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İçindekiler/ Context **Sayfa/Page**

Special Issue on International Symposium of Sustainable Logistics

This is the first special issue of Toros University FEAS Journal of Social Sciences. The articles published in this issue were found eligible for publication by being subject to the blind peer-review process applied within the scope of journal publication rules from the papers presented at The International Symposium on Sustainable Logistics (SUSTAIN-LGSTS) held on April 30, 2021, hosted by Toros University in 2021. The International Symposium on Sustainable Logistics was held online in cooperation with Toros University Faculty of Economics, Administrative and Social Sciences Department of International Trade and Logistics and Tokyo University of Marine Science and Technology (TUMSAT) with the support of the Logistics Association (LODER).

The SUSTAIN-LGSTS symposium was held for the first time and attracted attention by researchers and industry representatives from home and abroad. 60 papers were sent to the symposium and as a result of the peer review, 31 of them were found suitable for presentation.

Papers within the scope of the symposium focused on Applied Logistics, Logistics in Business, Environmental Logistics, Agricultural Logistics. In this context, an academic discussion platform has been established.

•Professor. Dr. Tetsuro Hyodo, Tokyo University of Marine Science and Technology, <u>Title:</u> Urban Freight Survey and the Availability for Policy Measures in Tokyo Metropolitan Area.

•Ali Riza Ersoy, ION Academy, Founder, <u>Title:</u> Sustainable Future: Managing the Digital Transformation.

•Assoc. Prof. Dr. Daisuke Watanabe, Tokyo University of Marine Science and Technology, <u>Title:</u> Sustainable Maritime Transport (TBD).

•Assoc. Prof. Dr. Daniel Bumblauskas, University of Northern Iowa, <u>Title:</u> Blockchain in Food Distribution for Public Good

We hopefully that this special issue of Toros University FEAS Journal of Social Sciences will be fruitful to the all-academic world.

Toros University FEAS Journal of Social Sciences

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RESEARCH ARTICLE/ ARAŞTIRMA MAKALESİ

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Freight Transportation and the COVID-19 Outbreak: Fresh Insights from the US Economy

Yük Taşımacılığı ve COVID-19 Salgını: ABD Ekonomisinden Güncel İçgörüler

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Mehmet Aldonat BEYZATLAR[2]

ABSTRACT

This study performs empirical analyzes to reveal the causal relationship between freight transportation and COVID-19 measures for the United States with monthly time-series data for the period January 2020 and April 2021. The Toda-Yamamoto approach is used in this study to reveal the causality relationship between four freight transportation and two COVID-19 variables. The empirical results indicate a unidirectional causality running from both COVID-19 cases and deaths to freight transportation services index, air freight revenues, rail freight traffic, and Cass freight index. The findings of this study clearly show that cases and deaths of COVID-19 cause freight transportation activities as determining factors. These results also emphasize that the contagion deserves much more attention from public and private transportation professionals, who are responsible for the governance and the regulation of the transportation market.

Keywords: Freight transportation, COVID-19, Toda-Yamamoto, United States

ÖZ

Bu çalışmada, Ocak 2020 ve Nisan 2021 dönemi için aylık zaman serisi verileriyle Amerika Birleşik Devletleri için yük taşımacılığı ile COVID-19 ölçümleri arasındaki nedensellik ilişkisini ortaya çıkarmak için analizler ampirik analizler yapılmıştır. Bu çalışma kapsamında, dört yük taşımacılığı ile iki COVID-19 değişkeni arasındaki nedensellik ilişkilerini ortaya çıkarmak için Toda-Yamamoto yaklaşımı kullanılmıştır. Ampirik sonuçlar, hem COVID-19 vakalarından hem de ölümlerden yük taşımacılığı hizmetleri endeksine, hava taşımacılığı gelirlerine, demiryolu yük trafiğine ve Cass yük endeksine doğru tek yönlü bir nedensellik olduğunu göstermektedir. Bu çalışmanın bulguları, COVID-19 vakalarının ve ölümlerinin, yük taşımacılığı faaliyetlerine belirleyici faktör olarak neden olduğunu açıkça göstermektedir. Bu sonuçlar aynı zamanda, salgınların, ulaşım piyasasının yönetiminden ve düzenlenmesinden sorumlu olan kamu ve özel ulaşım profesyonellerinden çok daha fazla ilgiyi hak ettiğini vurgulamaktadır.

Anahtar Kelimeler: Yük taşımacılığı, COVID-19, Toda-Yamamoto, Amerika Birleşik Devletleri

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1. INTRODUCTION

World economies have struggled with the effects of an unexpected health crisis, which is called coronavirus disease 2019 (COVID-19, hereafter), that emerged at the end of 2019. The virus was first detected in December 2019 in China and later spread from one country to another and became a pandemic. On 11 March 2020, the World Health Organization (WHO) officially declared the COVID-19 outbreak as a pandemic due to the global spread and severity of the disease (Açıkgöz and Günay, 2020). The first confirmed case in the United States (US was reported on January 19, and the first recorded death related to COVID-19 in the US was on March 2 (Boettke, 2021). Moreover, the virus transmitting to other healthy people mostly in hospitals, houses, offices, supermarkets, public transportation as well as many people have been infected by the virus and unfortunately lost their lives, the lifestyle of people and economic activities and have reshaped depending on the conditions of the pandemic in countries. It has caused great public health and economic challenges to countries around the world (Osotimehin, 2020).

As the virus spread internationally, many countries have taken action to limit the spread, through social isolation policies, such as shutting educational institutions, limiting work, and restricting the mobility of people (Maliszewska et al., 2020). The increasing number of cases and deaths has obliged governments to take some important precautions and apply policies in many areas to control the outspread of the virus. At the end of February and early in March 2020, the number of COVID-19 cases has exponentially increased in Asia, Europe, and the USA and it has been caused by taking decisions border closures and quarantines by policymakers (Ivanov, 2020). As a result of social distancing, travel demand has dropped due to an increased amount of working from home, e-learning, and a reduced number of public activities and events (De Vos, 2020). Besides, regulations have closely affected the transportation sector both positively and negatively, depending on economic and social restrictions. Especially, freight transportation activities are directly related to the process of the pandemic because functioning supply chains are a major success factor for economic prosperity enabled by freight transportation in today's increasingly globalized world (Loske, 2020). According to the European Commission Report, before the virus outbreak, while it was estimated that passenger transport would have grown by 42% between 2010 and 2050, freight transport was expected to grow by 60% during the same period (EC, 2019). COVID-19 spread to the world and became a pandemic, the transportation sector has been affected directly within the demand-supply and indirectly via economic effects. On the other hand, medical equipment is transported to countries with road, maritime, rail, and air shipments. US airlines have played a key role in providing cargo services to address the shortfall of medical supplies during the COVID-19 pandemic (Bartle et al., 2021). Besides, it has increased the importance in terms of transporting vaccines because it is provided to the time and optimum temperature while vaccines are distributing across the globe by transportation modes.

Considering the effects of the pandemic on the transportation industry, this study tries to reveal the causal relations between freight transportation and COVID-19 measures in the US. The study aims to answer the following research question in general: What is the causal relationship between the US freight transportation and COVID-19 statistics over the period from January 2020to April 2021? Especially, this paper empirically aims to analyze the impact of COVID-19 on freight transportation activities in the US economy, using the Toda and Yamamoto (1995) approach of Granger-causality. The study concentrated on the US as the sample country because: (i) the US has been one of the most affected countries by the COVID-19 pandemic, (ii) data availability of high frequency (monthly) and various freight transportation measures, and (iii) to monitor the indirect effects of economic policies for preventing the negative impacts of pandemic via freight transportation measures. By using causality analysis within the US freight transportation and COVID-19 measures as economic indicators, can show the reflections of the fluctuations in the number of confirmed cases and deaths of the COVID-19 to the US freight transportation measures.

The remainder of this paper is structured as follows. In section 2, a brief review of the literature is provided. Section 3 introduces the data and empirical methodology. Empirical findings are represented in Section 4. Finally, Section 5 concludes the paper.

1. LITERATURE REVIEW

The literature accumulation is increasing in COVID-19 studies, which are revealing the impact of the pandemic on economic activities, include various approaches to the transportation industry. While some studies are emphasized on negative impacts of COVID-19 on freight transportation, findings of the other studies are examined that there is a positive impact of the pandemic. Bombelli (2020), Cui et al. (2021), Ho et al. (2021), and Loske (2021) analyzed how freight transportation is affected by the economic results of the COVID-19, depending on the confirmed cases and deaths. For example, Ho et al. (2021) found that COVID-19 has a positive impact on the road freight transport turnover with the multi-region demand model, using monthly panel data of 13 Chinese provinces over the period from December 2019 to August 2020. Loske (2021) examined that the increasing freight volume for dry products in retail logistics does not depend on the duration of the COVID-19 pandemic but on the strength quantified through the total number of new infections per day, including 208 countries around the world between December 31, 2019, and April 30, 2020, as daily.

Besides, each form of freight transportation is affected differently from the COVID-19 statistics in terms of the supply-demand chain in the economy. Bouali et al. (2020), Danışman and Akkartal (2020), Gray and Torshizi (2021), Li (2020), and Vida et al., (2021) examined the relations between freight transportation modes and the COVID-19 pandemic to reveal the situation of the intercountry economic activities. Bouali et al. (2020) analyzed that volume of air freight decreased because of the closure or limited working of factories and only continuing to the transportation of medical equipment and food supplies in some countries. Nwokedi et al. (2021) determined by using Yarmanyaro’s formula that while Twenty-Foot-Equivalent-Units (TEU) transportation costs have a significant increase, container trade flow from the seaports damages and decline in trade relations with the restrictions and conditions of the COVID-19 pandemic.

This study aims to contribute to the literature by exposing the effects of the COVID-19 pandemic on various freight transportation measures for the US economy. The monthly data used in our analysis and the methodology, which is the Toda-Yamamoto approach of the Granger-causality test, can be found in the next section. The empirical analysis will cover the causality over the period between January 2020 and May 2021. Thus, the results of the study will give information about the cause or effect roles of freight transportation and how changes occur during the process of the COVID-19 pandemic.

2. DATA AND METHODOLOGY

The data used in the study are those covering freight transportation and COVID-19 measures in the US are as follows: Air Revenue Ton Miles of Freight and Mail (ARFM), Cass Freight Index (CASS), Freight Transportation Services Index (FTSI), Rail Freight Intermodal Traffic (RFIT), Number of Confirmed Cases in the US (CVCA), and Number of Deaths in the US (CVDE). FTSI consists of inland and air freight activities such as for-hire trucking and pipeline movements. CASS includes the freight expenditures and shipment volumes. Data of all four freight transportation variables were obtained from the Federal Reserve Bank St. Louis Economic Research database. Data of all two COVID-19 measures were extracted from World Health Organization (WHO). The descriptive statistics of all variables can be seen in Table 1.

Table 1. Descriptive Statistics

Variables*	Source	Mean	Median	Minimum	Maximum
ARFM	Federal Reserve Bank St. Louis Economic Research database	15,179	15,202	15,066	15,289
CASS		1,024	1,026	0,808	1,239
FTSI		4,885	4,889	4,833	4,919
RFIT		13,946	13,943	13,795	14,063
CVCA	World Health Organization database	12,886	14,306	2,398	15,661
CVDE		10,334	10,400	7,782	11,486

*ARFM is Air Revenue Ton Miles of Freight and Mail; CASS is Cass Freight Index; FTSI is Freight Transportation Services Index; RFIT is Rail Freight Intermodal Traffic; CVCA is Number of Confirmed Cases in the US; CVDE is Number of Deaths in the US. All variables are in natural log form.

The Toda-Yamamoto approach, which is proposed by Toda and Yamamoto (1995), is used to investigate the existence of a causality between freight transportation and COVID-19 measures in the US. This methodology, which follows a modified Wald test for the causality testing procedure, is important because it enables us to avoid the problems associated with the ordinary Granger-causality test by ignoring any possible non-stationarity and/or co-integration between series.

This approach fits a vector autoregression (VAR, hereafter) model to the levels of the variables, thereby minimizing the risks associated with possible incorrect identification of the order of integration of the series. The main idea of this approach includes the estimation of an augmented VAR (k+dmax) model where k is the optimal lag length in the original VAR system, and dmax is the maximum order of integration of the variables in the VAR system.

To apply the Toda-Yamamoto approach to the Granger non-causality test, the freight–covid model is used as the following VAR system:

$$\text{freight}_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i}\text{freight}_{t-i} + \sum_{j=k+1}^{dmax} \alpha_{2j}\text{freight}_{t-j} + \sum_{i=1}^{k} \beta_{1i}\text{covid}_{t-i} + \sum_{j=k+1}^{dmax} \beta_{2j}\text{covid}_{t-j} + \varepsilon_{1t} \quad (1)$$

$$\text{covid}_t = \theta_0 + \sum_{i=1}^{k} \theta_{1i}\text{covid}_{t-i} + \sum_{j=k+1}^{dmax} \theta_{2j}\text{covid}_{t-j} + \sum_{i=1}^{k} \delta_{1i}\text{freight}_{t-i} + \sum_{j=k+1}^{dmax} \delta_{2j}\text{freight}_{t-j} + \upsilon_t \quad (2)$$

3. EMPIRICAL FINDINGS

The causality relationship between freight transportation indicators and COVID-19 statistics in the US will be estimated by the following equations (1) and (2). Before these estimations, the unit root testing procedure is applied as a pre-estimation process. These tests will provide both freight transportation and COVID-19 variables are stationary or not. To test the stationarity of the variables with the unit root test, it is taken attention for this study to the Augmented Dickey-Fuller (ADF) and Dickey-Fuller Test with GLS Detrending (DF-GLS) unit root testing procedures, proposed by Dickey and Fuller (1979) and Elliot et al. (1996), respectively. As represented in Table 2, all variables are found stationary as integrated of order one, I(1).

Table 2. Unit Root Test Results

Tests		CVCA	CVDE	ARFM	CASS	FTSI	RFTI
ADF	Level	-1.152	-2.051	-1.672	-2.113	-2.189	-2.776
	1st dif.	-9.171***	-5.968***	-4.263**	-8.461***	-3.073***	-3.412**
DF-GLS	Level	-0.942	-2.781	-2.568	-1.137	-2.293	-3.214
	1stdif.	-3.616**	-4.855***	-4.754***	-3.266**	-3.391***	-4.147***

Note: ADF: Augmented Dickey-Fuller; DF-GLS: Dickey-Fuller GLS. ***, **, and * denotes the rejection of the null hypothesis at 1%, 5%, and 10% significance levels, respectively.

After the process of analyzing the unit root test, the Toda-Yamamoto causality test is applied for revealing any causal relationship between the variables in the study. According to the test results, all variables are found significant and stationary at a one percent significance level and the null hypothesis of being non-stationary is rejected. Table 3 clearly shows the causality test results and significant relations between freight transportation indicators and COVID-19 statistics for the US. Test results emphasize that there is unidirectional causality from CVCA to ARFM; to CASS; to FTSI; to RFIT. When we look at the effects of the number of deaths, it is also found a unidirectional causal relation from CVDE to ARFM; to CASS; to FTSI; to RFIT in this study.

Table 3. Toda-Yamamoto Causality Test Results

	Chi-sq.	Direction		Chi-sq.	Direction
CVCA→ARFM	16.096***	unidirectional	CVDE→ARFM	9.424***	unidirectional
CVCA←ARFM	3.536		CVDE←ARFM	1.462	
CVCA→CASS	5.934***	unidirectional	CVDE→CASS	9.232***	unidirectional
CVCA←CASS	0.022		CVDE←CASS	2.427	
CVCA→FTSI	10.972***	unidirectional	CVDE→FTSI	5.272***	unidirectional
CVCA←FTSI	3.632		CVDE←FTSI	1.304	
CVCA→RFIT	6.904***	unidirectional	CVDE→RFIT	7.375***	unidirectional
CVCA←RFIT	1.539		CVDE←RFIT	3.942	

Note: ***, **, and * denotes the rejection of null hypothesis at 1%, 5%, and 10% significance levels, respectively.

In the light of all results of the causality, it is inferred that a significant causal relationship between freight transportation and COVID-19 measures for the US economy. It explains to us that freight transportation is mostly affected by pandemic conditions. Besides, it is a part of the important elements in the economic activities while it is decided the COVID-19 pandemic for economic sustainability.

4. CONCLUSIONS

Transportation of goods and passengers is vital for economies and this relationship at the causal level was researched by some empirical studies (Beyzatlar et al., 2014; Beyzatlar and Yetkiner, 2017; Yetkiner and Beyzatlar, 2020). This paper investigates the causal relations between various freight transportation indicators and COVID-19 statistics for the US. COVID-19 pandemic affects economies through various sectors, and transportation is an important one that has a causality relationship with economic activities. Changing the number of cases and deaths causes the reshaping the economic activities. Restrictions, closure of borders, and new policies are implemented to prevent the negative effects of the pandemic. These decisions have mostly affected the transportation industry. Especially, freight transportation has a significant position in terms of sustaining the movements of goods and services across the world. The volume of freight transportation has changed because of the conditions of the pandemic. From this point of view, this study is constructed for analyzing the impacts of the pandemic on freight transportation activities and showing the direction of the causal relationship between the variables over the period January 2020 and April 2020, using the Toda-Yamamoto causality test.

The empirical results of the study emphasize clearly that there are significant causal relations between freight transportation and COVID-19 statistics for the US economy. Analyzing COVID-19 statistics, in terms of the number of cases and deaths, it is shown that a unidirectional causality relationship is found from COVID-19 cases to freight transportation indicators (CVCA to FTSI, RFIT, ARFM, and RFIT). COVID-19 deaths also cause all freight transportation indicators, and it is also determined a unidirectional causality for all indicators (CVDE to FTSI, RFIT, ARFM, and RFIT). The whole empirical results prove that the COVID-19 pandemic is a determining factor for the freight transportation activities in terms of providing goods and services to the market in the US. That means any changes in the number of cases and deaths affect the economic process of freight transportation in the same direction. In the light of these findings, the study has important policy implications. Regulations about the pandemic should give importance by taking attention to freight transportation because it has an important ring of the supply chain for the economy, and it connects to other sectors. The demand and supply sides of the economy are affected by decisions to be made and policies to be implemented during the pandemic. Therefore, it should be necessary the convenient conditions for continuing the freight transportation activities smoothly in the market.

One of the grey areas of this study lies in not considering variants and the determinants of transportation measures for the US. The contagion spreads through people, not goods. However, it is aimed to evaluate how much the economy is affected by only the movement of freight, and therefore we did not consider passenger mobility. Due to the COVID-19 outbreak, restrictions are placed in many countries. These short periods or the whole pandemic period could be considered in terms of how it affects the interaction between other variables as an externality. Lastly, data availability was an important limitation of our study.

Present study outcomes are significant in covering the causal linkage between freight transportation and COVID-19 measures in the US. Future studies may want to consider the impact of COVID-19 measures on various determinants of transportation, such as movement of passengers, infrastructure, investment, prices, and indexes may be taken up. Future alternative studies might also use different time and cross-sectional dimensions as a longitudinal investigation. Moreover, data availability is a challenging task of transportation economics especially in accessing high-frequency data to be compatible with not only COVID-19 data but also many other measures.

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Green Supplier Selection by Using COPRAS And EDAS Methods

COPRAS ve EDAS Yöntemleriyle Yeşil Tedarikçi Seçimi

Ayhan DEMİRCİ[1]

ABSTRACT

Sustainability as a concept; includes economic, social and environmental approaches in relation to each other and also supply chain components. In this context, the right suppliers were selected, which is the most important component for the integration of a sustainable supply chain process. The right suppliers that focus on green practices are important for sustainability. At this point, multi-criteria decision-making techniques, which provide the most important decision support opportunity, also provide rationality and convenience for decision makers in the selection of green suppliers. In this context, firstly a literature search was conducted in the study and the criteria used in the selection of green suppliers, which could be discussed in three sub-headings, were determined. At this stage; Resource Utilization and Green Competence (C1-Green Storage, C2-Green Recycling, C3-Green Production Capacity, C4-Green Packaging, C5-Resource Consumption, C6-Pollution Control), Economic Criteria (C7-Logistics Costs, C8-Product Costs, C9-Delivery Time) and Quality (C10-Error Rate, C11-Warranty and Rights Policies, C12-Environmental Competencies and Documents). Then, the determined criteria were weighted and finally, green suppliers were selected using COPRAS and EDAS, which are the multi-criteria decision-making techniques that have made significant improvements in recent years. As a result, the most suitable supplier was selected among the determined 7 alternative suppliers. Although there is a difference in the ranking made according to the selections by using both methods, the supplier A2 took the first places and came to the fore. The reason for choosing two different techniques in the study is that the techniques give similar results with each other and thus the strengths of the techniques are determined. In addition, it is to contribute to the correctness of a decision to be made at the strategic level at the first time, especially by preventing possible mistakes.

Keywords: Green Supplier, Logistics, Multi-Criteria Decision making, COPRAS, EDAS.

ÖZ

Kavram olarak sürdürülebilirlik; birbirleriyle ilişkili ekonomik, sosyal ve çevresel yaklaşımların yanı sıra tedarik zinciri bileşenlerini içerir. Bu kapsamda sürdürülebilir bir tedarik zinciri süreci için en önemli bileşen olan doğru tedarikçi seçimi önemlidir. Yeşil uygulamalara odaklanan tedarikçiler, sürdürülebilirlik için ayrıca önemlidir. Bu noktada en önemli karar destek fırsatını sağlayan çok kriterli karar verme teknikleri de yeşil tedarikçi seçiminde karar vericilere rasyonellik ve kolaylık sağlamaktadır. Bu kapsamda çalışmada öncelikle literatür taraması yapılmış ve üç alt başlıkta ele alınabilecek yeşil tedarikçi seçiminde kullanılan kriterler belirlenmiştir. Bu aşamada; Kaynak Kullanımı ve Yeşil Yetkinlik (K1-Yeşil Depolama, K2-Yeşil Geri Dönüşüm, K3-Yeşil Üretim Kapasitesi, K4-Yeşil Paketleme, K5-Kaynak Tüketimi, K6-Kirlilik Kontrolü), Ekonomik Kriterler (K7-Lojistik Maliyetleri, K8-Ürün Maliyetleri, K9-Teslim Süresi) ve Kalite (K10-Hata Oranı, K11-Garanti ve Haklar Politikaları, K12-Çevresel Yeterlilikler ve Belgeler). Daha sonra belirlenen kriterler ağırlıklandırılmış ve nihayet son yıllarda önemli gelişmeler kaydeden çok kriterli karar verme teknikleri olan COPRAS ve EDAS yöntemleri kullanılarak 7 alternatif tedarikçi arasından en uygun yeşil tedarikçi seçimi yapılmıştır. Her iki yöntem kullanılarak yapılan seçimlere göre yapılan sıralamada farklılık olsa da tedarikçi A2 ilk sırayı alarak öne çıkmıştır. Böylece tekniklerin birbirlerini destekleme durumlarına göre güçlü yönleri belirlenmiştir. Ayrıca olası uygulama hatalarının önüne geçilerek, stratejik düzeyde alınacak bir kararın ilk seferde doğru olmasına katkı sağlanmıştır.

Anahtar Kelimeler: Yeşil Tedarikçi, Lojistik, Çok Kriterli Karar Verme, COPRAS, EDAS.

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1. INTRODUCTION

In recent years, the world has been trying to understand the concept of sustainability and what needs to be done to achieve this. The concept of sustainability, which has three dimensions: economic, social and environmental, is a very broad concept. Therefore, there is a need for a perspective that handles all these dimensions together. Sustainability, which requires providing prosperity to present generations without consuming the resources of future generations, is the main problem especially of production processes. Because production is dependent on a wide variety of resources. The efficient use of resources is as important as their correct supply. At this point, choosing the right supplier becomes important.

The supplier selection problem is a common problem of all businesses. Because establishing a sustainable relationship is one of the most important issues in the selection of suppliers. Sustainability is directly related to the green practices of suppliers. It is possible to establish and maintain a longer-term relationship with a supplier that attaches importance to green practices.

In this context, the problem of choosing a sustainable supplier was solved by using some green application-oriented criteria. Multi-criteria decision-making techniques, which are very useful in decision making problems due to many criteria at different weight levels, are a good assistant in complex decision problems. For this purpose, COPRAS and EDAS methods, which are the multi-criteria decision-making techniques that have become increasingly important in recent years, have been used.

First, 12 criteria that were evaluated to define a supplier best were determined and these criteria were weighted by taking expert opinion. Then, 7 alternative suppliers were listed using COPRAS and EDAS methods. There are two main reasons for choosing two methods. By comparing the results of the two methods, the status of the methods to support each other was revealed. In addition, by avoiding possible mistakes, it is possible to make the right decision at the first time.

2. CONCEPTUAL FRAMEWORK

There are many studies in the literature on supplier and green supplier selection. Most of these include the analysis made with multi-criteria decision-making techniques. The methods and criteria used in these studies are different. In the selection of criteria, it is considered that the work field is important. Because it is normal for different criteria to gain importance for suppliers to be determined for different work fields. However, in this study, the common ones among these criteria were preferred. In this section, some of the studies using different methods and different criteria are shared.

Kuo et.al. (2010) selected the green supplier by neural artificial network and data envelopment analysis. They used 5 main criteria and 24 sub-criteria as follows; quality (reject rate, management commitment to quality, process improvement, warranties and claim policies, quality assurance), cost (price performance value, compliance with sectoral price behaviour, transportation cost), delivery (order fulfil rate, lead time, order frequency), service (responsiveness, stock management, willingness, design capability), environment (eco-design requirements for energy using products, ozone depleting chemicals, restriction of hazardous sunstances, certified requirement of environmental management system, waste electrical and electronic equipment), corporate social responsibility (the interests and rights of employee, the rights of stakeholders, information disclosure, respect for the policy). At the end of the study they selected the best alternative in between 12 different alternative green suppliers.

Lee et.al. (2009) selected the green supplier by using fuzzy analytic hierarchy process. They used 6 main criteria and 23 sub-criteria as follows; quality (quality-related certificates, capability of quality management, capability of handling abnormal quality), technology capability (technology level, capability of R&D, capability of design, capability of preventing pollution), pollution control (air emissions, waste water, solid wastes, energy consumption, use of harmful material), environment management (environment-related certificates, continuous monitoring and regulatory compliance, internal control process, green process planning), green products (recycle, green packaging, cost of component disposal), green competencies (material used in the supply components that reduce the impact on natural resources, ability to alter process and product for reducing the impact of natural resources, social responsibility, ratio of green customers to total customers). Finally they selected the best alternative in between three different alternative green suppliers.

Aguezzoul et.al. (2006) selected the best 3PL providers based on three criteria; geographical coverage, quality control and services provided. In the study, geographic coverage means; the 3PLs providers must have warehouses in France, can serve the Maghreb and East of Asia and must have warehouses in North of France and Paris departments. Quality control means, Total Quality Management and logistics audit. Range of services offered means, international transit, intermodal transport, inventory control, just in time, cross-docking, co-packing, and reverse logistics. In the study where they used the ELECTRE method, each criterion was weighted as 5, 3 and 4, respectively. They decided on the most suitable 3PL provider among 14 alternatives.

Min (1993) selected the best foreign supplier by using one of the multi-criteria decision making techniques, MAUT method. He used 7 main criteria and 18 sub-criteria for his study as follows; financial terms (cost, freight terms, payment terms), quality assurance (quality control, quality team visits), perceived risks (political stability, foreign Exchange rate, legal claims, labour disputes, local price control), services performance (on-time delivery, technical assistance), buyer-supplier partnerships (financial stability, negotiability), cultural and communication barriers (cultural similarity, ethical standards, ADI capability), trade restrictions (tariffs and customs duties, counter-trade). In this study he selected the best supplier from the alternatives of Mexican, Taiwanese, Korean, Japanese and Canadian suppliers.

