise, hard to make mistakes
	Demerit	▪ confusing turns if there are two streets very closer together ▪ hard to recognize the current position on the road network
	MA (Change Map-type information to Arrow-type information)	
	Merit	▪ able to get an overall view of the route ▪ easy to stand by for the next turn
	Demerit	▪ not precise, hard to know where to turn
Information selected by Driver's Intention	**SI** (Selectable Map-type information or Arrow-type information)	
	Merit	▪ able to see the information which he wants
	Demerit	▪ make efforts on pushing the switch to return to information
	SD (Separated Display of proving route guidance information)	
	Merit	▪ allow driver to receive two different information at the same time ▪ all necessary information is continuously available
	Demerit	▪ take too much attention to watch both display ▪ needs space in the cockpit

5.4. Discussion

Overall results of the glance behavior to the route guidance information showed that the AM (Change Arrow-type information to Map-type information) was mainly supported by arrow-type information produced the least visual demand, and the MA (Change Map-type information to Arrow-type information) was the greatest visual demand in the case of both driver groups. A significant difference between the right-lane drivers and the left-lane drivers was the increased glance fixation time and frequency for the arrow-type navigation of the right-lane drivers, being approximately 10% higher than those of the left-lane drivers as shown in Figure 5.5 and Figure 5.6. This tendency probably is right-lane driver preferred symbol-based information to amount of information provided with complex road network and illegible characters.

Although it is natural that less information the display includes, shorter period a driver to understand, the AM (Change Arrow-type information to Map-type information) was effective among the four types of route guidance information in terms of eye movements considering driver safety. However, the results of the subjective evaluation indicated that drivers preferred the systems which were mainly supported by map-type information to the AM (Change Arrow-type information to Map-type information), despite the AM had merits relating to the glance behavior. In addition, the results revealed that the arrow-type information attracted least fixation time. On the other hand, the arrow-type information produced the glance frequency to the navigation display comparing with the map-type information.

The map-type information provides drivers with much more information, e.g., the lane information on the road that should be useful for drivers. For the SI (Selectable Map-type information or Arrow-type information), drivers spent a lot of time on glancing to the map-type information rather than the arrow-type information. This tendency may have a notion that drivers preferred map-type information to simple arrow-type information on the hand. On the other hand, it means that foreign drivers could not understand map-type information at a glance. Although the map-type information had more information than the arrow-type information, overall results suggest that the system such a current navigation system was not appropriate for foreign drivers who could not understand Japanese.

The results of the MNASA-TLX and the subjective evaluation indicate that the AM (Change Arrow-type information to Map-type information) had the highest workload, and the SD (Separated Display of proving route guidance information) attracted more preference than the others. As a reason, when drivers used the AM (Change Arrow-type information to Map-type information), they should imagine the current location of the vehicle on the road because of its absence. Another reason for preferring the SD (Separated Display of proving route guidance information) to any other systems, the operation of the switch was not needed while driving. Drivers probably thought the operation of the switch was troublesome, nevertheless the switch control did not significantly affect the workload as the items of DS (difficulty of searching for devices) and DO (difficulty of operating devices) in MNASA-TLX had low values. As a matter of fact, the switch might be bad position due to installing on the edge of the windshield wiper controller; it is inevitable position due to configured restriction of driving simulator in this research, as one of limitations of this research.

A participant indicated at the end of the experiment, if someone has bad perception skills using the SD (Separated Display of proving route guidance information), having two displays may be too much information to handle while having to look for signs on the road and checking the speed of vehicle. The results of driving errors support this tendency. In addition, we could find the tendency from the glance behavior for the case of the SD (Separated Display of proving route guidance information). Drivers attempted to give a glance to the other type of information after glancing one of two navigation displays to reconfirm route selection. In fact, the number of glance occurrences which fixation time was over than 2 seconds had the greatest when drivers used the SD (Separated Display of proving route guidance information). This system encouraged drivers to increase their visual checking of the display, although the SD (Separated Display of proving route guidance information) attracted the highest preference in the four navigation systems.

Both driver groups made fewer fixations to the display, spent less overall time looking at the display while using AM (Change Arrow-type information to Map-type information). However, both types of drivers preferred SD (Separated Display of proving route guidance information) provided map-type and arrow-type simultaneously to AM (Change Arrow-type information to Map-type information). These results remain to us the trade-off situation between amount of information and driver safety. In terms of the driver safety, the results of the percentage of average total fixation time to the average journey time were important.

Overall, the results suggest that MA (Change Map-type information to Arrow-type information) was not appropriate the route guidance device for the right-lane drivers. Considering the driver safety, therefore, SI (Selectable Map-type information or Arrow-type information) system which drivers can select information is appropriate for both driver groups rather than SD (Separated Display of proving route guidance information) which had lots of information.

The results implied that the design regarding future navigation systems for foreign drivers should not rely on characters such as name of road, intersection, etc. Although these terms may be equal with the case of Japanese [35], the route guidance information should be more explicit and simple than that of Japanese for foreign drivers who drive in different traffic environments. In addition, prominent landmarks and distance to turns based on overview map should be used to provide visual confirmation as well as English voice information. Traffic signals are particularly suitable landmarks since they are ideally located at maneuvers and highly visible during the day and at night as a participant mentioned.

5.5. Conclusions

This research tried to find out characteristics and efficient factors of the route guidance system in order to improve driving safety and mobility of foreign drivers who drive in Japan temporarily and design the most suitable route guidance system in the future by developing and evaluating on four types navigation systems.

For this research, we developed four types of evaluating navigation systems which could find out the distinction of driver's favorite information type, and evaluated the usability of the systems. Developed four types of navigation systems were composed of the arrow-type and map-type information. The main findings from this research were that the foreign drivers benefited from the combination of map-type and arrow-type navigation when compared with the results of single-information type navigation systems evaluated in *Chapter IV*. The results indicate that the system which is mainly supported the map-type information such a current navigation system was not appropriate for foreign drivers who could not understand Japanese. The most suitable navigation system for foreign drivers is to provide selectable information by driver's control whenever they want. Considering the driver safety and usability, therefore, the SI (Selectable Map-type information or Arrow-type information) system which drivers can select the type of information plays a role as one of in-vehicle navigation systems for the foreign driver.

In terms of preventing traffic accidents in advance, the most important thing is to provide only necessary information for driver considering process capability and HMI (Human Machine Interface).

5.6. Summary

The main objective of this research was to investigate four types of RGI (Route Guidance Information) systems and evaluate the suitability of system, which will improve driver safety and mobility of foreign drivers who drive temporarily in Japan. Twenty-four drivers participated in this study. They consisted in two groups, twelve Japanese and twelve European and American drivers. They were asked to operate a driving simulator while using four types of route guidance information developed by utilizing arrow-type and map-type information. Glance behavior including fixation time, glance frequency, and mental workload were measured. Results indicated that the most suitable system for foreign drivers is to provide selectable information by driver's control, which is supported by more explicit and simple information than that of a current system.

Chapter Ⅵ

DISCUSSION

6.1. Relationship between Visual and Voice Information

The results of visual and driving behavior for the right-lane drivers showed that the language in which the voice information was presented was less important than the type of visual information. This result indicates that the right-lane drivers probably depend more strongly on visual information for route guidance than Japanese drivers. In terms of workload relating to languages, the subjective evaluation showed that the right-lane drivers had a higher workload when using the Japanese voice information than the English voice information. One of the reasons for this is that the right-lane drivers tried to understand the Japanese voice information while driving because most of the participants were studying Japanese.

