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Data Analysis of High-Capacity Vehicles By Machine Learning For Sustainable Logistics in Japan

Japonya'da Sürdürülebilir Lojistik İçin Makine Öğrenimi ile Yüksek Kapasiteli Araçların Veri Analizi

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ABSTRACT

In recent years, the Japanese logistics industry has been facing an increase in freight transportation demand and a serious shortage of truck drivers. To address the labor problems and improve efficiency for sustainable logistics, trucks with double trailers whose length is over 21 meters were introduced. They are called longer and heavier vehicles (LHV) or high capacity vehicles (HCV). In this study, the driving characteristics of the high capacity vehicles will be studied by applying k-means clustering algorithm in machine learning and geographic information system. The data used in this study were obtained from the experimental runs between October 2017 and July 2018, conducted by the Ministry of Land, Infrastructure, Transport and Tourism. Before k-means clustering algorithm is applied, the elbow method is applied to find the optimal number of clusters and the silhouette coefficient is calculated to evaluate the quality of clusters which indicates how well the data are clustered. By k-means clustering, the data are grouped into different clusters. The resultant clusters are visualized in the geographic information system. The clusters are studied and compared how the driving characteristics of the trucks differ in each cluster and how the characteristics correlate to each other. This study is focused on the heart rates and the fluctuations throughout the trip. The outliers of high heart rates and the associated characteristics are identified how they occur and in which areas the drivers can suffer stress. The emphasis is given to the comparison of the drivers' heart rates recorded near the logistics facilities.

Keywords: High-capacity vehicles, k-means clustering, heart rate, truck speed.

ÖZ

Son yıllarda, Japon lojistik endüstrisi yük taşımacılığı talebinde bir artış ve ciddi bir kamyon sürücüsü sıkıntısı ile karşı karşıyadır. İşgücü sorunlarını çözmek ve sürdürülebilir lojistik için verimliliği artırmak için, uzunluğu 21 metreden fazla olan çift römorklu kamyonlar tanıtıldı. Bunlara daha uzun ve ağır araçlar (LHV) veya yüksek kapasiteli araçlar (HCV) denir. Bu çalışmada makine öğrenimi ve coğrafi bilgi sisteminde k-ortalama kümeleme algoritması uygulanarak yüksek kapasiteli araçların sürüş özellikleri çalışılacaktır. Bu çalışmada kullanılan veriler, Kara, Altyapı, Ulaştırma ve Turizm Bakanlığı tarafından yürütülen Ekim 2017 ile Temmuz 2018 tarihleri arasındaki deneysel koşulardan elde edilmiştir. K- ortalama kümeleme algoritması uygulanmadan önce, en uygun küme sayısını bulmak için dirsek yöntemi uygulanır ve verilerin ne

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kadar iyi kümelendiğini gösteren kümelerin kalitesini değerlendirmek için siluet katsayısı hesaplanır. K-means kümeleme ile veriler farklı kümeler halinde gruplandırılir. Elde edilen kümeler coğrafi bilgi sisteminde görselleştirilir. Kümeler incelenir ve kamyonların sürüş özelliklerinin her kümede nasıl farklılık gösterir ve özelliklerin birbirleriyle nasıl ilişkili olduğu karşılaştırılır. Bu çalışma, yolculuk boyunca kalp atış hızlarına ve dalgalanmalara odaklanmıştır. Yüksek kalp atış hızlarının aykırı değerleri ve ilişkili özellikler, nasıl meydana geldiği ve sürücülerin hangi alanlarda strese maruz kalabileceği tespit edilir. Lojistik tesislerin yakınında kaydedilen sürücülerin kalp atış hızlarının karşılaştırılmasına vurgu yapılır.

Anahtar Kelimeler: Yüksek kapasiteli araçlar, k-kümeleme, kalp atış hızı, kamyon hızı.

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1. INTRODUCTION

1.1. Background of High Capacity Transport

The International Transport Forum (ITF, 2019a) speculates that developments in merchandise trade drive the higher demand in freight transport. It is forecasted that the total freight transport demand will be increased three times from 112 000 to 329 000 billion t-km from 2015 to 2050. The annual global road freight transport demand is estimated to increase 3.2% from 2015 to 2030, and 2.8% from 2015 to 2050 (ITF, 2017b). This increase in demand will be mainly driven by continued economic growth and international trade (ITF, 2019a).

According to ITF (2019b), decarbonization of freight transport has become one of political priorities to achieve Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development, adopted by the United Nations General Assembly. Two sets of approaches to decarbonizing freight transport are identified by ITF. The first method is through engineering and technological solutions by improving energy efficiency and switching to alternative low- or zero-carbon emission energy sources. The second approach comprises of logistical, managerial, behavioral and regulatory solutions. The solutions include reducing the number of freight vehicle movements, shifting to lower carbon emitting transport modes, and improving road freight efficiency by raising load factors. The first approach will have a larger impact and improvement on the environment in the longer run while the latter can be applied to implement short-term solutions.

In addition, the Organization for Economic Co-operation and Development (OECD, 2011) estimated that the shortage of truck drivers will have an impact on the future of road freight transport. OECD (2011) predicted that the increased demand for road transport increased the number of truck drivers required in the early part of 21st century. However, it was found that the supply of drivers could not match the demand of the industry. This result was not restricted to any particular region but applicable in countries such as the United States, Canada, Europe, and Australia (OECD, 2011). According to Australian Trucking Association (2003), one of the causes of truck drivers is the average age. Employees in the trucking business are found to be typically older than in other occupations. OCED (2011) again saw the similar data with Canadian trucking industry where truckers aged 55 and over outnumbered those under 30 for the first time in 2004.

To answer the problems of trade and freight traffic level increase, decarbonization of road freight transport, the availability of skilled drivers, and the limitation of existing transport infrastructure to accommodate the growth, ITF (2019a) speculated that high capacity vehicles (HCV) are a potential solution. They are sometimes referred to as longer and/or heavier vehicles (LHV) or high productivity vehicles (HPV). By the definition (ITF, 2019a), they are the freight trucks that are heavier and/or longer than vehicles currently permitted to operate on the general road network. By allowing HCVs, they can have better utilization of existing infrastructure, without additional pavement ware. Due to the ability to reduce freight movements, HCVs can reduce road freight transport costs for operators and consumers and produce lower emissions and less impacts on the climate. With developments in vehicle automation, the governments, the logistics industry, original equipment manufacturers (OEM), and IT (information technology) sector look forward to driverless road transport (ITF, 2017a). The concept ranges from truck platooning to full automation. Overall, high capacity transport (HCT) can provide a smarter, greener and safer road transport, and a more efficient use of transport infrastructure.