3. METHODOLOGY

Decision making is a process that starts with the existence of a problem. In order for a problem to be decided, there must be at least two alternative solutions for the solution of this problem. The majority of decisions to be made in environments of certainty, uncertainty and risk are complex (Demirci, 2020: 36-37). Because there are many criteria that affect the problem most of the time and the weights of these criteria are also different from each other. At this point, multi-criteria decision-making techniques, which have made significant progress in recent years and are frequently used in the literature, provide significant support to decision makers. Nowadays, there are numerous multi-criteria decision making techniques, which are widely used, are applied.

The use of multi-criteria decision making techniques will allow decision problems to be handled in small pieces and greatly facilitated, and will help decision-makers make more rational decisions (Demirci, 2018: 846).

Two different multi-criteria decision making techniques were used in this study. In this section, the theoretical background about COPRAS and EDAS methods used in green supplier selection is shared. Thus, it is aimed that if both methods support each other and to prevent possible mistakes during the application phase.

3.1. COPRAS Method

COPRAS (COmplex PRoportional ASsessment), which has an application similar to the Weighted Sum method, was proposed by Zavadskas et al in 1994. The Weighted Sum method takes into account only the utility criteria, and the cost criteria must be converted into utility criteria before normalization. This application requirement, which may pose a problem in other methods, was eliminated by the COPRAS method and made it superior (Kaklauskas vd., 2006: 460; Mousavi-Nasab ve Sotoudeh-Anvari, 2017: 241; Podvezko, 2011: 137-138).

The method involves a simpler process than some other Multi-Criteria Decision making Methods. COPRAS method is based on maximization of benefit criteria and minimization of cost criteria. Hence, the method can be applied to decision problems for maximization and minimization purposes. In the solution process, both groups of criteria are handled separately. Here, one of the issues that will occupy the decision maker the most is data with negative value and they need to be transformed (Arslan, 2018: 61). While many methods aim to rank the decision alternatives according to a certain superiority, the COPRAS method reveals how much better / worse one is than the other in percentage when comparing the alternatives. The COPRAS method, which is suitable for both quantitative and qualitative criteria, is based on the direct and proportional dependencies of the importance and priority of the alternatives. In the implementation phase, the importance of the alternatives compared with each other is determined depending on their positive or negative status according to their characteristics. The criterion values are used in maximizing the utility criteria and minimizing the cost side criteria.

Some important advantages of the method over other methods can be listed as follows (Özbek, 2017: 243-244);

- There is a much simpler application process compared to most of the multi-criteria decision making techniques.

- Allows the alternatives to be listed according to their performance.

- Can evaluate both quantitative and qualitative criteria.

- Whether minimization or maximization of criteria, it has the ability to calculate both ways.

- It generates information as a percentage not only about the good / bad status of the compared alternatives, but also about how good / bad they are.

- It has the ability to produce solutions with a simple Excel application without the need for a special program.

- No matter how high the number of alternatives is, the application time is short and easy, as it does not require binary comparison of the alternatives.

The implementation stages of the management can be specified as follows (Hashemkhani Zolfani ve Bahrami, 2014: 542-543; Özbek, 2017: 246-247);

Determining the Decision Matrix; At this stage, there is a mxn-dimensional decision consisting of m decision alternatives to be compared (i is to be 1 to m) and n number of decision criteria (j is to be 1 to n) to be based on this comparison. matrix is created. The decision matrix will be seen by Equation 1.

$$X = \begin{matrix} x_{01} & x_{02} & \cdots & x_{0n} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix} \qquad 1.$$

Standardization of Decision Matrix; At this stage, first of all, the decision matrix should be normalized by using the equation 2. Accordingly, criterion weights should be determined by using some other multi-criteria decision making techniques or expert opinions. In this study, expert opinion was obtained for the criterion weights. At the equation 2. q_j shows criterion weights.

$$d_{ij} = \frac{x_{ij} q_j}{\sum_{i=1}^{m} x_{ij}} \qquad 2.$$

Sum of Weighted Normalized Indexes; For the larger S_{+i} value of the maximization criteria calculated with the help of Equation 3. And also, The smaller the S_{-i} value of the minimization criteria calculated with the help of Equation 4.

$$S_{+i} = \sum_{j=1}^{n} d_{+ij} \qquad 3.$$

$$S_{-i} = \sum_{j=1}^{n} d_{-ij} \qquad 4.$$

Calculating the Relative Importance of Alternatives; Relative importance values (Q_i) of all alternatives compared with each other by using the Equation 5. According to this calculation, the largest Q_i value in the ranking has the highest relative importance.

$$Q_i = S_{+i} + \frac{S_{-min.} \sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{=1}^{m} \frac{S_{-min.}}{S_{-i}}} \qquad 5.$$

Determining the Benefit Level of Alternatives; At this stage the benefit level of the alternatives N_i is calculated by using the equation 6. All alternatives are ranked in descending order.

$$N_i = \left(\frac{Q_i}{Q_{maks.}}\right) * 100\% \qquad 6.$$

3.2. EDAS Method

The main basis of the EDAS (Evaluation Based on Distance from Average Solution) method proposed by Ghorabaee et al. (2015) is the two distance measurements defined as Average Positive Distance (PDA) and Mean Negative Distance (NDA). Accordingly, evaluation of alternatives in practice is made according to the average of these two values with the high PDA and low NDA values they obtain (Stanujkic vd., 2017: 7).

The application stages of the EDAS method are as follows (Keshavarz Ghorabaee vd., 2015: 438-441; Karabasevic, 2018: 58-59);

Determining the alternatives and the criteria that best represent them; At this stage, the alternatives to be evaluated and the criteria that will best explain these alternatives are determined.

Determining the Decision Matrix; At this stage, there are m number of decision alternatives to be determined and compared with each other and n number of decision criteria. The decision matrix prepared will be as seen in Equation 7.

$$X = \begin{matrix} x_{01} & x_{02} & \cdots & x_{0n} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{matrix} \qquad 7.$$

Determination of Average Solutions of Criteria; At this stage, the average solutions of each criterion are determined with the help of Equation 8.

$$AV_j = \frac{\sum_{i=1}^{n} X_{ij}}{n} \qquad 8.$$

Calculation of Average Positive Distance (PDA) and Average Negative Distance (NDA); At this stage, paying attention to the benefit and cost aspects of the criteria; Average Positive Distance Values (PDA) and Average Negative Distance Values (NDA) are calculated. Accordingly, the Average Positive Distance Values (PDA) of the utility-oriented criteria are calculated with the help of Equation 9. and the Average Negative Distance Values (NDA) with the help of Equation 10. Likewise, Average Positive Distance Values (PDA) of cost-oriented criteria are calculated with the help of Equation 11.and Average Negative Distance Values (NDA) are calculated with the help of Equation 12.

$$PDA_{ij} = \frac{maks.(0; (X_{ij} - AV_j))}{AV_j} \qquad 9.$$

$$NDA_{ij} = \frac{maks.(0; (AV_j - X_{ij}))}{AV_j} \qquad 10.$$

$$PDA_{ij} = \frac{maks.(0; (AV_j - X_{ij}))}{AV_j} \qquad 11.$$

$$NDA_{ij} = \frac{maks.(0;(X_{ij} - AV_j))}{AV_j} \quad 12.$$

Calculation of Weighted Total Values of PDA and NDA Values; At this stage, the Weighted Total PDA and NDA values are calculated using the previously determined criteria weights and PDA and NDA values calculated in the previous stage by using another multi-criteria decision making technique by using the Equation 13 and Equation 14.

$$SP_i = \sum_{j=1}^{m} w_j \, PDA_{ij} \quad 13.$$

$$SN_i = \sum_{j=1}^{m} w_j \, NDA_{ij} \quad 14.$$

Normalization of SP and SN Values; At this stage, the SP and SN values calculated for each alternative are normalized by using the Equation 15 and Equation 16.

$$NSP_i = \frac{SP_i}{maks._i \, (SP_i)} \quad 15.$$

$$NSN_i = 1 - \frac{SN_i}{maks._i \, (SN_i)} \quad 16.$$

Calculation of Evaluation Score; At this stage, an evaluation score is calculated for all alternatives by using the Equation 17.

$$AS_i = \frac{NSP_i + NSN_i}{2} \quad 17.$$

Ranking Alternatives: At this stage, all alternatives are ordered in descending order according to the calculated Evaluation Score. According to the ranking, it is decided that the alternative with the highest score is the best alternative.

4. ANALYSIS and RESULTS

In this study, it is selected 12 commonly used criteria, which most of them are about to green applications, under three main dimensions, based on the literature. These are as follows; Resource Utilization and Green Competence (C1-Green Storage, C2-Green Recycling, C3-Green Production Capacity, C4-Green Packaging, C5-Resource Consumption, C6-Pollution Control), Economic Criteria (C7-Logistics Costs, C8-Product Costs, C9-Delivery Time) and Quality (C10-Error Rate, C11-Warranty and Rights Policies, C12-Environmental Competencies and Documents). The criteria list and their explanations are shown in Table 1.

Table 1. Criteria List and Explanations

Criteria	Explanation
C1-Green Storage	It is rated on a scale of 1-9 by evaluating the resource utilization and green competence of alternatives.
C2-Green Recycling	
C3-Green Production Capacity	
C4-Green Packaging	
C5-Resource Consumption	
C6-Pollution Control	
C7-Logistics Costs	It is determined as numeric scale for all alternatives.
C8-Product Costs	
C9-Delivery Time	
C10-Error Rate	It is rated on a scale of 1-9 by evaluating the quality of alternatives.
C11-Warranty and Right Policies	
C12-Environmental Competencies and Documents	

Then it is determined 7 alternative suppliers (A1-A7) and firstly it is prepared the decision matrix based on expert opinion. It is also weighted all criteria based on expert opinion. In this stage, of course the weights of criteria can determine by using some other multi-criteria decision-making techniques. And finally the decision matrix prepared as shown in Table 2.

Table 2. Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	Maks.	Maks.	Maks.	Maks.	Min.	Maks.	Min.	Min.	Min.	Min.	Maks.	Maks.
A1	6	9	7	8	6	8	76	90	16	7	7	8
A2	8	6	4	9	9	7	78	91	18	5	8	9
A3	9	5	9	7	8	9	80	89	19	9	9	8
A4	7	8	6	7	7	6	81	88	14	7	7	9
A5	9	3	8	9	9	7	76	90	16	4	9	7
A6	8	9	6	8	8	9	74	92	18	8	6	9
A7	6	6	8	6	9	8	82	91	17	6	8	9
Weight	0,10	0,11	0,12	0,05	0,07	0,02	0,08	0,04	0,12	0,10	0,10	0,09

As shown in Table 2.; some criteria are benefit-oriented, and some criteria are cost-oriented. All criteria (except C7, C8 and C9) scored as 1 to 9 by an expert, and C7, C8 and C9 scored numerically. And also the weights of criteria determined by expert by doing binary comparison.

Then, as explained in section 3, the application steps of the methods were followed and analyses were made with the help of the COPRAS and EDAS methods, respectively. Accordingly, the normalized decision matrix for the COPRAS method is presented in Table 3.

Table 3. Normalized Decision Matrix for COPRAS Method

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	0,01	0,02	0,02	0,01	0,01	0,00	0,01	0,01	0,02	0,02	0,01	0,01
A2	0,02	0,01	0,01	0,01	0,01	0,00	0,01	0,01	0,02	0,01	0,01	0,01
A3	0,02	0,01	0,02	0,01	0,01	0,00	0,01	0,01	0,02	0,02	0,02	0,01
A4	0,01	0,02	0,02	0,01	0,01	0,00	0,01	0,01	0,01	0,02	0,01	0,01
A5	0,02	0,01	0,02	0,01	0,01	0,00	0,01	0,01	0,02	0,01	0,02	0,01
A6	0,02	0,02	0,02	0,01	0,01	0,00	0,01	0,01	0,02	0,02	0,01	0,01
A7	0,01	0,01	0,02	0,01	0,01	0,00	0,01	0,01	0,02	0,01	0,01	0,01

Finally, all the parameters of the COPRAS method were calculated and the alternatives were ranked. The calculated parameters and the ranking values of the alternatives are presented in Table 4.

Table 4. COPRAS Parameters and Ranking Values

	S_(+i)	S_(-i)	S_(-min)	S_(-i-Top)	S_(-min)/S_(-i)	S_(-min)/S_(-i) *Top.*	Q_i	N_i	Rank
A1	0,06	0,09	0,08	0,59	0,92	6,56	0,14	0,94	7
A2	**0,06**	**0,08**			**1,00**		**0,15**	**1,00**	**1**
A3	0,07	0,09			0,88		0,14	0,98	3
A4	0,06	0,08			0,95		0,14	0,96	5
A5	0,05	0,08			0,96		0,14	0,94	6
A6	0,06	0,09			0,90		0,14	0,97	4
A7	0,06	0,08			0,95		0,15	0,98	2

According to COPRAS method the second alternative supplier that involved in the first rank must be chosen.

In the application of the EDAS method, first of all, the total and average values of the criteria are determined according to the values in the decision matrix. Calculated total and average values of criteria are presented in Table 5.

Table 5. Total and Average Values of Criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Total V.	53	46	48	54	56	54	547	631	118	46	54	59
Average V.	7,57	6,57	6,86	7,71	8,00	7,71	78,14	90,14	16,86	6,57	7,71	8,43

And then by using the same decision matrix and the values that shown in Table 5. İt is calculated the average positive distances, weighted average positive distances, average negative distances, weighted average negative distances respectively and presented Table 6., Table 7., Table 8. and Table 9. respectively.

Table 6. Average Positive Distances

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	0,21	0,00	0,00	0,00	0,25	0,00	0,03	0,00	0,05	0,00	0,09	0,05
A2	0,00	0,09	0,42	0,00	0,00	0,09	0,00	0,00	0,00	0,24	0,00	0,00
A3	0,00	0,24	0,00	0,09	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,05
A4	0,08	0,00	0,13	0,09	0,13	0,22	0,00	0,02	0,17	0,00	0,09	0,00
A5	0,00	0,54	0,00	0,00	0,00	0,09	0,03	0,00	0,05	0,39	0,00	0,17
A6	0,00	0,00	0,13	0,00	0,00	0,00	0,05	0,00	0,00	0,00	0,22	0,00
A7	0,21	0,09	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,09	0,00	0,00

Table 7. Weighted Average Positive Distance

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	0,02	0,00	0,00	0,00	0,02	0,00	0,00	0,00	0,01	0,00	0,01	0,00
A2	0,00	0,01	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,00
A3	0,00	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
A4	0,01	0,00	0,02	0,00	0,01	0,00	0,00	0,00	0,02	0,00	0,01	0,00
A5	0,00	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,00	0,02
A6	0,00	0,00	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00
A7	0,02	0,01	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00

Table 8. Average Negative Distances

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	0,00	0,37	0,02	0,04	0,00	0,04	0,00	0,00	0,00	0,07	0,00	0,00
A2	0,06	0,00	0,00	0,17	0,13	0,00	0,00	0,01	0,07	0,00	0,04	0,07
A3	0,19	0,00	0,31	0,00	0,00	0,17	0,02	0,00	0,13	0,37	0,17	0,00
A4	0,00	0,22	0,00	0,00	0,00	0,00	0,04	0,00	0,00	0,07	0,00	0,07
A5	0,19	0,00	0,17	0,17	0,13	0,00	0,00	0,00	0,00	0,00	0,17	0,00
A6	0,06	0,37	0,00	0,04	0,00	0,17	0,00	0,02	0,07	0,22	0,00	0,07
A7	0,00	0,00	0,17	0,00	0,13	0,04	0,05	0,01	0,01	0,00	0,04	0,07

Table 9. Weighted Average Negative Distance

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00
A2	0,01	0,00	0,00	0,01	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,01
A3	0,02	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,02	0,04	0,02	0,00
A4	0,00	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,01
A5	0,02	0,00	0,02	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,02	0,00
A6	0,01	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,00	0,01
A7	0,00	0,00	0,02	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,01

Finally, all the parameters of the EDAS method were calculated and the alternatives were ranked. The calculated parameters and the ranking values of the alternatives are presented in Table 10.

Table 10. EDAS Parameters and Ranking Values

	SPi	*SNi*	*NSPi*	*NSNi*	*Asi*	Rank
A1	0,06	0,05	0,4860	0,5994	0,5427	4
A2	0,09	0,04	0,6872	0,6853	0,6863	2
A3	0,04	0,13	0,2896	0,0000	0,1448	7
A4	0,07	0,04	0,5702	0,6976	0,6339	3
A5	**0,12**	**0,07**	**1,0000**	**0,4435**	**0,7217**	**1**
A6	0,04	0,09	0,3334	0,3233	0,3283	6
A7	0,05	0,04	0,4030	0,6579	0,5304	5

According to EDAS method the fifth alternative supplier that involved in the first rank must be choosen.

As can be seen, the results of the analysis made by both methods differed from each other. This difference is due to the formulations of the methods. However, at this point, it would be appropriate to prefer a compromised solution. The ranking results obtained by both methods are presented in Table 11.

Table 11. Ranking Results for COPRAS and EDAS Methods

	COPRAS Method Ranking	EDAS Method Ranking
A1	7	4
A2	**1**	**2**
A3	3	7
A4	5	3
A5	6	1
A6	4	6
A7	2	5

Considering the differences in ranking results, it would be appropriate to choose the second alternative. Because the second alternative is in the first place according to the COPRAS method and the second according to the EDAS method.

5. DISCUSSION and CONCLUSION

In this study, the most suitable one among seven alternative green suppliers was selected. For this, first of all, the literature was searched and 12 criteria that are important in green supplier selection were determined. Then, based on expert opinion, the criteria were scored and weighted. Thus, the decision matrix has been obtained.

Since many criteria with different weights gained importance in the study, multi-criteria decision making techniques were used. Multi-criteria decision making techniques have made significant progress in recent years and are widely used in the literature. COPRAS and EDAS methods were used together in the study.

The main reason for choosing the two methods is to determine whether the methods produce reliable results. As a result of the study designed as a hybrid application, different suppliers took the first place according to both methods. Therefore, it is considered that it would not be appropriate to reach a conclusion and make a decision with a single method. It is considered that it would be better to confirm the results obtained with any multi-criteria decision making technique by another method. In the study, this condition was fulfilled and the common solution that ranked first according to the results of both methods was accepted.

Another reason for conducting the study with two methods is to avoid making a possible wrong decision. As a matter of fact, if this study was designed with a single method, the 2nd supplier should have been selected according to the COPRAS method and the 5th supplier should have been selected according to the EDAS method. This situation could have been quite misleading.

It is quite common for multi-criteria decision making techniques to produce different results. Because the formulations of all methods are quite different. However, due to their ease of application and their ease in solving complex problems, they are frequently used in the solution of decision making problems in recent years.

Subsequent studies can be done by considering different criteria and defining different weight values. In addition, different multi-criteria decision making techniques can be used in subsequent studies.

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Determination of Factors That Affect Use of E-Commerce in Eastern Turkey Through Categorical Data Analysis

Türkiye'nin Doğu Bölgesinde E-Ticaret Kullanımını Etkileyen Faktörlerin Kategorik Veri Analizi ile Belirlenmesi

Ömer ALKAN[1]
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ABSTRACT

E-commerce can be defined as carrying out, handling and facilitating commercial activities over computer networks. E-commerce is an output of the latest technological developments witnessed in recent years that further facilitate free trade on a global scale as well as communication of information. This study aimed to investigate the differences in the use of e-commerce by individuals living in eastern part of Turkey and determine the relationship between demographic, economic and personal characteristics of individuals and use of e-commerce. Microdata set obtained from Household Information Technologies Use Survey was used in the study. Sampling method employed in the study was stratified 2-stage cluster sampling. Binary logistic regression analysis was used to determine factors associated with the individuals' use of e-commerce. According to the study, the likelihood of an individual with an income level of ₺6001 and above in the eastern region to use e-commerce was found to be 54.5% higher compared to the reference group (₺2000 and below).

As a result of the study, variables such as income level, age, gender, occupation, use of social media, searching for information on goods and services on the internet, selling goods or services on the internet, use of internet banking, use of e-government, number of information equipment available in the household and household size were found to be associated with the use-of e-commerce.

Considering the findings of the study, it is necessary to make internet use widespread by facilitating development of e-commerce in less developed regions and improving infrastructure for information and communication technology in these regions. Therefore, interventions specific to region need to be taken into consideration for access to information on e-commerce.

Keywords: Electronic commerce, online shopping, online purchase, e-commerce, Turkey, binary logistic regression.

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ÖZ

E-ticaret, bilgisayar ağları üzerinden ticari faaliyetlerin yürütülmesi, işlem görmesi ve olanak tanınması olarak tanımlanabilir. E-ticaret, küresel ölçekte ticaretin serbestleştirilmesinin yanı sıra, bilgi iletişimini daha da kolaylaştıran son yıllarda tanık olunan en son teknolojik gelişmelerin bir ürünüdür. Bu çalışmanın amacı, Türkiye'de doğu bölgesinde yaşayan bireylerin e-ticaret kullanım farklılıklarını araştırmak ve bireylerin demografik, ekonomik ve kişisel özellikleri ile e-ticaret kullanımı arasındaki ilişkiyi belirlemektir. Çalışmada, Hanehalkı Bilişim Teknolojileri Kullanım Araştırmasından elde edilen mikro veri seti kullanılmıştır. Araştırmanın örnekleme yöntemi 2 aşamalı tabakalı küme örneklemesidir. Bireylerin e-ticaret kullanımı ile ilişkili faktörlerin belirlenmesi için binary logistic regresyon analizi kullanılmıştır. Çalışmaya göre doğu bölgesinde geliri ₺6001 ve üstünde olan bir bireyin referans gruba (₺2000 ve altı) göre e-ticaret kullanma olasılığı 54.5% daha fazladır.

Çalışmanın sonucunda eğitim durumu, gelir düzeyi, yaş, cinsiyet, meslek, sosyal medya kullanımı, internette mal ve hizmetler hakkında bilgi arama faaliyetinde bulunma, internette mal veya hizmet satışı faaliyetinde bulunma, internet bankacılığı kullanımı, e- devlet kullanımı, hanedeki bilişim ekipmanı sayısı ve hanehalkı büyüklüğü değişkenlerinin e-ticaret kullanımıyla ilişkili olduğu tespit edilmiştir.

Çalışmanın sonucuna göre gelişmişlik düzeyi düşük olan bölgelerde e-ticaretin geliştirilmesi kolaylaştırılarak ve bu bölgelerde bilgi ve iletişim teknolojisi altyapısı iyileştirilerek internet kullanımının yaygınlaştırılması gerekmektedir. Dolayısıyla e-ticaret ile ilgili bilgilere ulaşmada bölgeye özgü müdahalelerin hesaba katılması gerekmektedir.

Anahtar Kelimeler: Elektronik ticaret, çevrimiçi alışveriş, çevrimiçi satın alma, e-ticaret; Türkiye, lojistik regresyon**.**

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1. INTRODUCTION

Various shopping techniques and methods have been used throughout human history in line with the conditions of periods. As one of the great changes in this period, internet environment is among these shopping methods (Barnes and Vidgen, 2002). It can be argued that today's technologies and innovations have a great effect on the change in people's shopping habits. Rapid development in information and internet technologies, use of these technologies in almost all areas of daily life affect individuals' motivations regarding internet shopping (Corbitt et al. 2003).

Internet, a new marketing channel, offers different types of products and services for consumers (Silahtaroğlu & Dönertaşlı, 2015). An electronic marketplace has the advantage of offering more choice, lower prices, easy search and access to online customers. For this reason, the market share of internet is increasing every passing day. Accordingly, demographic characteristics and behavior patterns of consumers gain importance in terms of buying or not buying (Thompson & Teo, 2000). Mostly written as e-commerce, electronic commerce refers to trade products and services or to ease commerce by using computer networks such as internet (Gümüş & Kısa, 2016).

Online commerce provides consumers with 24 hours shopping opportunity. In addition, consumers should not visit physical stores of sellers, which locate in a different city or country, in order to do shopping (Gökmen, 2012). Therefore, consumers save both time and travel expenses. When compared to traditional shopping, it is seen that online shopping provides consumers with more control and bargaining power. Because it is likely to get more information about the products and services available on the internet in online shopping (Huseynov & Yıldırım, 2016).

As the contribution of shopping made by internet in the economy has increased, the competition has also raised in this field. As internet shopping has some advantages compared to traditional business, enterprises are also in a tendency towards internet shopping (Lee et al. 2017). It is seen both in the world and in our country that there has been a significant increase in both the number and volume of internet shopping that individuals do by smart devices such as mobile phones, personal digital assistant (PDA), computers, tablets (Changchit et al., 2019). Consumers tend to cross border shopping due to permanent growth in global trade and rapid development in digital society (Stoklosa, 2020). These tendencies have promoted traditional foreign trade styles to be raised in various dimensions of sustainability. Consumers can be offered attractive products by competitive prices and wide product range, thus, time and space distance between consumers and suppliers can be significantly shortened (Valarezo et al., 2018). Consumers use internet for searching information regarding products, and they are expected to carry out this more in the future (Afsar, Qureshi, Rehman and Bangash, 2011). Contrary to traditional shopping, internet shopping saves consumers time in finding a product. In addition, internet shopping offers lower search cost due to a decrease in energy cost used when comparing product prices. For this reason, internet shopping help consumers obtain price and product information from various sellers more rapidly and easily (Shin and Biocca, 2017).

Economic and social development differs in time and space on earth (Tvrdoň & Skokan, 2011). While this difference allows advantageous spaces to progress, others fall behind. Accordingly, it is seen that this results in a spatial inequality. This problem may occur between countries as well as between regions in a country. Today, regional development difference applies to all countries, whether these are developed and developing countries. In this case, countries show a great effort to overcome this problem (Gezici & Hewings, 2007).

The digital divide between the regions with different development levels influences the use of telecommunications and other advanced technologies (Donnermeyer and Hollifield, 2003). Socioeconomic factors affect the use of information and communication technology, and also leads to regional differences. Each region has its special infrastructure, economy and population. It is observed that this provides a basis for environmental diversification of related location (Mills & Whitacre, 2003). Accordingly, this also affects individuals' difference in internet shopping according to regions (Yeh, Hsiao, &Yang, 2012).

Although traditional shopping methods are still used more across the world, internet shopping is observed to increase rapidly. According to Global E-Commerce Report, the two shopping categories that consumers do more via internet than stores in 2018 are book, music, movie & video games (60%) and toys (39%). In general, the purchases made online are as follows: 43% of electronics & computer category, 36% of sports equipment & outdoor, 37% of health & beauty, 40% of clothing & footwear, 32% of jewelry/watches, 33% of household appliances, 30% of DIY/home improvement, 30% of furniture & homeware and 23% of grocery (Global E-Commerce Statistics, 2019). When examining the sectors, in which internet shopping was used, by continents, the sectors in which most internet shopping done are as follows: packaged food (40%) in Asia-Pacific region, video games in North America (31%), personal care products in South America (28%), fashion in Eastern Europe (49%), electronic goods (36%) in Western Europe and fashion (35%) in the Middle East and Africa (Global E-Commerce Statistics, 2019).

It is seen that e-commerce first started in the 1990s and then achieved a rapid increase at the beginning of the 2000s (Kaya et al., 2019). In research carried out in 28 countries, the average internet use of people, who ordered or purchased a product or service over the internet in the last year, was 87% in Europe while it was 72% in Turkey. The average rate of people who ordered or purchased a product or service was found to be 60% in Europe whereas it was 25% in Turkey (Eurostat, 2018).

In literature, there are some studies on the fact that demographic factors affect individuals' attitudes towards online purchasing behavior (Cheung, Chan, & Limayem, 2005; Lightner, 2003; Sim & Koi, 2002). The distribution of different demographic groups is worth analyzing in terms of the use of e-commerce by region. This study conducted a systematic analysis to investigate the impact of selected demographic factors on e-commerce use among individuals.