In contrast, the Japanese drivers, who could not understand the English voice information, probably regarded the English voice information in the same way as a tonal signal, i.e., as a signal to pay attention to the display. When the foreign drivers who cannot understand Japanese at all drive temporarily on Japanese roads, their workload can be reduced by the provision of English voice information. In addition, provision of a tonal signal is better than providing Japanese voice information. However, the result revealed that no providing auditory information leads higher number of glances through resulting from simple arrow information. Consequently, through this research, results reveal that visual performance related to amount of visual information. It also revealed that more information, higher workload and worse visual performance.

6.2. Evaluating Methods and Analysis

6.2.1. Visual Glance Behavior

In this research, the visual glance behavior relating to in-vehicle information system to the driver was kept constant throughout the researches in order to find out the differences between the right-lane driver and the left-lane driver and try to develop the next generation navigation system considering user-centered for driver. An interesting finding was that the right-lane driver made longer fixation time to the arrow-type display than those of the left-lane driver, however, they preferred to the map-type navigation resulted from participants' comments. This underlines that the right-lane driver preferred to simple-based information potentially because they could not allocate much attentaional demand to in-vehicle visual information, which would be guideline to develop in-vehicle information such as a navigation system.

Map-type route guidance systems, indeed SD (Separated Display of proving route guidance information) system, resulted in significant eyes-off-the-road time. However, the difficulty lies in deciding what constitutes "unacceptable" or "unsafe" behavior. The route guidance systems introduced here have attempted to address this by adding context to visual behavior, thus aiding in the examination of system in terms of potential safety-related issues.

6.2.2. Driver Behavior

It was clear that, for particular maneuvers relating to speed on straight road section, when the information presented by the symbol-based systems, the vehicle speed was close to the speed limit resulted from studying in *Chapter IV*. Furthermore, it is clear that the resulting visual behavior has strong implications for driver safety. Despite the reduced attentional demand associated with the audio system, the eye fixation was not effective to the navigation display. Some participants found it annoying and wanted to have the option of shutting it off.

However, it is impossible, based on the results of this analysis, to identify the optimum timing of route guidance messages. Even in the system conditions, where no obvious unsafe driving occurred, drivers did not indicate or change lanes as early as for the "ideal" (i.e., the Instructions condition). Again, further research is needed to determine guidelines for the timing of route guidance message.

Traditionally, drivers have operated devices in the vehicle, such as radios, heating and air conditioning, and other auxiliary controls as secondary tasks; in addition to the primary task of following the prescribed path at the desired speed. Historical accident data and anecdotal evidence suggest that drivers have been able to adapt to these additional attentional workloads without affecting primary task performance unduly. The intrusion of the navigator has already been discussed with respect to visual time-sharing demands. In the case of the left-lane drivers, there were no accidents or near misses in the course of running the experiment. Furthermore, there were no differences in the number of lane excess or brake actuations among the three experiments of navigation. However, some of the right-lane drivers conducted various types of mistakes and errors on the changed driving environments. These findings suggest that the additional time-sharing demands of the navigator drew largely upon spare driver resources.

6.3. Driving Workload and Subjective Evaluation

Through the results of six types of route guidance information, driver's mental workload in terms of mental resources is considered.

Mental resources related to route selection and driving operation were considered. A conceptual image of mental resources is shown in Figure 6.1. It indicates results for the foreign drivers driving in their home country, in Japan, and driving in Japan using route guidance information, respectively. The paper map was excluded from this image because there were individual differences of comprehension among the foreign drivers [65]. In the case of driving in their home country, only a limited quantity of mental resources is dedicated to driving operations. However, when driving in Japan, the remaining resources available to non-driving operations are reduced because more mental resources are dedicated to driving operations due to different driving environments such as differences in language, position of the driver's seat, and the side of the road on which cars are driven. In addition, the remaining resources available to the driver are further reduced by route guidance information, which requires the use of a large amount of mental resources.

In this study, the use of car navigation systems with Japanese or English voice information required the dedication of the most mental resources, which resulted in several errors when operating the steering wheel and in route selection. Temporary changes in remaining available mental resources may be caused by the traffic situation. However, when the right-lane drivers used the arrow information, which does not require a large amount of mental resources while driving, no mistakes in route selection were made, although there were a few errors related to steering wheel operation. Such operating errors may not only cause driver confusion, but may also cause danger to other vehicles in real traffic situations. Therefore, when foreign drivers drive in Japan temporarily, it is necessary to provide route guidance information that leaves as many mental resources available as possible.

When foreign drivers drive on the road in Japan temporally, it is necessary to support the route guidance information which needs not much residual of mental workload.

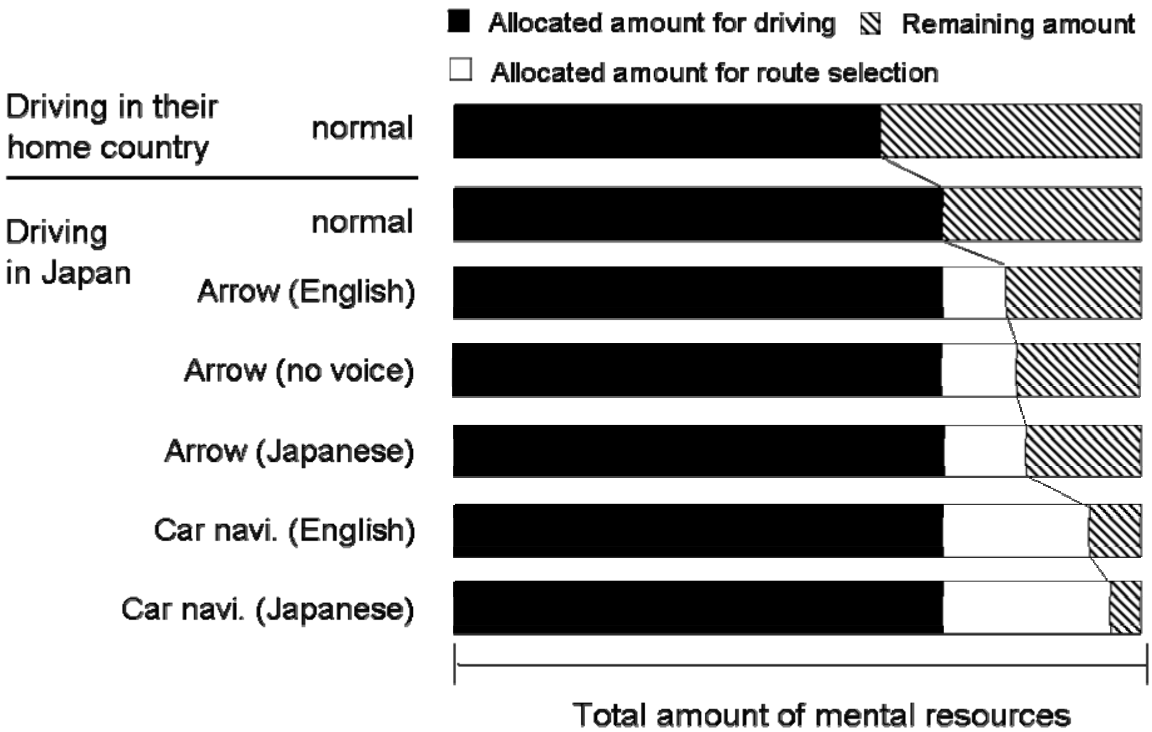


Figure 6. 1 Modeling concept of mental resources in various conditions in case of foreign driver

The results for perceived driver workload failed to detect any differences according to either the systems or the driver group, although the NASA-TLX has been successfully employed within driving research to demonstrate effects due to a range of independent variables such as form or modality of information presentation. It is likely that this measure was insufficiently sensitive to the intermittent impact on driver demand [48].

Subjective Evaluations are quite popular in some areas of human factors to assess some quantifiable results from the research. In-vehicle technology is no exception and in recent years there has been some activity in the field [59]. However, some of the limitations of subjective evaluations are exist.

