論文 / 著書情報
Article / Book Information

題目(和文)	日本の鉄道会社の効率性評価研究：COVID-19の影響とビジネスモデルの視点から
Title(English)	Evaluation Study of Japanese Railway Companies: Impact of COVID-19 and Business Model Perspective
著者(和文)	遠藤英明
Author(English)	Hideaki Endo
出典(和文)	学位:博士(工学), 学位授与機関:東京科学大学, 報告番号:甲第346号, 授与年月日:2025年3月26日, 学位の種別:課程博士, 審査員:後藤 美香,辻本 将晴,中丸 麻由子,木村 英一郎,笹原 和俊
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Institute of Science Tokyo, Report number:甲第346号, Conferred date:2025/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Type(English)	Doctoral Thesis

Institute of Science Tokyo

School of Environment and Society

Department of Innovation Science

Doctoral Thesis

Evaluation Study of Japanese Railway Companies: Impact of COVID-19 and Business Model Perspective

Supervisor: Mika Goto

Hideaki Endo

Abstract

The prolonged COVID-19 pandemic and resultant sporadic lockdowns have led to a decline in demand for travel, causing the number of railway passengers to decline. In Japan, private railway companies, which had been profitable in the railway business before the pandemic, became unprofitable after the pandemic. The motivation of this study is to provide vital information to railway company management and policymakers by quantitatively assessing the profit structures and the cost efficiency of railway operations and qualitative analysis of management strategies through text analysis.

This doctoral thesis consists of the following two analyses. The first analysis is how the COVID-19 pandemic influenced a decline in their revenues and changes in their profit structures which are based on Japanese listed railway companies' investor relations information. In addition, I conducted a text analysis of the differences in management strategies between loss-making and profitable companies and explored the management strategies that characterize profitable companies. The second analysis is that I examined the cost efficiency of railway companies by Stochastic Frontier Analysis (SFA) using data from 2005 to 2020, covering the early years of the COVID-19 pandemic. Then, I analyze the factors that influenced the cost efficiency of railway companies before and after the pandemic. Furthermore, I classify the companies into four groups by cost efficiency levels and the characteristics of the best-practice companies. Finally, I discuss the sustainable business practices and measures of digital transformation (DX) that can be applied to improve efficiency and survive severe events like the pandemic.

The result of the first analysis is that the companies' passenger transportation revenues showed a drastic drop from 4Q FY2019 to 1Q FY2020, hitting the lowest level, and increased thereafter. I observed a minor change in the revenue structure in business segments such as Retail, Real estate, and Leisure. Before the pandemic, all business segments were profitable, but after the pandemic, only Non-transportation businesses were profitable, and Transportation-related businesses turned loss-making. The findings suggest that a sustainable profit structure for private railway companies, post-pandemic, would require effectively strengthening the Non-transportation segment that generates enough revenue to compensate for the loss-making segments.
The analysis also showed that profitable companies are characterized not only by their management strategies but also by the accuracy of their earnings forecasts for profits. This may be related to the accuracy of forecasting uncertainties in Transportation-related business due to the pandemic. The results of these analyses indicate that, as a management strategy, profitable companies structure a sustainable business portfolio that takes pandemic risk into account and forecasts earnings with a high level of accuracy.

The result of the second analysis is that during the measurement period, the worst cost efficiency (highest cost efficiency values) for the Japanese listed railway companies was in 2020, due to the COVID-19 pandemic. The second-worst efficiency (second-highest cost efficiency values) was in 2009 due to the financial crisis. No significant impact of the Great East Japan Earthquake in 2011 was observed in this study. On the contrary, the best cost efficiency (lowest cost efficiency values) was in 2014. The results of this study showed that the best-practice railway companies were operating exclusively in the Tokyo

Metropolitan area. This implies that better cost efficiency is correlated with high population density. Moreover, I identified that the top-ranking railway companies were operating in large cities such as the Tokyo Metropolitan area and Osaka prefecture, holding Japan's first and second largest population. I suggest how railway companies can improve cost efficiency from the empirical results of this thesis. The results imply that high cost efficiency companies succeeded in securing profits through the creation of new services in cooperation with the local community by making effective use of customer databases through proactive DX investments in marketing and asset management.