In this study, the research questions regarding the e-commerce made by individuals living in the Eastern regions of Turkey are as follows: "What are the socio-demographic characteristics of individuals living in the eastern regions?" and "Is there a relationship between the demographic, economic and personal characteristics of individuals living in the Eastern regions and their use of e-commerce?".

2. MATERIAL and METHOD

2.1. Data

In this study, the Household Information Technologies (IT) Usage Survey micro data set performed by the Turkish Statistical Institute in 2019 was used. The Household Information Technologies Survey has been carried out since 2004 in order to provide information on information and communication technologies in houses and the use of these tools. The Household Information Technologies Survey is also a primary data source providing information about the use of these technologies (TÜİK, 2019). In this study, the data obtained from 8002 individuals who participated in the Household Information Technologies Survey 2019 from eastern regions were used.

2.2. Outcome Variables

In the Household Information Technologies Survey, the Statistical Territorial Unit where people live is given. Turkey is classified into 12 regions in Level 1 under Nomenclature of Territorial Units for Statistics (NUTS). Only eastern regions were used in this study. The provinces in the eastern regions are shown in detail in Table 1. The eastern region was employed in the study (Ünver & Alkan, 2021).

Table 1. Nomenclature of Territorial Units for Statistics - Level 1

Region	Code	NUTS -1	Provinces
Eastern Regions	TR9	Doğu Karadeniz	Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane
	TRA	Kuzeydoğu Anadolu	Erzurum, Erzincan, Bayburt, Ağrı, Kars, Iğdır, Ardahan
	TRB	Ortadoğu Anadolu	Malatya, Elâzığ, Bingöl, Tunceli, Van, Muş, Bitlis, Hakkâri
	TRC	Güneydoğu Anadolu	Gaziantep, Adıyaman, Kilis, Şanlıurfa, Diyarbakır, Mardin, Batman, Şırnak, Siirt

The dependent variable of the study is the e-commerce use of individuals in the eastern regions in the last year. The individuals participating in the research received the code "1" if they used e-commerce in the last year as of the period of the survey and "0" if they did not.

2.3. Independent Variables

The independent variables to be included in this study are the ones obtained by the Household Information Technologies Usage Survey and the ones to be determined as a result of the literature search. The quantitative independent variables of the study are the number of information equipment in the household and the size of the household. The categorical variables included in the model were measured by a nominal and ordinal scale. Qualitative variables are as follows: income level (₺2000 and below, ₺2001-₺4000, ₺4001-₺6000 and ₺6001 and above), age (15-24, 25-34, 35-44, 45- 54, 55-64 and 65, and above), gender (male, female), education level (uneducated, primary school, secondary school, high school, university), use of social media in the last three months (yes, no), search for information about goods and services on the internet in the last three months (yes, no), goods or service selling activity on the internet in the last three months (yes, no), internet banking use (yes, no), e-government use in the last 12 months (yes, no). Ordinal and nominal variables were identified as dummy variables in order to observe the effects of the categories of all variables to be included in binary logistic regression (Alkan, Oktay, Ünver, & Gerni, 2020).

2.4. Statistical Analysis

Survey statistics in Stata 15 (Stata Corporation) were used to account for the complex sampling design and weights. Weighted analysis was performed. One of the main areas of statistical inference is to test hypotheses. SPSS 20 and Stata 15 programs were utilized to analyze the data. First of all, the frequencies and percentages of the individuals participating in the research were obtained for demographic, economic and personal factors by regions. In this study, binary logistic regression method was used to explore the relationship between demographic, economic and individual factors and e-commerce use by region.

Binary logistic regression analysis was conducted to determine the factors that were influential on e-commerce use. This particular analysis is used to study the relationship between the dependent variable and the independent variable(s) in cases where the result (dependent) variable has two options (binary/dichotomy). Binary logistic regression not only provides the opportunity to evaluate the statistical significance of each independent variable as a risk factor but also the opportunity to calculate the odds ratio. The cumulative logistic distribution function is used in the binary logit model (Alkan & Ünver, 2020).

3. RESULTS

3.1. Characteristics of Participants

The frequencies and percentages of the variables used in the study are provided in Table 2. According to Table 2, while 20.3% of the individuals were between 25-34, 8.7% of them were in the age group of 65 and over. When examining the variable of education, it was seen that 27.4% of the participants graduated from primary school, whereas 12.5% of them had a university graduate. In addition, 53% of the participants were male, and 47% of them were female. While the monthly income of 49.7% of individuals was ₺2000 and below, 6.2% of them had an income of ₺6001 and above. When examining Table 2, it is seen that while 45.6% of the participants used social media, 20.4% of them used internet banking. It is observed that 34.1% of the participants used the e-government application in the last 12 months.

When examining Table 2, it is specified that 31.6% of the participants engaged in a search for information about goods and services on the internet in the last three months, and 13.3% of them carried out a goods or service selling activity on the internet in the last three months. In the study, it was tested whether there was a multicollinearity between the independent variables to be included in the binary logistic regression model. Those with variance inflation factor (VIF) values of 5 and above were considered to cause moderate, whereas those with 10 and above caused a high degree multicollinearity (Alkan & Abar, 2020). In this study, there is no variable causing a multicollinearity problem between variables.

Table 2. Findings on Factors Related to E-Commerce Use

Qualitative Variables		**n**	**%**	**VIF**	**1/VIF**
Income level	₺2000 and below	3973	49.7	1.35	0.742
	₺2001-₺4000	2770	34.6	ref.	ref.
	₺4001-₺6000	763	9.5	1.24	0.807
	₺6001 and above	496	6.2	1.3	0.77
Age	15-24	1615	20.2	3.85	0.26
	25-34	1621	20.3	3.32	0.301
	35-44	1618	20.2	3.18	0.314
	45-54	1355	16.9	2.7	0.37
	55-64	1096	13.7	2.27	0.44
	65 and above	697	8.7	ref.	ref.
Gender	Male	4240	53	ref.	ref.
	Female	3762	47	1.27	0.787
Education level	Uneducated	2027	25.3	4.44	0.225
	Primary School	2191	27.4	3.95	0.253
	Secondary School	1569	19.6	3.06	0.327
	High School	1214	15.2	2.22	0,45
	University	1001	12.5	ref.	ref.
Social media	Yes	3652	45.6	1.84	0.543
	No	4350	54.4	ref.	ref.
Goods/service information	Yes	2532	31.6	1.95	0.512
	No	5470	68.4	ref.	ref.
Goods/service sales	Yes	1066	13.3	1.36	0.736
	No	6936	86.7	ref.	ref.
Internet banking	Yes	1636	20.4	1.91	0.524
	No	6366	79.6	ref.	ref.
E-government use	Yes	2731	34.1	2.14	0.466
	No	5271	65.9	ref.	ref.
Quantitative Variables		**Mean**	**S. Dev.**		
The number of information equipment in the household		1.82	1.05	1.40	0.71
Household size		4.85	2.41	1.27	0.79

3.2. Model Estimation

The binary logistic regression model was used to determine the factors associated with the e-commerce use of the participants. The results of the estimated model are provided in Table 3. When examining Table 3, it is seen that income level, age (15-24, 25-34, 35-44, 45-54), gender, education level, social media use, goods/services information, goods/services sales, internet banking use, e-government use, the number of information equipment in the household and the household size variables were found to be significant.

Table 3. Estimated Coefficients of Factors Associated with Individuals' Use of E-Commerce

Variables	**β**	**S.E**
Constant	-3.77[a]	0.382
Income level (reference category: ₺2001-₺4000)		
₺2000 and less	-0.374[a]	0.121
₺4001-₺6000	-0.383[b]	0.162
₺6001 and above	0.304[c]	0.171
Age (reference category: 65 and above)		
15-24	1.89[a]	0.357
25-34	1.912[a]	0.346
35-44	1.529[a]	0.346
45-54	0.758[b]	0.354
55-64	-0.091	0.415
Gender (reference category: male)		
Female	-0.683[a]	0.115
Education level (reference category: university)		
Uneducated	-1.835[a]	0.339
Primary School	-1.047[a]	0.192
Secondary School	-0.801[a]	0.168
High School	-0.327[b]	0.152
Social media (reference category: no)		
Yes	0.712[a]	0.139
Goods/service information (reference category: no)		
Yes	0.692[a]	0.12
Goods/service sales (reference category: no)		
Yes	1.185[a]	0.12
Internet banking (reference category: no)		
Yes	1.072[a]	0.125
E-government use (reference category: no)		
Yes	0.672[a]	0.134
The number of information equipment in the household	-0.132[a]	0.048
Household size	0.277[a]	0.028

[a]p<.01; [b]p<.05; [c]p<.10

The estimated odds ratios of the factors related to the e-commerce use of individuals are given in Table 4. If it is OR<1 according to the logistic regression analysis, the examined factor (relative to the reference) has little effect on the investigated case. When it is OR>1, It has an enhancing effect compared to the reference group (Alkan, Oktay, & Ünver, 2020).

According to the logistic regression analysis results provided in Table 4, the odds ratio of e-commerce uses of an individual with an income ₺6001 and above is higher than the reference group (OR=1.355; 95% CI =0.969–1.895). The odds ratio of e-commerce use of an individual with an income between ₺4001-₺6000 is lower than the reference group (OR=0.682; 95% CI=0.496–0.937). The odds ratio of e-commerce use of an individual within 25-34 age group has a higher odds of e-commerce use compared to the reference group (OR=6.765; 95% CI=3.435–13.321). Similarly, an individual in 45-54 age group has a higher odds of e-commerce use compared to the reference group (OR=2.135; 95% CI=1.067–4.272). The odds ratio of e-commerce use of a female living in the easter region is lower than a male (OR=0.505; 95% CI=0.403–0.633). An individual with a high school graduate has a lower odds ratio of e-commerce use than the reference group (OR=0.721; 95% CI=0.536–0.971). The odds ratio of e-commerce use of an individual with uneducated is lower than the reference group (OR=0.16; 95% CI=0.082–0.31). In a similar vein, while the odds ratio of e-commerce use of an individual with primary school graduate is lower than the reference group (OR=0.351; 95% CI =0.241–0.511), the odds ratio of e-commerce use of an individual with secondary school graduate is lower than the reference group (OR=0.449; 95% CI=0.323–0.624). An individual using social media uses e-commerce more than others (OR=2.038; 95% CI=1.553–2.675). The odds ratio of e-commerce use of an individual having a goods or service sales on the internet in the last three months is higher than others (OR=3.271; 95% CI=2.588–4.134). The odds ratio of e-commerce use of an individual performing an information search activity on the internet in the last three months is higher than others (OR=1.999; 95% CI =1.581–2.528). An individual using internet banking has a higher odds ratio of e-commerce use than others (OR=2.922; 95% CI=2.285–3.737). The odds ratio of e-commerce use of an individual using the e-government application in the last twelve months is higher than others (OR=1.958; 95% CI=1.507-2.545). As the number of information equipment in the household increases, the odds ratio of e-commerce use increases (OR=1.319; 95% CI=1.202–2.448). As the household size increases, the odds ratio of e-commerce use decreases (OR=0.876; 95% CI=0.83–0.925).

Table 4. The Estimated Odds Ratios of The Factors Related to the E-Commerce Use of Individuals

Variables	OR	S.E	95% CI	
			Lower	Upper
Constant	0.23[a]	0.009	0.011	0.049
Income level (reference category: ₺2001-₺4000)				
₺2000 and less	0.688[a]	0.083	0.542	0.872
₺4001-₺6000	0.682[b]	0.111	0.496	0.937
₺6001 and above	1.355[c]	0.232	0.969	1.895
Age (reference category: 65 and above)				
15-24	6,62[a]	2.361	3.290	13.32
25-34	6.765[a]	2.338	3.435	13.321
35-44	4.613[a]	1.596	2.342	9.088
45-54	2.135[b]	0.755	1.067	4.272
55-64	0.913	0.379	0.405	2.058
Gender (reference category: male)				

Female	0.505[a]	0.058	0.403	0.633
Education level (reference category: university)				
Uneducated	0.16[a]	0.054	0.082	0.31
Primary School	0.351[a]	0.067	0.241	0.511
Secondary School	0.449[a]	0.076	0.323	0.624
High School	0.721[b]	0.109	0.536	0.971
Social media (reference category: no)				
Yes	2.038[a]	0.283	1.553	2.675
Goods/service information (reference category: no)				
Yes	1.999[a]	0.239	1.581	2.528
Goods/service sales (reference category: no)				
Yes	3.271[a]	0.391	2.588	4.134
Internet banking (reference category: no)				
Yes	2.922[a]	0.367	2.285	3.737
E-government use (reference category: no)				
Yes	1.958[a]	0.262	1.507	2.545
The number of information equipment in the household	1.319[a]	0.063	1.202	1.448
Household size	0.876[a]	0.024	0.83	0.925

[a]p<.01; [b]p<.05; [c]p<.10

4. DISCUSSION and CONCLUSION

It is seen that e-commerce has become one of the biggest megatrends of the global economy after internet has become rapidly widespread. In this study, the data obtained from 8002 individuals who participated in the Household Information Technologies Survey 2019 from eastern regions were used. The factors affecting the e-commerce use of individuals in Turkey were determined using binary logistic regression analysis. The analysis results suggested that education level, income level, age, gender, social media use, search for information about goods and services on the internet, goods or service selling activity on the internet, internet banking use variables have been found to have a relationship with the e-commerce use.

It has been concluded in the study that as the education level of individuals has increased, their possibility to use e-commerce has increased. The studies in the literature have shown similar results (Akman & Rehan, 2014; Ünver &Alkan, 2021; Tarafdar &Vaidya 2006). As the income levels of individuals have increased, their possibility to use e-commerce has increased. Similar conclusions have been achieved in the prior studies (Hwang, Jung, & Salvandey, 2006; Cristóbal-Fransi, et al. 2015; Akman &Mishra, 2010). In the study, it has been identified that as the age of the individuals has increased, their possibility to use e-commerce has decreased. The studies in the literature have shown similar results (Bhatnagar, & Ghose, 2004; Alqahtani, Goodwin, & de Vries, 2018; Beneke, Scheffer, & Du, 2010). The study suggested that the e-commerce use rate of males is higher than females. Similar conclusions have been achieved in the prior studies (Zhang, 2005; Hashim, Ghani, & Said, 2009; Potosky, 2007). It has been found that individuals using social media have higher e-commerce more use than others. The studies in the literature have shown similar results (Pucci, 2019; Çera, Phan, Androniceanu, & Çera, 2020). It has been concluded that the individuals carrying out goods or service sales activity on the internet have had a higher e-commerce use than others. Similar conclusions have been achieved in the prior studies (Vicente, 2015; Ünver& Alkan, 2020). The individuals using internet banking has been found to use e-commerce more than other individuals. The studies in the literature have shown similar results (Duroy, Gorse, & Lejoyeux, 2014; Çera et al., 2020). As the number of information equipment increases, the possibility of using e-commerce increases. Similar conclusions have been achieved in prior studies (Hossein et al., 2017; Abar and Alkan, 2020). It has been concluded that as the household size increases, the possibility to use e-commerce decreases. The studies in the literature have shown similar conclusions (Stranahan, 2007; Abar and Alkan, 2020).

At the end of the study, it has been specified that as the educational level of individual raises, their tendency towards online shopping also increases. The study suggests that as the income levels of individuals increase, their possibility to use e-commerce also enhances. This may be associated with the fact that individuals with higher incomes have higher qualifications and new technologies. It has been also identified that males have a higher e-commerce use rate than females. Prior studies have explained this by time efficiency, avoiding crowd environments and 24-hour shopping opportunity (Javadi et al., 2012). Demographic characteristics affect the actions of individuals before engaging in a certain behavior. Accordingly, it is of paramount importance that the factors related to online shopping should be understood by those doing online shopping.

As regional development is an important factor in the development of individuals' e-commerce use, the effect of development level on e-commerce use is seen to become more important. The conclusions of the study suggest that region-specific interventions should be taken into account in accessing e-commerce-related information. Accordingly, the development of e-commerce should be facilitated in the regions with low development level, and internet use should be expanded by improving the information and communication technology infrastructure in these regions. The conclusions of this study may provide policy makers with important information on increasing e-commerce shopping volume in Turkey and how to promote the use of e-commerce in developing countries to increase social welfare and life quality by ensuring effective customer satisfaction with the operational efficiency provided by e-commerce practices.

The share of Turkey in e-commerce is increasing every passing day, and provides significant profits to the country's economy by raising the commerce volume and potential in both national and international markets. Despite the e-transformation rates observed in public and private sectors, increasing number of e-commerce users, legal and sectoral regulations, it is observed that e-commerce potential could not be fulfilled completely, lagged behind in developed countries. Development and standardization of technological infrastructure is the first step that should be taken in this regard. Despite high urbanization rates, regional differences in internet access rates still pose a serious problem. The most important steps to be taken in terms of the development of e-commerce may be ranked as follows: to remove regional differences, to increase investments in fixed and mobile infrastructures, to decrease taxes on products and services to make ICT technologies accessible to everyone, to promote and support new entrepreneurs to enter the market. In addition, development of legal regulations, raising entrepreneurship ecosystem, increasing investments in techno-parks will both revive domestic market and result in micro and macroeconomic advances by drawing foreign investments and significantly increase Turkey's competitive power.

As in every study, this study has several limitations. First of all, it should be taken into consideration that the data used in this study consist of secondary data, and the variables required for statistical analysis comprised of the variables in the data set. Secondly, as they are not included in the data set, some variables such as internet access in the household, internet use duration, household members' having electronic devices allowing them to do online shopping, internet shopping attitudes of parents, siblings, other members of the household or close friends. Furthermore, as the data were cross-sectional, an absolute causal relationship between socioeconomic factors related to e-commerce use could not be obtained. Another limitation is the inability to observe direct or indirect effects of the factors between themselves as no modelling has been used in the analysis process. For this reason, the data obtained in this data gathering method may be biased.

It is considered that the study will fill the related gap in the literature since it has been carried out on a large sample and some demographic factors that are not generally included in the studies conducted in this regard have been included in the analysis. In addition, as the study has a methodological perspective and has been carried out by using data gathering and analysis methods in accordance with the modelling, it provides a basis for different scenarios, such as identifying personal and environmental factors affecting individuals regarding e-commerce use, having more use options, having a wider duration of use, increasing sectoral occupational groups, diversification of demographic characteristics and determining the relationship of these factors with each other.

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Research on Sustainable Criteria Affecting the Logistics Sector

Lojistik Sektörü Sürdürülebilirliğini Etkileyen Kriterler Üzerine Araştırma

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ABSTRACT

The understanding of sustainability can be applied in almost every sector and has a very wide impact in the logistics sector. Today, taking into account the sustainability criteria is among the basic conditions of doing business for companies in the supply chain, and it is becoming more and more important. In this study, 15 articles that studied with sustainable logistics criteria between 2008 and 2020 are reviewed and the sustainable logistics criteria included in each study are determined. These 103 logistics criteria, which are determined, are ranked in importance by Pareto analysis, in consultation with expert academicians and logistics sector employees, and it is concluded that 33 criteria can be more important than others. This criterion evaluation study, compiled from the literature, shows the companies that will apply sustainability methodology in the logistics sector, in a unique way, where to start. With the understanding that it is possible to minimize the damage caused by the sector to the environment with an effective sustainability strategy if these sustainable logistics criteria are given importance, logistics companies will reach a competitive level in the field of sustainability.

Keywords: Sustainable logistics, logistics criteria, sustainability, sustainable logistic literature, pareto analysis.

ÖZ

Sürdürülebilirlik anlayışı hemen hemen her sektörde uygulanabilmekle birlikte lojistik sektöründe çok geniş bir etkiye sahiptir. Günümüzde sürdürülebilirlik kriterlerinin dikkate alınması tedarik zincirinde yer alan şirketler için iş yapmanın temel koşulları arasında yer almakta ve giderek daha önemli hale gelmektedir. Bu çalışmada 2008-2020 yılları arasında sürdürülebilir lojistik kriterleri ile çalışılan 15 makale incelenmiş ve her bir çalışmada yer alan sürdürülebilir lojistik kriterleri belirlenmiştir. Belirlenen bu 103 lojistik kriteri, uzman, akademisyenler ve lojistik sektörü çalışanları ile istişare edilerek Pareto analizi ile önem derecesine göre sıralanmış ve 33 kriterin diğerlerinden daha önemli olabileceği sonucuna varılmıştır. Literatürden derlenen bu kriter değerlendirme çalışması, lojistik sektöründe sürdürülebilirlik metodolojisini uygulayacak firmaları özgün bir şekilde nereden başlamaları gerektiğini göstermektedir. Sektörün çevreye verdiği zararı etkin bir sürdürülebilirlik stratejisi ile bu sürdürülebilir lojistik kriterlerine önem verilmesi halinde en aza indirmenin mümkün olduğu anlayışı ile lojistik firmaları sürdürülebilirlik alanında rekabetçi bir seviyeye ulaşacaktır.

Anahtar Kelimeler: Sürdürülebilir lojistik, lojistik kriterler, sürdürülebilirlik, sürdürülebilir lojistik literatürü, pareto analizi.

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1. INTRODUCTION

Sustainability studies have a wide impact in the logistics sector. Because logistics activities are one of the basic business functions that can directly affect our environment and climate changes. So, it is becoming more and more important to consider the sustainability criteria. Sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Sustainability studies address three factors called the Triple Bottom Line (TBL) as economic, social and environmental (Elkington, 1994). The logistics sector is not only a significant contributor to national economic performance and development, but also plays a vital role in environmental and social aspects. Logistics, on the other hand, is to maintain the efficiency of operations with the integration of material supply, transportation and storage activities (Heizer and Render, 2014).

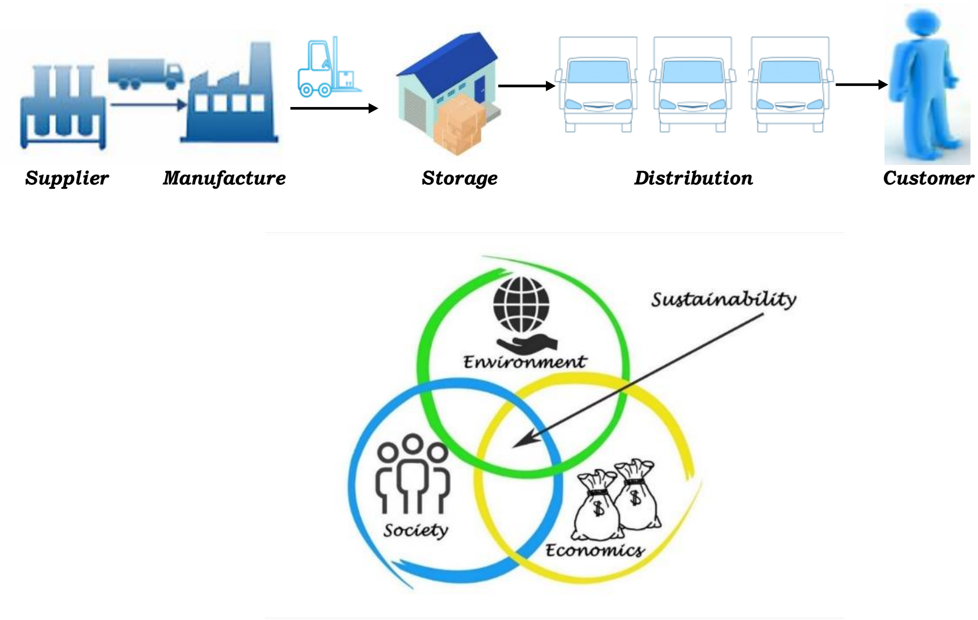

Figure 1. Logistics and Sustainability

The visuals of logistics and sustainable logistics concepts are given in the Figure 1. Logistics is the science of managing the flow of goods, information and other resources between the point of origin and the point of consumption in order to meet the needs of customers. Includes integration of information, shipping, inventory, warehousing, material handling and packaging.

Sustainable logistics has emerged with the aim of reducing the environmental impact of all logistics activities (Mayfield, 2021). Sustainable development of logistics calls for activities that lead to the highest economic and social gains while reducing the negative environmental losses. Sub-headings that need attention regarding the environment are noise, air quality, land use, biodiversity and waste management. Improvement studies in this direction are of great importance (Beken, 2016). Considering these factors, sustainable logistics is a major determinant in terms of economy as well as society and environmental gains.

There are certain reasons why the sustainable logistics approach is accepted by many companies today. Jørsfelt et al. (2017) listed these reasons as follows; (1) Pressures exerted by the developing social awareness and non-governmental organizations. (2) Rapid depletion of raw material resources and anxiety caused by this situation. (3) Global warming results begin to manifest themselves. In the field of economy, the effects of sustainable logistics are positive, especially in the long run. Although the applications to be made make companies think in terms of cost, the investments to be made in this field will show their return as soon as possible with the awareness of the consumers.

There are a number of benefits when sustainable logistics is implemented. These are;

- Companies engaging in sustainable logistics seek to lower their CO_2 emissions and accidents (such as chemical leaks).
- They might also focus on lowering air pollution, noise pollution and all of which can negatively impact people and life.
- Reducing energy use in logistics activities increases the use of renewable energy sources.
- It can be ensured that recycled products are preferred within the activities and additive values are created from their recycling.
- In the packaging activity, gains are achieved in terms of cost and nature.
- With its environmentally friendly identity, customer satisfaction increases and employee rights are at the forefront.

About sustainable logistics performance measurement; nowadays, businesses that want to be sustainable need to constantly examine their performance and improve themselves according to this review. For an effective performance measurement, "What do we want to measure?", "Why do we want to measure?" The answers to the questions are sought. In order to measure the sustainable logistics performance, it is important to choose the indicators correctly. For this reason, criteria that can be used for sustainable logistics are determined in this study. The criteria discussed in the study can also be used in performance evaluation studies.

The aim of the study is to emphasize the importance of the concept of sustainability in the logistics sector and to determine the contributing criteria. From this point of view, in the second section of the study, studies based on the logistics sector on sustainability are examined. In the third section, sustainability criteria are investigated in the light of the studies obtained in the literature. The ranking of the criteria according to the degree of importance is made by Pareto Analysis. A total of 103 sustainable logistics criteria have been determined. These criteria are ranked in importance by Pareto Analysis by taking the opinions of experts in their field and it is concluded that 33 criteria can be more important than others. The criteria determined in the fourth section are explained and grouped under the main criteria title. In the conclusion section, the findings are discussed and suggestions are made for new studies.

2. LITERATURE REVIEW

Sustainability has become a growing concern for consumers, businesses and governments in recent years. Increasing regulatory rules, scarcity of natural resources and increasing population are forcing companies to remain competitive and constantly offer new products and services in today's market. There are also increasing levels of waste and demands from customers and stakeholders. Due to these problems, efficient and sustainable supply chain operations are mentioned in the literature.

Zhang and Zhao (2012) emphasized the need for green packaging and stated that green packaging, supported by the government, should be produced with a strength that can be easily recycled and reused in accordance with hygiene rules. Lin and Ho (2011) investigated the key determinants of logistics performance in Chinese industry and found that logistics performance is influenced by technological dimensions, environmental factors and corporate competitiveness. In addition, government support found that regulatory measures significantly increased the adoption of green practices in Chinese logistics companies.

In the Helm (2018) study, 'How can sustainability be a source of competitive advantage for logistics in remote locations?' is asking the question. To answer this question, it uses an interdisciplinary framework and conducts a detailed literature review, integrating the academic disciplines of business and sustainability. Abbasi and Nilsson (2016), the aim of their study is to explore the themes and challenges in developing environmentally sustainable logistics activities. Findings show the main themes by analyzing activities in the development of environmentally sustainable logistics activities. Accordingly, four categories of challenges were identified: customer priorities, administrative complexity, network imbalance, and technological and legal uncertainties. It was concluded that there is a great need for a holistic perspective where logistics service providers and product owners can together analyze and design the logistics installations of the future. Çamlıca and Akar (2014) reveals the level of sustainability-related practices in the logistics sector, and the concepts of environmental, economic and social sustainability are discussed in terms of the logistics sector, the importance of the concept of sustainability for the sector and the requirements for ensuring sustainability.