(a) In the case of evaluating the new development which evaluators are not able to have been used so far, there is any possibility to be measured in a high workload. (b) Since the majority of subjective evaluations are designed to be applicable across all types of systems, many questions are often little relevance to detail aspects under evaluation. (c) Questions on current subjective evaluations often encourage general response. Although there are many limitations of subjective evaluations, they can be used to ensure full coverage of system aspects by human factors experimenter or as a tool during product development.

The subjective evaluation or comment identified more usability problems than any other methods but on closer examination many of the problems were closely related to one another. The most important things is that the evaluation results provided little context to the problems, and were less able to identify severe usability problems. Subjective opinions or comments can be valuable in obtaining users initial perceptions of product or service. This will be useful when some experimenters plan the next experiment for establishing the aim of the product.

6.4. Usability Evaluations and User Interface

Many vehicle manufactures and system suppliers are now well advanced in their development of in-vehicle information systems. They also understand the contribution that the human factors research can make towards the development of systems that are safe, usable and acceptable to vehicle customers.

Much can be learnt from the experience of evaluation one ubiquitous technology (navigation systems) that can be applied to others. Some of the issues relating to appropriateness of evaluation methods are often affect the development of ubiquitous systems that it is appropriate to look afresh at the methodological approaches that are appropriate for these technologies.

The novelty factor may affect users' judgment. Where the system is a novel technology users may be so impressed by what the technology can do that HMI issues are overshadowed. Experts who have been used the similar systems can make comparisons with other products and methods and see beyond the technology to the likely human factors problems. Therefore, the results of user evaluation are depended on the participant population. Participants will come to the systems with different expectations of the product, other system experience, varying physical or cognitive abilities and so on.

6.5. Limitations to Study

There were several potential limitations to the study. In the map-type system studied in Chapter 5, the character presented on display was only Japanese when navigation systems provided route guidance for two types of drivers. This is likely to have reduced or increased the glance frequency according to the foreign driver's Japanese ability. In addition, the researches in this thesis revealed a number of deficiencies in terms of the interface to all route guidance systems. For example, the information represented road network did not present on the arrow-type system. It meant that driver's workload was sometimes high.

In terms of overall point of view, as with developing an in-vehicle route guidance system, there was a relative lack of control over potentially confounding factors such as the context associated with each target maneuver, and the influence of other traffic. In addition, although based on recognized driving error categories and severities, the reliability of the driving error score has not been tested. Further, due to the relatively challenging nature of the trial, it proved difficult to recruit foreign participants, and hence a lower bound was used to define this age group.

Participants' comments revealed some interesting observations relating to the route guidance systems. Although the map-type navigation system had the least workload and was most preferred, some subjects found the map-type navigation system to be needed a number of glance frequency and wanted to change to the arrow-type navigation system when they drive on straight road. The comments also revealed two deficiencies in the design of the display: First, the information represented by the map-type navigation system was two much information to know once glance time. Second, the arrow-type navigation system was some differences between the position and the vehicle position in the simulated world.

In spite of its complexity, the map-type navigation system was received favorably although associated with higher workloads compared with the arrow-type navigation system, because drivers liked knowing the number of blocks to a decision point.

Chapter Ⅶ

CONCLUSIONS

This thesis consisted of three experimental researches which were performed to evaluate and test various types of information on human interface aspects of in-vehicle route guidance systems. The first experimental research was conducted to find out differences and characteristics by applying to SD method of Kansei Engineering and evaluating driver behavior between two types of driver, right-lane and left-lane driver in *Chapter Ⅲ*. The second research aimed to evaluate driver behavior while using six types of in-vehicle route guidance information in *Chapter Ⅳ*. And then tried to evaluate and usability test of two types of providing methods by developing the four types of navigation system in *Chapter Ⅴ*. The results through these researches give guideline on next design of navigation system for foreign driver, as well as for in-vehicle information system considering user-centered design.

The first research addressed many differences of driver behavior and sensibility between the right-lane and left-lane driver. The second research addressed the driver attention demand requirements while navigating with map-type information (car navigation) system, and found out different a visual sampling process between two driver groups. This research was to compare two types of drivers' visual attentional demand requirements for tasks associated with the route guidance system with those of a wide variety of evaluating methods while driving. The third research addressed the effectiveness of combining types of information, the arrow-type and the map-type navigation system. This research had objects which were to make recommendations for improvements in the navigation system design that would optimize the human factors aspects of that design. It also addressed the efficiency of the arrow-type route guidance system as a navigation tool. Furthermore, the numbers of data with respect to glance and driver behavior were valued between right-lane and left-lane drivers, while other previous researches studied those between older and younger or novice and expert driver.

7.1. Validation in field of Intelligent Transport Systems

One of objectives of this thesis was to increase traffic safety by reducing the number of traffic accidents caused by using in-vehicle route guidance systems. In order to achieving the objective, this thesis intended to develop the route guidance system which will alleviate driver's mental workloads and reduce the glance time to in-vehicle information based on the research of human factors such as visual behavior, driving behavior, etc. The developed system will achieve an enhanced reliability in terms of driver vigilance and minimized driver workload while driving.

The primary or secondary cause of over 30% of accidents is driver impairment due to a variety of reasons. Also, almost 30% of accidents could be avoided by reducing the driver related reaction time by just 0.5 second, which may be achieved through reducing the amount of in-vehicle route guidance information. Therefore, the results of these researches will be one of contributable research to develop next in-vehicle route guidance systems.

In the past, comparisons between separate evaluations of specific in-vehicle systems in different test environments have been made more difficult by dissimilar approaches in experimental techniques, operational definitions and analysis methods. However, this research was conducted with the step-by-step concept using the driving simulator and the methods referred to evaluate in-vehicle information systems. Different concepts are first introduced in the laboratory, while proven design can then be easily transferred to the simulator and to real traffic in the car.

Driving safety can be improved by assistance systems when causes for driver errors have been recognized and assistance functions have been defined accordingly. Psychological and ergonomics considerations demand that driving assistance is realized such that the cognitive system of the drivers and their expectations are respected. This research contributes as a preliminary research on developing in-vehicle route guidance system for foreign drivers based on HMI experiments.

7.2. Improving The Mobility for Foreign Tourists

The government of Japan set a goal of attracting 10 million foreign tourists to visit Japan by the year 2010, and places special emphasis on the promotion of tourism. The prime minister established and presided over the Tourism Promotion Council, which published a report on the basic strategy for tourism promotion. Tourism is said to be the biggest industry in the world. Tourism has a ripple effect on many industries and contributes to regional development. Visits by tourists will lead to a renewed interest and pride in regional communities. Therefore the improvement of mobility is very indispensable factor in the tourist industry. However, there is little mobility which is able foreign tourists to adapt for changed road environments. This research was performed to facilitate the mobility of foreign tourists driving temporarily in Japan, and several experiments were conducted.

The car navigation systems provided the number of information such as area names, traffic signs, and the like, in addition to the route guidance information that directs drivers to the destination. These amount of information caused confusion in the foreign drivers during route selection. Therefore, when foreign drivers drive temporarily on Japanese roads, it is more efficient to provide indispensable information which is requisite route guidance to direct driver to the destination.

From the results, the amount of visual information provided on current car navigation systems, although translating the voice information from Japanese to English, were too much for foreign drivers driving temporarily in Japan. Visual arrow display information is considered to be more effective than auditory information. Therefore, the results of this research suggested that the necessity of reducing the amount of information to alleviate drivers' workload through various interface researches on in-vehicle route guidance system for design safe and effective in-vehicle Information systems, because the in-vehicle information is increasing.

