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R&D ACTIVITIES IN AUTONOMOUS VEHICLES USING PATENT INFORMATION

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Abstract

This paper focuses on firm's R&D activities in autonomous vehicles. Using patent information with patent map and HITS algorithm, we demonstrate in this paper that R&D patterns of automobile manufacturers, parts suppliers and ICT companies. First, our patent map shows increasing R&D activities of autonomous vehicles along with development of artificial intelligence (AI) technology in recent years. Second, regarding to the levels of autonomous vehicles technology, HITS algorithm shows activities of autonomous vehicles development changes from Lv.0 through Lv.5. Third, since the year 2000, R&D activities of 3D241 in these three industries are lively. Fourth, using HITS algorithm, we find that most of the top thirty companies of automotive driving patent ranking are automotive manufacturers. Fifth, since in the late 1990s, R&D activities in automotive suppliers and ICT companies are lively. Finally, R&D activities in ICT companies once have declined, but since 2015, R&D activities in ICT companies are lively.

Keywords: Autonomous vehicles, R&D activities, automobile manufacturers, parts suppliers, ICT companies patent information.

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1. Introduction

R&D activities in autonomous vehicles are increasing in the world, so autonomous vehicle technology concern to international competitiveness. Autonomous vehicles are products of the highly developed computer science, such as AI. So, strategy of these companies will concern to autonomous vehicle technology. So, CASE is a topic of automotive manufacturers, automotive suppliers, and ICT companies. R&D activities in autonomous vehicles are increasing in the world. Autonomous vehicles consist of autonomous recognition, judgment, and operation. According to NHTSA and SAE (the National Highway Traffic Safety Administration and Society of Automotive Engineers) autonomous vehicle is classified under six levels (Lv.0 through Lv.5.) Lv.0 is completely human operated vehicles, and Lv.5 is fully autonomous vehicles. So, we can find the changes of R&D activities by analyzing the changes of patent information. Specifically, we classify these companies as automotive manufacturers, automotive suppliers, and ICT companies. And using patent map, we analyze and consider R&D activities in these companies. In addition, we analyze the core technologies by using HITS algorithm, and analyze the trend of core technologies of autonomous vehicle technology.

2. Problem Statement

2.1. Overview of Automobile Industry

In the automotive industry, CASE which is initials of connected, autonomous car, sharing and electric vehicle has been focused. Above all, autonomous driving is rapidly developing technology by the reason of improvement of computer science. The sales amount of the world's automakers is shown in Figure 1. Among these manufacturers, TOYOTA, VW, Ford, GM, HONDA, BMW and NISSAN have entered the automated autonomous vehicles industry. Also, the list of impacts by the practical application of autonomous driving is shown in Table 1. Significant effects are expected such as reduction of traffic accidents, elimination of traffic congestion, response to declining birth rate and aging population, improvement of productivity, and strengthening of international competitiveness.

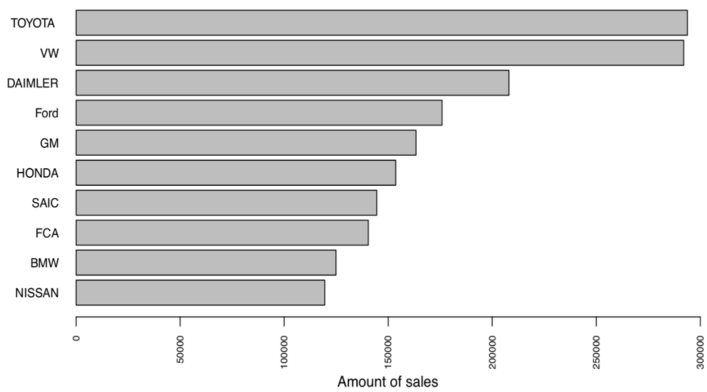

Figure 01. Sales amount of automobile company

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Table 01. Effects by autonomous vehicle

Effects	**Summary**
Traffic accident reduction	Preventing Accidents Caused by Driver Mistakes
Congestion cancellation and mitigation	Suppression of driving that leads to traffic jam
Responding to decline birth-rate and aging population	Transportation for the elderly
Productivity improvement	Reduction of drivers' burden and improvement of domestic productivity
Strengthening of international competitiveness	International business development based on technology and know-how