Byrne et al. (2013), provides a comprehensive literature review showing the evolution of logistics activities. Based on this document, the results of the face-to-face exploration research conducted to analyze the attitude, knowledge and readiness among sellers but more comprehensive logistics service buyers to implement sustainable logistics in Ireland are also presented.

In addition to the literature review studies, the subject of sustainable logistics, which take place between the years 2008-2020, is discussed in this study. The difference from the existing studies is to bring together the evaluation criteria found in the literature. Comprehensive criteria research of the study is presented in the methodology section.

3. METHODOLOGY

In this section, the path followed in the study is explained. The conceptual model of the study is as shown in Figure 2.

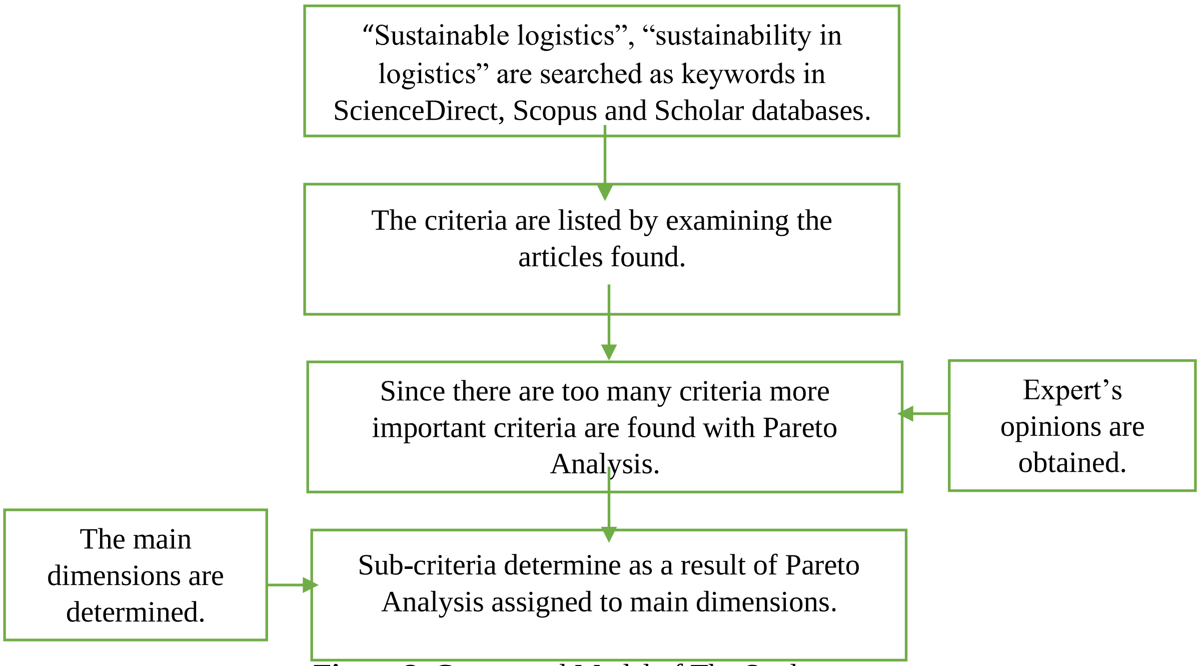

Figure 2. Conceptual Model of The Study

In the study, firstly, "sustainable logistics" and "sustainability in logistics" are researched as keywords in ScienceDirect, Scopus, Scholar databases. Due to the narrow frame, a total of 15 articles are found. The articles found are examined and the criteria are given in Table 1. Since there are 103 sub-criteria, it is aimed to find more important criteria with Pareto Analysis by taking the opinions of experts. Then the main dimensions are determined. The sub-criteria determined as a result of the Pareto analysis are classified into main dimensions.

Table 1. Author and Criteria

Criterion-Authors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Consumer behavior	*														
Existing practices	*														
Environmental factors	*				*						*				
Minimizing environmental problems				*											
Environmental uncertainty											*				
Supply chain integration	*														
Taking supply/value chain view		*													
Government support	*										*		*	*	
Compliance with legislation and standards		*													
Adaptation to future policies and corporate governance		*													

Product value	*							
Reverse logistics costs	*							
Reverse logistics applications						*		
Quantity of returned products	*							
Quality of returned products	*							
External Factors	*							
Internal Factors	*							
Internal resources efficiency, effectiveness, and utilization		*						
Economy/Economic Performance/Economic factors	*			*				
Economic support								*
Economic growth				*				
Return On Investment	*							
Recapturing Value	*							
Logistics Cost Optimization	*							
Recycle Efficiency	*							
Annual Sales of remanufactured products	*							
Disposal Costs	*							
Minimum Energy Consumption	*							
Energy and fuel efficiency		*						
Energy production			*					
Energy use					*			
Use of recycled material	*							
Optimum use of raw material	*							
Product use			*					
Product use by consumers			*					
Production and distribution planning							*	
Transport Optimization	*							
Transportation			*					
Transport from supplier to manufacturer and vice versa			*					
Transport from supplier to consumers and vice versa			*					
Transport from supplier to end-oflife facilities and vice versa			*					

Transport from manufacturers to end-of-life facilities and vice versa			*					
Goods transport					*			
Choice of mode of transport and intermodal transport							*	
Reduced Packaging	*							
Green packaging						*		
Waste Reduction	*							
Waste management				*				
Social Performance/Social factors	*							
Society				*				
Community complaints	*							
Consumer Health and Safety	*							
Stakeholders Participation	*							
Rate of job creation					*			
Quality of human resource								*
Donations to Community	*							
Employee Benefits	*							
Sustainability behavioral cautiousness		*						
Measurement and assessment		*						
Taking initiatives		*						
Efficient utilization of external logistical infrastructure		*						
Vertical and horizontal collaboration		*						
Innovation and research		*						
Technological development		*						
Technological and legislative uncertainties		*						
Technological dimensions								*
Design for sustainability		*						
Customer priorities		*						
Customer pressure								*
Managerial complexity		*						
Complexity								*
Network imbalance		*						

Manufacturing			*												
Manufacturing at suppliers			*												
Manufacturing at manufacturers			*												
Testing			*												
End-of-use alternatives			*												
Re-use			*												
Refurbishing			*												
Air quality					*										
Bio diversity					*										
Noise					*										
Land use					*										
Greenhouse gas emissions (GHGE)						*									
Transition to green practices				*											*
Consumer awareness studies				*											
Increasing awareness		*													
Competitiveness					*										
Corporate competitiveness											*				
Customs							*								
Infrastructure							*								
Arranging Shipments							*								
Logistics Competence							*								
Tracking & Tracing							*								
Timeliness							*								
Vehicle selection and efficiency										*					
Selection of fuel type to be used										*					
Conveying speed										*					
Compatibility											*				
Organizational support											*				
Company size											*				
Well-connected information and goods flows		*													
Using advanced technology and software in logistics activities												*			

(Authors; 1-Agrawal and Singh, 2019; 2-Abbasi and Nilsson, 2016; 3-Neto et al., 2008; 4-Beken, 2016; 5-Altuntaş and Türker, 2012; 6-Rashidi and Cullinane, 2019; 7-Arvis et al., 2010; 8-Zhang and Zhao 2012; 9-Krajewski, 2013; 10-Görgün and Bardakçı, 2014; 11-Lin and Ho, 2011; 12-Geiger, 2016; 13-Chunguang et al., 2008; 14-Lai and Wong, 2012; 15-Pazirandeh and Jafari, 2013)

Table 1 is created for the criteria and authors in this study. These are the authors who study with sustainability criteria. Table 1 shows the author and criteria relationship. The numbers represent to the authors. For example; 1 is Agrawal and Singh, (2019) studied consumer behavior, existing practices, environmental factors, supply chain integration, product value, reverse logistics costs, quantity of returned products, quality of returned products, external factors, internal factors, economy/economic performance/economic factors, return on investment, recapturing value, logistics cost optimization, recycle efficiency, annual sales of remanufactured products, disposal costs, minimum energy consumption, use of recycled material, optimum use of raw material, transport optimization, reduced packaging, waste reduction, social performance/social factors, community complaints, consumer health and safety, stakeholders participation, donations to community, employee benefits. Another one, 14 is Lai and Wong, (2012) and they studied government support and economic support.

Table 1 give the intersection of criterion and author. A total of 103 criteria are achieved. Due to the large number of sub-criteria obtained after extensive research, it is asked to simplify and determine the importance of these criteria.

At this point, Pareto Analysis is used because it is shown with the help of graphics and concentrates attention on the most important cause of the problem and helps to determine the priorities. According to Pareto Analysis quality tool, which is also called "80-20 Rule" in the literature, it is concluded that "80% of the problems are caused by 20% activity and this important share is concentrated above 20%". In other words, it represents the "visible majority, influential minority"

With the Pareto Analysis, the importance of the problems, the number of realization of the errors and the reasons are clearly determined. In this way, the areas where the improvements will be applied first are determined and studies are carried out (Özgüvenç, 2011).

According to these statements, the opinions of 12 people, including 5 sector representatives and 7 academicians, are asked to score these criteria between 1-10 according to their importance. The expert group consisting of 12 people are people who have studies in the field of logistics and work on logistics. Together with the calculations make after the answers, the Pareto Graph of 103 criteria is defined as in the Figure 3.

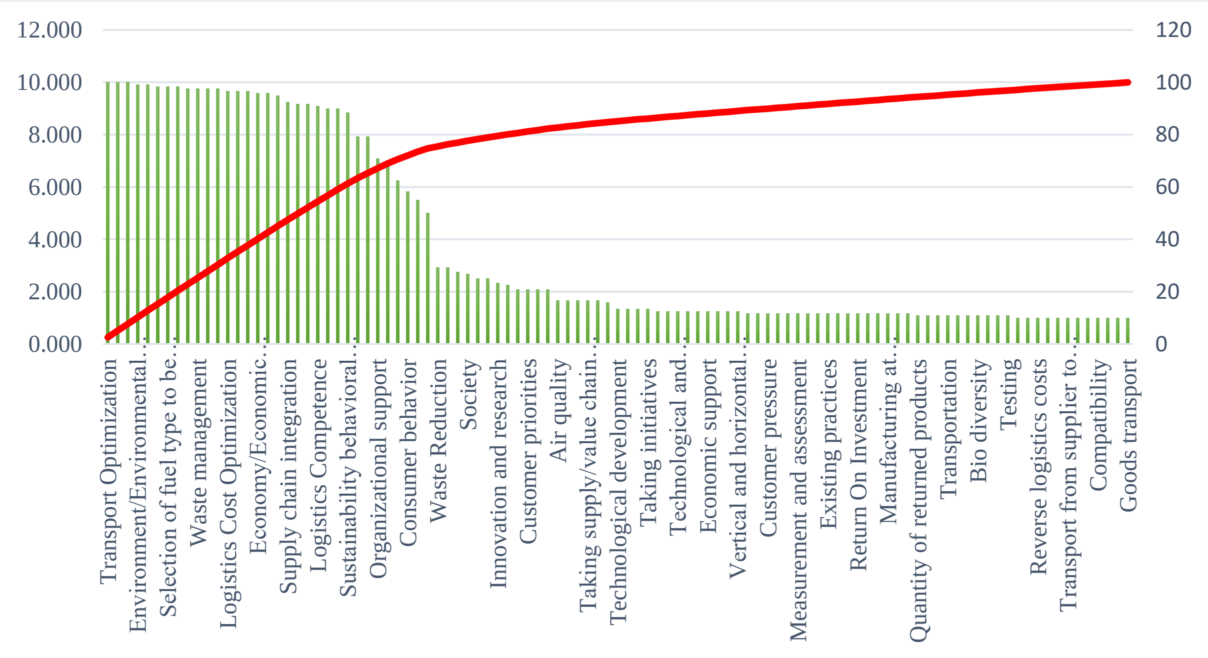

Figure 3. Pareto Graph for Sustainability Logistics Criteria

4. FINDINGS AND DISCUSSION

According to the Pareto Analysis results, it is understood that 33 criteria out of 103 criteria are more important. These are shown in Table 2.

Table 2. 33 Important Criteria From Pareto Analysis

No	Criteria
1	Transport optimization
2	Energy and fuel efficiency
3	Production and distribution planning
4	Environment/Environmental conditions/Environmental factors/Environmental Performance
5	Well-connected information and goods flows
6	Internal resources efficiency, effectiveness, and utilization
7	Selection of fuel type to be used
8	Choice of mode of transport and intermodal transport
9	Energy use
10	Waste management
11	Recycle efficiency
12	Vehicle selection and efficiency
13	Logistics cost optimization
14	Using advanced technology and software in logistics activities
15	Minimum energy consumption
16	Economy/Economic Performance/Economic factors
17	Greenhouse gas emissions (GHGE)
18	Reduced packaging
19	Supply chain integration
20	Consumer awareness studies
21	Social Performance/Social factors
22	Logistics competence
23	Reverse logistics applications
24	Government support / Government regulated laws/Government rules & regulations
25	Sustainability behavioral cautiousness
26	Use of recycled material
27	Increasing awareness
28	Organizational support
29	Employee benefits
30	Green packaging
31	Consumer behavior
32	Infrastructure
33	Product value

The definitions of some of these criteria are as follows:

Internal resources efficiency, effectiveness, and utilization: The most common activities to increase effectiveness and efficiency of internal logistical resources are related to the mode of transportation used and vehicle energy usage (Abbasi and Nilsson, 2016).

Energy and fuel efficiency: Energy is an inseparable part of environmentally sustainable logistical activities. It can be used in sustainable logistics as follows:

- To energize and utilize resources like vehicles and facilities fed by non-fossil/renewable fuels.
- Collaboration with vehicle manufacturers to design more environmentally friendly trucks, trains, vessels, as well as aircrafts that are lighter and more aerodynamic, have more efficient engines, and emit zero GHG emissions.

Sustainability behavioral cautiousness: The behavior of different stakeholders are by most of the cases as an important area affecting sustainable development. Suppliers can be scanned to make sure they meet social and environmental requirements (Abbasi and Nilsson, 2016).

Use of recycled material: It can be ensured that recycled products are preferred within the activities and additive values are created from their recycling.

Green packaging: The packaging used in the product is recyclable.

Government rules and regulations: Government rules and regulations are important for disposition decisions making. Research on certain activities of sustainability by the regulatory bodies greatly impact the disposition decisions in sustainability (Lambert et al., 2011).

Consumer behavior: More conscious consumers may return the products timely rather than storing or disposing them in the environment (Jack et al., 2010).

Product value: Product value is one of the important factors of the decision-making decision. Low value products are generally preferred for material recovery through recycling. The higher cost of reproduction is one of the reasons for this. Also, consumers will probably prefer the new product because absolute savings in terms of money are low. (Chung and Wee, 2011).

Logistics cost optimization: These costs include storage, transportation, packaging, etc. consists of costs. The decisions are taken according to the cost-benefit analysis of the logistics and it is desired to be optimized.

Supply chain integration: It relates to an organization's ability to adopt RL and integrate it into its existing supply chain. It is aimed to provide resources for the successful operation of RL (Hazen et al., 2012).

Logistics Competence: The overall level of competence and quality of core logistics services providers such as transport operators, distributors, freight forwarders, customs and border agencies, and shippers.

Infrastructure: The quality of trade and transport-related infrastructure such as ports, railroads, roads, information technology, etc.

In addition, the frequency of using these criteria by the authors is examined (Figure 4). Government regulations, economy and environmental factors are mostly taken into account. Others take part in the studies once.

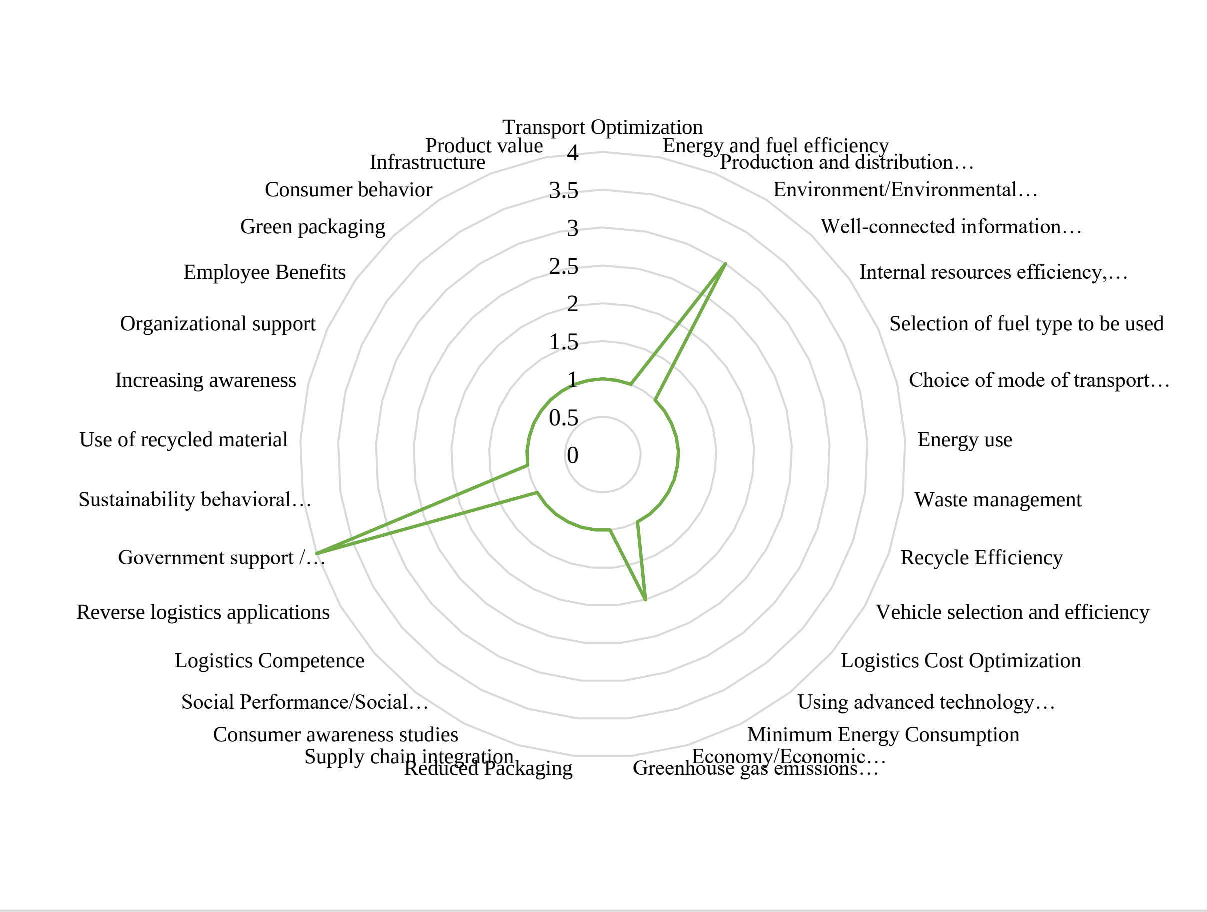

Figure 4. Frequency of Using Importance Criteria

Then, 33 criteria are asked to be classified under main dimensions (Figure 5). This study includes four criteria for main dimensions. These are economic, social, environmental and internal factors. Economic, social and environmental factors have been involved with TBL. Internal factor is the criterion in which company information will be included.

Figure 5. Main Dimensions for Sustainable Logistics

A classification is made according to these four main dimensions and 33 criteria are matched with the main dimensions (Figure 6).

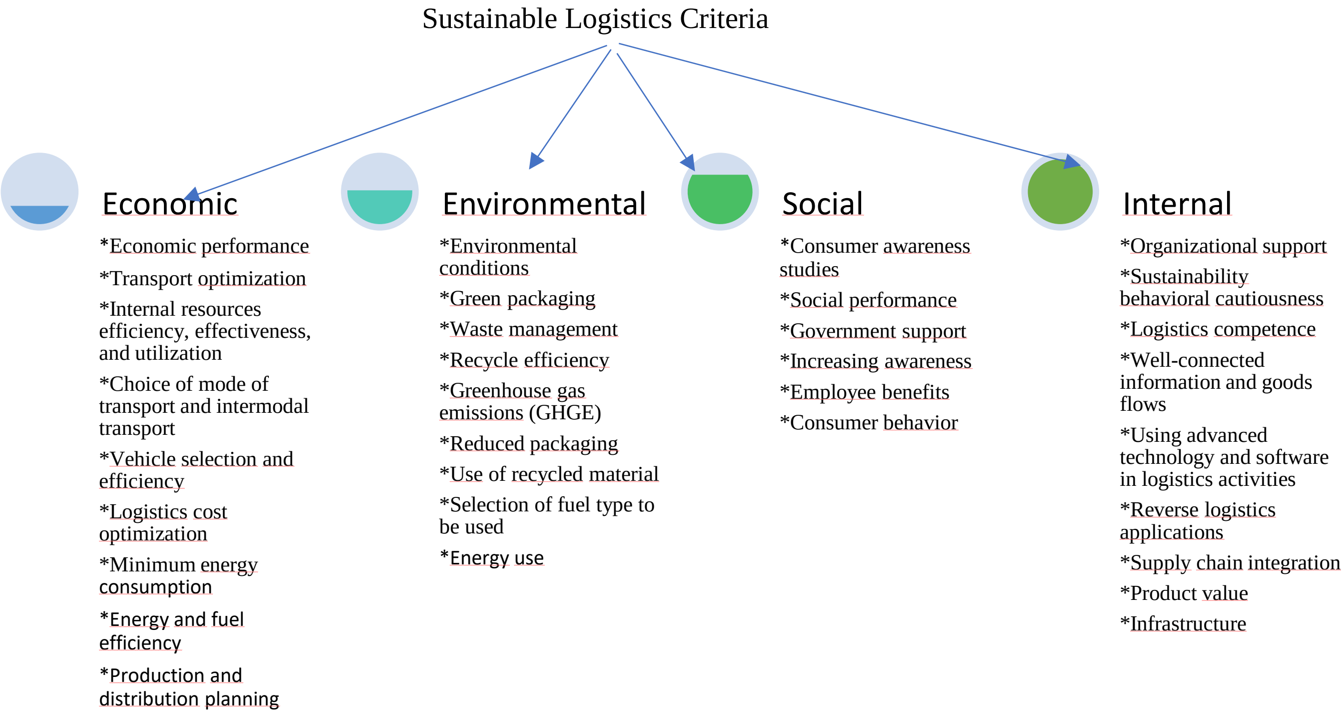

Figure 6. Main Dimensions With Sub-Criteria.

The sub-criteria under the main dimensions determined according to this study are as follows (Figure 6). In economic dimension, there are criteria for economic performance, transport optimization, internal resources efficiency, effectiveness, and utilization, choice of mode of transport and intermodal transport, vehicle selection and efficiency, logistics cost optimization, minimum energy consumption, energy and fuel efficiency, production and distribution planning. In environmental dimension; there are criteria for environmental conditions, green packaging, waste management, recycle efficiency, greenhouse gas emissions (GHGE), reduced packaging, use of recycled material, selection of fuel type to be used and energy use. In social dimension; there are criteria for consumer awareness studies, social performance, government support, increasing awareness, employee benefits and consumer behavior. In internal dimension; there are criteria for organizational support, sustainability behavioral cautiousness, logistics competence, well-connected information and goods flows, using advanced technology and software in logistics activities, reverse logistics applications, supply chain integration, product value and infrastructure. These dimensions and criteria are based on the classification of the criteria in the study.

The criteria used in this study reflect economic, environmental, social and internal factors of the logistics industry. The criterion “logistics cost optimization” reflects the economic aspect, “energy use” and “greenhouse gas emissions” reflect the environmental aspect, the “Increasing awareness” reflects the social aspect and "organizational support" reflect the internal aspect of the logistics sector. Together, they all reflect the overall sustainability performance of a nation's logistics sector.

5. CONCLUSION AND IMPLICATIONS

Logistics is one of the sectors that includes many activities from the supplier to the customer and has recently been regulated in terms of the environment. In this context, sustainability studies are one of the most important issues for the logistics industry. In the study, inspired by these issues, it is requested to investigate the criteria affecting the activities in the logistics sector on the basis of sustainability. Thus, the table of criteria developed by literature review is limited to Pareto Analysis and grouped under the main dimensions and made original.

The highlights covered in this study are as follows**;**

- Within the scope of the study, sustainable logistics performance criteria are determined as a result of a detailed analysis.
- During the determination, Pareto Analysis is used by taking the opinions of academics and representatives from the sector.
- The criteria created as the final table are classified under the main criteria.
- Logistics companies should take into account the sustainability criteria in the study in order to minimize the damage they cause to the environment and increase their competitiveness.

The study is studied in addition to other studies in the literature and brought together all possible sustainable logistics criteria. The literature review on the criteria is detailed. In addition to contributing to the literature on this subject, it has been an original study by collecting sustainable logistics criteria in four main groups.

As a result of these findings, this study is important for companies. First, they can examine the criteria and decide where they want to start and what they want to apply. They can measure the sustainable logistics performance of their own companies with the determined criteria. They can identify their shortcomings and develop in that area. For sustainable logistics, they work for a more livable world by taking into account the social and economic factors as well as the environment. Also, the study provides the opportunity for companies to evaluate themselves by using these criteria in future studies. Evaluation can be made on criteria by using multi-criteria decision making methods.

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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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Daisuke WATANABE[2]
Tetsuro HYODO[3]

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 gruplandırilir. 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).

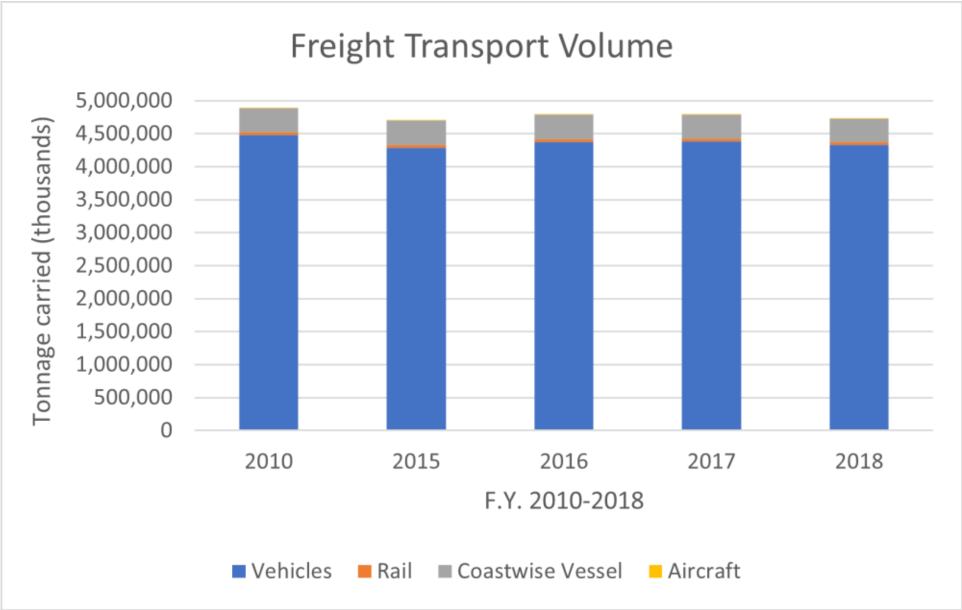

Figure 1. Freight Transport Volume in Japan (Source: Statistics Bureau of Japan, 2021)

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.