The theoretical contribution of this study proposes that managers of railway operators or public sector policymakers can assess the impact of a severe one on the demand for railway services, such as the COVID-19 pandemic. It enables quantitative analysis, such as examining business portfolios to avoid risk and estimating future railway passenger forecasts.

The practical contributions of this study are: quantifying the deterioration in the efficiency of Japanese private railway companies due to the pandemic; analyzing the cost efficiency of railway companies to characterize best-practice railway companies, and clarifying the relationship between cost efficiency levels and measures and investments for improved efficiency. It also proposes a new analytical framework that combines existing methods.

The results of this thesis provide suggestions for management strategies for corporate groups centered on railways to sustain and develop stable railway operations by improving efficiency in the event of a significant decline in demand for railways such as a pandemic. And it can be used for subsidies and other support from the public sector to railway operators as well as private railway companies, and policy making.

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Background

The new coronavirus disease (COVID-19) pandemic started spreading rapidly worldwide in 2019. Therefore, the lives and economic activities of people were significantly affected at a global level (Watanabe 2020). The rapid increase in COVID-19 infections in major cities led to city lockdowns and curfews. In Japan, a state of emergency was declared to control human flow and prevent the spread of infection even during eating and drinking, which significantly impacted economic activities. The spread of the COVID-19 pandemic has significantly impacted railway operations as well. The number of railway passengers decreased due to the decline in the number of commuters and business travelers to avoid crowded trains, the promotion of telework and online meetings, a sharp drop in inbound tourists visiting Japan, and the stagnation in travel demand because of the voluntary curfew on outings under the state of emergency. This affected not only railway businesses but also related businesses, including hotels, leisure businesses, and retail businesses at station buildings.

Before the COVID-19 pandemic, most Japanese listed railway companies were profitable until 2019; of the 26 listed railway companies, 25 were in a profit and one was in a loss-making trend. However, in 2020, when the COVID-19 pandemic broke out, all railway companies recorded losses. In 2021, five companies were in profit, and twenty-one were in a loss-making trend. Table 1 shows the number of Japan's 26 listed railway companies with railways operating in profit/loss-making.

Table 1 The number of Japan's 26 listed railway companies with railways operating in profit/loss-making

Fiscal Year	The Number of Profitable Companies	The Number of Loss-Making Companies
2019	25	1
2020	0	26
2021	5	21

Data Source: Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2019a), Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2020a), Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2021a).

In response, Japanese railway companies have taken measures to reduce costs and increase revenues to protect their operations. Cost-cutting measures included reducing the number of regular trains, earlier last train times, reducing the number of staffed ticket counters at stations, shortening opening hours, and discontinuing local railway lines (Ishida 2020; The Asahi Shimbun 2021; The Asahi Shimbun 2022; Ichijo 2020). Table 2 shows changes in passenger train kilometers (thousand kilometers) from 2019 to 2021. Here, passenger train kilometers refer to the number of kilometers traveled by passenger trains operating on commercial lines, which facilitates an understanding of the number of trains in operation. Table 2 shows that most railway companies operated fewer trains in 2020 and 2021 compared with 2019. Table 3 shows the earlier regularly scheduled last train times for Japanese major railway companies. Table 4 shows examples of reductions in the number of stations with staffed ticket counters. Table 5 shows the local lines discontinued by Japanese listed railway companies after 2020. Meanwhile, measures to increase revenue included fare increases and raising the price of regular commuter passes, combined with the introduction of cheaper off-peak commuter passes (Ichijo 2021; The Asahi Shimbun 2023; Matsumoto 2023). This impact on railway operations was not just a temporary event but became the norm.