Source: http://www.mlit.go.jp/common/001155023.pdf (in Japanese)

2.2. Overview of Autonomous Vehicles Industry

2.2.1. Definition of Autonomous Driving and Entry Companies

A definition of the autonomous driving levels proposed by SAE (Society of Automotive Engineers) in U.S. is shown in Figure 2. There are significant differences between greater than or equal to level 3 and less than or equal to level 2 in the definition. The driver has responsibility for recognizing the driving environment in up to level 2, but the control system is ultimately responsible it in level 3 or higher. Therefore, the core technologies required for automated driving in level 3 or higher are considered control system and software. In addition, significant technological innovation is required for its practical application. The end product manufacturers including Toyota, Nissan, Honda, Mercedes, GM, BMW and etc. have entered from Japan, Europe and the United States. However, it is said that it has been limited to practical operation up to level 2 of automatic operation. In the future, intensified competition is predicted including ICT companies that are not car-made manufacturers (Osawa & Nakamura, 2015).

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
Human driver monitors the driving environment								
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Figure 02. Effects by autonomous vehicle
(Source: http://cyberlaw.stanford.edu/blog/2013/12/sae-levels-driving-automation)

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2.2.2. Technical knowledge required for fully automated driving

As indicated in the autonomous driving levels, the technology for "control" and "system" is required for the realization of fully automatic operation. The technologies related to fully automated driving and its investment ratio are shown Figure 3.

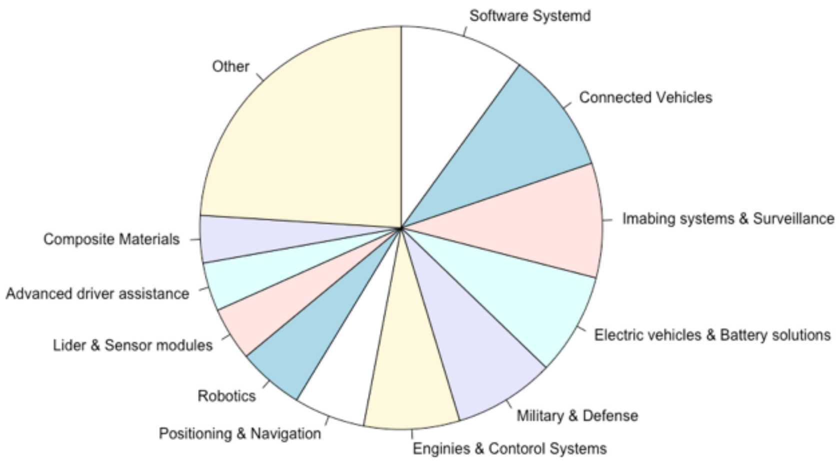

Figure 03. Investment ratio for autonomous vehicle

Thus, it can be seen the circumstances that the investment in technologies related to "software and control" are high. The control system is more important than the vehicle in itself in the automatic driving field. There is “IoT” in ICT industry. IoT is a technology that acquires information with sensors, stores data in the cloud, analyzes the data with artificial intelligence, and then activates the results. This technology can be applied to automatic driving. Because "prediction, recognition and judgment" are required to operate the vehicle, and these are controlled by software. A concrete representation of the technology required for such operations are shown in Table 2 (Suda & Aoki, 2015).

Table 02. Effects by autonomous vehicle

Outline	Technology
Sensor	Preventing Accidents Caused by Driver Mistakes
Judgment	Local dynamic mapping technology and modelling of driving environment recognition
Positioning technology	High accuracy and high reliability by using Quasi-Zenith Satellite, 3D digital map and IMU sensor (3-axis gyro)
Link with external information	Inter-vehicle and road-vehicle communication and cloud computing cooperation
System reliability	Development of fail-safe technology and redundant technology
HMI and drive recorder	Advancement of driver monitoring and drive recorder

Source: http://cyberlaw.stanford.edu/blog/2013/12/sae-levels-driving-automation (in Japanese)

The process of operating automatic operation by these technologies is as follows:

- Measure using GPS

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- Create a local dynamic map that integrates the map information and the information read by the sensor. After recognizing the driving environment and the destination, the artificial intelligence module understands the environment and makes decision to correct the target driving.
- Perform actual speed control and steering control based on the information from the artificial intelligence module.