A study by ITF (2019a) have found that several countries have set up research programs, investigations, and committees to prepare policies and regulations to support introduction and implementation of high capacity transport. The policy study and development for HCT have been ongoing in countries such as Australia and the Netherlands as far as the early 2000s. Since the early 2010s, HCV introduction and regulations have been established in countries such as Australia, the Netherlands, Finland, Denmark, Sweden, Norway, Spain, Germany, Brazil, Argentina (ITF, 2019a).

1.2. Adoption of High Capacity Vehicle in Japan

In recent years, Japan has been facing similar issues in their logistics industry (Watanabe et al. 2021). With an increasing demand in freight transportation and a serious shortage of truck drivers, the Ministry of Land, Infrastructure, Transport and Tourism (hereinafter referred to either as the Ministry or MLIT) proposed to introduce high capacity vehicles (HCV) with double trailers of vehicle length over 21 meters to 25 meters. Not only HCVs but also autonomous driving and truck platooning were suggested to address the labor problems and improve the operation efficiency (MLIT, 2019). In October 2016, MLIT set up the council on experimenting HCVs with double trailers. Starting in November 2016, the trials began with 21m trucks. In 2017, experiments with trucks of vehicle length 25m started and were conducted till January 2019. The experiments were run by four logistics companies: Nippon Konpo Unyu Soko Co., ltd, Yamato Transport Co., Ltd, Fukuyama Transporting Co., Ltd, and Seino Transportation Co., Ltd. In January 2019, the Ministry relaxed the vehicle length from 21m to 25m and HCVs with double trailers were fully introduced to operate in Japan.

1.3. Purpose of Study

In this study, high capacity vehicle movement data from the trial experiments are studied. Using the truck movement data, the driving characteristics of high capacity vehicles will be analyzed by applying the geographic information system (GIS) and K-means clustering algorithm. The purpose of clustering is to differentiate how the driving characteristics can differ in various locations and which factors cause different truck movement behaviors. The study shall explore the high capacity vehicle deployment in Japan in detail, their impacts on freight movement, driver requirement, and the environment. Then, data collection, computation, and K-means clustering algorithm will be reviewed. Finally, the results after analysis will be discussed.

2. STATUS OF HIGH CAPACITY TRANSPORT IN JAPAN

2.1. High Capacity Vehicle Deployment in Japan

In Japan, road freight transport is the most common transport mode. Motor vehicles account for 91~92% of the total freight transportation movement while coastal vessels are responsible for about 7% of the freight transport while rail and air modes carry the rest 1% (Statistics Bureau of Japan, 2021).

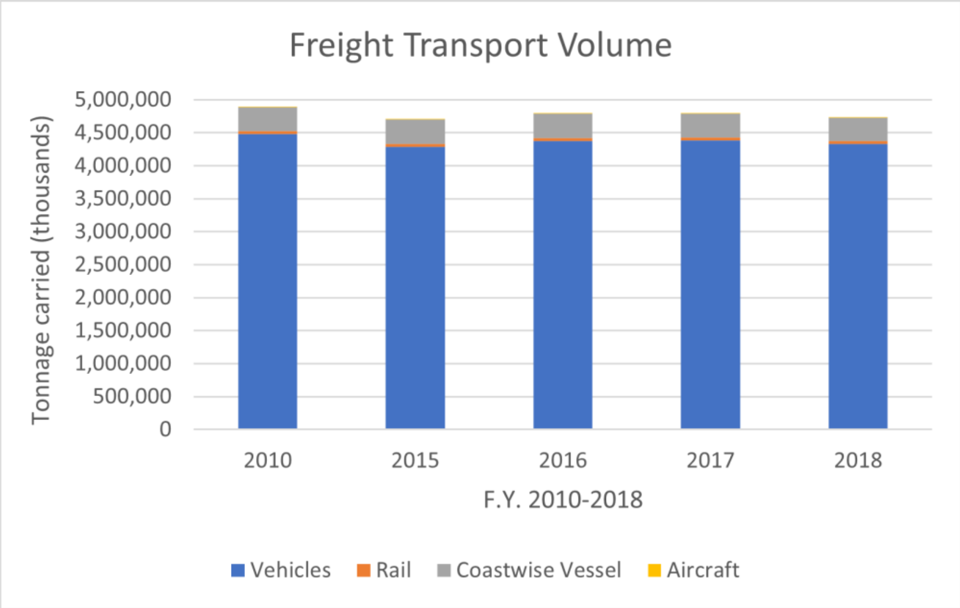

Figure 1. Freight Transport Volume in Japan (Source: Statistics Bureau of Japan, 2021)

A report by the Statistics Bureau of Japan (2021) shows that the average age of Japanese truck drivers is over 45. Large-sized truck drivers for business are aged average 48.6, small-sized or regular-sized truck drivers being 46.6, and the average age for private truck drivers is 47.7. Since about 40% of truck drivers are aged over 50 years old, and almost 70% being over 40 years old, trucking in Japan is severely under-staffed (MLT, 2019). To promote labor saving, MLIT experimented HCVs with double trailers which can transport freight capacity of two regular trucks with only one vehicle as well as truck platooning and autonomous driving.

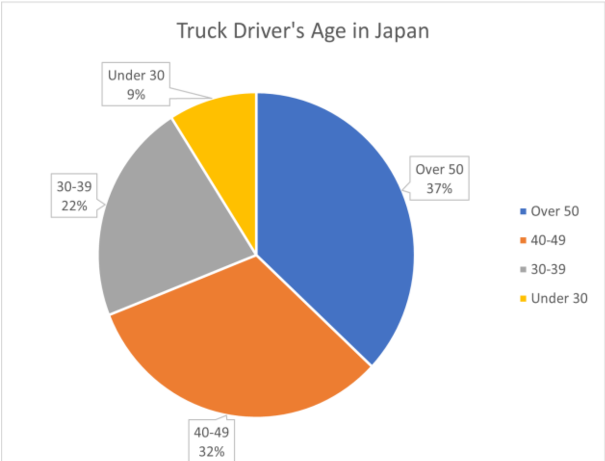

Figure 2. Truck Driver Age in Japan (Source: MLIT, 2019)

On 14 September 2016, the council for experimenting high capacity vehicles with double trailers was established by MLIT. The Ministry then called for participants to take part in the driving experiments.