Table 2 Change in passenger train kilometers (thousand kilometers) (from 2019 to 2021)

No	Company	2019 (a)	2020 (b)	2021 (c)	Percentage in 2020 to 2019 (b)/(a)	Percentage in 2021 to 2019 (c)/(a)
1	JR-EAST	254,877	252,115	248,331	98.9%	97.4%
2	KEIO	14,713	14,582	14,404	99.1%	97.9%
3	KEISEI	13,933	13,524	13,804	97.1%	99.1%
4	SHIN-KEISEI	2465	2469	2683	100.2%	108.8%
5	TOBU	37,895	38,329	38,294	101.1%	101.1%
6	SEIBU	20,247	20,115	20,100	99.3%	99.3%
7	TOKYU	19,995	20,065	19,440	100.4%	97.2%
8	KEIKYU	15,823	15,761	15,546	99.6%	98.2%
9	ODAKYU	20,998	20,883	20,614	99.5%	98.2%
10	SOUTETSU	5052	5215	4941	103.2%	97.8%
11	CHICHIBU	2075	1649	1729	79.5%	83.3%
12	FUJIKYU	723	532	662	73.6%	91.6%
13	JR-CENTRAL	112,178	104,671	103,473	93.3%	92.2%
14	MEITETSU	40,075	39,522	38,685	98.6%	96.5%
15	JR-WEST	189,530	182,932	175,333	96.5%	92.5%
16	NANKAI	16,347	15,760	15,714	96.4%	96.1%
17	KINTETSU	56,638	55,820	53,302	98.6%	94.1%
18	KEIHAN	13,240	13,169	11,937	99.5%	90.2%
19	KEIFUKU	940	934	920	99.4%	97.9%
20	HANKYU	21,889	21,827	21,766	99.7%	99.4%
21	HANSHIN	8404	8410	8391	100.1%	99.8%
22	KOBE	4308	4154	4138	96.4%	96.1%
23	SANYO	6847	6871	6819	100.4%	99.6%
24	HIRODEN	4817	4817	4208	100.0%	87.4%
25	JR-KYUSHU	63,352	59,658	59,767	94.2%	94.3%
26	NISHITETSU	8686	8435	8302	97.1%	95.6%

Data Source: Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2019b), Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2020b), Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2021b).

Table 3 Earlier regularly scheduled last train times in Japanese major railway companies

Company	Region	Start Year and Month	Number of Implemented Lines	Time to Move Up the Last Train (Minutes)	Source
JR-EAST	KANTO	March 2021	17	3–37	(JR-EAST 2020b)
KEIO	KANTO	March 2021	2	10–30	(KEIO 2021a)
KEISEI	KANTO	March 2021	5	10–20	(KEISEI 2020)
TOBU	KANTO	March 2021	3	9–15	(TOBU 2021)
SEIBU	KANTO	March 2021	10	20–30	(SEIBU 2020b)
TOKYU	KANTO	March 2021	7	8–26	(TOKYU 2021a)

KEIKYU	KANTO	March 2021	4	14–30	(KEIKYU 2020b)
ODAKYU	KANTO	March 2021	3	7–23	(ODAKYU2020)
SOTETSU	KANTO	March 2021	2	15–20	(SOTETSU 2021a)
JR-CENTRAL	CHUKYO	March 2022	2	15–21	(JR-CENTRAL 2021)
MEITETSU	CHUKYO	May 2021	5	5–30	(MEITETSU 2021a)
JR-WEST	KANSAI	March 2021	12	10–30	(JR-WEST 2020d)
NANKAI	KANSAI	May 2021	2	15–17	(NANKAI2021a)
KINTETSU	KANSAI	July 2021	14	8–29	(KINTETSU 2021a)
KEIHAN	KANSAI	September 2021	5	13–21	(KEIHAN 2021)
KEIFUKU	KANSAI	March 2021	1	15	(KEIFUKU 2021)
HANKYU	KANSAI	March 2021	3	13–32	(HANKYU 2021)
HANSHIN	KANSAI	March 2021	1	10–14	(HANSHIN2021)
KOBE	KANSAI	March 2021	2	15–21	(KOBE 2021)
JR-KYUSHU	FUKUOKA	March 2021	2	18–20	(JR-KYUSHU(2020c)
NISHITETSU	FUKUOKA	March 2021	1	13–30	(NISHITETSU 2020d)