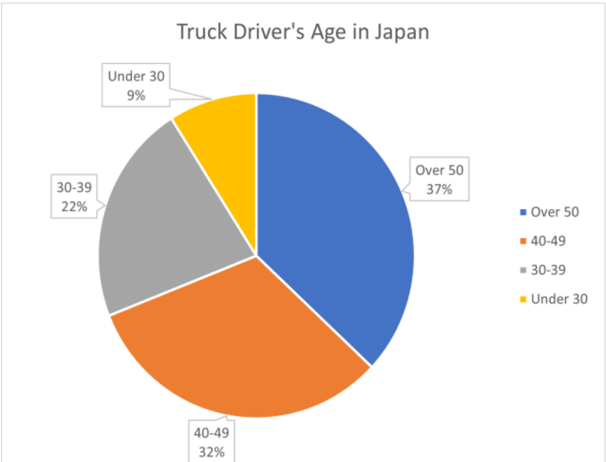

Figure 2. Truck Driver Age in Japan (Source: MLIT, 2019)

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.

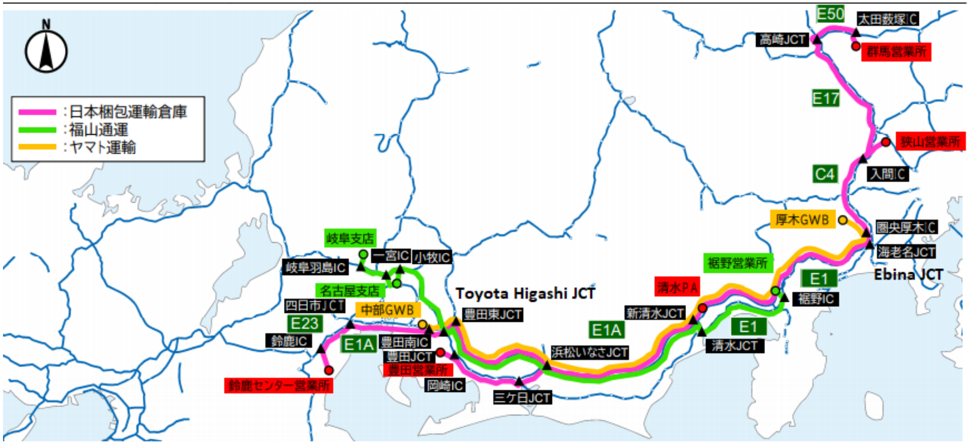

Figure 3. 21m HCV experiment route (Source: MLIT, 2019)

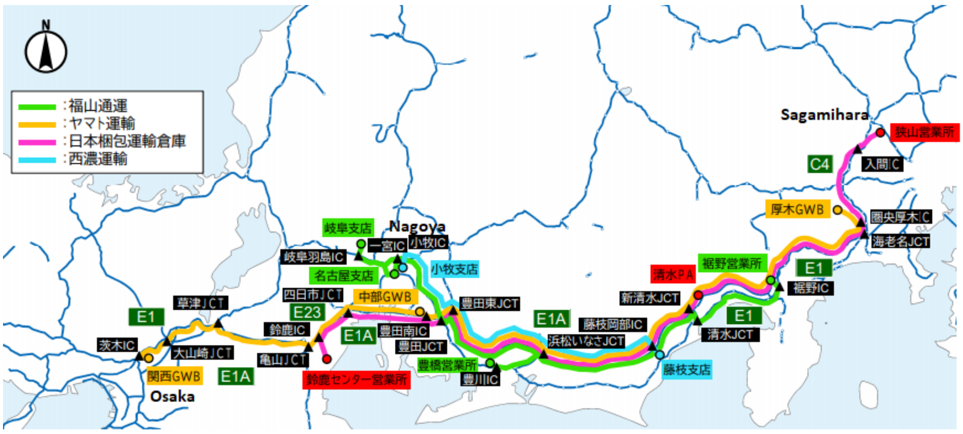

Figure 4. 25m HCV experiment route (Source: MLIT, 2019)

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)

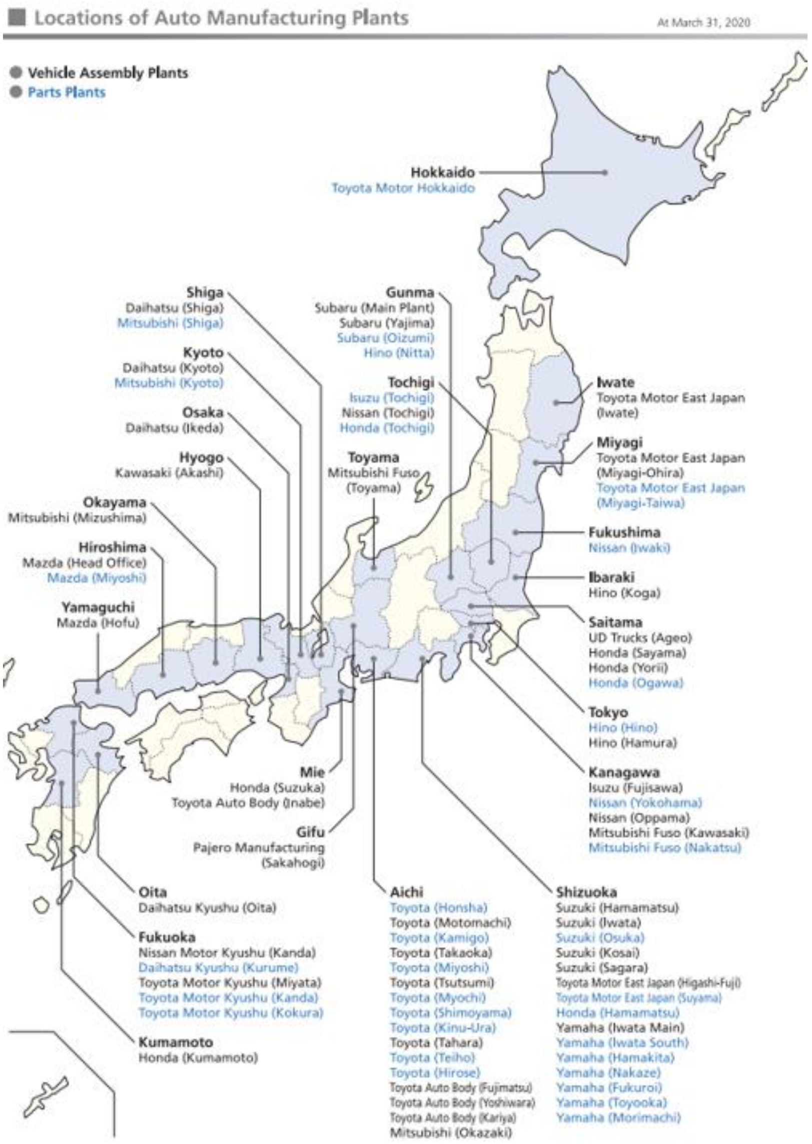

Figure 6. Automobile Manufacturing Plant Locations (Source: JAMA, 2020)

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.

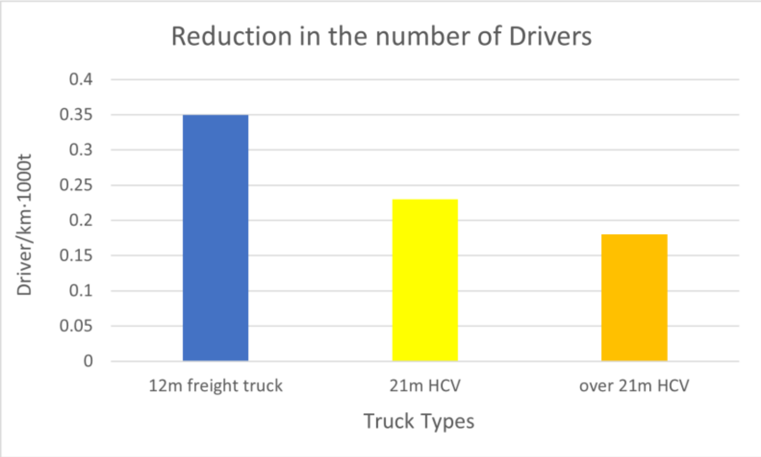

Figure 7. Comparison of the number of Drivers Required by Truck (Source: MLIT, 2019)

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.

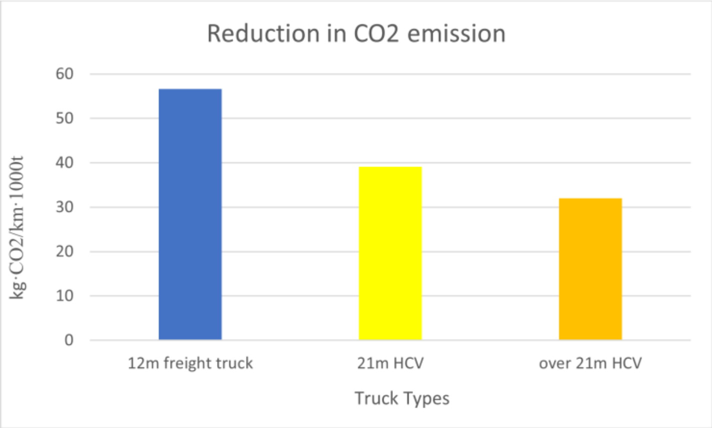

Figure 8. Comparison of CO2 Emission by Truck (Source: MLIT, 2019)

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).

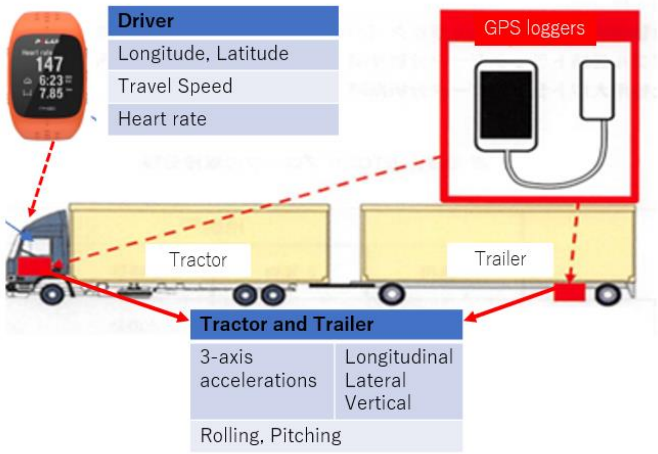

Figure 9. Data Logger on an HCV (Source: Watanabe and Hyodo, 2021)

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.

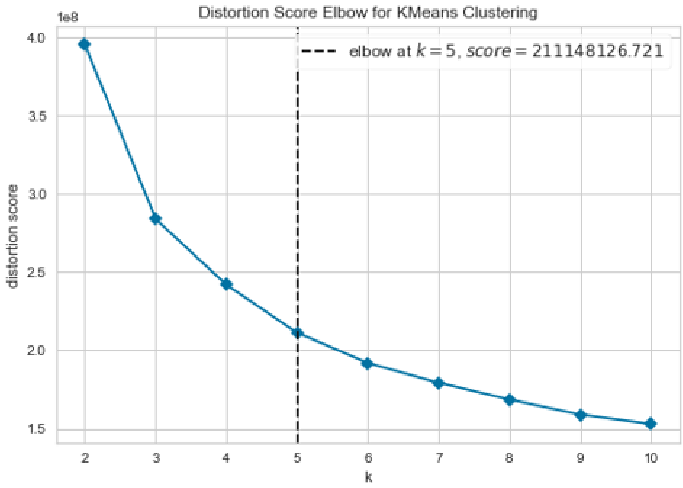

Figure 10. Elbow Curve Calculation Result

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.

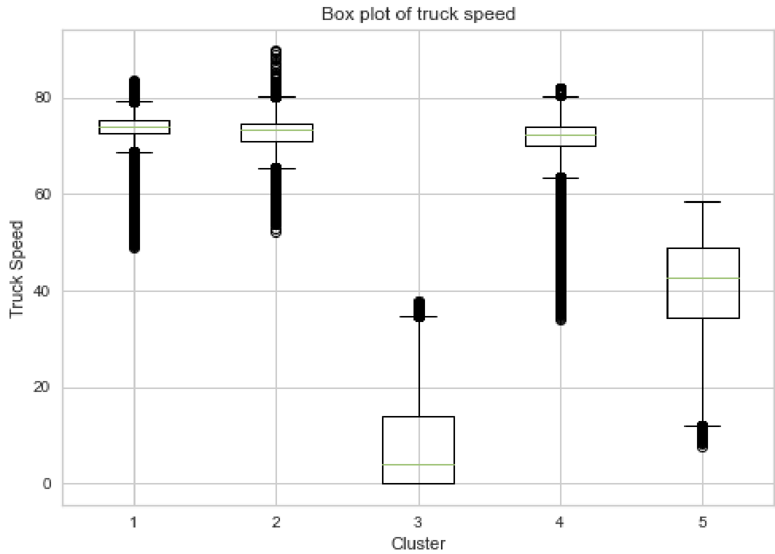

Figure 12. Box Plot of Truck Speed by Each Cluster

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.

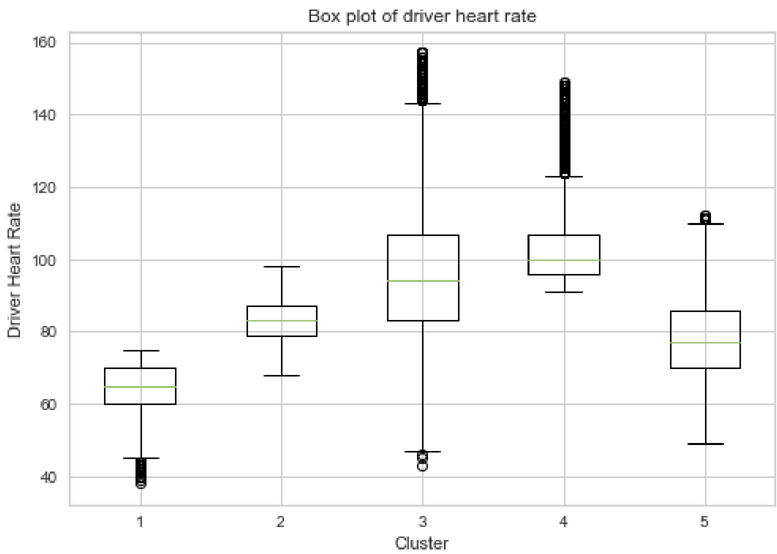

Figure 13. Box Plot of Heart Rate by Each Cluster

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.

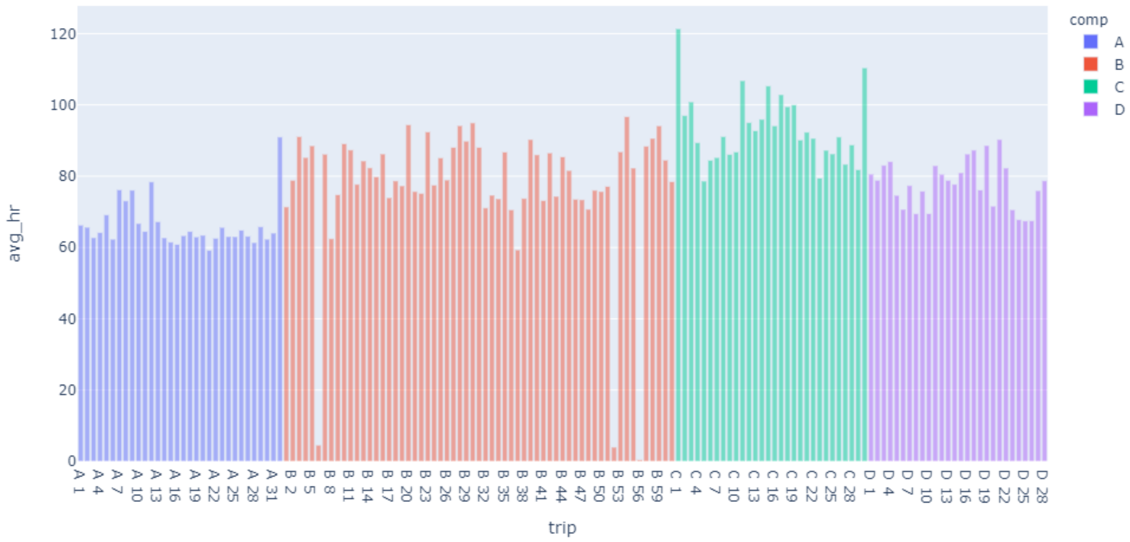

Figure 15. Average Heart Rate Comparison by Trip

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.

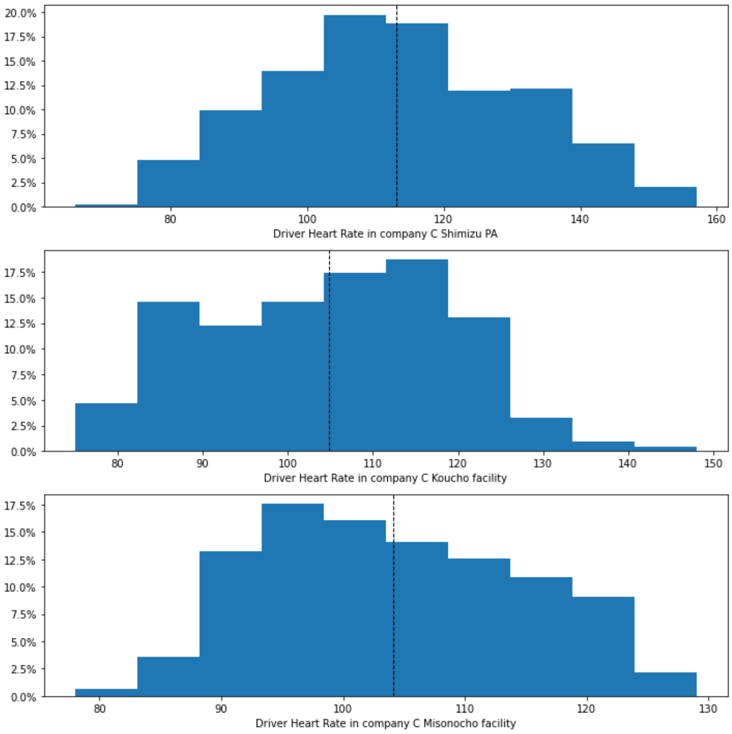

Figure 16. Driver Heart Rate in company C Facilities

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.

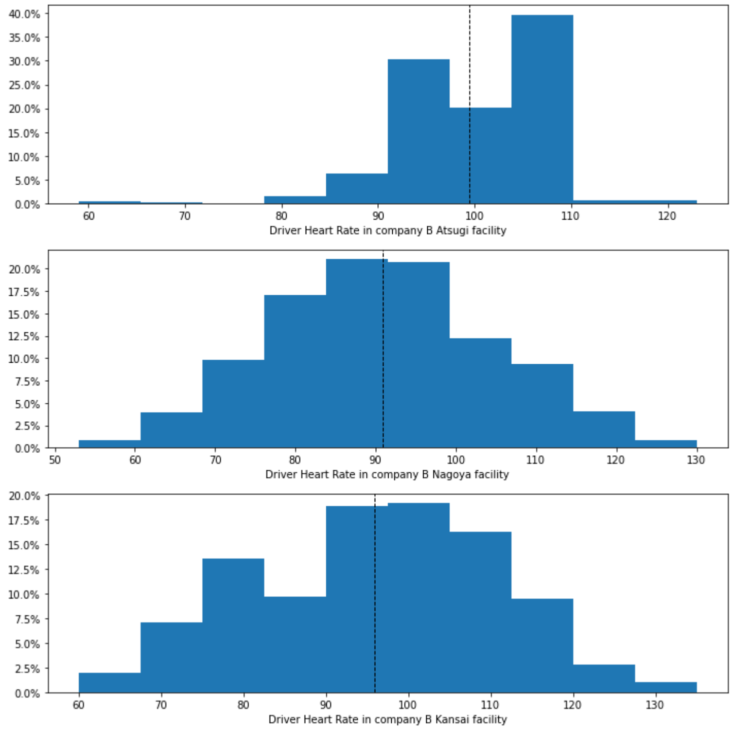

Figure 17. Driver Heart Rate in company B Facilities

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.

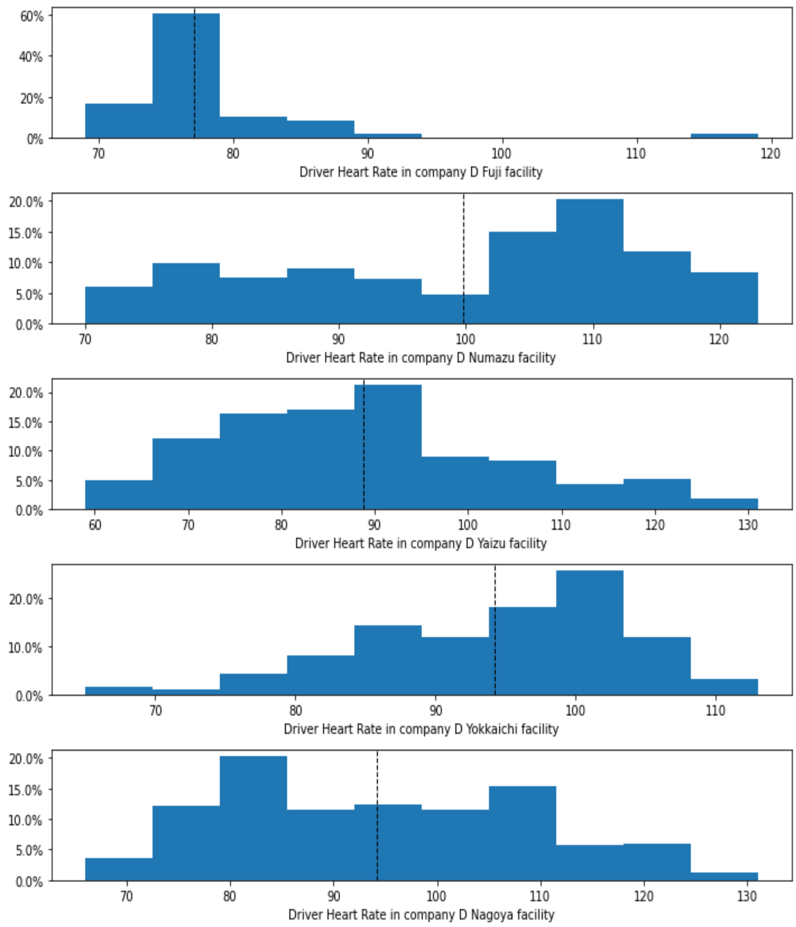

Figure 18. Driver Heart Rate in company D Facilities

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 CO_2 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.

Acknowledgement

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Effects of Center of Gravity Position on Rollover Based Upon Detection of Three-Dimensional Center of Gravity

Üç Boyutlu Ağırlık Merkezinin Tespitine Dayanarak Ağırlık Merkezi Konumunun Devrilme Üzerindeki Etkileri

Kailun YU [1]
Yutaka WATANABE[2]

ABSTRACT

Preventing truck rollover accidents is of great importance to ensure traffic safety, which is United Nations Sustainable Development Goal (SDG) Number 9. It is a misunderstanding of rollover accidents that trucks with heavier loads are more likely to roll over. In fact, when a truck passes through a curve, the truck will tend to roll over if the centrifugal force moment is greater than the gravitational moment. Even if the truck's speed is low and the load is not heavy, if the center of gravity (COG) is high, then the centrifugal torque will be strong. Therefore, finding the COG position is important.

Trucks usually carry multiple types of cargo simultaneously. Each type of cargo has different quantity and volume. Considering the time and economic costs, it is almost impossible to find the position of COG of the entire truck through piece-by-piece calculation. But Detection of the Three-Dimensional Center of Gravity (D3DCG) can indicate the COG position in a short time when a truck is moving.

This paper first introduces the principle of truck rollover, showing that whether a truck rolls over is related to the curve radius, speed, COG height, and the distance between the wheels on both sides. Secondly, results of this study demonstrate the theory of D3DCG which can calculate the COG position based upon the natural frequency of the moving truck. Then, after the authors use a truck scale model to verify the D3DCG accuracy, they conduct a controlled experiment to prove that even if the load remains the same, a truck with higher COG rolls over more easily. The achievement of this study presents new possibilities to prevent rollover accidents. Fruits of this study can also contribute to sustainable development of transportation industries.

Keywords: D3DCG, Natural frequency, Rollover accident, Traffic safety

ÖZ

Kamyon devrilme kazalarının önlenmesi, Birleşmiş Milletler Sürdürülebilir Kalkınma hedefi (SDG) numarası 9 olan trafik güvenliğini sağlamak için büyük önem taşımaktadır. Daha ağır yüklere sahip kamyonların devrilme olasılığının daha yüksek olduğu düşüncesi, devrilme kazalarına ilişkin bir yanlış anlaşılmadır. Aslında, kamyon bir eğimden geçtiğinde, merkezkaç kuvveti momenti yerçekimi momentinden daha büyükse, kamyon devrilme eğiliminde olacaktır. Kamyonun hızı düşük olsa ve yük ağır olmasa bile, ağırlık merkezi (COG) yüksekse, merkezkaç momenti güçlü olacaktır. Bu nedenle, ağırlık merkezinin konumunu bulmak çok önemlidir. Kamyonlar genellikle aynı anda birden fazla tür yük taşır. Her kargo türü farklı miktar ve hacme sahiptir. Zaman ve ekonomik maliyetler göz önüne alındığında, parça parça hesaplama ile tüm kamyonun ağırlık merkezi konumunu bulmak neredeyse imkansızdır. Ancak üç boyutlu ağırlık merkezinin (D3DCG) tespiti, bir kamyon hareket ederken ağırlık merkezinin konumunu kısa sürede gösterebilir. Bu makale ilk olarak, bir kamyonun devrilip devrilmediğinin yatay kurp, hız, ağırlık merkezi yüksekliği ve her iki taraftaki tekerlekler arasındaki mesafe ile ilgili olduğunu gösteren kamyon devrilme prensibini tanıtmaktadır. İkinci olarak, bu çalışmanın sonuçları, hareket eden kamyonun doğal frekansı temel alınarak ağırlık merkezi konumunu hesaplayabilen Üç Boyutlu Ağırlık Merkezinin Tespiti teorisini göstermektedir. Daha sonra, yazarlar üç boyutlu ağırlık merkezinin doğruluğunu tespit etmek için

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bir kamyon ölçekli model kullandıktan sonra, yük aynı kalsa bile, daha yüksek ağırlık merkezine sahip bir kamyonun daha kolay yuvarlandığını kanıtlamak için kontrollü bir deney yaparlar. Bu çalışmanın başarısı, devrilme kazalarını önlemek için yeni olanaklar sunmaktadır. Bu çalışma, ulaştırma endüstrilerinin sürdürülebilir kalkınmasına da katkıda bulunabilir.

Anahtar Kelimeler: D3DCG, Doğal frekans, Devrilme kazası, Trafik güvenliği.

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1. INTRODUCTION

Since vehicles were first invented, they have provided great convenience for people's daily traffic and the transportation of goods, but with inherent benefits and shortcomings. As the utilization rate of vehicles increases year by year, vehicles have caused numerous and severe social difficulties such as environmental pollution, oil resource shortage, and serious road traffic hazards. With needs for urban construction and continuously increasing speeds, the numbers of trucks are increasing. Because of trucks' high centers of gravity (COGs) and large freight vehicle volume, traffic accidents are more likely to occur at special areas of roadways, such as curves. Once an accident occurs, high mortality seriously threatens the safety of people's life and property.

A rollover accident is one by which two wheels on the same side or all wheels of a vehicle are suspended off the ground. Subsequently, the vehicle body touches the ground. Reasons for rollover accidents include the following: (1) Road factors, such as the curve radius through which a vehicle passes is too small, the super-elevation design is unreasonable, or an overly low friction coefficient. (2) Excessive vehicle speeds cause excessive centrifugal force. The vehicle's overturning moment increases gradually and exceeds the limit, leading to sideslip or rollover. (3) Improper driver operation such as sudden braking and slamming direction are caused by tension. (4) The COG position of the vehicle is too high, causing the vehicle to roll over.