7.3. Contributions to Evaluation Methods

In-vehicle navigation systems are an example of ubiquitous computing, where the computing facility is embedded in an every car for an every driving. The maturing navigation systems market of the over last

10 years has prompted academic and commercial research into the Human-Machine Interface (HMI) for these systems. A significant body of research now exists in this specialized area and a contribution has been made towards guidelines for interface design. There are so many researched as an evaluating method of in-vehicle driving assistant system by using visual behavior. However, there is little standardization of evaluating method on eye movement.

This research evaluated on driver behaviors, characteristics of various types of in-vehicle route guidance information through conducting various evaluating methods. These would include evaluation of the visual demands of in-vehicle information systems, assessment of visual attention, workload, and individual differences in driving. Assessment of driver visual behavior provides a method to quantify the driver's visual allocation to the road-way, in-vehicle information sources, controls and mirrors and as such can be a useful tool in many ergonomic studies of the driver. This thesis contributes that how the results can assist in the evaluation of providing the in-vehicle route guidance information.

In SAE Recommended Practice and some researches (Burnett, et.al. 1994, 1997), the scene of driver's view was divided into 8 parts composed of the ahead, left, right, in-vehicle information, right side mirror, left side mirror, rearview mirror and speedometer. However, it is necessary to divide the front part of driver's view. Because driver receives traffic information from infrastructures such as traffic signal, road sign, way mark on the road surface, the parts of upper ahead, near ahead, middle ahead from driver's view were included. In this research, the scene available to the driver was divided into the 10 areas of the roadway including the rear-view mirror, two side mirrors and the speedometer. It is more detail than any other previous researches. Through this dividing method, the result revealed that foreign drivers had the different glance behavior with Japanese driver.

This approach will be utilized to evaluate how drivers respond to vehicle and equipment design, the road environment, or other driver related tasks in both real and simulated road conditions. It is based on the assumption that efficient processing of visual information is necessary to the safe performance of the driving task in a given driving situation. This thesis would contribute to human interface researches and promote the development of ITS devices in the field of in-vehicle systems.

7.4. Recommendation to next navigation system

Navigation systems are likely to be used by foreign drivers due to unfamiliar area, and the potential benefits that these systems offer. The considering factors of design recommendations regarding future navigation systems that may be used by foreign drivers are clear. They rely on visual information much more than auditory information to operate forthcoming maneuvers. It is also important that comprehensible visual and auditory information is supported for foreign drivers. Prominent landmarks and distance information at or near maneuvers should be used to provide visual confirmation of the location of turns, and help indicate the required direction of travel. In addition, distance information should not be excluded totally, since it provides initial confidence on approach to a maneuver when a landmark is not yet visible. Traffic lights are particularly suitable landmarks since they are ideally located at maneuver, familiar, and highly visible during the day and at night.

If visual displays are used to design for foreign drivers, then particular care should be taken to (a) avoid complex visual displays, and (b) to test the visual demand characteristics using techniques such as visual occlusion as described in emerging international standards.

7.5. Future Studies

Research needs to be conducted using various subject populations, for example, older drivers, female drivers, novice drivers. Further research is needed with alternative formats of arrow-type displays based on map scale modes. This would help in determining whether an arrow-type display leads to better driving performance compared to a map-type display. Also, further research is needed concerning the usability and effectiveness of various information types of in-vehicle route guidance systems.

As a future study, it is necessary that evaluation on navigation systems in which the driver can control the amount of information with a “phase step of information” (e.g., increase (or decrease) amount of information presented on display by phase change based on the zoom function) as reducible or increasable information according to driver’s preference, and how much information should be provided by the in-vehicle navigation system in terms of human interface. Finally, the evaluation if such assistance systems have to take place in real traffic to validate results from simulator experiments, and evaluate the safety issues associated with varying traffic conditions.

References

[1] Asoh, T., Muraki, T., and Itoh, T.; Comparative study of effectiveness of maps and turn-by-turn navigation systems, JARI Research Journal, Vol. 22, No. 2, pp.82-85, 2005.

[2] Bianchi, A.; The "genetics" of driving behavior: parents' driving style predicts their children's driving style, Accident analysis and Prevention, Vol.6, No.4, pp.655-659 2004.

[3] Bloomfield, J., Levitan, L., Grant, A., Brown, T., and Hankey, J.; Driving performance after an extended period of travel in an automated highway system, U.S. Department of Transportation, Report No. FHWA-RD-98-051, 1998.

[4] Brochure of ERTICO, ITS for Europe: Keeping people and goods moving, ERTICO-ITS Europe, 2006.

[5] Brochure of Universal Traffic Management Society of Japan (UTMS), 2003.

[6] Brochure of ITS Standardization Activities in Japan, Vol. 05-1, Japan Automobile Research Institute and ITS Japan, 2005.

[7] Burnett, G. E., and Joyner, S. M.; An assessment of moving map and symbol-based route guidance systems, Ergonomics and Safety of Intelligent Driver Interfaces, pp.115-136. 1997.

[8] Campagne, A., Pebayle, T., and Muzet, A.; Oculomotor changes due to road events during prolonged monotonous simulated driving, Biological Psychology, Vol. 68, No. 3, pp.353-368, 2005.

[9] Cha, D.; Design of driver's workloads prediction model through virtual AHS simulator development, doctor dissertation, Ajou University, Korea, 2002.

[10] Chiang, D. P., Brooks, A. M., and Weir, D. H.; On the highway measures of driver glance behavior with an example automobile navigation system, Applied Ergonomics, Vol. 35, No. 3, pp.215-223, 2004.

[11] Cooper, G.E., and Harper, R.P.; The use of pilot rating in the evaluation of aircraft handling qualities, NASA TN-D-5133, National Aeronautics and Space Administration, 1969.

[12] Curzon, P., Wilson, J., and Whitney, G.; Successful strategies of older people for finding information, Interacting with Computers, Vol. 17, No. 6, pp.660-671, 2005.

[13] Daimon, T., Nishimura, M., and Kawashima, H.; Study of driver's behavioral characteristics for designing interfaces of in-vehicle navigation systems based on national and regional factors, JSAE Review Vol.21, pp.379-384, 2000.

[14] Denaro, R., Wilson, C., Seyffert, M., Schamberger, M., and Schupfner, M.; The role of digital map

in active safety systems, 13th ITS World Congress, London, U.K., 2006.

[15] Dobson, A., Smith, N., McFadden, M., Walker, M., and Hollingworth, S.; I Australia are people born in other countries at higher risk of road trauma than locally born people?, Accident Analysis and Prevention, Vol. 36, No. 3, pp.375-381, 2004.

[16] Editorial of Interacting with Computers; HCI and the older population, Interacting with Computers, Vol. 6, No. 17, pp. 613-620, 2005.

[17] Hart, S.G., and Staveland, L.E.; Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research, Human Mental Workload, Elsevier Science Publishers B.V. (North-Holland), 1988.

[18] Hegeman, G., and Minderhoud, M.M.; ADAS Safety Potential on Overtaking Frequency, 11th ITS World Congress, Paper no. 2203, Nagoya, Japan, 2004.

[19] Hill, S.G., Iavecchia, H.P, Byers, J.C., Bitter, A.C, Zaklad, A.L., and Christ, R.E.; Comparison of four subject workload rating scales, Human Factors, Vol.34, No.4, 1992.

[20] Homepage of Advanced Cruise-Assist Highway System Research Association (AHSRA), http://www.ahsra.or.jp

[21] Homepage of Highway Industry Development Organization (HIDO), http://www.hido.or.jp

[22] Homepage of Immigration Bureau of Japan, http://www.immi-moj.go.jp

[23] Homepage of Vehicle Information and Communication System Center (VICS Center), http://www.vics.or.jp

[24] Immigration Bureau of Japan, Immigration Control Report, pp.2-21, 2005.