On 22 November 2016, Nippon Konpo Unyu Soko Co., Ltd first started their driving experiments with 21m long trucks. On 17 March 2017, Yamato Transport Co., Ltd and Fukuyama Transporting Co., Ltd began experimental driving with 21m long trucks. Later in October 2017, trial runs were relaxed to 25m trucks with Fukuyama Transporting Co., Ltd starting the experiments on 16 October, which was later followed by Yamato Transport Co., Ltd experimenting on November 1st. In February 2018, Nippon Konpo Unyu Soko Co., Ltd began the trial driving of 23m long trucks. Finally in March 2018, Seino Transportation Co., Ltd started their experimental driving of 25m long trucks.

On January 29, 2019, the Ministry finally announced the relaxation of the special vehicle length from 21m to 25m and it was made possible to transport two normal heavy trucks with one vehicle. As a result, the full-scale introduction of high capacity vehicles with double trailers came into effect. The Ministry (2019) started to allow the operation of HCVs of 25m along the Shin Tomei Expressway between Ebina section and Toyota Higashi section.

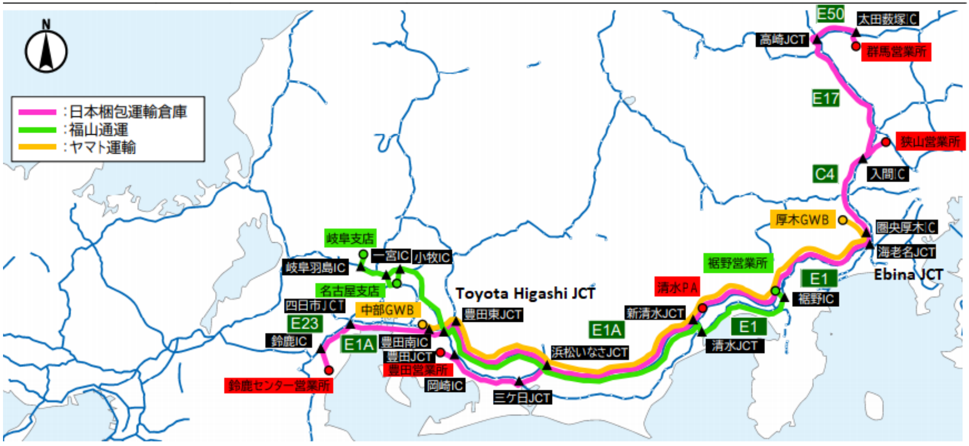

Figure 3. 21m HCV experiment route (Source: MLIT, 2019)

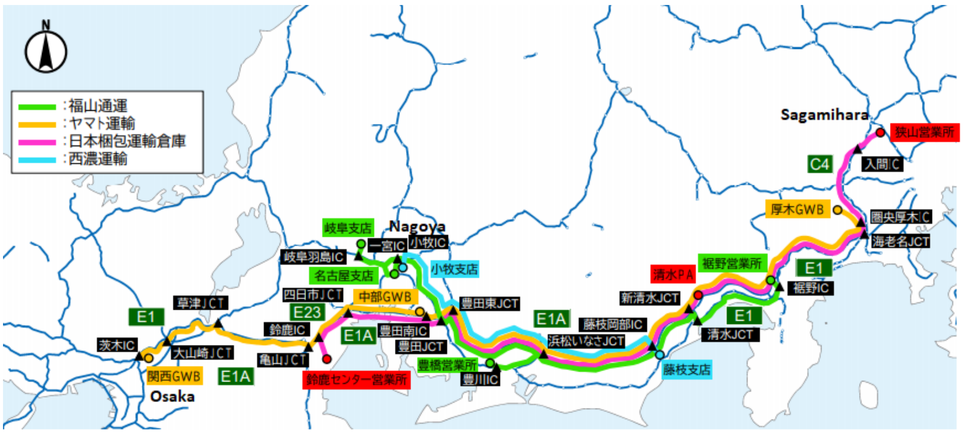

Figure 4. 25m HCV experiment route (Source: MLIT, 2019)

Based on the needs of the logistics companies, MLIT (2019) in August approved the expansion of operation routes for HCVs from Tohoku region in northern Japan to Kyushu region in western Japan along the Pacific coastline. The approved operation routes include the Tohoku Expressway, the Tomei Expressway, the Ken-O Expressway, the Meishin and Shin-Meishin Expressways, Sanyo Expressway, and Kyushu Expressway. The expansion route is as shown in Fig 4.

Figure 5. Expansion Route for HCV Operations (Source: MLIT, 2019)

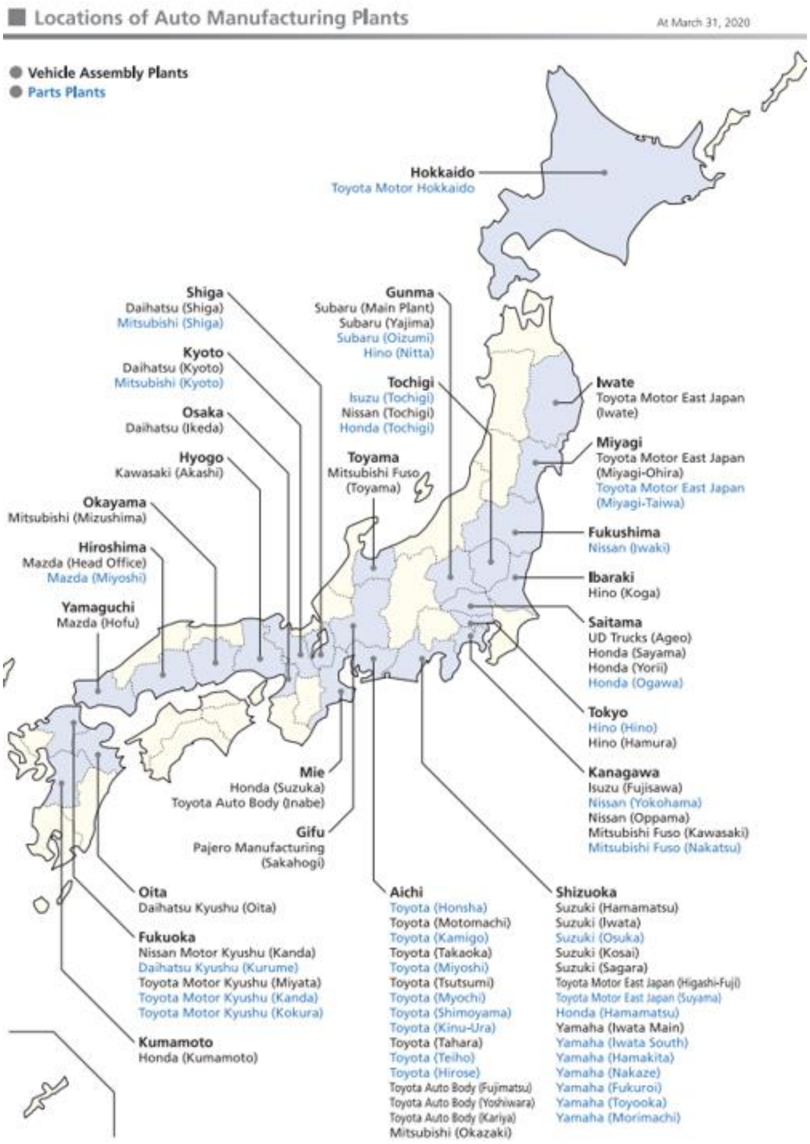

Figure 6. Automobile Manufacturing Plant Locations (Source: JAMA, 2020)