According to an annual report of traffic accident statistics of Japan's Ministry of Land Infrastructure, Transport and Tourism in 2019, 191 rollover accidents occurred, of which 176 were truck rollover accidents, thereby accounting for 92.147% of all rollover accidents. The truck rollover accidents account for the vast majority of rollover accidents. Trucks usually carry various goods, including flammable, explosive, toxic and corrosive goods. Once a truck rolls over, risk of further damage is high. Preventing the occurrence of truck rollover accidents is important to ensure traffic safety, which is a United Nations Sustainable Development Goal (SDG No. 9).

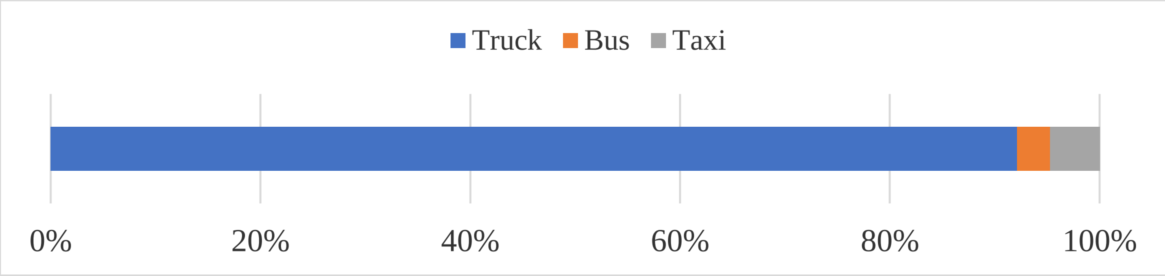


Figure 1. Rollover Accidents of Vehicles İn Japan İn 2019.

Data source: Annual report on automobile accident statistics for automobile transportation business from Ministry of Land, Infrastructure, Transport and Tourism

2. THEORY OF ROLLOVER AND DETECTION OF THREE-DIMENSIONAL CENTER OF GRAVİTY (D3DCG)

This chapter describes that, through force analysis of a vehicle passing through a curve, factors affecting vehicle rollover include the vehicle speed, the distance between the wheels on two sides, the curve radius, and the vehicle COG height. When the curve radius and the distance between the wheels are fixed, one must find the COG height of the vehicle to ascertain the safe speed for passing through the curve. The conventional method for finding the COG requires calculation using the target object volume, shape, and weight. The cost of using a truck scale is too high. Therefore, that method is not suitable for detecting the COG position of the truck. The low-cost and accurate method introduced herein to ascertain the position of the truck's COG using D3DCG imposes no requirements on the vehicle.

2.1 Principle of Rollover

Trucks usually carry more weight and have a higher COG than ordinary cars have. Therefore, when a truck is turning, if its speed is too high, then the body will roll over to the outside of the curve, usually leading to catastrophe. Therefore, analyzing the forces acting upon the vehicles when passing through a curve is very important. One must then find the main factors affecting traffic safety for that critical state of the vehicle in the curve section.

When a truck turns, it is subjected to centrifugal force (Yang and Qiu, 2019: 393). Centrifugal force is not a real force, but a virtual force, a manifestation of inertia, which keeps a rotating object away from its center of rotation. At the same time, the ground imposes frictional forces on the wheels pointing to the curvature center of the curve, which is used to provide the centripetal force which acts when the truck turns. When the centripetal force and centrifugal force are balanced, the truck can pass the curve steadily, but if the centrifugal force is greater than the centripetal force, the truck will start to roll outward. To maintain the torque balance of the vehicle, the support force received by the outer wheels must be greater than that received by the inner wheels. When the truck speed is too high, the inner wheels will lift from the ground; the vehicle might then roll over.

This report describes the study following idealized assumptions about the vehicle and its movement: (1) Suspension structure deformation of the vehicle is not considered. (2) Tire deformation is not considered. (3) Tire width is not considered. (4) The front and rear wheels on the same side are probably subjected to the same force when turning, which can be equivalent to one wheel. (5) Super-elevation of the road surface on the curved section is not considered.

The vehicle movement when turning is rotation along a fixed axis. The rotation axis passes through the center of curvature of the curve. For this study, it is assumed that the vehicle is subjected to a traction inertia force (centrifugal force). Figure 2 is a force diagram of a vehicle turning left through a curve.

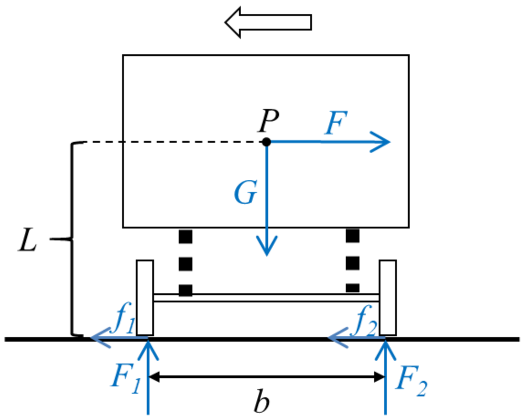


Figure 2. Force Diagram When a Vehicle Turns Left Through A Curve.

Note: *P* is the COG position. *G* represents gravity. *F* represents traction inertia force (centrifugal force).

F_1 and F_2 respectively represent the vertical forces on the outer and inner wheels provided by the ground. f_1 and f_2 respectively represent the lateral forces (frictional forces) on the outer and inner wheels.

To keep the body moment balance when the vehicle passes through the curve, F_2 will be greater than F_1. The difference between them will increase with increased vehicle speed. When the vehicle speed reaches a certain value, F_1 decreases to 0. The inner wheel starts to leave the ground. This speed is designated as the critical speed of rollover.

According to Figure 2, the torque equation of the contact point between the outer wheel and the ground is given as

$$G \cdot \frac{b}{2} = F \cdot L \qquad (1)$$

where *b* represents the distance between two wheels and *L* denotes the COG height. Also, *G* and *F* can be expressed by the following equations.

$$G = mg \qquad (2)$$

$$F = m\frac{v^2}{R} \qquad (3)$$

Therein *m* signifies the vehicle mass, *v* stands for the velocity, *R* denotes the turning radius of curve, *g* expresses the gravitational acceleration, and π is the circular constant.

By substituting equations (2) and (3) into equation (1), the expression of the critical rollover speed of the vehicle during passage through a curve can be obtained as shown below.

$$v = \sqrt{\frac{gRb}{2L}} \qquad (4)$$

According to the equation presented above, when *R* and *b* increase, *v* increases monotonously; when *L* increases, *v* decreases monotonously. Therefore, if the distance between the wheels and the curve radius is fixed, then a higher COG position and lower critical speed will be reached when the vehicle rolls over. Ascertaining the COG position can enable the driver to adjust the speed in time before passing through the curve. Thereby, a driver can avoid the occurrence of rollover accidents.

2.2. Theory of D3DCG

The conventional and easiest method of finding the COG position of multiple objects is to find the COG position of each object first, then to calculate the combined position of two objects based on the weight and the distance between their COG, and then to add the objects one by one (Watanabe, 2017: 11). Nevertheless, this computation procedure presents some difficulties. This method can be used on the premise that the COG, weight, shape, and other information of each component are known, but trucks are often loaded with goods of different weights and shapes. In fact, the truck itself is composed of numerous parts. Therefore, it is almost impossible to ascertain the truck COG in this way. Even if this method were feasible, the errors caused by the calculation would be large. In addition, the operation of trucks must consume gasoline or diesel. With fuel consumption and refueling operations, the COG position of the truck would also change. This method is not flexible. It is not available.

Reportedly, a truck's COG can be detected using a truck scale (Mikata, Yamanaka, et al., 2011: 405). A truck scale is a fixture. Therefore, this method can only be implemented if the driver has sufficient time to drive the truck to a place with a truck scale. Additional costs of measurements and fuel are not considered. Actually, it is not realistic to neglect the time and economic costs. Therefore, the only means of low-cost, accurate, and flexible detection of the COG position of a truck is D3DCG.

The theory of D3DCG can be derived from the floating behavior of ships. It is applied to prevent the rollover of railway cars (Kawashima and Watanabe, 2016: 8). D3DCG finds the COG position based upon the natural frequency of a moving vehicle. It works by inverse operation of the period of the vertical simple harmonic oscillation in the vertical direction and rolling in the transverse direction of the body of a vehicle. Figure 3 presents a schematic drawing of free oscillation of a vehicle during motion.

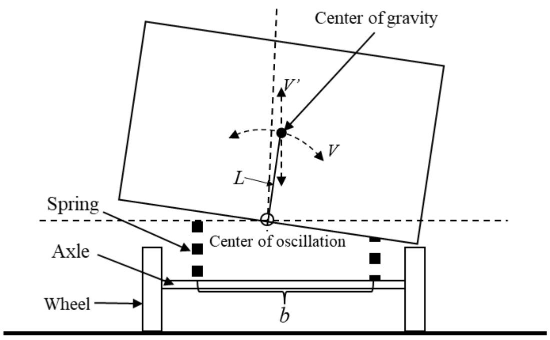


Figure 3. Concept of D3DCG.

The road surface disturbs a moving vehicle so that some elastic structures such as springs and tires generate vertical acceleration. This simple harmonic motion can be formulated as the following equation.

$$V' = \frac{1}{2\pi}\sqrt{\frac{2k}{m}} \tag{5}$$

Therein, *V'* denotes the frequency of vertical simple harmonic oscillation of the body, *k* represents the spring constant on each side, and *m* expresses the vehicle mass. Also, π is the circular constant.

Heaving has a tendency to alleviate itself by horizontal movement so that rolling occurs. Rolling is a circular motion around the center of oscillation as in the following equation.

$$V = \frac{\sqrt{\frac{kb^2}{2m} - gL}}{2\pi L} \tag{6}$$

In that equation, *V* stands for horizontal shaking (rolling) frequency, *L* denotes the COG height from the axis of center of oscillation, *g* represents the gravitational acceleration, and *b* expresses the width of a portion that supports the vehicle weight.

In equations (5) and (6), *k/m* can be regarded as one variable. After eliminating it, the D3DCG theory can be expressed as shown below.

$$L^2 + \frac{g}{4\pi^2 V^2} L - \frac{b^2 V'^2}{4V^2} = 0 \tag{7}$$

In the equation above, the values of g and π are fixed; *b* can be measured. The values of *V* and *V'* can be ascertained with a motion sensor and a computer. For that reason, *L* can be calculated if the values of other variables are substituted into equation (7).

3. ACCURACY OF D3DCG

In the preceding chapter, the relation between rollover and the COG position of the vehicle in a curved section is introduced. A method of using D3DCG to measure the COG position is also proposed. This chapter introduces the truck model as the experiment object, through the conventional hanging method and the method of D3DCG to detect the position of its COG. Then results are compared to demonstrate the accuracy of D3DCG.

3.2. **Measurement Of COG by Hanging A Truck Model**

A static object is subject to balancing forces. If a hung object is static, it will only be subject to two forces: gravity and tension. If the two forces are balanced, then they must be equal and opposite and in a straight line (to ensure the balance of torque). Therefore, the extension line of the tension must pass through the COG. The authors hang the empty truck model from three directions by a rope, as Figure 4 shows. Extension lines of the rope intersect in the same point. Therefore, this point represents the COG position, the height of which is 9.5 cm.

However, the hanging method is inapplicable for detection of the COG position of a truck because, on one hand, the truck is too heavy to hang. It is very dangerous. On the other hand, the internal structures of the truck and the loading cargoes are not completely fixed. Therefore, if it is hung, then the COG position will change. The result will not be accurate.

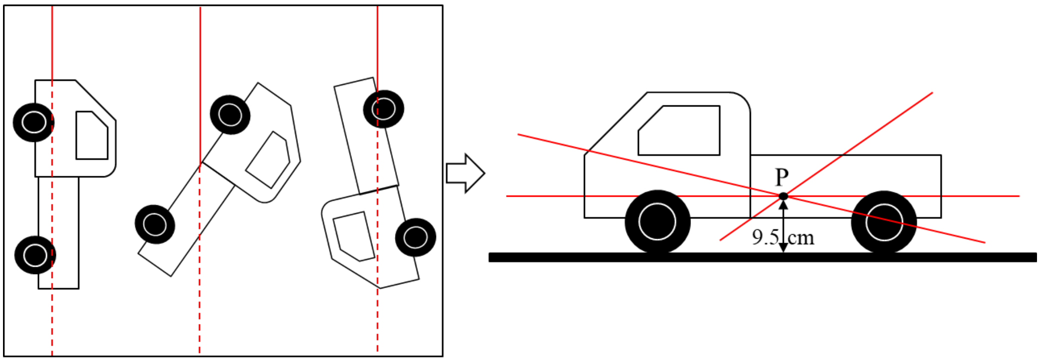


Figure 4. Measurement of COG by hanging.

3.3. Detecting The COG of A Moving Truck Model Using D3DCG

D3DCG can find the COG position of a moving object based upon its natural frequency. Authors install a motion sensor on the truck model carriage, as shown in Figure 5(a). Figure 5(b) portrays sensor details, where *x* is made to be consistent with the direction of movement. Therefore, *y* represents the horizontal direction; *z* represents the vertical direction. The sensor records the displacement changes in these three directions every 0.005 s. It then sends the collected data to the PC through a Bluetooth connection.

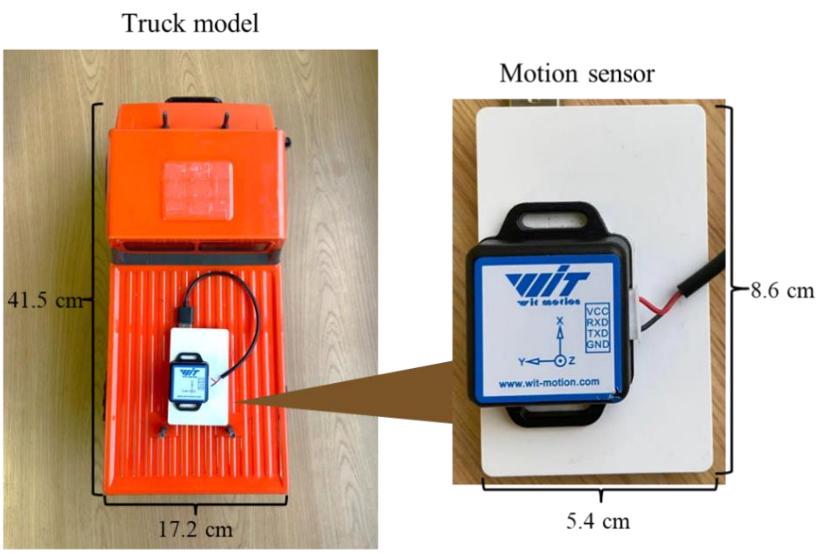


Figure 5. Truck model and Motion Sensor.

The model is controlled to move straight along the road for about 1 min. The collected data are processed by Fast Fourier Transformation (FFT), which processes 2048 data as a group. FFT is done continually, shifting the starting point to next. For example, the first group includes the 1st data to the 2048th data. The second group includes the 2nd data to the 2049th data, etc. When the ending point of FFT reaches the end of the whole data set, the average of FFT results is calculated to divide the accumulation by the number of FFT done. The truck model is so small that the road conditions strongly influence on its motion state. The average frequency can reduce the disturbance from the road surface. Thereby the time-based displacement change is converted to frequency-based displacement change. Figure 6 depicts FFT results obtained for one set of data. In the figure, the peak amplitude in a specific range is regarded as the natural frequency of the moving object in a certain direction. Therefore, the frequency of heaving and rolling of the empty truck model can be ascertained.

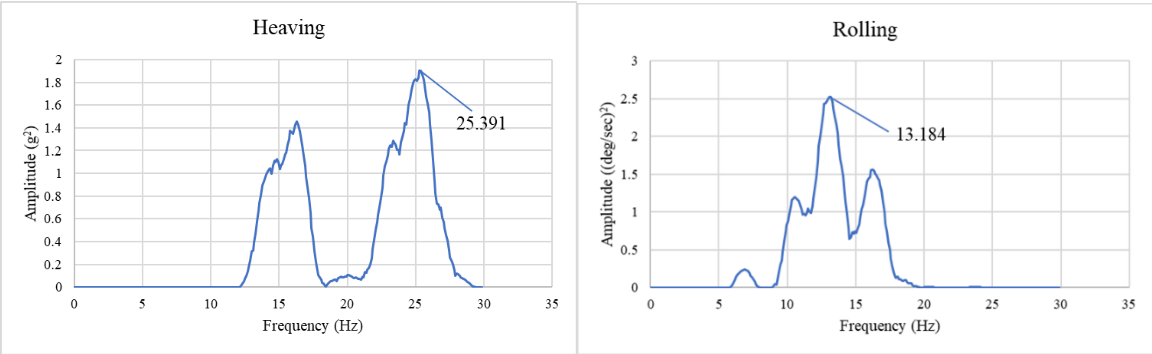


Figure 6. Frequency Image from the FFT Analyzer.

Two elastic structures cause heaving and rolling: springs and tires. When the truck model is empty, springs play the main role. Therefore, in this case, the width of a portion that supports the vehicle weight is the distance between two springs, denoted as b_s.

Table 1. COG Of An Empty Moving Model Detected Using D3DCG

	V' (Hz)	*V* (Hz)	b_s (m)	*L* (m)
	Vertical simple harmonic oscillation	Horizontal rolling frequency	Width of a portion supporting the weight	Height of COG
Exp. 1	25.391	13.184	0.100	0.096
Exp. 2	24.805	12.793		0.096
Exp. 3	25.977	12.988		0.099
Exp. 4	24.707	12.500		0.098
Exp. 5	25.293	12.695		0.098
Average	25.234	12.832	-	0.098
Standard deviation	0.456	0.234	-	0.001

The experiment is repeated five times. The results are presented in Table 1. The average FFT results are applied to equation (7). Therefore, the COG position of the empty moving model is detected. It is 0.098m.

Compared to the position measured by hanging, the result detected using D3DCG is about 0.3 cm higher. Some disturbances, such as the condition of road surface and the remote control of adjusting direction, cause errors. The result detected using D3DCG shows the COG position of both the truck model and the sensor. The sensor is not much lighter than the model. Therefore, it might raise the COG height. The result detected by hanging only shows the position of the empty truck model. If the volume and mass of the model are sufficiently large, then some error can be ignored.

Hanging method is a precise method to measure the COG position for objects that are small and light. It will not change the internal structure because of the change of the position of the hanging point. For objects that are heavy and bulky and which have an internal structure is not fixed, the hanging method is difficult to practice. In this case, D3DCG can work. Moreover, D3DCG does not cost a lot. It can find the COG accurately and quickly.

4. CONTROLLED EXPERIMENTS BETWEEN MODELS WITH HIGHER AND LOWER COG

The rollover principle is introduced in chapter 2. The following conclusions were drawn: when other variable values are fixed, a truck with higher COG rolls over more easily. Nevertheless, this supposition is not proved by experiments. Therefore, in this chapter, controlled experiments were conducted to verify the relation between rollover and the COG height. The experiments were designed to produce models with different heights of COG to pass through the same curve at the same speed. Then, based on the motion states of two models with different heights of COG, the rollover theory can be proved.

4.2. Center of Gravity of Objects in The Controlled Experiments

For the controlled experiments, values of all other variables except the height of COG remain unchanged. And the change in the overall COG height is realized by changing the position of the load carried by the truck model, shown as Figure 7. Devices used for the controlled experiments are shown in Figure 8, including the remote control truck model, motion sensor, plastic foam and a load with 1 kg weight. Unlike the empty truck model, the sensor is installed on the cab instead of the carriage. When the load is put on the upper side of the plastic foam, the overall COG position is higher. When it is put under the plastic foam, the position is lower.

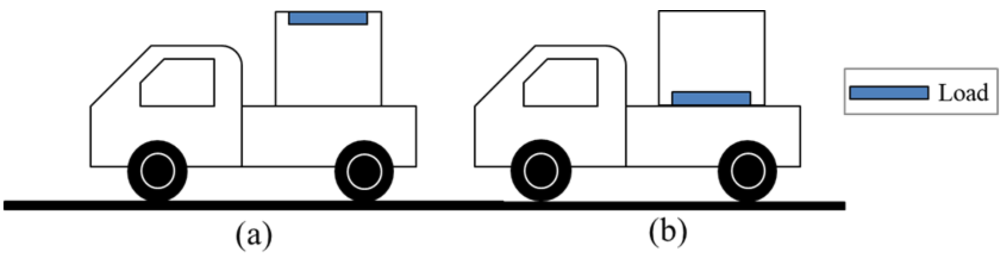


Figure 7. Model with a higher COG (a) and model with a lower COG (b).

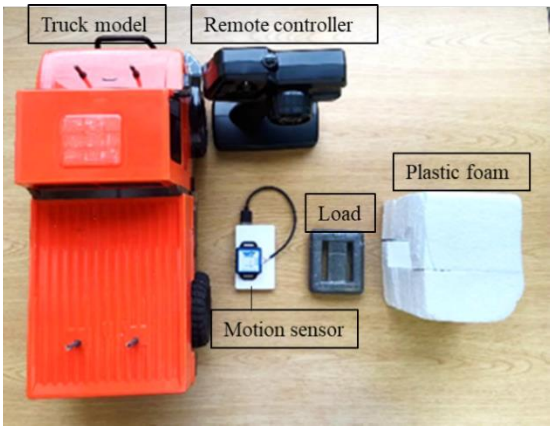


Figure 8. Experiment devices used for controlled experiments.

The COG positions of different models detected using D3DCG and the results are shown in Table 2 and Table 3. Both springs and tires are elastic structures that can cause heaving and rolling. In the loaded condition, heaving and rolling mainly occurs on tires. Therefore, the width of a portion that supports the weight of the vehicle is the distance between two tires, denoted as b_l. The higher COG position is 0.153 m. The lower one is 0.117 m.

Table 2. Results of Model with Higher COG Detected by D3DCG

	V' (Hz)	*V* (Hz)	b_l (m)	*L* (m)
	Vertical simple harmonic oscillation	Horizontal rolling frequency	Width of a portion supporting the weight	Height of COG
Exp. 1	8.398	3.906	0.150	0.153
Exp. 2	8.398	4.004		0.150
Exp. 3	7.910	3.711		0.151
Exp. 4	8.510	3.809		0.159
Exp. 5	8.308	3.906		0.152
Average	8.305	3.867	-	0.153
Standard deviation	0.208	0.096	-	0.003

Table 3. Results of Model with Lower COG detected by D3DCG

	V' (Hz)	*V* (Hz)	b_l (m)	*L* (m)
	Vertical simple harmonic oscillation	Horizontal rolling frequency	Width of a portion supporting the weight	Height of COG
Exp. 1	11.914	7.422	0.150	0.118
Exp. 2	12.012	7.520		0.118
Exp. 3	11.719	7.324		0.118
Exp. 4	12.598	7.813		0.119
Exp. 5	11.700	7.520		0.113
Average	11.953	7.520	-	0.117
Standard deviation	0.363	0.163	-	0.002

4.3. Velocity Detection Process and Results of The Loading Truck Model

Because of constraints of the model itself, adjusting the speed by remote control as needed is impossible, but its maximum speed can be regarded as uniform. The truck model speed is influenced only by the loading weight, instead of the COG position. Therefore, models with both higher and lower positions of the COG have the same maximum speed. According to the formula of uniform rectilinear motion $v = s / t$, where v represents the velocity, s stands for the displacement, and t denotes the time that the object takes to pass through displacement s at speed v, the model velocity is calculated by measuring the duration of model passage through 10 m distance at its maximum speed. As Figure 9 shows, the timing starts when the front of the truck model passes the starting point. It ends when the front of the model reaches the ending point. The elapsed time is the time at which the model passes the 10 m mark at maximum speed. The truck model accelerates for some distance before the starting point. Thereby, we ensured that the model reached its maximum speed at the starting point. The average velocity of the loading truck model was 5.119 m/s, as shown in Table 4.

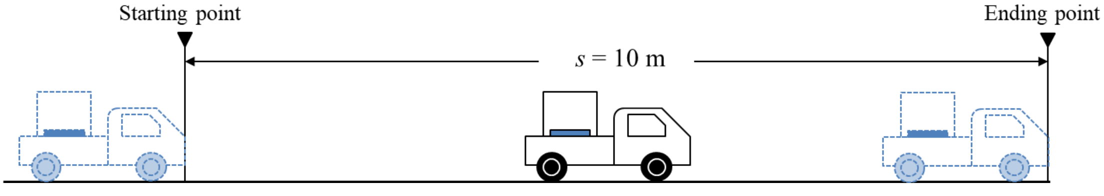


Figure 9. Velocity Detection Process of The Loading Truck Model.

Table 4. Average Maximum Velocity of The Loading Truck Model

	s (m)	*t* (s)	*v* (m/s)
	Displacement	Time	Velocity
Exp. 1	10.0	1.960	5.102
Exp. 2		1.850	5.405
Exp. 3		2.020	4.950
Exp. 4		2.040	4.902
Exp. 5		1.910	5.236
Average	-	1.956	5.119
Standard deviation	-	0.078	0.207

4.4. Process and results of controlled experiments

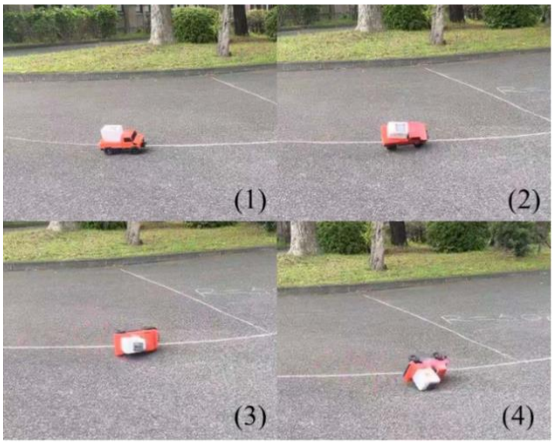
To ascertain the rollover critical radius of the curve, equation (4) can be converted as shown below.

$$R = \frac{2Lv^2}{gb} \quad (8)$$

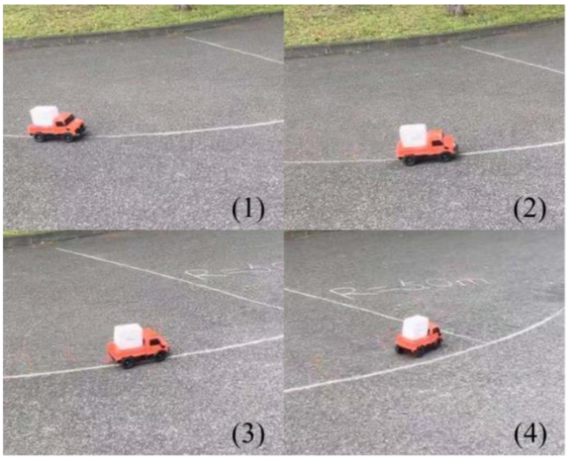
When the velocity and COG height of the two models are put in the equation (8), the rollover critical radii of the curves can be calculated. The critical radius for the model with lower COG was 4.171 m. That for the model with higher position was 5.455 m. Drawing a curve with the rollover critical radii of the two models that have different positions of COG will cause errors. It is also difficult to make the truck model move completely along the drawn curve. Therefore, the curve radius in the experiment is taken as 5.000 m (between 4.171 m and 5.455 m). The motion states of the models are portrayed in Figure 10, in which the moving direction and the speed remain unchanged.

When the truck model with higher COG enters the curve, the whole body tilted outwards, its outer wheels are compressed. Then its inner wheels start to leave the ground. If the speed is reduced in time, the truck model might not roll over. If the speed is not lowered and the direction of movement is not changed, the model will eventually roll over. If the moving direction is changed to avoid rollover, the body of the truck model will shake violently and rush out of the curve. The model with lower COG passes through the curve steadily, but only with the outer wheels undergoing a slight compression deformation.