This process also requires big data analysis including not only road and traffic information such as inter-vehicle distance and white line distance but also traveling environment sensing and obstacle recognition.

3. Research Questions

This paper focuses on firm's R&D activities in autonomous vehicles. The differences of R&D patterns on automobile manufacturers, parts suppliers and ICT companies are indicated using patent information with patent map and HITS algorithm. Our research questions are first, as we classify these companies as automotive manufacturers, automotive suppliers, and ICT companies, whether there are the significant differences between R&D patterns of these three industries, or not. Second, whether there are the significant characteristics of technological development and changes in core technology in these three industries. So, we can find the changes of R&D activities by analyzing the changes of patent information.

4. Purpose of the Study

CASE is a topic of automotive manufacturers, automotive suppliers, and ICT companies. R&D activities in autonomous vehicles are increasing in the world. Autonomous vehicles consist of autonomous recognition, judgment, and operation. Autonomous vehicles are one of traffic accident preventing equipment. Also, another purpose of autonomous vehicles is for counter traffic congestion. First, regarding traffic accident preventing, autonomous recognition, judgment, and operation means exclusion of human errors, which are major reason of traffic accidents. So, it contributes traffic safety. Second, regarding counter traffic congestion, autonomous vehicles can accurate operation even on alley. It contributes for counter traffic congestion. R&D activities in autonomous vehicles are increasing in the world, so autonomous vehicle technology concern to international competitiveness. Japanese government aims to reducing a senior driver's crash risk. So, Japanese government promotes the adoption of "safe driving support cars," vehicles equipped with advanced safety technology, such as automatic braking systems. The number of companies focused on autonomous vehicle technology, and autonomous vehicle technology is advancing quickly through the 2010s. Autonomous vehicles are products of the highly developed computer science, such as AI. So, strategy of these companies will concern to autonomous vehicle technology. Therefore we analyze and consider the R&D project structures of these companies reported as important in technology development using patent information that is considered to indicate technology development capabilities in this paper.

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5. Research Methods

5.1. Patent Information and Patent map

Patent documents are an ample source of technical and commercial knowledge. The patent is one of the indicators of capacity for technological development. There are some researches aimed at visualizing and analysing patents, or proposing efficient text-mining approaches for creating patent maps (Arai, 2003; Chen et al., 2018). Therefore, patent information is used as indicator of R&D capability in this research. All Japanese patent information is managed in the Patent Information Platform (J-PlatPat) operated by the Japanese Patent Office and everyone can search, browse and download the patent information. All patents are classified according to each of three classification codes, IPC (International Patent Classification), FI (File Index) and F-term (File Forming Term). In this research, all patent publications related to autonomous vehicle based on both of following conditions from 1990 to 2015 are collected, as in the case of previous research.

((AUTONOMO+ AND CAR) OR (UNMAN+ AND VEHICLE) OR (DRIVERLESS AND (CAR OR VEHICLE)) OR (SELF-DRIV+ AND (CAR OR VEHICLE)) in Claim
B60W in IPC code

There are following three ways to analyze patent information.

(1) Quantitative analysis: An analysis method to grasp patent information as the number of applications, the number of inventors, the number of keywords, etc.

(2) Qualitative analysis: A method of analyzing patent information based on the technical content.

(3) Correlation analysis: A method to analyze the existing relationship between patent information.

End product manufactures, component suppliers and the ICT industry have entered the automated driving industry. Therefore, we investigate trends in the number of patents and technology development by each industry using heat maps and changes of core technology using HITS algorithm in this research. Specifically, we will clarify the characteristics of technological development and changes in core technology in these three industries. The list of companies in each industry is shown in the Table 3.