From a supply chain point of view (Japan Automobile Manufacturers Association (JAMA), 2020), logistics for automobile part suppliers and production plants is linked by wide-area transportation using expressways. In Japan, logistics is tended to high- frequency and low-volume transportation as the production systems are established based on JIT approach (just in time). Therefore, the expansion of the routes is closely related to the locations of automobile manufacturing plants for the distribution of automobile parts with HCVs as shown in Fig 6.

2.2. Economic Impacts

As the Ministry anticipated to address the problem of driver shortage in trucking by introducing HCVs, a positive result was produced in terms of driver requirements. Since both 21m and 25m long HCVs were experimented, a comparison of driver requirement in terms of different vehicles could be studied. It was found that HCVs could reduce the number of truck drivers required to 0.23 driver per 1000 t-km for a 21m HCV from 0.35 person per 1000 t-km for a normal 12m freight truck. In the case of an HCV over 21m, it was found to be further reduced to 0.18 driver per 1000 t-km (MLIT, 2019). Therefore, the reduction in the number of drivers required was found to be reduced about 50% for vehicles over 21m compared to normal freight trucks when they carry the same capacity.

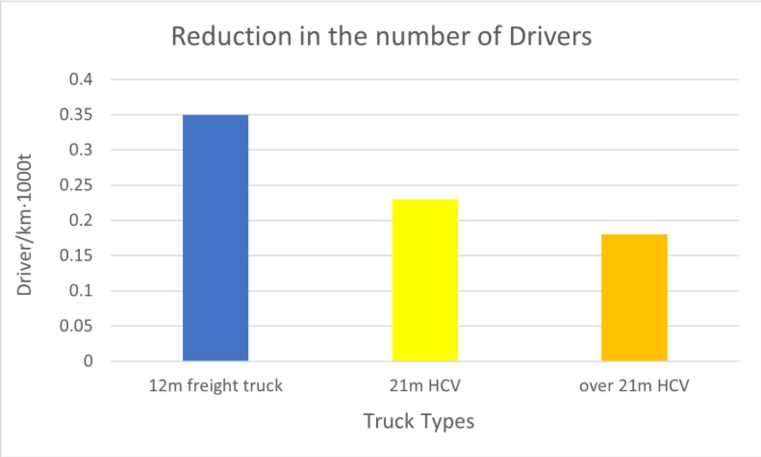

Figure 7. Comparison of the number of Drivers Required by Truck (Source: MLIT, 2019)

In addition to labor shortage problems, MLIT also aimed to improve working efficiency and their work environment by introducing the relay transportation system. The relay transportation is the system where the drivers would be exchanged at service areas or parking areas (SA/PA) to drive a truck instead of one driver driving the whole trip. In the case of one driver driving the whole trip, truckers would need to spend their break time at the lodging house at SA/PA whereas in the relay transportation system, drivers would be able to return home daily. MLIT (2019) saw that an average driver would spend 280 hours of rest at home and 90 hours of rest at a lodging house in the direct transportation without driver exchange, but a driver would have 370 hours of rest on average at home in the relay transportation. About 40% increased rest time was found in the relay transportation. MLIT interview results with relay transportation drivers found that 70% of truckers were in favor of being able to return home daily, felt physically comfortable due to little fatigue, and in favor of increasing the transfer service. Nemoto (2021) stated that the relay transportation is effective for long-distance trips and could become a factor that will bring in young people to trucking.

2.3. Environmental Impacts

In addition to labor saving and improving their work environment, HCVs had better impact on the environment in terms of CO2 emission and fuel consumption. The experiments by MLIT (2019) found that CO2 emission could be reduced about 40% when an HCV over 21m was used instead of a normal freight truck of 12m. MLIT saw the reduction in CO2 emissions to 39.1kg-CO2 per 1000 t-km in a 21m HCV from 56.6kg-CO2 per 1000 t-km. Emissions were further lowered to 32kg-CO2 per 1000 t-km when an HCV over 21m was used. In terms of fuel consumption, HCVs consumed less than about 44% (12.2L per 1000 t-km in an HCV of vehicle length over 21m) and 14.9L per 1000 t-km (about 31%) in an HCV of 21m, compared to 21.6L per 1000 t-km in a 12m freight vehicle.

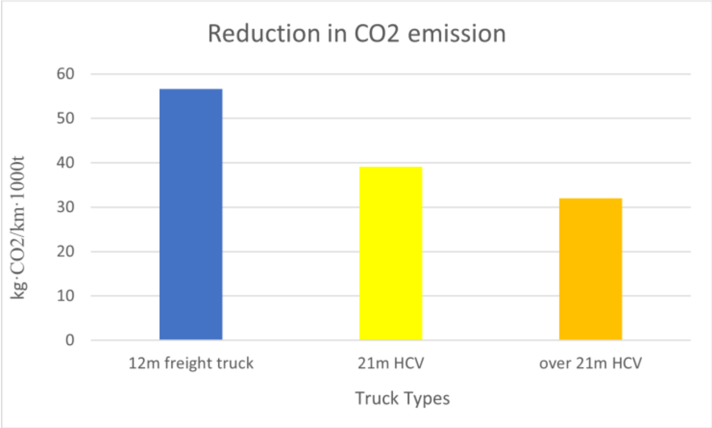

Figure 8. Comparison of CO2 Emission by Truck (Source: MLIT, 2019)

3. METHODOLOGY

3.1. Data Collection

The truck movement data used in this study were obtained from the HCV experimental runs conducted by MLIT and the Chubu Regional Development Bureau. The experiments which produced the results were conducted in October 2017, November 2017, and from March to July 2018. Table 1 shows the overview of vehicle type of each company.