[25] Isaksson, J. P., Nordquist, J., and Bengtsson, P.; Evaluation of a haptic interface for in-vehicle systems, International Ergonomics Association Congress, Paper No. 568, Seoul, Korea, 2003.

[26] ISCAN Operating Instructions, Version 3.10, pp.1-3, ISCAN, Inc.

[27] Itoh, N., Yamashita, A., and Kawakami, M.; Effects of car-navigation display positioning on older driver’s visual search, International Congress Series, No. 1280, pp.184-189, 2005.

[28] ITS Handbook 2003-2004, pp.78-83, 2003.

[29] ITS Handbook 2006-2007, pp.80, 2006.

[30] ITS Handbook, ITS as a national project, Highway Industry Development Organization, pp.74-75, 2003.

[31] ITS Highlights, ERTICO Public Authorities Platform, ERTICO, 2003.

[32] ITS Japan Homepage, http://www.its-jp.org.

[33] ITS Planning Handbook, Intelligent City Transport, ERTICO, ITS City Pioneers Consortium, 1998.

[34] Jansen, O. P., and Wiedenbauer, G.; The representation of landmarks and routes in children and adults: A study in a virtual environment, Journal of Environmental Psychology, Vol. 24, No. 3, pp.347-357, 2004.

[35] Japan Automobile Manufactures Association, Guideline for in-vehicle display systems – Version 2.1, 2000.

[36] Japan Research Center for Transport Policy; Transport Policy in Perspective: 2004, pp.16-17, 2004.

[37] Jeon, Y.; Evaluation of driver's physiology signal and sensibility according to changes of speed and gap of platoon on AHS, Master dissertation, Ajou University, 2002.

[38] Jeon, Y., Okada, R., Daimon, T., and Kawashima, H.; Preliminary study of foreign driver behavior based on various types of route guidance information, JSAE Annual Congress (Fall), No. 270-20065771, 2006.

[39] Jeon, Y., Daimon, T., and Kawashima, H.; In-vehicle route guidance systems for improving mobility of foreign drivers, Society for Tourism Informatics, Vol. 3, No. 1, pp.19-28, 2007.

[40] Kato, T.; What "question-asking protocols" can say about the user interface, International Journal of Man-Machine Studies, vol. 25, pp.659-673, 1986.

[41] Kawashima, H.; New generation ITS; The road traffic society of the state of art made by Smart-way, Nikkei construction, pp.161-182, 2007.

[42] Kennedy, R.S., Lane, N.E., Berbaum, K.S., and Lilienthal, M.G.; A Simulation Sickness Questionnaire (SSQ): A new method for quantifying simulator sickness, The International Journal of Aviation psychology, Vol.3, No.3, pp.203-220, 1993.

[43] Kinoe, Y.; Applying formal Verbal Protocol Analysis to practical usability evaluation, Human Aspects in Computing: Design and Use of Interactive Systems and Work with Terminals, pp.609-613, 1991.

[44] Kinoe, Y.; The VPA method: A method for formal Verbal Protocol Analysis, Designing and Using Human-Computer Interfaces and Knowledge Based Systems, pp.735-742, 1989.

[45] Lansdown, T. C., and Stevens, A.; Driver assistance systems: Guidance for designers regarding human capabilities, International Ergonomics Association Congress, Paper No. 433, Seoul, Korea, 2003.

[46] Lee, J.D., Caven, B., Haake, S., and Brown, T.L.; Speech-based interaction with In-vehicle computers: The effect of speech-based E-mail on drivers' attention to the roadway, Human Factors, Vol. 43, No. 4, pp.631-640, 2001.

[47] Liu, Y.; Driving performance differences for driver's attention switch requirements using head-up

display in automobile, International Ergonomics Association Conference, Seoul, Korea, 2003.

[48] May, A., Ross, T., and Osman, Z..; The design of next generation in-vehicle navigation systems for the older driver, Interacting with Computers, Vol. 17, No. 6, pp.643-659, 2005.

[49] Meng, L., and Wevers, K.; ADAS Applications for Road Traffic Safety: Exploring the Technical Feasibility, 11th ITS World Congress, Paper no. 2162, Nagoya, Japan, 2004.

[50] Nowakowski. C., Green, P., and Tsimhoni. O.; Common automotive Navigation system usability problems and a standard test protocol to identify them; 13th ITS-America Annual Meeting (CD-ROM), Washington, D.C., Intelligent Transportation Society of America, 2003.

[51] Pardo, J., Dols, J. Knoll, C., and De Waard, D.; Trainer: Improving road safety by applying multimedia and simulation in novice drivers' education, International Ergonomics Association Congress, Paper No. 1186, Seoul, Korea, 2003.

[52] Park, P., and Cha, D.; Comparison of subjective mental workload assessment techniques for the evaluation of in-vehicle navigation system usability, Proceedings of the 5th ITS World Congress, 1998.

[53] Park, S., and Kim, C.; The evaluation of seating comfort by the objective measures, SAE paper no. 970595, 1997.

[54] Piao, J., McDonald, M., and Vöge, T.; An Assessment of User Acceptance of ADAS/AVG Systems from a Questionnaire in Southampton, 11th ITS World Congress, Paper no. 2200, Nagoya, Japan, 2004.

[55] Piechulla, W., Mayser, C., Gehrke, H., and Konig, W.; Reducing driver's mental workload by means of an adaptive man-machine interfac, Transportation Research Part F, Vol. 6, No. 10, pp.233-248, 2003.

[56] Proctor, R. W., and Zandt, T.V.; Human factors in simple and complex systems, Allyn and Bacon, pp.204-209, 1994.

[57] Reason, J., Human Error, Cambridge University, pp.42-44, 1990.

[58] Reed, M. P., and Green, P. A.; Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialing task, Ergonomics, Vol. 42, No. 8, pp.1015-1037, 1999.

[59] Ross, T., and Burnett, G..; Evaluating the human- machine interface to vehicle navigation systems as an example of ubiquitous computing, International Journal of Human-Computer Studies, Vol. 55, No. 4, pp.661-674, 2001.

[60] Road Bureau, Ministry of Land, Infrastructure and Transport, Roads in Japan, http://www.mlit.go.jp

[61] SAE Recommended Practice; Definition and experimental measures related to the specification of driver visual behavior using video based techniques. SAE J2396, Warrendale, PA, 2000.

[62] SAE Recommended Practice; Navigation and route guidance Function Accessibility while driving; SAE J2364, 2004.

[63] Sato, T.; Study on human interface of information devices based on elderly user's cognitive characteristics and process of use, doctor dissertation, Keio University, Japan, 2005.

[64] Srinivasan, R.; Effect of selected in-vehicle route guidance systems on driver reaction times, Human Factors, Vol. 39. No. 2, pp.200-215, 1997.

[65] Streeter, L., and Vitello. D.; A profile of driver's map-reading abilities, Human Factors, Vol. 28, No. 2, pp.223-239, 1986.

[66] Stevens, A., Quimby, A., Board, A., Kersloot, T., and Burns, P.; Design guidelines for safety of in-vehicle information systems, TRL Limited, Project report No. PA3721/01, 2002.

[67] Suda, Y., Shladover, S.E., Takahashi, Y., Onuki, M., Matsushita, K., Kanoh, M., Honda, K., and Shiraishi, T.; Validation of the universal driving simulator, CD, London, U.K., 13th ITS world congress, 2006.

[68] Susa, Y., Onuki, M., Hirasawa, T., Ishikawa, H., Kano, M., Mashiyama, Y., Oda, T., Tagaya, A., Taguchi, T., and Kanki, Y.; Development of Driver Model using Driving Simulator with Interactive Traffic Environment, 11th ITS World Congress, Paper No. 3469, Nagoya, Japan, 2004.