Table 03. List of companies in each industry

Industry	Companies
End product manufactures	TOYOTA JIDOSHA KABUSHIKI KAISHA, FORD GLOBAL TECHNOLOGIES LLC, GM GLOBAL TECHNOLOGY OPERATIONS LLC, NISSAN MOTOR CO LTD, HONDA MOTOR CO LTD, TOYOTA MOTOR ENGINEERING MANUFACTURING NORTH AMERICA INC, AUDI AG, JAGUAR LAND ROVER LIMITED, HYUNDAI MOTOR COMPANY, TOYOTA MOTOR CORP, VOLVO TRUCK CORPORATION, VOLVO CAR CORPORATION, GM GLOBAL TECHNOLOGY OPERATIONS INC, DAIMLER AG, KOMATSU LTD, VOLKSWAGEN AG and etc.
Parts supplier	AISIN AW CO LTD, GENERAL ELECTRIC COMPANY, DENSO CORPORATION, HERE GLOBAL B V, ZF FRIEDRICHSHAFEN

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	AG, ALLISON TRANSMISSION INC, CONTINENTAL TEVES AG - CO OHG, SUPERPEDESTRIAN INC, JATCO LTD, PAICE LLC, LUK LAMELLEN UND KUPPLUNGSBAU BETEILIGUNGS KG and etc.
ICT	GOOGLE INC, FLEXTRONICS AP LLC, AUTOCONNECT HOLDINGS LLC, NTERNATIONAL BUSINESS MACHINES CORPORATION, MOBILEYE VISION TECHNOLOGIES LTD, HITACHI LTD, HITACHI AUTOMOTIVE SYSTEMS LTD, INTEL CORPORATION, WAYMO LLC, MAGNA ELECTRONICS INC, SONY CORPORATION, VISION WORKS IP CORPORATION, FTS COMPUTERTECHNIK GMBH, ZETTA RESEARCH AND DEVELOPMENT LLC - FORC SERIES, ATIGEO CORP, CISCO TECHNOLOGY INC, CONTINENTAL AUTOMOTIVE SYSTEMS INC, FORD GLOBAL TECHNOLOGIES, FUJITSU TEN LIMITED and etc.

5.2. HITS Algorithm

The HITS algorithm is a method to extract highly important information by performing link analysis (Kleinberg, 1999). The Authority indicates what has important information and the Hub, and the Hub indicates what is linked to the Authority. The Authority Score and Hub Score are extracted by repeating the following equations.

$$Auth(p) = \sum Hub(q)$$

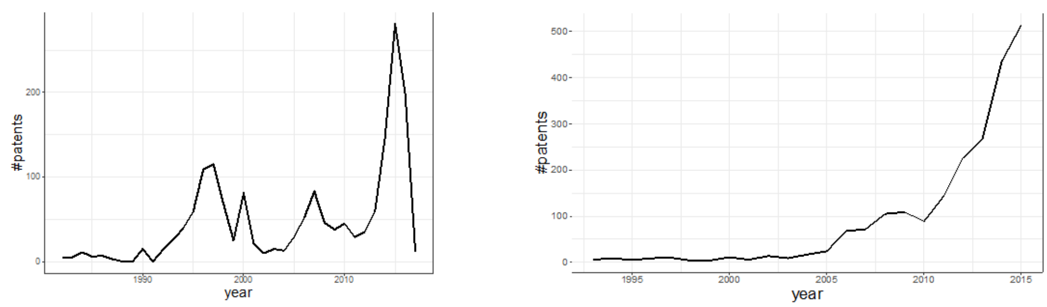
$$Hub(p) = \sum Auth(q)$$

In the above equation, q means the score before the evaluation, and p means the score after the evaluation. Therefore, there are relation that a good authority is linked by multiple good hubs, and a good hub is linked by multiple good authorities. In this research, we apply this HITS algorithm to a patent citation network to extract core technologies that are attracted attention from other companies in the industry.

6. Findings

6.1. An Approach Based on the Number of Patent Publications

As our first approach, the numbers of patent publications related to R&D of autonomous vehicle in Japan and U.S. are shown in Figure 4. The horizontal axis represents the year, and the vertical axis represents the number of patents based on application year in the figures.



(a) The number of patents in Japan (b) The number of patents in U.S.