The data were logged by using GPS (global positioning system) loggers, accelerometers, and heart rate sensors. Smartphones equipped with a GPS logger, a 3-axis gyro sensor, a rolling moment sensor were equipped in the front and rear of each truck. The equipment measured the following items of both tractors and trailers: location information, 3-axis accelerations and combined acceleration, and rolling and pitching. Drivers in the experiment wore wristwatch heart rate monitors equipped with GPS functions. The purpose of the monitors is to measure the psychological stress of drivers by recording the heart rates, location information, and truck speed. The equipment also recorded the date and time of the experiment, trip ID, the operating company and their driver ID. The equipment used in the experiments logged the data to the shortest time interval of one second.

There were a total of 151 experimental runs conducted by four logistics companies, and total 940736 data points were generated by the experiments. The data comes in a comma-separated value format (csv).

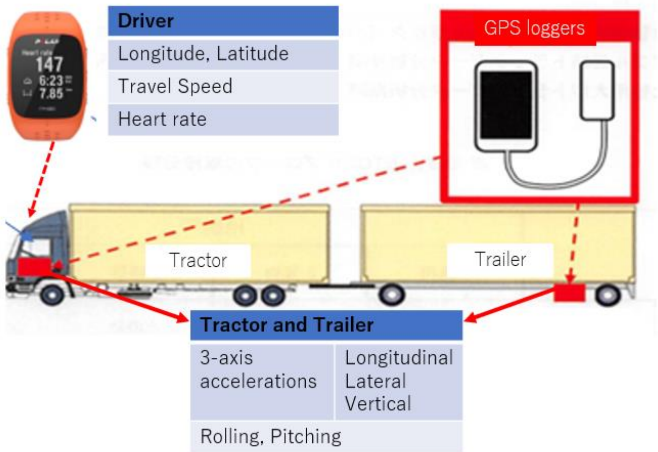

Figure 9. Data Logger on an HCV (Source: Watanabe and Hyodo, 2021)

Table 1. Attributes of HCVs in each company

Company Name	Length(m)	Height(m)	Width(m)	Axles in Tractor	Axles in Trailer	Max. Load Capacity(t)
A	24.975	3.79	2.49	4	2	26.3
B	24.995	3.78	2.49	4	2	26.3
C	22.965	3.79	2.49	4	3	27.8
D	24.790	3.79	2.49	4	3	26.3

Source: Soma and Hyodo, 2020.

3.2. K-means Clustering

In this study, K-means clustering algorithm was applied to analyze how the truck movement behavior could differ based on their running characteristics.

Clustering is one of the unsupervised machine learning techniques. Gupta (2019) defined clustering as the process of grouping similar entities together. It is the process of splitting the dataset into groups based on their similarity. K-means clustering is a centroid-based clustering algorithm, which clusters data with similar features together with the help of Euclidean distance (Prasad, 2020). K is the number of clusters to which the dataset will be clustered and assigned. In the algorithm, K value needs to be defined at first. The algorithm is initialized by placing the k centroids randomly in the dataset. Then each data point is calculated to one of the closet available centroids using the Euclidean distance. The centroids of each cluster are recalculated as a mean of data points assigned to the cluster. By this way, the algorithm is iterative; the centroid locations are updated constantly until no further changes occur. Finally, the updated centroid is the center of all points which fall in the cluster.

3.2.1. Elbow method for an optimal k value

One of the disadvantages of K-means clustering is the requirement to define the K value. Therefore, it is difficult to see whether the pre-input K value is the correct or appropriate value. One of the methods to calculate the optimal number of K value is called the Elbow method (Dabbura, 2018). The method provides the optimal number of clusters based on the sum of squared distances between data points and their assigned clusters' centroids. K value is decided at the point where the sum of squared distance becomes linear and flattens to form an elbow curve. The point at which the elbow shape gets formed is called the elbow point and is taken as the optimal K value for the clustering algorithm.

3.2.2. Silhouette coefficient for cluster evaluation

As the Elbow method calculates the K value for the optimal number of clusters, it is important to measure the accuracy or goodness of the clustering algorithm (Bhardwaj, 2020). In the clustering, the Silhouette analysis is applied for cluster quality evaluation. The goodness of a clustering technique is measured by a metric called the Silhouette Coefficient or Silhouette Score. The value of the coefficient lies between -1 and +1, which determines how well the objects are clustered. On approach to +1, it means the clusters are well apart from each other and they can be clearly distinguished. When the value approaches to 0, the clusters become indifferent, meaning the objects could overlap each other from another cluster. As the coefficient approaches to -1, the objects are not well clustered, and the clusters could be assigned in the wrong way.

3.3. Computation Environment

The calculations were carried out in the following environment. Spyder 1.4.1 IDE (integrated development environment) was the main IDE where the computations were mostly done. Python 3.8.3 was used as the main programming language. Moreover, the python packages were applied in computation processes: pandas 1.18.5 for data frame manipulation and analysis, matplotlib 3.2.2 for data visualization, and sklearn 0.23.1 for machine learning purposes. For the visualization purposes in this study, QGIS 3.10.13 A Coruna version was used.

4. FINDINGS AND DISCUSSION

4.1. K Value and Silhouette Score for Analysis

When the Elbow method is applied to the dataset of 940736 data points, the following elbow curve is produced as a result. In this curve, the elbow point is found to be at the K value of 5 as in Fig 10. The Silhouette score for k=5 is 0.26685947388019654. In terms of the cluster quality, the Silhouette score is not too high. In this study, k=5 is taken to further analyze the driving characteristics of high capacity vehicles.

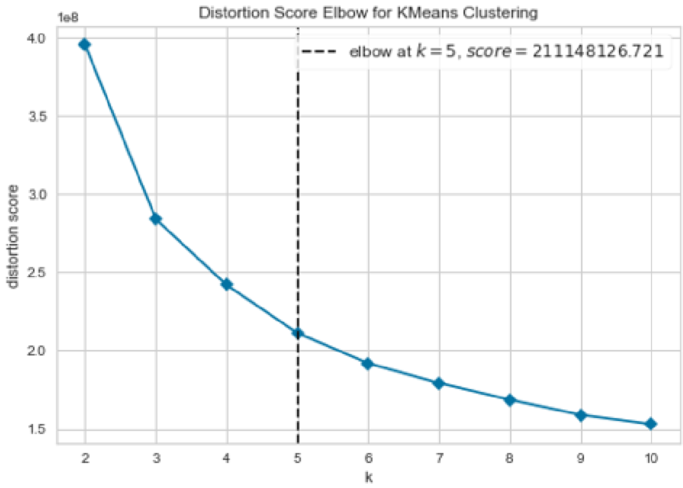

Figure 10. Elbow Curve Calculation Result

4.2. Cluster Descriptions

Fig 11 shows the resultant clusters of the k-means clustering analysis.