[69] Sun, X., and Zhang, K.; In-vehicle navigation information display: Integration of visual and auditory presentation, International Ergonomics Association Congress, Paper No. 701, Seoul, Korea, 2003.

[70] Terashita, H.; Physiological assessment while using in-vehicle information system, International Ergonomics Association Congress, Paper No. 863, Seoul, Korea, 2003.

[71] The Ministry of Justice, Basic Plan for Immigration Control (The 2nd edition), http://www.moj.go.jp.

[72] Uang, S., and Hwang, S.; Effects on driving behavior of congestion information and of scale of in-vehicle navigation systems, Transportation Research Part C: Emerging Technologies, Vol. 11, No. 6, pp.423-438, 2003.

[73] Ulleberg, P., and Rundmo, T.; Personality, attitudes and risk perception as predictors of risky driving behaviour among young drivers, Safety Science, Vol.41, pp.427-443, 2003.

[74] Underwood, G., Chapman, P., Brocklehurst, N., Underwood, J., and Crundall, D.; Visual attention while driving: sequences of eye fixations made by experienced and novice drivers, Ergonomics, Vol.

46, No. 6, pp.629-646, 2003.

[75] U.S. Department of Transportation homepage, www.its.dot.gov/faqs.htm

[76] Wevers, K., and Blervaque, V.; MAPS & ADAS - Safety Enhanced Digital Maps and Standard Interface to ADAS, 11th ITS World Congress, Paper no. 2193, Nagoya, Japan, 2004.

[77] What is ITS?, Linking people, their vehicles and the environment, Aichi ITS Conuncil, pp.3-7, 2004.

[78] Wierwille, W.W., Antin, J.F., Dingus, T.A., and Hulse, M.C.; Visual attentional demand of an in-car navigation display system. Vision in Vehicles Ⅱ, pp.307-316. 1988.

[79] Wittmann, M., Kiss, M., Gugg, P., Steffen, A., Fink, M., Poppel, E., and Kamiya, H.; Effects of display position of a visual in-vehicle task on simulated driving, Applied Ergonomics, vol. 37, no. 2, pp.187-199, 2006.

[80] Yamasaki, H., Yamada, T., Ishigaki, H., Nakano, T., Tsugawa, S., and Yamamoto, S.; Development of driving simulator for human-friendly in-vehicle systems 2-An information system adjustable to driver's status and individual difference, 11th ITS World Congress, Paper No. 3360, Nagoya, Japan, 2004.

Appendix

Appendix A: Results of Factor Analysis

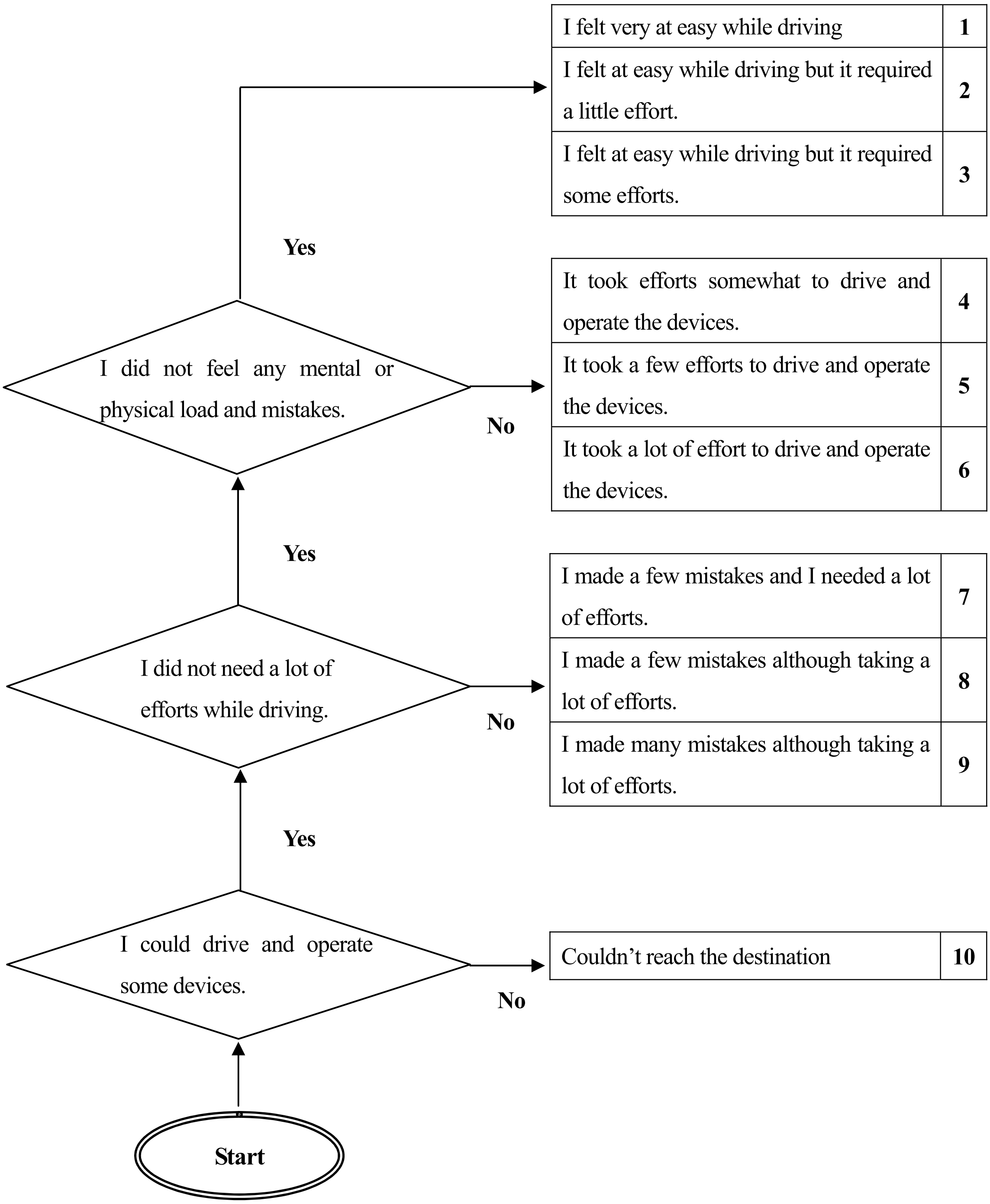
	Left-lane drivers				Right-lane drivers							
	Japanese				Korean				European and American			
	Adjective	Mean	SD	Value	Adjective	Mean	SD	Value	Adjective	Mean	SD	Value
Factor 1	embarrassed	2.15	1.07	0.95	intense	3.00	0.71	0.97	tedious	3.00	1.00	0.99
	insensible	2.23	1.17	0.94	future inclining	3.00	1.22	0.93	smooth	4.00	1.00	0.99
	modern	2.15	1.07	0.88	splendid	3.20	0.45	0.91	clean	4.00	1.00	0.99
	charming	2.23	1.01	0.85	impressive	2.60	0.89	0.90	fantastic	3.00	1.00	0.99
	firm	2.08	1.38	0.80	right	2.60	1.52	0.83	tense	3.33	1.53	0.98
	uneasy	2.54	1.13	0.75	reliable	3.20	1.09	0.81	exciting	2.33	1.53	0.98
	strong	2.38	0.96	0.74	sporty	3.20	0.84	-0.84	mere	3.33	1.53	0.98
	harmonic	3.08	1.32	0.72	neat	3.60	0.89	-0.91	Future inclining	3.67	1.53	0.98
	hard	2.31	1.18	0.70	unusual	3.20	1.30	-0.93	conservative	2.67	2.08	0.96
	stimulative	2.46	1.20	0.64	insensible	3.00	0.71	-0.97	unpleasant	3.33	0.58	0.87
	unpleasant	2.31	1.11	0.64	sharp	3.00	0.71	-0.97	charming	4.33	0.58	0.87
	smooth	2.62	1.33	0.59					heavy	4.33	0.58	0.87
Factor 2	perfect	2.38	1.33	0.88	exhilarant	3.40	0.89	0.99	embarrassed	3.67	0.58	0.99
	wild	2.23	1.01	0.86	brawling	2.80	1.30	0.91	massive	2.67	0.58	0.99
	brawling	2.62	1.19	0.80	equilibrium	2.80	1.10	0.89	blunt	3.00	1.73	0.99
	lighthearted	2.46	1.13	0.74	relax	3.60	0.55	0.88	overbearing	3.67	0.58	0.99
	mere	3.46	1.20	0.71	tedious	2.60	0.55	0.88	harmonic	3.33	1.15	0.99
	chaotic	2.69	1.03	0.71	strong	3.40	1.34	0.87	crude	3.33	2.08	0.97
	sporty	2.54	1.05	0.68	blunt	2.60	1.52	0.84	mighty	3.33	2.08	0.97
	fantastic	2.38	0.77	0.65	embarrassed	2.00	0.71	0.82	visionary	2.66	1.53	0.94
	crude	3.54	1.27	-0.63	comfortable	2.80	0.84	-0.85	mild	3.00	1.00	0.87
	vivacious	3.00	0.82	-0.64	heavy	3.20	0.45	-0.90	impressive	3.00	2.00	0.87
	exotic	3.92	1.04	-0.68					splendid	4.00	1.00	-0.87