Results obtained from controlled experiments verify that when a truck model has a constant load and a constant speed, a truck with higher COG rolls over more easily. Similarly, to avoid rollover, the higher a vehicle's COG becomes, the lower its speed should be when passing through a curve of a given radius.



(a) Rollover process of model with higher COG



(b) Passing of a model with lower COG

(c)

Figure 10. Motion States of Models with Different Heights of COG When Passing Through a Curve.

5. CONCLUSION

This report first describes causes of vehicle rollover accidents and data of Japanese truck rollover accidents from 2019. Subsequently, it explains the importance of research on preventing truck rollovers.

Then the study described herein elucidated the rollover mechanism, with results suggesting that the critical speed of rollover decreases with the increase of the COG height and increases with the increase of the curve turning radius. Among the factors affecting rollover, the curve turning radius is fixed. Therefore, only the height of COG should be detected. D3DCG finds the COG position based on the natural frequency of the moving truck. This method requires only a motion sensor and a PC. The motion sensor transmits data to a PC. Then the PC converts it into frequency-based data through Fast Fourier Transformation, subsequently outputting the conversion results and image. According to the image, the frequency corresponding to the peak amplitude in a certain range is regarded as its natural frequency. It is substituted into the equation to calculate the COG position of the truck.

To prove the accuracy of D3DCG for detecting the COG position, a truck model is taken as the experimental object. The COG is first detected using the hanging method. Then it is detected by D3DCG. By comparing the results obtained using these two methods, it was found that the COG found by D3DCG is close to the figure found through detection by hanging the vehicle.

Controlled experiments prove that when trucks with the same load but with different heights of COGs pass through the same curve at the same speed, the truck with a higher COG position is more likely to roll over.

The theory of D3DCG can be used not only to avoid truck rollover accidents. It can also be applied to other vehicles such as buses and trains. With further development of science and technology, research into intelligent automobiles is becoming increasingly popular. Application of D3DCG can contribute to safe driving. Trucks carry various cargoes, including dangerous goods. The study presented herein is of great importance for the safeguarding of life and property, in addition to sustainable development of transportation industries.

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Network-Based Optimization of Liquefied Natural Gas Transportation Routes

Sıvılaştırılmış Doğal Gaz Taşıma Yollarının Ağ Tabanlı Optimizasyonu

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ABSTRACT

In recent years, one affordable and efficient clean energy resource has entered a period of rapid development: liquefied naturam gas (LNG) emits less carbon dioxide during combustion than oil or coal. In fact, LNG has not only been used widely for power generation, urban gas, and industry. It has also been adopted gradually as an automotive fuel, leading to the rapid growth of LNG trucks. However, safety issues related to LNG truck transportation have become increasingly prominent. Because LNG is flammable and entails risk of explosion, once an accident occurs, it is prone to cause fire and explosions because of leakage. Earlier studies simplified the shortest path problem for dangerous goods transportation routes. However, this method does not readily reflect actual situations in which rescue capabilities after accidents must also be considered. Therefore, optimizing LNG transportation routes is important. That optimization is premised on ensuring transportation efficiency with low accident risk, securing rescue facilities, and with little effect on the environment.

Keywords: Accident simulation, LNG transport, risk analysis, route selection.

ÖZ

Son yıllarda, uygun fiyatlı ve verimli temiz enerji kaynakları hızlı bir gelişme dönemine girmiştir. Bunlardan biri de sıvılaştırılmış doğal gazdır (LNG). LNG yanma sırasında petrol veya kömürden daha az karbondioksit yayar. Aslında, LNG sadece enerji üretimi, kentsel gaz ve sanayi için yaygın olarak kullanılmamış, kamyonların hızla artmasında başı çeken bir otomotiv yakıtı olarak kademeli biçimde de benimsenmiştir. Bununla birlikte, LNG kamyon taşımacılığı ile ilgili güvenlik sorunları giderek daha belirgin hale gelmiştir. LNG yanıcı olduğundan ve patlama riski içerdiğinden, bir kaza median geldiğinde, sızıntı nedeniyle yangına ve patlamalara neden olmaya eğilimlidir. Daha önceki çalışmalar, tehlikeli madde taşıma yolları için en kısa yol sorununu basitleştirmiştir. Ancak, bu yöntem, kazalardan sonra kurtarma yeteneklerinin de göz önünde bulundurulması gereken gerçek durumları basitçe yansıtmaz. Bu nedenle, LNG taşıma yollarının optimize edilmesi önemlidir. Bu optimizasyon, düşük kaza riski ile ulaşım verimliliğinin sağlanması, kurtarma tesislerinin güvenliğinin sağlanması ve çevre üzerinde çok az etkiye sahip olması üzerine yoğunlaşmaktadır.

Anahtar Kelimeler: Kaza simülasyonu, LNG taşımacılığı, risk analizi, rota seçimi.

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1. INTRODUCTION

One representative affordable and efficient clean energy resource, liquefied natural gas (LNG), emits less carbon dioxide during combustion than petroleum or coal. Actually, LNG is entering a period of rapid development to counter air pollution and realize a low-carbon society.

In recent years, China has promoted the natural gas use as a policy. A shift of China's natural gas through various policies is progressing rapidly. Not only is LNG used widely for power generation, city gas, and industry; it is gaining ground gradually as an automotive fuel.

Figure 1 shows that LNG consumption is becoming increasingly likely to exceed production. As a result, China's dependence on LNG imports has increased recently (BP Statistical Review of World Energy 2019, 2019). Currently, China's natural gas supply mainly includes three channels: domestic gas fields, pipeline imports from Asia, and coastal LNG terminals.

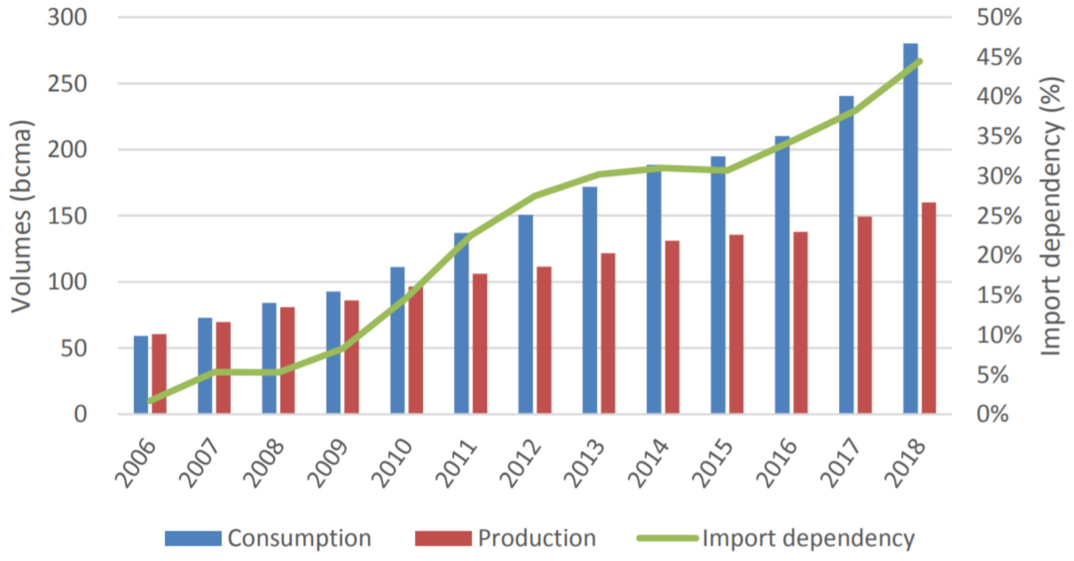

Figure 1. Consumption and Production of LNG in China during 2006–2018.(BP, 2019)

By constructing an LNG terminal in a coastal area, long-term stable gas consumption of urban residents and large-scale industrial enterprises can be satisfied there. Nevertheless, in small and medium-sized cities with a small natural gas consumption market, building a long-distance natural gas pipeline is impossible because of small construction budgets. Many small and medium-sized cities rely on LNG trucking to meet LNG demand. Because of the rapid development of LNG use as a power source to supply vehicles such as city buses, sanitary vehicles, and heavy trucks, attention is increasingly being devoted to LNG filling stations and LNG road transportation by trucks. In the future, LNG is expected to be used more widely in China.

However, LNG truck safety issues are becoming increasingly prominent. The number of LNG transportation accidents is increasing along with increased LNG demand. In the event of a transportation accident, LNG, a dangerous substance, might leak, leading to a fire or explosion, or polluting the water or air in a city. For that reason, LNG route optimization is an important issue that must be resolved for LNG transportation. Through-route optimization can reduce pollution to the surrounding environment, improve economic efficiency in transportation, guarantee efficient and safe LNG transportation, and minimize risks to areas along the road transportation route. Therefore, improving transportation safety while ensuring transportation efficiency constitutes a necessary issue that must be considered for LNG: an affordable and efficient clean energy source.

Determination of an optimal LNG truck transportation route is usually complicated with various spatial location parameters. For instance, LNG transportation routes should avoid densely populated areas while maintaining a designated proximity to emergency facilities. To facilitate data processing and reduce system complexity, traditional LNG transportation route selection methods often ignore spatial route constraints. The geographic information system (GIS) method can fully incorporate spatiality of the road transportation system. Moreover, it can combine multiple factors to select routes presenting least overall risk (Garrido & Bronfman, 2017). That method therefore provides a new way of solving and managing more complex dangerous goods transportation problems. Prevention of dangerous goods transportation risks is important.

This study will use a network analysis module with GIS technology to establish an optimization model, the output of which can provide a graphical reference for government and enterprise personnel engaged in the transportation and the management of dangerous materials.

2. CONCEPTUAL FRAMEWORK

For earlier studies, issues about ensuring efficiency were prioritized. Risks and securing of rescue facilities were not fully considered. By contrast, this study is intended to be able to calculate the optimal route and evaluate visible results based on actual situations.

Therefore, for this study, network analysis is used to select the optimal route. Such an analysis can calculate the optimum route while considering multiple constraints such as the travel time and route risk, using efficiency, risk, and access to rescue facilities.

First, 81 cases of LNG truck transportation accidents were collected during the past decade. The accidents were analyzed from three perspectives to obtain rules and characteristics of LNG truck transportation accidents: accident characteristics, accident causes and accident consequences.

Secondly, a truck transportation LNG risk analysis model is produced and presented with the improved multipurpose LNG transportation analytical model with consideration of multiple constraints such as travel time, accident risk, efficiency, and rescue facility access.

Finally, Dalian, a medium-sized city in China, applies LNG truck transportation as an example to perform risk analysis. With the multipurpose transportation system achieved on ArcGIS, the Network Analysis extension module is used to calculate the optimal route and to evaluate the visible results.

3. METHODOLOGY

3.1. Basic Methodology for Optimization

3.1.1. GIS Technology

As a dangerous material, LNG has transportation routes differing from route selection problems associated with road transportation of ordinary materials. It is influenced by more factors of the external environment.

The most commonly used method of route selection for LNG or other dangerous goods transportation is mathematical planning designed to find the route with the least risk, given a set of constraints such as time, distance, and cost (De Beer, Fisher & Jooste, 1996). The emphasis of this method is mathematical model establishment and complex algorithm development to solve the model.

However, to facilitate the solution, accuracy of the spatial representation is often sacrificed. In addition, in dealing with the multi-objective characteristics of dangerous goods route selection, both the establishment and solution of mathematical models are too complicated. It is not easy for decision-makers to participate and understand. Numerous risk factors affect the decisions made for dangerous goods transportation routes. These factors often have spatial characteristics such as population distribution, environmental characteristics, and transportation road network characteristics. Quantification of these risk factors is crucially important for route selection analysis.

Therefore, GIS is applied to assess risk factors based on existing models to be more realistic and to realize road network visualization. This study uses total distance or total time to measure the transportation efficiency. Risk analysis is used to describe safety from the three aspects of accident rates, accident effects, and rescue capabilities. Furthermore, with network analysis, the extension module of GIS is used to integrate the two parts to achieve route optimization because of its great ability to facilitate the management and processing of road network information in transportation.

Using GIS, various road information such as road length, road type, and population density can be added as necessary. Database technology is also used. Query, statistics, and unique visualization and geographic analysis capabilities are integrated to facilitate the use of decision-makers. Therefore, when analyzing the risk of dangerous goods transportation, GIS is useful to quantify the relevant risk indicators as basic data for multi-objective optimization.

3.1.2. Risk Analysis

Risk analysis is the process of identifying, elucidating, and estimating risk and judging whether the risk is acceptable to a society (Phillips, 2013). The method of combining quantitative and qualitative methods to evaluate risks comprehensively is recognized universally as a practical risk evaluation method. It not only retains data accuracy to a certain degree; it also increases flexibility. This study is based on such a method to conduct a qualitative and quantitative comprehensive analysis of LNG truck transportation risk factors, yielding a suitable risk evaluation model for route optimization under specific input conditions.

The historical accident rate of dangerous materials transportation routes, population density, meteorological conditions and other influential factors of the surrounding environment are the main factors used for risk analysis of dangerous materials transportation. These factors directly affect the risk level. The main concern of government regulators is also the risk of exposing populations to dangerous goods transportation. Therefore, the main responsibility is to plan a minimum-risk transportation route to realize safe LNG transportation management.

3.2. Establishment of a Transportation Route Optimization Framework

(1) Transportation cost

The costs of road transportation of dangerous goods are divisible into two types involving time and distance. For the economic benefits of enterprises or individuals, the time it takes to complete the transportation directly affects costs and profits. Therefore, transportation time can provide indirect economic benefits. The transportation distance determines amounts of fuel consumption, mechanical losses of transportation vehicles, and transportation costs such as drivers' labor resources and fuel. These costs often account for a larger share of total transportation costs.

(2) Risk analysis

Main considerations for transportation risk factors are exposure and the possibility of accidents. The United States "Guidelines for the Application of Dangerous Goods Designated Routes" outlines dangerous goods route selection processes (Zeng, Wang & Liu Y, 2011). In addition to exposing the population, the guide points out the existence of some facilities such as schools, hospitals, fire stations, and reservoirs. These factors might affect route selection decisions. In addition, emergency response capabilities are a key consideration.

Therefore, based on independent variable factors of LNG truck transportation optimization and dependent variable factors of transportation, this study establishes the LNG truck transportation optimization framework, mainly in terms of aspects of transportation costs and risk analysis, respectively, as presented in Figure 2.

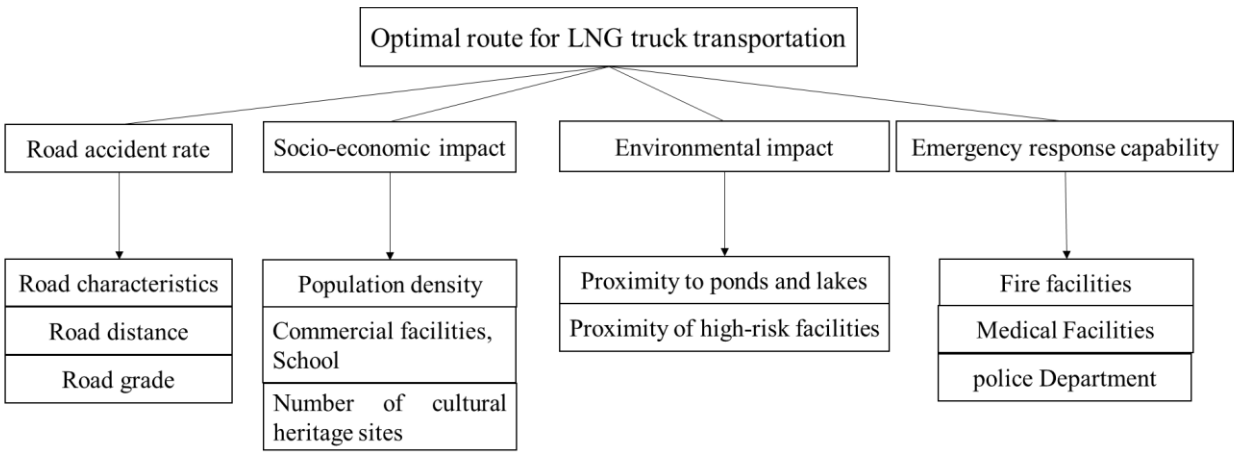

Figure 2. LNG Truck Transportation Optimization Framework.

3.3. Technical Framework of LNG Route Optimization Model

Based on earlier analyses, this study adopts the following methodology.

First, this study presents a spatial data platform of the urban road network of ArcGIS. Then the arc-node spatial data structure is used based on ArcGIS as the platform to abstract the surrounding entities affecting the transportation risk cost as spatial entities in the GIS platform. The extent of the effects of interest is divided into corresponding levels of a buffer zone. By modifying the attributes of the road segments in the buffer zone, the risk costs of the corresponding items of the road segments can be evaluated. Finally, a road network with attributes of risk costs is obtained. Using a qualitative and quantitative risk assessment method, a multi-objective optimization model based on the influence of factors on the road section is established after eliminating interference and noise. The multi-objective optimal route is solved by application of the Network Analysis extension module to obtain a graphical display result.

For urban road transportation of dangerous goods, the main research object is the road itself. Because of road effects and the surrounding environment, a road represents both favorable and unfavorable characteristics for transportation. Many factors affect road characteristics. For instance, undulation of the road surface can affect the vehicle speed. When analyzing the road network weight, because the surrounding entities and environment of different sections of the road are changing constantly and because they are very different from each other, the road cannot be used as the research object overall.

Road characteristics must be further divided into several small sections (Zhou, Ruan & Wang, 2009). In this way, when the vehicle is running, the road section is selected reasonably to achieve the purposes of reducing costs and risks. Taking the road section as a unit, one can mark the road section entity attribute field as a specific factor weight, which is used as a network analysis parameter to ascertain the technical frame of the study.

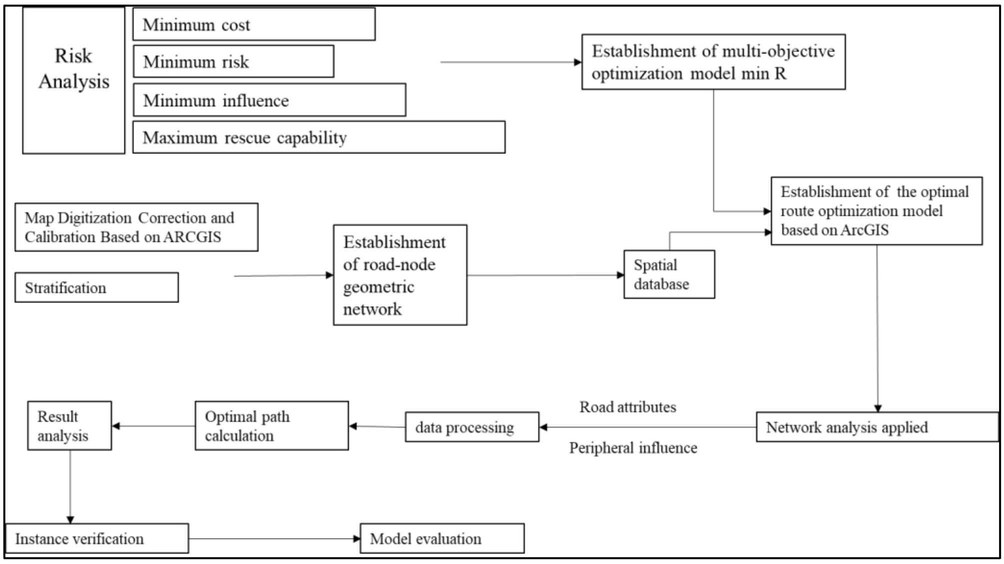

Figure 3. Technical Framework of an LNG Truck Transportation Route.

For the road section, the analysis is conducted from two levels: inside and outside, as shown in Figure 4. Attributes determined by road design and construction are natural attributes. The influence of surrounding facilities on their transportation characteristics is regarded as an external influence attribute. Among them, C1 and C2 belong to attributes of the road section. The indicators are written into the attribute field directly when the basic data are established during calculation and analysis, whereas C3 and C4 are influenced by the surrounding environment on the cost risk of the road section, which must be initialized. The risk characteristics accumulate the initial value to indicate the final cost.

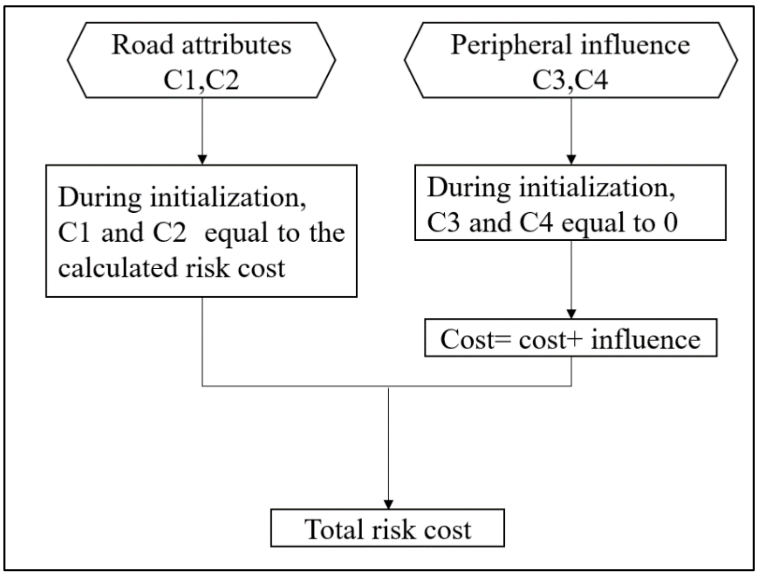

Figure 4. Analytical Framework of Each Road Section.

3.4. Establishment of The Optimization Model

3.4.1. Factors Influencing LNG Route Optimization

In addition to transportation costs, risk factors affecting route optimization include historical accident rates, the population effects of accident consequences, and rescue capabilities.

(1) Accident rate

Single-vehicle accidents, double-vehicle accidents, and continuous collisions of multiple vehicles can occur during road transport using large transport vehicles. The following model is typically used to calculate road transport accident rates (Ren, 2007).

$$TAR_i = \sum_j \frac{A_{ij}}{VKTij} \quad (1)$$

In equation 1, TAR_i stands for the annual average accident rate of large transport vehicles on the i^{th} road in units of year/vehicle /km, A_{ij} denotes the annual number of accidents of large transport vehicles in the j^{th} section in number of cases, and VKT_{ij} expresses the annual mileage of large transport vehicles in the j^{th} section of the i^{th} road in units of vehicles/ km. If all large transport vehicles have LNG truck data, then the accident rate for LNG road transport is calculable using the following model.

$$P(i) = TAR_i \times \frac{N_{LNG}}{N} \times l_i \times n \quad (2)$$

In equation 2, $P(i)$ represents the LNG truck accident rate on type i roads in units of cases / year, N_{LNG} denotes the total number of LNG trucks transported on i^{th} roads in units, N stands for the total number of large transport vehicles on i^{th}roads in units, l_i denotes the road length of i^{th} in kilometers, and n expresses the number of large transport vehicles in units.

Relevant data and information are not available because China has not yet established a detailed indicator classification or statistical system related to road transport. In 1993, Harwood, Viner, and others investigated lane-type accident rates in rural and urban areas in California, Illinois, and Michigan in the United States. They obtained accident rates for large transport vehicles (Harwood, Viner & Russell, 1993). Therefore, for this study, the accident rate of large transport vehicles is adjusted and quoted according to actual road conditions in China.

Table 1. Accident Rates of Heavy Transport Vehicles on the Three Continents of The U.S. (Harwood Et Al., 1993)

Area	Lane	Accident rate (per/million units • km)			
		California	Illinois	Michigan	Aggregated average
Rural	Dual lane	1.07	1.94	1.33	1.36
	Multi-lane (undivided)	3.38	1.32	5.90	2.79
Rural	Multi-lane (divided)	0.76	2.98	3.52	1.34

Area	Lane	Accident rate (per/million units • km)			
		California	Illinois	Michigan	Aggregated average
	highway	0.33	0.29	0.73	0.40
Urban	Dual lane	2.63	6.90	6.79	5.38
	Multi-lane (undivided)	8.09	10.59	6.44	8.65
	Multi-lane (divided)	2.17	9.20	6.59	7.75
	Single lane	4.1	16.38	5.02	6.03
	Highway	0.99	3.63	1.74	1.35

To bring the accident rate in Table 1 more in line with the actual situation in China, based on the basic accident rate, road grades, road characteristics, number of lanes, and traffic volume (Dai, 2017) will be introduced for correction, as shown in Table 2.

Table 2. Influential Factors, Weighting Factors and The Road Transport Accident Rate (Dai, 2017)

Influencing factors		Weighting factor
Road grade (K_1)	Highway	1
	First-level road	1.05
	Second-level road	1.13
Road characteristics (K_2)	Straight road	1
	detour	1.73
	Up and downhill	1.43
	Intersection	1.69
	bridge	1.63
	tunnel	1.61
Number of lanes (K_3)	dual lanes per direction	1.18
	Dual lane and emergency lane	1.13
	Three lanes and emergency lanes	1
Weather (K_4)	Sunny	1
	Rainy, foggy	2.77
	Snowy, hail	3.81

Influencing factors		Weighting factor
Traffic (K_5)	Low density	1
	Medium density	1.48
	High density	1.66
	Ultra high density	1.74

Usually, LNG trucks are involved in accidents such as collisions, rollovers, and rear-end collisions during transportation, but not all accidents will cause leakage of the transported gas. Therefore, it is necessary to calculate the probability of truck leakage after an accident. The specific calculation model is the following.

$$P(R)_i = P'(i) \times P(R|A)_i \quad (3)$$

In that equation, $P(R)_i$ represents the probability of leakage accidents of i^{th} road LNG transportation per year. Also, $P(R|A)_i$ denotes the i^{th} road leakage probability of LNG transportation conditions with a given transportation accident rate. The probability of leakage accidents under transportation conditions of LNG in the U.S. is shown in Table 3, which presents useful details as a reference value.

Table 3. Probability of Leakage Accidents in the U.S. under LNG Transportation Conditions (Harwood et al., 1993)

Area	Road type	Leakage rate under conditional probability
rural	Dual lane	0.0184
	Multi-lane (undivided)	0.0353
	Multi-lane (divided)	0.0169
	highway	0.0061
urban	Dual lane	0.0568
	Multi-lane (undivided)	0.0737
	Multi-lane (divided)	0.0737
	Single lane	0.0522
	Highway	0.0123

(2) Population effects

Because LNG transportation accidents might cause leakage or even explosion, which would be catastrophic to surrounding areas, when optimizing LNG truck transportation routes, one must consider surrounding densely populated areas, parks, reservoirs, and substations.

In terms of densely populated places, schools have concentrated populations. Students in school areas have weak self-protection ability against accidents. Schools are at a higher level of damage.

Places such as reservoirs and substations are defined as high-risk locations because the leaked LNG might pollute water resources and cause further danger to nearby substations. Therefore, for route optimization, one must consider reservoirs and substations and other high-risk facilities.

For this study, buffer analysis will be used to establish a buffer zone radius based on the different characteristics of key locations as the center of the circle. A greater number of radiated roads within the buffer zone will give a greater effect of LNG truck transportation on surrounding places if an accident occurs on this route.

(3) Rescue capacity

Rescue capabilities are the maximum emergency response capacities of rescue units in the event of an accident. It can be expressed as the proximity of the accident road section to a police station, fire station, hospital, etc. This study constructs a risk evaluation index system that incorporates effects of transportation accidents on people, environments, and property. It also considers the emergency response capability of the route.

Rescue capacity refers to the degree of access to rescue facilities such as hospitals and fire stations after an LNG transportation accident. Although a hospital itself is also a densely populated location, this study assigns priority to characteristics of hospitals as providing medical assistance.