Figure 11. Resultant Clusters of HCVs

After clustering, the data are grouped in the following clusters as shown in Table 2.,

Table 2. Number of data points in each cluster

Cluster No.	The number of data points
1	266845
2	351355
3	85633
4	142174
5	94729

As depicted in Fig 11, cluster 1 (green) is present throughout the Tomei Expressway starting from Kanagawa prefecture to Nagoya city. Cluster 2 (light green) is also similarly exhibited throughout the Tomei Expressway. Unlike cluster 1, cluster 2 tends to show its characteristics near the urban areas on the said expressway such as Nagoya and on the urban roads near Osaka and Kyoto. Cluster 3 (red) is mostly exhibited in specific areas such as SA/PA, interchange areas or junction areas (IC/JCT), and logistics facilities located at the origin and destination. Cluster 4 (purple) exhibits their characteristics on the Shin-Tomei Expressway and the Isewangan Expressway starting from Shizuoka Prefecture to Mie Prefecture. Finally, cluster 5 (blue) is dominant on the urban roads located near the logistics facilities at the origin and destination. Their characteristics can be identified in areas such as Sagamihara, Nagoya, cities in Shizuoka Prefecture such as Numazu, Fuji, and Shizuoka, and Suzuka and Yokkaichi cities in Mie Prefecture.

4.3. Evaluation on Truck Speed and Heart Rates

After clustering the dataset, two of the most differentiating driving characteristics in HCVs are found to be the truck speed and the driver's heart rate. As it is already described above that clusters 1, 2 and 4 are present on the expressways, the truck speeds show the similar values with their average speed around

72 km/h. Since cluster 5 is present throughout the urban road networks, its average speed is about 41 km/h. For cluster 3 which exhibits near SA/PA and logistics facilities, trucks run the slowest.

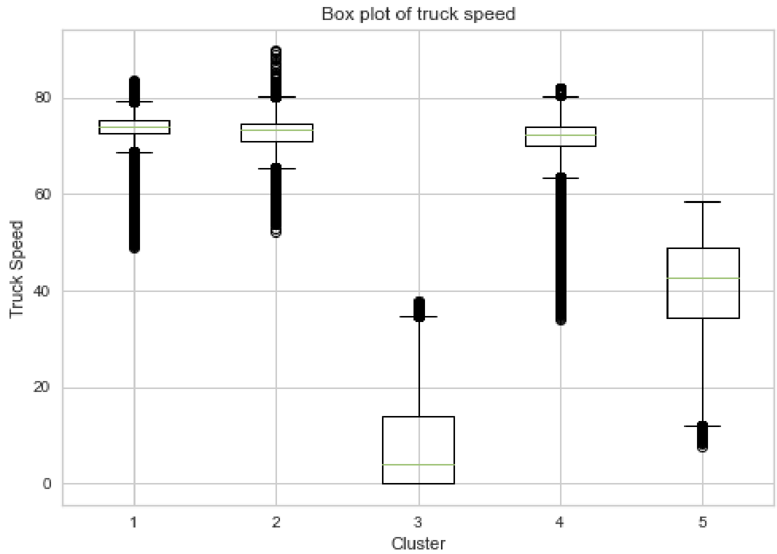

Figure 12. Box Plot of Truck Speed by Each Cluster

Fig 13 shows the boxplot of the driver's heart rates among the clusters. Although the clusters 1, 2 and 4 are exhibited mostly on the expressways and the trucks run at similar speeds, the heart rates of the drivers experienced are found to be different from each other. In cluster 1, the drivers tend to experience lower average heart rates (64.59 bpm) than in cluster 2 (82.92 bpm). However, the drivers experience the highest mean heart rates in cluster 4, which averages 102.55 bpm and outliers over 120 bpm can also be identified in this cluster. In cluster 3, the average heart rate of drivers is 95 bpm, and the outlying heart rates over 140 bpm and as low as around 40 bpm also detected in the cluster. However, in cluster 5, the average heart rate tends to be 77 bpm.

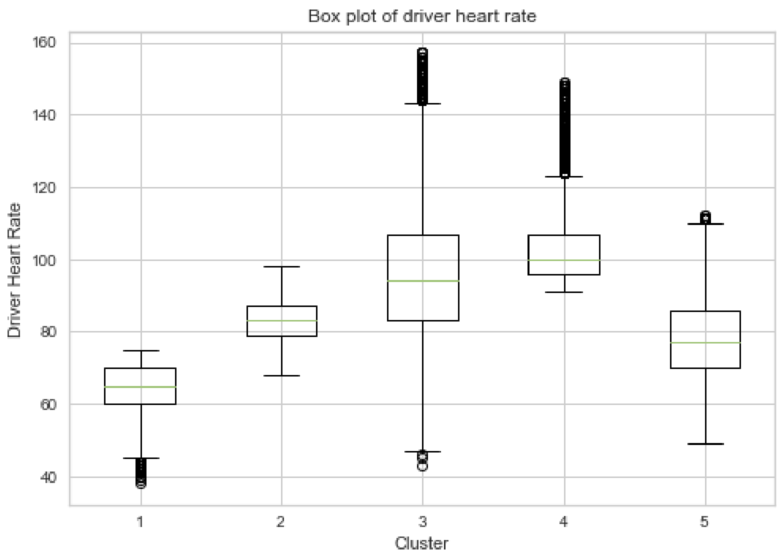

Figure 13. Box Plot of Heart Rate by Each Cluster

4.4. Detecting Outliers in Heart Rate

Soma and Hyodo (2020) studied the driver stress related to the high acceleration of longer and heavier vehicles and the safety of truck operation. In the study, RRI analysis, the high stress related to the high acceleration data and their relations were primarily focused. In this study, outlying heart rates obtained after clustering analysis will be observed.

The outliers in the clusters 3 and 4 are selected and visualized on the map as shown in Fig 14. After visualization, the outliers in cluster 3 are found to be located near Shimizu PA on the Shin-Tomei Expressway and 2 company C logistics facilities in Suzuka area (Koucho logistics facility and Misonocho logistics facility) on the normal roads to Suzuka city. The heart rates are recorded over 143 bpm. The outliers in cluster 4, whose recorded heart rates exceed 124 bpm, are present throughout the Shin-Tomei Expressway and the Isewangan Expressway in Aichi prefecture and Mie Prefecture.