Factor 3	flexible	3.23	0.93	0.92	tough	3.20	0.84	0.94				
	irritating	2.85	1.07	0.89	modern	2.20	0.84	0.94				
	blunt	2.92	1.32	0.88	lighthearted	2.00	1.00	0.94				
	overbearing	3.46	1.27	0.79	peculiar	3.00	0.71	0.89				
	melancholy	3.15	0.99	0.64	stimulative	2.20	1.09	0.84				
	visionary	2.38	0.96	0.54	perfect	2.00	1.22	-0.83				
					active	4.00	0.71	-0.89				
					clean	3.40	0.55	-0.90				

Note: Only first 3 factors presented in this table in order to comparing three groups. Loadings of less than 0.5 were omitted for the sake of clarity. The adjective in values greater than 0.5 presented, and was excluded from the factor appeared in two more factors.

Appendix B: Modified Cooper & Harper rating scale

The questionnaire starts from left of bottom (Start) and proceeds along with the arrow. Answer the questions and select the statement which best describes your driving experience.



Appendix C: Modified NASA-TLX

MNASA-TLX (1/2)

This questionnaire is prepared for measuring feel of the guide information. Please check the point that you felt while driving (the unit scale is 5).

Ex)

The least load ← 0 10 20 30 40 50 60 70 80 90 100 → the most load

(1) Needs of Mental workload

How much ***mental effort*** was required while driving and operating the driving devices (navigations and switches except factors of the driving simulator)

The least load ← 0 10 20 30 40 50 60 70 80 90 100 → the most load

(2) Driving Uncomfortableness

How much ***uncomfortable*** did you feel while driving and operating the driving devices (navigations and switches except factors of the driving simulator)

Comfortable ← 0 10 20 30 40 50 60 70 80 90 100 → Uncomfortable

(3) Timing Stress

How much ***timing stress*** did you feel from operating the driving devices (navigations and switches except factors of the driving simulator) for using them on time.

The least load ← 0 10 20 30 40 50 60 70 80 90 100 → the most load

(4) Difficulty of Searching for devices

How much did you feel the difficulty of ***searching for the driving devices*** (navigations and switches except factors of the driving simulator) while driving.

The least load ← 0 10 20 30 40 50 60 70 80 90 100 → the most load

(5) Difficulty of Operating devices

How much did you feel the difficulty of ***operating the driving devices*** (navigations and switches except factors of the driving simulator) while driving.

The least load ← 0 10 20 30 40 50 60 70 80 90 100 → the most load

(6) Difficulty of Perceiving the outside environment

How much did you feel the difficulty of ***perceiving the outside environment*** (navigations and switches except factors of the driving simulator) while driving.

The least load ← 0 10 20 30 40 50 60 70 80 90 100 → the most load

MNASA-TLX (2/2)

This portion of the questionnaire addresses the related importance of the above questionnaire. Please indicate the degree to which you felt one stress compared to the other.

Ex)

	1	0	1	
Timing Stress	X			**Difficulty of searching devices**

0: equal the left item and the right.

	1	0	1	
Needs of mental workload				Driving Uncomfortableness
Needs of mental workload				Timing Stress
Needs of mental workload				Difficulty of searching for devices
Needs of mental workload				Difficulty of operating devices
Needs of mental workload				Difficulty of perceiving the outside environment

	1	0	1	
Driving Uncomfortableness				Timing Stress
Driving Uncomfortableness				Difficulty of searching for devices
Driving Uncomfortableness				Difficulty of operating devices
Driving Uncomfortableness				Difficulty of perceiving the outside environment

	1	0	1	
Timing Stress				Difficulty of searching for devices
Timing Stress				Difficulty of operating devices
Timing Stress				Difficulty of perceiving the outside environment

	1	0	1	
Difficulty of searching for devices				Difficulty of operating devices
Difficulty of searching for devices				Difficulty of perceiving the outside environment

	1	0	1	
Difficulty of operating devices				Difficulty of perceiving the outside environment

Appendix D: Questionnaire relating to information of devices

Devices Comparison

＊ Now we would like you to consider the clarify of the four types of routing information used this time about 【 Comprehension 】.

* You can think that the average is 5.

1. Was it comprehensible to use the changing information for a little from Car navigation to Arrow indicator by pushing the switch to drive to the destination and to perceive the outside situation?

0 1 2 3 4 5 6 7 8 9 10

easy to understand← →hard to understand

2. Was it comprehensible to use the changing information for a little from Arrow indicator to Car navigation by pushing the switch to drive to the destination and to perceive the outside situation?

0 1 2 3 4 5 6 7 8 9 10

easy to understand← →hard to understand

3. Was it comprehensible to use the continuously changing information from Arrow indicator to Car navigation and from Car navigation to Arrow indicator by pushing the switch to drive to the destination and to perceive the outside situation?

0 1 2 3 4 5 6 7 8 9 10

easy to understand← →hard to understand

4. Was it comprehensible to use the separated display, Arrow indicator and Car navigation to drive to the destination and to perceive the outside situation?

0 1 2 3 4 5 6 7 8 9 10

easy to understand← →hard to understand

＊ Now we would like you to consider the clarify of the four types of routing information used this time about 【Usability 】. This question is almost same as above. But, the point of this question is "Which is the easiest use when you drive?"

* You can think that the average is 5.

1. Was it user-friendly information to use the changing information for a little from Car navigation to Arrow indicator by pushing the switch to drive to the destination?

0 1 2 3 4 5 6 7 8 9 10

easy to use← →hard to use

2. Was it user-friendly information to use the changing information for a little from Arrow indicator to Car navigation by pushing the switch to drive to the destination?

0 1 2 3 4 5 6 7 8 9 10

easy to use← →hard to use

3. Was it user-friendly information to use the continuously changing information from Arrow indicator to Car navigation and from Car navigation to Arrow indicator by pushing the switch to drive to the destination?