For this study, buffer analysis will be used to establish the buffer zone radius based on different characteristics of key locations as the center of the circle. A greater number of radiated roads within the buffer zone implies a wider range of rescue services that might be provided. Correspondingly, more buffer zones that a road intersects implies that faster medical or fire rescue services will be obtained if an accident occurs on this road. For that reason, this road would be prioritized.

3.4.2. Quantification of Risk Factors

Quantitative analysis of transportation risks requires GIS software as a supporting platform. The analysis incorporates buffer analysis, spatial statistical analysis, and other functions among them. According to the corresponding scoring standards (Bo & Fery, 2005), each sub-factor is quantified with a score of 1–5. For example, by counting sensitive areas within 0.8 km of a certain road section and comparing them using a scoring standard, a quantitative score is obtainable. The GIS software provides a database function for processing attribute data. Attribute queries and statistics can be processed very easily and accurately. Therefore, quantification of the score of each sub-factor is completed in the geographic information processing software based on statistical analysis of the attribute values.

Because the transportation of dangerous goods involves various parties, their interests or goals are often inconsistent or even conflicting. Therefore, when choosing a route, it is necessary to weigh multiple benefits to minimize the overall risk cost. The Analytic Hierarchy Process (AHP) provides an objective mathematical method (Saaty, 1980) to address subjectivity and personal preferences that cannot be avoided by individual or group decision makers. After determining the evaluation criteria for route selection, questionnaire results and the findings from other inquiry methods are useful to consult.

Table 4 shows the weights of the respective factors and sub-factors under risk analysis, as determined using AHP method. In this table, the road accident rate represents data revised by the weighing factor from Table 3.2 and the leakage rate under conditional probability from Table 3.

Table 4. Weight of Each Factor and Sub-factor Under Risk Analysis (Bo & Fery, 2005)

Factor	Weighing (W_j)	Sub-factor	Weighing (W_{jk})
Road accident rate	0.226		
Socioeconomic effect	0.358	Population density	0.309
		Commercial facilities and school	0.582
		Cultural heritage sites	0.109
Environmental impact	0.211	Proximity to ponds and lakes	0.365
		Proximity to high-risk facilities	0.635
Emergency response capability	0.205	Medical facilities	0.329
		Fire facilities	0.451
		Police department	0.220

3.4.3. Establishment of LNG Truck Transportation Route Optimization Model

$$MinR = \sum_{i=0}^{D} R_i \quad (4)$$

$$R_i = \sum_{j=1}^{n_j} (w_j \sum_{jk=1}^{n_{jk}} (-1)^p C_{jk} W_{jk}), where, p = \begin{cases} 1 & Positive\ index \\ 0 & Negative\ index \end{cases} \quad (5)$$

This model is based on comprehensive risk values R_i of the respective road sections. Through network analysis of the GIS platform, all possible route options between origin *O* and destination *D* are analyzed. The route with lowest total score R is the optimal transportation route for LNG trucks under the current input conditions. The comprehensive risk cost value R_i of road section i in the road network is obtainable by accumulating the weight and score, where j represents the risk influencing factor, n_j is the number of risk influencing factor j, and w_j is the value of risk influencing factor j. Also, n_{jk} is the number of the sub-factor k under risk factor j., $w_{jk}$is the weight of sub-factor k under risk factor j, and C_{jk} represents the score of sub-factor f under risk factor j.

Among them, when C is a positive indicator, it can help reduce the value of the total risk cost R; also p takes a value of 1. When C is a negative indicator, it will increase the value of the total risk cost R, the value of which is 0.

3.5. Analyze The Optimal Route Based On The Network Analysis Extension Module

3.5.1. Network Analysis Pre-processing

Before performing network analysis, the network initialization has been built to include network analysis parameters. The parameters set in the model are the following.

Impedance: Determine the weight of the shortest path, i.e., increase the total cost when passing the road section. Here, the cost field is used as the impedance of the calculated path.

Constraints: When calculating the route, restrict the road section attributes. Here, the one way field is used as the sign of the one-way line. In GIS, From To (FT) and To From (TF) are often used to express the space of the one-way line.

Time window: Some entities in the road network can only be accessed at some special times. Then the time window stores the properties of these entities. This study includes no consideration of time variables for the time being. Therefore, the time window is set as disabled (Disable).

Record the target location: When there are multiple target points that must be passed, the optimal path between each two locations is calculated in turn to obtain the total optimal path.

Whether U-Turns is allowed: U-Turns means that the road section can be driven in both directions. Here it is set that there is a U-turn anywhere.

Output shape type: Select the true shape. The result is the shortest path based on the road segment.

Use hierarchy: Not used.

Ignore invalid sites: Ignore.

In this way, on the GIS platform, through the Network Analysis extension module, the target value of each route plan between OD can be calculated. The route with the minimum value is the best dangerous materials transport route under the current input conditions.

Additionally, it is possible to list the top several route plans, and to consider other influencing factors of route plan selection such as traffic conditions and environmental impact conditions, whether emergency alternate routes exist. One can finally find the best road transportation for a dangerous goods route. The cost field is established in the road segment layer to indicate the total risk cost as the total target for calculating the route. Then one can establish a calculation expression for the cost field according to formulae 3-4 and 3-5:

3.6. Example application

This study used ArcGIS from Environmental Systems Research Institute (ESRI) as a platform for example applications that use Dalian, a small and medium-sized city in China, as the research object to optimize the LNG transport route.

3.6.1. Create a Database

Use software to produce a thematic map of the Dalian dangerous goods transportation road based on the existing electronic map. Use the basic modules of the software to collect and process data, establish a spatial database, and establish a road network in urban Dalian.

(1) Data collection

The following data are now collected to provide support for the construction of a spatial data platform. The data mainly include attribute data collection and graphic data collection. The data content is the following:

1 – Format of the road distribution map in Dalian

2 – Names and geographical locations of major roads, schools, hospitals, fire departments, government agencies, and public security departments in Dalian

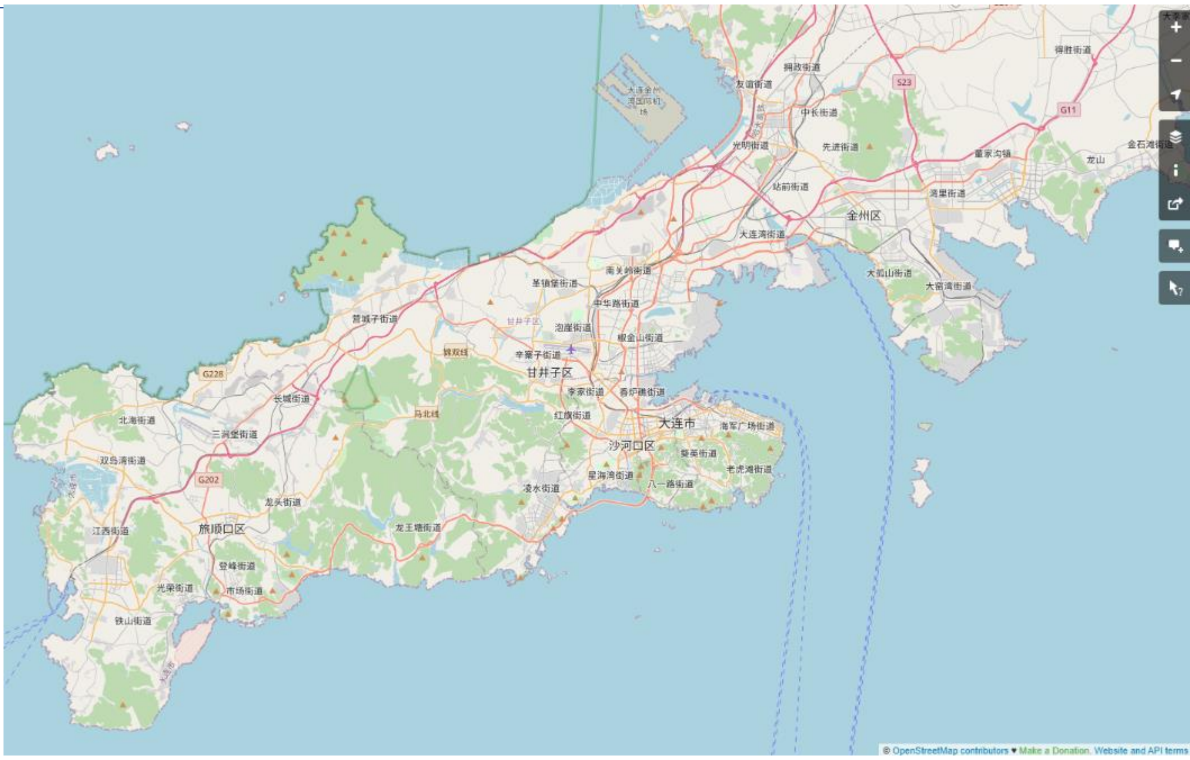

Figure 4. Map of Dalian city referred from OpenStreetMap (OpenStreetMap,2021)

(2) Data processing

1 – Vectorized raster data based on ArcScan

2 – Registration, establishment of map coordinate system and map layering. This study adopts the GCS_WGS_1984 coordinate system. The main parameters are the latitude and longitude of the earth. The World Geodetic System (WGS) is a standard used for cartography, geodesy, and satellite navigation including GPS. The latest revision is WGS 84 (also known as WGS 1984, EPSG:4326), established and maintained by the United States National Geospatial – Intelligence Agency since 1984. It was last revised in 2014.

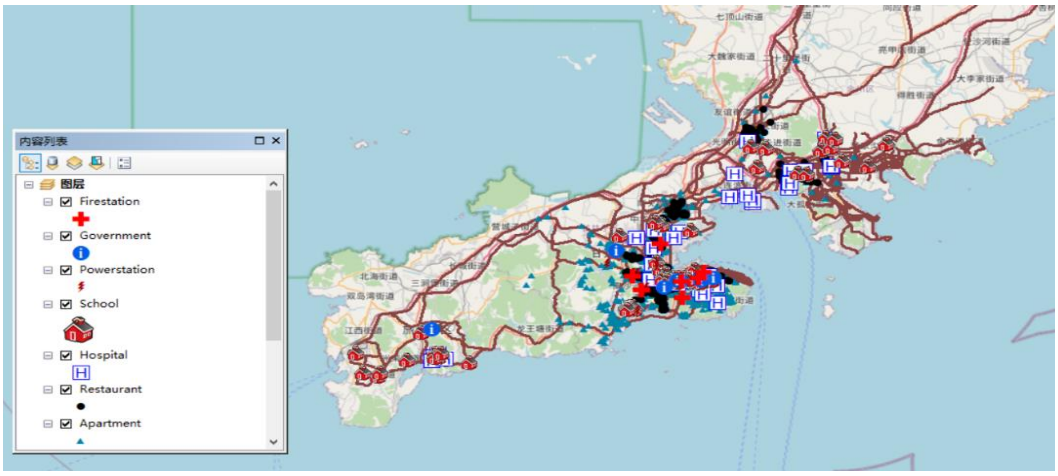

Figure 5. Road Network with Symbols of Dalian City Digitized Based on GIS by Arcgis.

According to research needs, general map symbols were used to create layers, set the symbology parameters of entities in the map and perform symbolization processing to correspond to the actual map. The processing results are presented in Figure 5. The data were stored using the shapefile data organization method. The shapefile comprises main file (.shp) contains the geometry data for storing spatial data, a file that stores attributes for each shape (dbase) for storing attribute data, and a file containing positional index of the feature geometry (.shx) for storing the relation between spatial data and attribute data.

(3) A spatial road traffic database was established

After setting the data structure of the road section layer, the other entity layer attributes were determined in turn. The data structure of other entity layers was established. Then the data structure of all the entity layers was completed. The spatial database on the ArcGIS platform was obtained.

FID	name
0	Dongbei University of Finance and
1	Dalian shuxiangyuan primary schoo
2	Liaoning Provincial Taxation Coll
3	Dalian Yuming High School
4	School of Foreign Economics and T
5	Middle School of Dalian Universit
6	Dalian Maritime University of Con
7	Dalian No. 39 Middle School
8	Dalian No. 16 Middle School
9	Dalian Zhongshan Senior High Scho
10	Dalian No. 71 Middle School
11	Dalian No. 65 Middle School
12	Dalian Zhongshan Experimental Mid
13	Dalian University of Foreign Lang
14	Dalian No. 24 Middle School
15	Dalian No. 9 Middle School
16	Dalian No. 65 Middle School
17	Dalian No. 13 Middle School
18	Dalian No. 45 Middle School
19	Dalian No. 21 Middle School
20	Dalian No. 8 Middle School
21	Dalian No. 79 Middle School
22	Dalian No. 6 Middle School
23	Dalian No. 1 Middle School
24	Dalian No. 7 Middle School
25	Dalian Experimental Primary Schoo
26	Dalian Malan Primary School
27	Dalian Datong Primary School

Figure 6. School Information in The Database After Digitization by ARCGIS.

One example of established database is presented in Figure 6. It shows the attribute data structure of the school layer.

(4) A road network established in an urban area of Dalian

First, based on the established road network data mining, its rule was set to the endpoint.

Secondly, the U-TURN model was established, which allows turning during driving at the intersection.

Thirdly, the cost field and the constraint field were set. The cost field is the total risk cost. The constraint field is a Boolean field, i.e., whether it is a one-way line, to limit the driving direction in the topology data structure to simulate the actual single driving section.

Finally, set the driving direction parameters, complete the above steps, and get the entire road network data. The established road network in Dalian city is shown as the figure below.

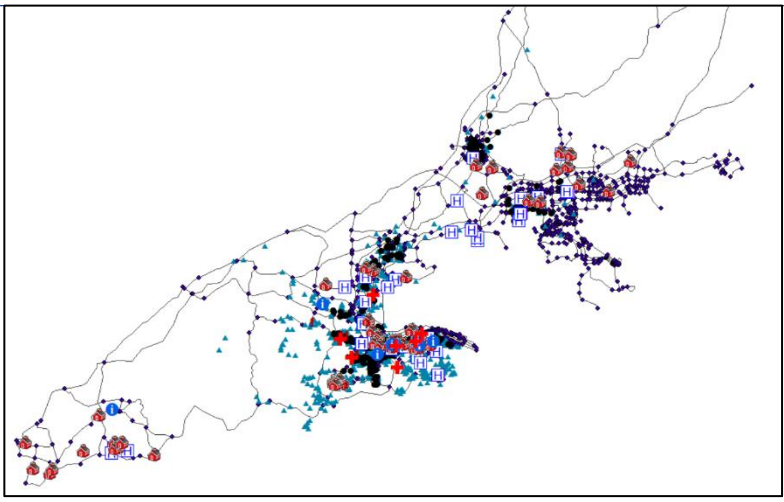

Figure 7. Established Road Network of Dalian City Based on GIS.

Figure 7 is the final road network map of Dalian city based on GIS. There are not only actual roads but also marks of key places such as schools and hospitals, which lay the foundation for subsequent analysis of the surrounding environmental impact and emergency relief.

3.6.2. Accident Rate Analysis

Analyses were done by collecting data related to road transportation of dangerous goods in Dalian, calculating and sorting out the line length of each road section involved in LNG road transportation in Dalian, making corrections based on road characteristics based on the basic accident rate, and obtaining the accident rate data for each road section, which is shown in Table 5.

Table 5. Accident Rates of Partial Roads in Dalian After Revision

Road name	Total weighing factor	Basic accide nt rate	Annual_leakage_rate (per/million units・km)	Distance	Leakage accident rate (per/million units)
Xinghai Square 1	3.172	7.75	1.812	3.170	5.745
Xinghai Square 2	3.172	7.75	1.812	0.738	1.337
Xinghai Square 3	3.172	7.75	1.812	2.116	3.833
Xinghai Square 4	3.172	7.75	1.812	0.526	0.953
Xinghai Square 5	1.834	7.75	1.047	0.882	0.924
Youting Road	3.172	7.75	1.812	1.563	2.833
Xingyu Road	1.834	7.75	1.047	1.956	2.049

3.6.3. Population and Environmental Risks

Once LNG leaks, gas diffusion will cause great damage to the surrounding environment and nearby residents. Therefore, for LNG truck transportation, one must avoid passing through densely populated areas and high-risk areas to the greatest extent possible. This study identifies schools, shopping malls, and restaurants as indicators of particular hazards for population exposure on-road sections and classifies these population exposure sites according to the scale of population gathering. Through buffer analysis of schools, shopping malls, and restaurants, the risk costs of road sections posed by population exposure can be analyzed.

Crowds at schools are young people who are vulnerable in terms of their ability to resist disasters and to achieve self-protection when disasters occur. Therefore, they represent a higher level of harm and require special treatment. According to school characteristics, the ages of students, and the number of students, this study uses the following treatment. A 500-m buffer zone was used to simulate effects on teachers and students at a school because of LNG leakage accidents. After investigation, the student numbers of primary and secondary schools in Dalian were divided roughly into three levels: below 1000, 1000 to 2000, and above 2000. According to student age, it is more appropriate to divide the numbers of students into elementary schools and junior high schools or above; schools of different sizes have different scores, as shown in Table 6.

Table 6. Grades of Schools Based on Numbers of Students

Level / Population	Primary school	Middle and High school
<1000	0.5	0.1
1000–2000	1	0.2
>2000	2	0.4

Figure 8. Partial School Buffer Zones With Various Radius Around Dalian.

After categorizing schools, different radius lengths were used for buffer analysis. Figure 3.8 portrays a partial schematic diagram of school buffer analysis.

3.6.4. Rescue Capacity Analysis

Once a vehicle accident occurs, its consequences are determined by the following aspects: amount of leakage, climatic conditions, possibility of combustion, potentially exposed population, and the time interval from start to calming down. At the road network level, it is generally expressed as the sum of factors such as the level of hazardous materials and the location of the leakage of accidents and possible disaster risks.

It is apparent that the delay in handling dangerous materials accidents might directly engender an increase in the number and degree of harm to persons and property. For example, an accident involving a truck loaded with LNG might cause LNG leakage. If it is not handled in time, then it will be poisonous, with effects which might last for 24 hours or more. Therefore, rapid accident response is of greater importance to dangerous goods transportation accidents (Lv, 2011). Under conditions in which the existing rapid response conditions are certain, the distance between the accident location and the nearest rescue facility is used to evaluate the rapid response capability of the road section (Ren, Wu & Li, 2008). Because the rapid response department has traffic priority, to avoid increasing the system complexity, this study uses the straight-line distance to evaluate the rapid response capability of the road section so that the calculation can be performed on the GIS platform through the buffer analysis function, making full use of the GIS spatial analysis. Additionally, it makes the calculation effect of the model more intuitive.

In urban planning processes, fire departments, public security departments, and medical institutions the respective communities have been considered. To facilitate analyses, the ranks are divisible according to distance. An increase in the rank will engender an increase in the degree.

Because a buffer zone with the radius set too small is not ideal for actual experiments, the response range such as that for public security departments is 500 m. Furthermore, considering the actual rescue capabilities of local hospitals and fire stations in Dalian, as recorded in ArcGIS, it is more appropriate to take 1 km as the response range for fire and medical facilities. According to the actual situation, the following divisions were made:

Table 7. Buffer Length of Emergency Rescue Facilities

	Buffer length
Fire station	1 km
Security department	0.5 km
Medical department	1 km

3.6.5. Evaluation Results

Use ArcGIS as a GIS platform for analysis. Calculation of sub-factor scores was done using geographic information processing software. According to the collected road network related data and actual conditions, the relevant attribute data associated with each risk factor were analyzed. The scoring standard was an improved system based on that reported by Huang. (Bo & Fery, 2005)

Table 8. Score Table of Relevant Attributes of Rescue Capability

Score	1	2	3	4	5
Number of fire station	0~2	3~5	6~8	9~11	>11
Number of security department	0~2	3~5	6~8	9~11	>11
Number of medical department	0~2	3~5	6~8	9~11	>11

Table 8 shows the emergency response capability: each sub-factor is assigned a score of 1–5 according to its attribute value. The purpose of this assignment is to process data where the number of buffers is not the same as the road accident rate, etc., to facilitate calculations.

Based on the results described above, the formula for calculation *R* can be written as shown below.

R = 0.026 × [accident_rate] + 0.358 × (0.309 × [population_density] + 0.582 × [commercial_facilities_school] + 0.109 × [cultural_heritage])+0.211 × (0.365 × [pond_reservoir] + 0.635 × [highrisk_facilities])-0.205 × (0.329 × [hospital] -0.451 × [fire_station] - 0.220 × [police_department])

Among those expressions, the items in square brackets are the various fields in the road network table, which can be queried in the attribute table. Positive factors similar to the hospital fire station can help reduce the size of R. Negative factors similar to the accident rate and high-risk settings are expected to increase the size of R. After a series of calculations, each road will get its own R score.

Finally, the route with the smallest cumulative R along the road can be regarded as the optimal route.

4. FINDINGS AND DISCUSSION

4.1. Optimal Transportation Route Calculation Result

After calibrating the network parameters, the network data are modified and improved. The network operability and connectivity are edited according to the collected road section attributes. Because the total cost in the actual network analysis changes with the weight relation, the optimal path was calculated using a dynamic method. The model was used to calculate the optimal path (min cost), the shortest path (min length), and the accident occurrence. The visual calculation results of the optimal route are shown in Figure 9. Table 9 presents the distance between the two routes and the value of the total risk cost MinR.

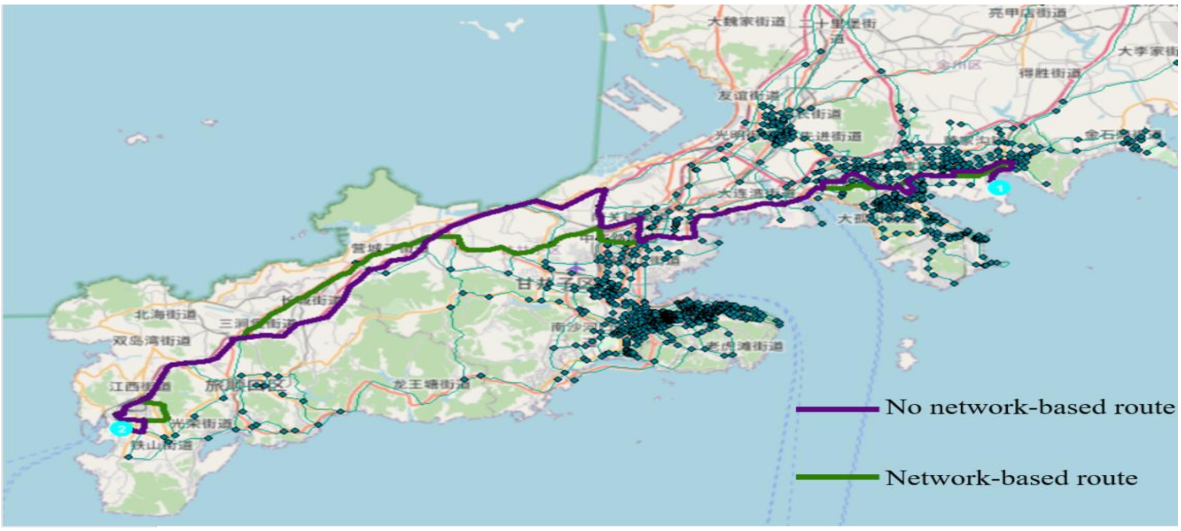

Figure 9. Visual Calculation Result of The Optimal Route.

Table 9. Comparison of Routes with And Without Network-Based Analysis

	Type	Total distance	MinR
Purple Route	No Network-based	92610.944862	0.966114
Green Route	Network-based	103434.091438	0.60757

4.2. Optimization Result Analysis

4.2.1. Route Comparison

From the three aspects of the cost comparison chart of the two routes, as shown in Table 9, it is apparent that although the travel distance of the shortest route is reduced by nearly 10.46%, the total cost after considering other factors is nearly 37.11% higher.

In contrast, the optimal route calculated using the model selects road sections with fewer historical accidents, avoids locations where the population is exposed, and shows a route that is closer to rescue facilities. Therefore, the route calculated using the model is safer and more reasonable than the route with the shortest time and travel distance.

Using GIS graphical expression technology, the conclusions were displayed more clearly and intuitively. Figure 9 shows that the number and extent of population exposure risk areas through the optimal route were much less than for the shortest route.

4.3. Model Evaluation

Through the use of spatial analysis and other methods on the ArcGIS platform to analyze and solve various factors, including cost analysis, accident risk analysis, post-accident disaster analysis and accident rescue capability analysis, the cost risk multi-objective comprehensive evaluation result of the road section was obtained. The network analysis expansion module was used to find the optimal route under the known input conditions. The optimal route and the route with the shortest itinerary were compared and analysed in terms of cost and risk.

5. CONCLUSIONS AND IMPLICATIONS

With increasing economic development, social production and people's living needs, the logistics and transportation volume of hazardous chemical materials, which are necessities of production and life, are increasing by leaps and bounds. Along with this development, an increasing number of dangerous goods transportation accidents are occurring, presenting hazards which differ from those posed by general traffic. The loss of life and property and damage to the environment caused by transportation accidents and dangerous goods transportation accidents are huge. Therefore, improving the safety and overall costs of the transportation of dangerous goods scientifically and through standardized management has become an urgent task.

This study conducted a systematic assessment of how to choose transportation routes reasonably. Through the ArcGIS platform, a model that can calculate the optimal transportation route was established. A method was proposed that can help decision-makers choose a reasonable route before transportation of dangerous materials.

The main research conclusions of this study are explained below.

(1) Using GIS for management of dangerous goods transportation can assist decision-makers in planning LNG transportation routes. The powerful ArcGIS spatial information processing and expression functions also include a network analysis extension module as a platform for calculating the optimal route.

(2) This study systematically analyzed the current research status, development trends, and existing problems for risk analysis and route optimization of road dangerous goods transportation, analyzed risk factors of road dangerous materials transportation, and divided them into route-independent variable factors and dependent variable factors of two types. A risk analysis system has been constructed for road transportation of dangerous goods.

(3) Combined with existing data conditions, characteristics of urban road transportation were analyzed. An effective plan for calculating the optimal routes of both costs and risks was established on the GIS platform. Through spatial analysis such as buffer analysis, coverage analysis and network analysis of the ArcGIS platform, an optimal path calculation model was established for LNG transportation.

(4) The Dalian city road network spatial data platform was used with model input conditions based on consideration of cost factors and risk factors. It was realized on the platform through spatial analysis such as buffer analysis, overlay analysis, and network analysis. Visualization of the optimal selection of road transportation routes for dangerous goods has been improved. Comparison of the shortest path and the optimized path after optimization highlights the superiority of path optimization. This process can be applied to research of dangerous goods transportation routes to make up for shortcomings caused by classic route algorithms that rely on ideal mathematical models.

Prospects for future work:

1) The risk probability model used for this study relies completely on historical data of accident rates. The accident data represent the greatest source of error. In response to this situation, scholars have studied characteristics of accident rates from internal mechanisms of the accidents, thereby reducing excessive reliance on historical data. When this method is mature, further research can be combined with characteristics of dangerous goods transportation. This risk assessment method based on accident mechanisms can be integrated into the risk evaluation of dangerous goods transportation.

2) Intersection delay is a very complex traffic analysis project. No good stable model with popularization value exists. However, along with development of domestic ITS research, the intersection delay analysis model will become increasingly perfected. When it has become sufficiently useful, it can augment transportation cost and risk analysis of dangerous goods.

3) This study uses ArcGIS system software for spatial analyses. Underlying its powerful spatial data processing and spatial analysis functions are huge time and economic costs associated with data collection and processing, as those related to this study. Time collection and processing of spatial data and attribute data are also a common difficulty for all GIS development projects. Since most of the causes of LNG accidents are due to the unstable rollover of the center of gravity of the vehicle, the prevention of LNG accidents based on the perception of the center of gravity should also be further studied in the future.

Moreover, the cost of ArcGIS series software (with network analysis module) itself is high. Solutions of cost difficulties of spatial information technology research must be investigated further.

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