Figure 04. The number of patent applications related to autonomous vehicle

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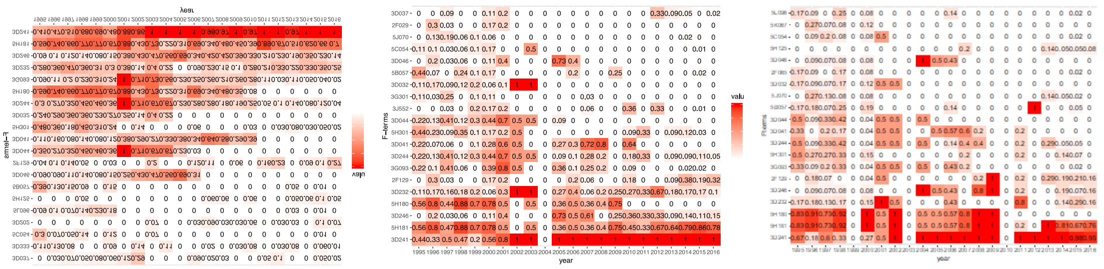
The number of applications for Japanese patents increased around 1997 and then decreased, but it can be seen that the number of patents increased sharply with the development of AI and image processing technology in 2015. Looking at the change in the number of English patents, it can be seen that the number has gradually increased since around 2005, and has grown rapidly in recent years. By these figures, it can be understood that interest in automatic vehicle development has increased.

6.2. An Approach Based on the Research Fields

6.2.1. Research Fields in Japanese Patent

Heat maps that is represented the R&D fields based on patents by each industry in Japan are shown in Figure 5. The region where the color is dark red in the heat-map indicates that the technology development factor is highly focused in the figures. The vertical axis in the figures uses F-term with a large number of occurrences in their patents. The degrees of emphasis in the all industry are increased in 3D241 (related to control of drive devices and motor control of vehicles), which is an essential element in automatic driving technology, in the 2000s. It can be seen that end product manufactures have begun a wider range of technology areas than other industries by the industry comparison. In addition, there is a feature that the start area differs according to each industry.

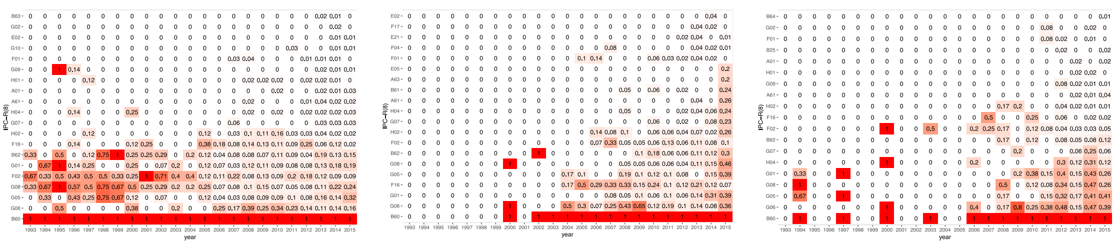


(a) End product manufactures (b) Parts suppliers (c) ICT

Figure 05. Heat maps on Research fields in Japan

6.2.2. Research Fields in U.S. Patent

Heat maps that is represented the R&D fields based on patents by each industry in U.S. are shown in Figure 6. IPC is used in the figures because F-term deals with only Japanese patent documents. As a result, it can be seen that there is no involvement in the R&D for autonomous vehicle in the 1990's without end product manufactures. However, the R&D fields are expanding in the parts supplier industry and the ICT industry unlike the heat map of the Japanese patent.



(a) End product manufactures (b) Parts suppliers (c) ICT

Figure 06. Heat maps on Research fields in U.S.

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6.3. An Approach Based on the Core Technology

6.3.1. Autonomous Level of Core Technology

The automatic operation levels of the top 30 core technologies in every year that is applied HITS algorithm to citation network are shown in Figure 7. The core technology that corresponds to the level 1 of automatic operation is red, the core technology that corresponds to the level 2 is yellow, and the core technology that corresponds to the level 3 automatic operation is green in the figure. Patents for driving assistance, steering wheel operation, emergency accident prevention, navigation in order to cope with level 2 (system supports both steering operation and acceleration / deceleration) are ranked in almost every year. Also, there are some patents for toll road charging on freeway and IC merging devices since 2000. Therefore, there is a possibility that autonomous driving level 3 (the system operates all at a specific place except emergency) can be realized on a freeway.