Figure 14. Outliers in Heart Rate

4.4.1. Comparison of the heart rates around the logistics facilities

The outliers in heart rates detected in the clusters 3 and 4 are suffered by company C drivers. In this context, the average heart rate of the driver throughout the trip is calculated to check how they vary among 151 experimental trips. The result shows that the average company C driver tends to suffer higher heart rates compared to the drivers of other companies. All the company C experimental trips were conducted along the Shin-Tomei Expressway and most of their trips were run between the Shimizu PA and their logistics facilities in Suzuka area.

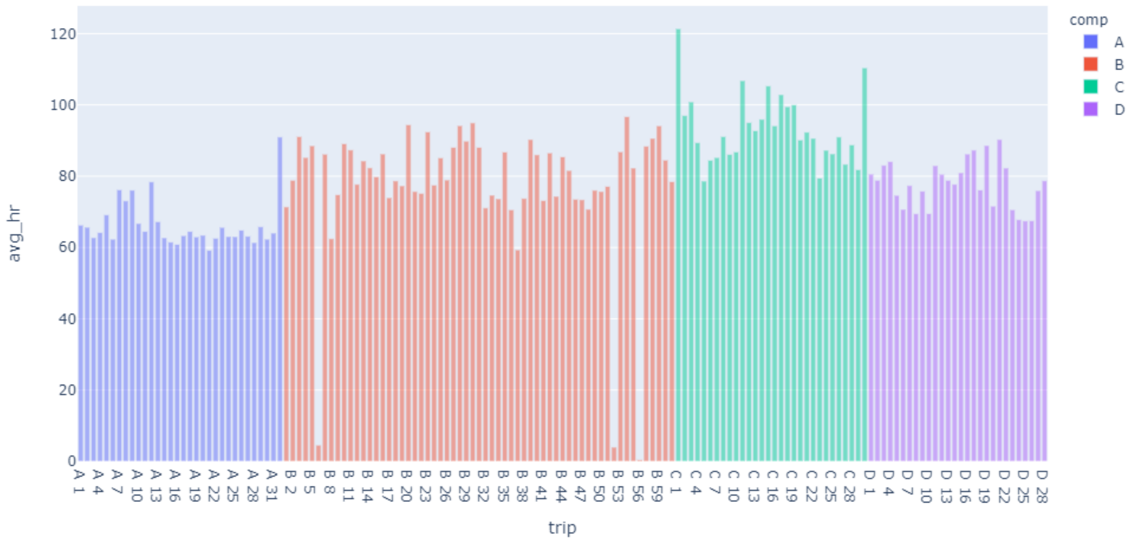

Figure 15. Average Heart Rate Comparison by Trip

Therefore, the average heart rates detected near the logistics facilities and the origin locations where trucks departed and arrived are further explored in this study. Company C's Koucho facility, Misonocho facility and Shimizu PA, company B's Atsugi facility, Nagoya facility and Kansai facility, and company D's Fuji-shi, Numazu-shi, Yaizu-shi facilities in Shizuoka Prefecture, Nagoya facility and Yokkaichi facility are selected in this study.

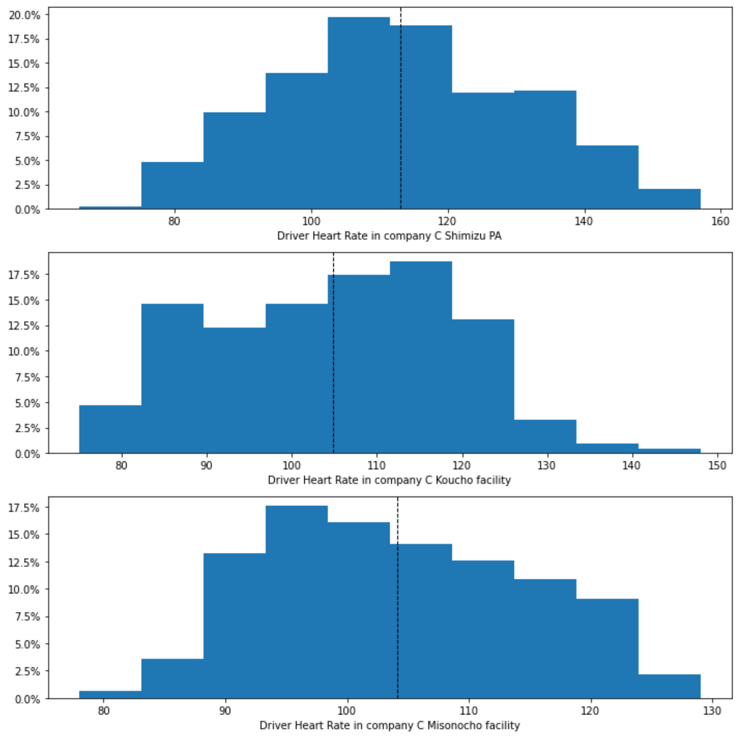

Figure 16. Driver Heart Rate in company C Facilities

As shown in Fig 16, it is found that company C drivers tend to experience the higher heart rates at the departure and arrival points of their facilities and they range from 80 bpm to 157 bpm. At Shimizu PA, they show the high heart rates up to 157 bpm and at their Suzuka area facilities, the drivers heart rates are found to be higher over 100 bpm (over 60%).

In the case of company B, the drivers experience their heart rates, ranging from 60 bpm to 130 bpm. In their Nagoya and Kansai facilities, the driver exhibits the average of 90 bpm, and the heart rate distributions at those facilities are found to be normal. In Atsugi facility, the drivers could experience higher heart rates, averaging 100 bpm, which covers over 65% of the observations.