0 1 2 3 4 5 6 7 8 9 10

easy to use← →hard to use

4. Was it user-friendly information to use the separated display, Arrow indicator and Car navigation to drive to the destination and to perceive the outside situation?

0 1 2 3 4 5 6 7 8 9 10

easy to use← →hard to use

謝　辞

本研究を行うにあたり，論理的で懇切丁寧な御指導を行って下さった指導教授である慶應義塾大学理工学部准教授　大門樹先生に深く感謝致します. 夜遅くまでの研究に関する議論を通じて, 様々なコメントや御助言を下さって現在に至ったと思います.

慶應義塾大学で研究の機会を与えて下さった理工学部教授　川嶋弘尚先生に謹んで感謝致します．先生の御指導による有益なアドバイスが，博士課程の初歩を踏み出した時から現在に至るまでの重要なガイドラインになり，ヒューマンマシンインターフェースに関する研究を進めていく上で大変貴重な知識となりました．心より感謝致します．

お忙しいところ，本論文の副査を引受けて頂いた，慶應義塾大学理工学部教授　岡田有策先生，情報工学科准教授　重野寛先生には，研究の流れや不明確な部分に関しての鋭い御指摘を頂きました．本研究において先生方の的確なアドバイス及びコメントがなければ，本論文の完成には至らなかったことと思います．論文全般に渡り多くの貴重な御意見を頂き，心から感謝致します．

日本留学を応援して下さった恩師である亜州大学産業情報システム工学科　朴犯先生と啓明大学の産業システム工学科　辛承憲先生に深く感謝致します．

松下電器産業株式会社パナソニックデザイン社と富士重工株式会社スバル技術研究所との共同研究を通じ，多くの研究者の方々から車載ナビゲーションシステムに関する数々の有益な御助言と幅広いアドバイスを頂きました．また，本研究で実施した実験に参加して頂いた慶應義塾大学別科・日本語研修過程の学生様と彼らの友人達に御協力頂いたことを感謝致します．大門研究室の岡田亮氏及びその他の皆様，川嶋研究室の皆様に多くの御助力を頂き，感謝致します．

一生忘れることが出来ない日本での留学生活において，精神的な父，及び教授として激励とコメントを下さった慶應義塾大学電子工学科　山下久直先生，日本での精神的な母として支えて下さった慶應義塾大学同窓会の萬利乃道代様に心を込めて感謝致します．いつか御二方には必ず恩返しすることを約束致します．

本論文を完成させるにあたり，誰よりも無限な愛で私を精神的にサポートし，資金面でも支援をしてくれた両親と義両親に深く感謝致します．本論文をもってわずかながらも感謝の心を示せればと思います．誰よりも常日頃から私を励まし，健康面及び精神面ともに支えてくれた妻の安宣昤に愛を込めて感謝の心を送ります．また，母国で応援してくれた祖母，姉，義兄，弟にも感謝致します．

留学の際に経済的支援をして下さった韓国科学財団，実吉奨学会，船井情報科学振興財団，文部科学省に謹んで深謝の意を表すると共に，日本留学生活において関わった全ての人々との出会いがあって現在に至ることが出来たと実感し，皆様にこの紙面を借りて心から謝意を表します．

平成 20 年 3 月

田　容旭

감사의 글

본 논문이 완성되기까지 논리적으로 정중히 지도 해 주신 지도교수이신, 게이오대학(慶應義塾大學) 이공학부교수, 다이몽(大門 樹)교수님께 진심으로 감사 드립니다. 늦은 밤까지 연구에 대한 논의를 통하여 다양한 충고와 조언을 해 주셨기에 오늘에 이르렀다고 생각합니다.

게이오대학(慶應義塾大學)에서 연구의 기회를 주신 이공학부교수, 가와시마(川嶋 弘尚)교수님께도 깊이 감사 드립니다. 교수님의 지도와 유익한 충고가 박사과정의 첫걸음을 내 딛는 순간부터 현재에 이르기까지 중요한 가이드 라인이 되었고, 인간–기계 인터페이스 (Human-Machine Interface) 연구의 진행 방법에 대해서 대단히 귀중한 지식이 되었습니다. 진심으로 감사 드립니다.

바쁘신데도 불구하고 논문의 부심사를 맡아, 연구 흐름 및 불명확한 부분에 대하여 날카로운 지적을 해 주신 게이오대학(慶應義塾大學) 이공학부교수 오카다(岡田 有策)교수님, 정보공학과 교수이신 시게노(重野 寛)교수님께 감사 드립니다. 본 연구에 있어서 교수님들의 정확한 지적과 충고가 없었더라면 논문의 완성이 미흡했을 거라 생각합니다. 논문전반에 걸쳐 많은 귀중한 의견을 주신 점, 진심으로 감사 드립니다.

그리고, 일본 유학에 있어 많은 조언과 격려를 해 주신, 아주대학교 산업정보시스템공학과 박범 교수님과 계명대학교의 산업시스템공학과 신승헌교수님께 깊은 감사를 드립니다.

또한, 마쓰시타전기산업(松下電器産業)의 파나소닉 디자인사와 후지(富士)중공업의 스바루 기술 연구소와의 공동연구를 통하여, 여러 연구자 분들에게 차량용 네비게이션 시스템에 관한 여러 유익한 조언과 폭넓은 충고를 얻게 되어 감사 드립니다. 또, 본 연구를 위하여 실험에 참가 해 주신 게이오대학(慶應義塾大學) 별과・일본어연수과정의 외국인 유학생들과 그의 친구분들의 협력에 감사 드립니다. 다이몽(大門) 연구실의 오카다(岡田 亮)군 및 그 외 학생들과, 가와시마(川嶋) 연구실의 학생 여러분의 많은 도움에 감사합니다.

일생에 있어서 절대 잊을 수 없는 일본 유학생활에서, 정신적 아버지로서, 게이오대학(慶應義塾大學)의 교수로서 격려와 충고를 해주셨던 전자공학과 야마시타(山下 久直) 교수님과, 일본에서의 정신적 어머니로서 정성 어린 지원을 해주셨던 게이오대학(慶應義塾大學) 이공학부동창회의 마리노(萬利乃 道代)님께 진심으로 감사 드리며, 언젠가 두 분의 은혜에 보답하리라 약속 드리겠습니다.

본 논문의 완성에 있어서, 누구보다도 무한하고 언제나 아낌없는 사랑으로 성심 어린 마음으로 보살펴 주시며, 적지 않은 유학자금을 지원해 주신 아버지와 어머니, 장인어른과 장모님께 본 논문을 빌어 조금이나마 감사의 마음을 전해 드립니다. 먼저 학위를 마치고 공부하는 남편을 뒷바라지 해 가며, 누구보다 항상 격려해 주며 몸과 마음을 보살펴 준 아내, 안 선영에게 사랑을 담아 감사의 마음을 전합니다. 또한, 언제나 저를 걱정해 주시는 할머니, 모국에서 응원과 격려로 지원해 주신 자형, 누나, 언제나 믿음직한 동생 용호와, 형님, 처재를 비롯한 처가댁 가족 및 친지 분들께도 깊은 감사를 드립니다.

유학에 있어서 경제적 도움을 주신 한국과학재단, 사네요시(實吉)장학회, 후나이(船井)정보과학

진흥재단, 일본 문부과학성에 감사 드리며, 일본 유학생활에 있어서 관련된 모든 사람들과의 만남이 있었기에 지금에 이를 수 있었다고 실감하며, 그분들에게 본 논문을 빌어 마음으로부터 감사의 뜻을 전합니다.

끝으로, 앞으로의 길이 더욱 힘들 것이라는 것을 알기에, 항상 처음 시작하는 마음으로 최선의 노력을 다하는 모습을 보여드리도록 하겠습니다.

2008 년 3 월

전 용 욱