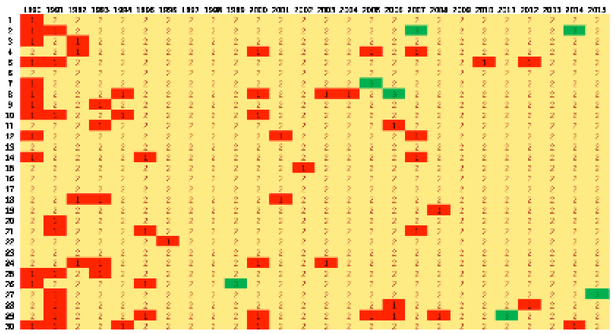
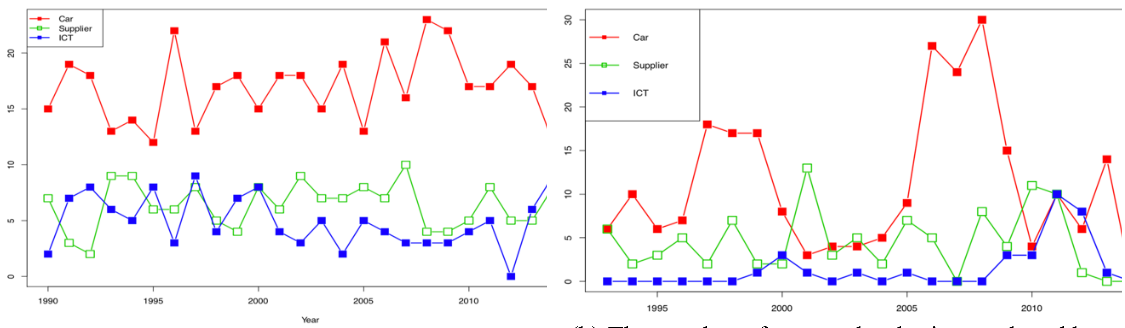


Figure 07. Heat maps on Research fields in U.S.

6.3.2. Transition of Leading Companies

The trends in the number of patents by each industry in the top 30 major technologies are shown in Figure 8. It can be seen that almost all major technologies were generated by end product manufacturers. In addition, the technologies produced by the ICT industry fell temporarily in the 2000s, but their technology constructed around 2015 has gained much attention.



(a) The number of core technologies produced by each industry in Japan

(b) The number of core technologies produced by each industry in U.S.

Figure 08. Heat maps on Research fields in U.S.

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6.4. Discussion

Autonomous vehicle technology involves various technologies. So, not only companies of automotive manufacturers, but also automotive suppliers, and ICT companies can be major in certain areas of autonomous vehicle technology. Using HITS algorithm, we find most of the top thirty companies of automotive driving patent ranking are automotive manufacturers. Autonomous vehicle technology involves not only automotive technologies, but also various technologies. But it is said that the most major cost of building cars is factory of automotive manufacturers, not materials. And for development of products, technological development of manufacturing is needed. So, even in era of autonomous vehicles, the importance of technology of automotive manufacturers will be still high.

7. Conclusion

We analyze and consider the R&D project strategies of these companies by using patent information. First, our line graph shows R&D activities in autonomous vehicles are increasing recently. Second, our heat map about R&D activities in automotive manufacturers, automotive suppliers, and ICT companies shows R&D activities in automotive manufacturers are wide. Third, since 2000, R&D activities of 3D241(related to control of drive devices and motor control of vehicles) in these three industries are lively. Fourth, using HITS algorithm, we find most of the top thirty companies of automotive driving patent ranking are automotive manufacturers. Fifth, since late 1990s, R&D activities in automotive suppliers and ICT companies are lively. Finally, R&D activities in ICT companies once have declined, but since 2015, R&D activities in ICT companies are lively. For further study, we analyze and consider the cooperation between industries and companies.

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