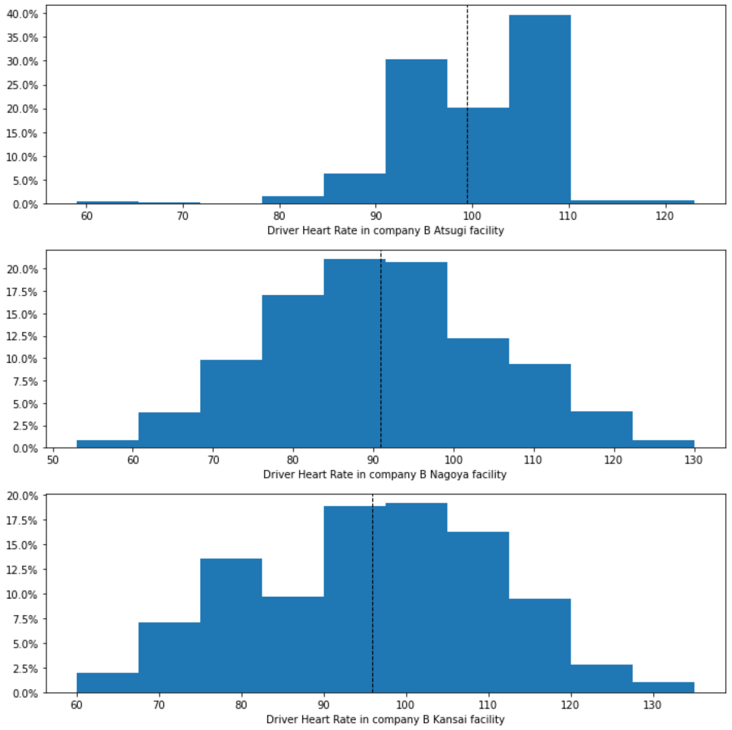

Figure 17. Driver Heart Rate in company B Facilities

In company D facilities, the drivers tend to show lower heart rates compared to the rest company facilities which range as low as 70 bpm to 130 bpm. Among 3 facilities in Shizuoka Prefecture, the average heart rate drivers suffer is around 77 bpm and about 20% of the heart rate distribution is over 80 bpm at Fuji-shi facility. In Numazu facility, the higher heart rates tend to occur and Yaizu facility show the average lower heart rates. The average heart rate at company D's Nagoya facility is found to be similar to that of company B, averaging over 90 bpm. The drivers in Yokkaichi facility tend to exhibit the average heart rate of 94 bpm but overall, their maximum bpm does not exceed over 120 bpm among all company D facilities.

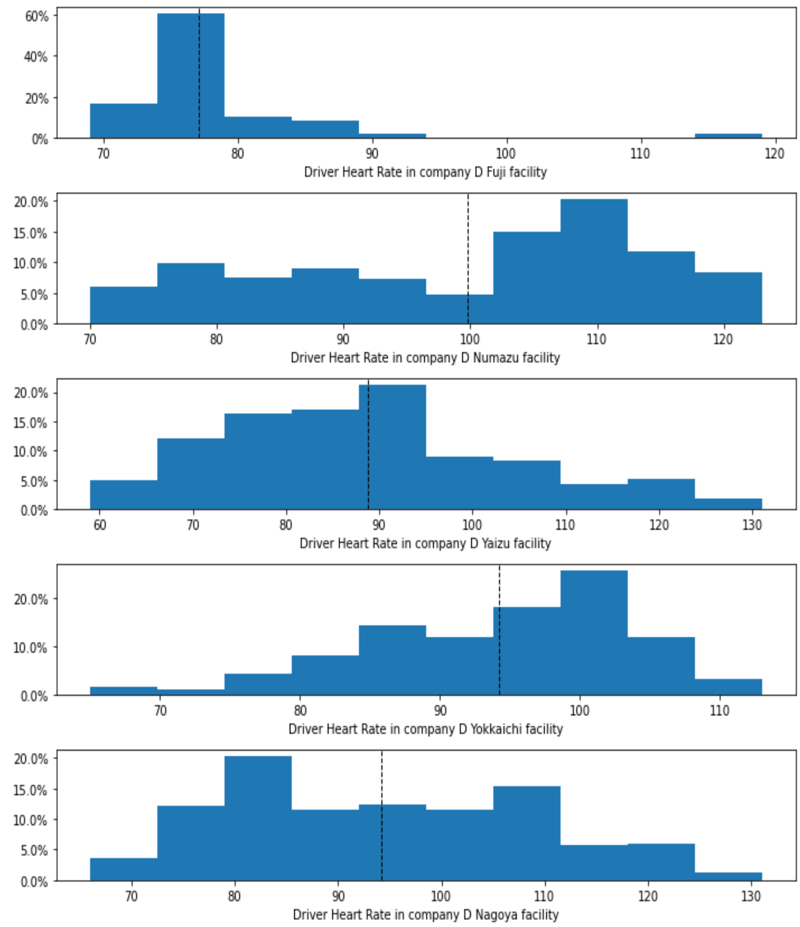

Figure 18. Driver Heart Rate in company D Facilities

5. CONCLUSIONS

In this study, the trends in road freight transport which led to the adoption of high capacity vehicles was explored and the current status of high capacity transport in Japan was studied. In addition, the driving characteristics of high-capacity vehicles in Japan were analyzed by applying the k-means clustering algorithm.

Economic developments, considerations for sustainable environment and the availability of skilled drivers in the trucking industry have led to the adoption of high capacity transport in road freight transportation. High capacity transport applies both HCVs with longer trailers and advanced technology which leads to innovation of autonomous driving in freight transport as well as truck platooning. The trend is on the rise in OECD countries and several countries have implemented the regulations and practices for high capacity road freight transport. Japan has started the experiments of HCVs with double trailers and truck platooning to address the issues of truck driver shortage. Positive results in terms of labor saving, fuel consumption and $CO2$ emissions were produced in the experiments. The data obtained from the experiments were used to study for clustering analysis in this research. In this study, k=5 was selected to create 5 clusters to study the running characteristics of the truck experimental data. From the results of the analysis, it was discovered trucks tend to exhibit different driving behaviors from each cluster. Even though the trucks' speed show similar values in different clusters, their average heart rates vary from each cluster. The varying heart rates are found to depend on the locations and the expressways they operate on. In addition, only one company exhibits higher outliers in heart rates and their route is operated solely by them. Therefore, further research in vehicle and trailer type used, their logistics facility location and design, and the truck entry and exit behavior at the facilities should be studied.

The authors believe that different results can be expected in case the different k values are applied in the analysis so it is suggested that such difference should be studied by applying each k value. Moreover, other clustering algorithm can also be applied in the study to check how the driving characteristics could differ.

The analysis was done by applying the available variables contained in the dataset. Further analysis can be expanded by studying the 3-axis acceleration and the combined acceleration data that are already applicable in this dataset. From the acceleration analysis, the study of acceleration impacts on cargo safety can be continued. The authors believe that further analysis could be conducted if more attributes were available. Therefore, more analysis could be done on the types and amounts of freight carried in each experimental runs, the operating vehicle and trailer type, CO2 emission data with respect to time or the distance travelled. As HCVs are expected to become widely used, their impacts on road and other transport infrastructure and their applicability in densely populated urban areas would need to be further studied.

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