Table 4 Examples of reduction in the number of stations with staffed ticket counters

Company	Reduction in the Number of Stations with Staffed Ticket Counters	Source
JR-EAST	300 (2021–2025)	(JR-EAST 2021b)
JR-WEST	160 (2020–2022)	(JR-WEST 2020c)
JR-KYUSHU	48 (2022)	(JR-KYUSHU 2021)
CHICHIBU	27 (2022)	(CHICHIBU2022)
NISHITETSU	24 (2020)	(NISHITETSU2020b)
	9 (2022)	(NISHITETSU 2022a)

Table 5 Discontinued local lines by Japanese listed railway companies (since 2020)

Company	Region	Line Name	Operating Kilometers	Date of Abolition
JR-EAST	TOHOKU	Ofunato	43.7	1 April 2020
JR-EAST	TOHOKU	Kesennuma	55.3	1 April 2020

Data Source: Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2024).

Subsequently, in 2021, the companies could be divided into profitable and loss-making companies. This division suggests that railway companies, particularly loss-making companies, needed to decrease operational inefficiency. Japanese listed railway companies are classified into the JR Group companies (JR), which were established by the privatization of Japanese National Railways (JNR) in 1987, and the original private railway companies (OPR). JR maintained profitability before the pandemic through an internal compensation mechanism, whereby profits in metropolitan areas and high-speed railway operations were used to cover the losses on regional local lines. The COVID-19 pandemic made this internal compensation mechanism infeasible because of the reduction in the number of passengers on high-speed railways and in metropolitan areas.

The influence of the pandemic has also been discussed abroad. Rothengatter *et al.* (2021) conducted an analysis of the impact of the COVID-19 pandemic on urban transport in air, railway, and bus transport. The study on people's attitudes towards public transport use found that people were more aware that it was safer to use bicycles and private cars compared with pre-pandemic levels. In the air transport sector, a study by the International Civil Aviation Organization (ICAO) found that air transport worldwide would provide approximately 50% fewer seats, 2.9 billion fewer passengers, and economic losses of approximately USD 390 billion in 2020. In the railway sector, a study for the first half of 2020 revealed economic losses of approximately EUR 3.7 billion for Deutsche Bahn (Germany) and EUR 4 billion for SNCF (France), with passenger numbers down by around 21%. In 2020, the US Metropolitan Transportation Authority (MTA) estimated an economic loss of USD 12 billion and INR 1609 crore (one crore is INR 10 million) for the Delhi Metro in India. In Switzerland, railway and tram traffic fell by more than 80% (Rothengatter *et al.* 2021).

These circumstances resulted in a loss-making profit in the transportation business during the pandemic period, and therefore the efficiency of railway operations needs to be improved in order to ensure as much profit as possible for the sustainable operation of the railway business. By improving the efficiency of their railway operations, railway companies can minimize the damage caused by the pandemic.

1.2 Motivation

The motivation for this thesis is mainly two points as follows. The first point is to propose a method to objectively determine the impact of the COVID-19 pandemic on the management of railway companies and to analyze measures to ensure the survival of their operations. Additionally, it seeks to obtain risk aversion measures to sustain the railway business in the event of a significant decrease in the number of railway passengers due to unpredictable external factors. For railway companies to sustainably operate after a pandemic, it is necessary to increase the revenues and profits of the railway business, which would otherwise be at a loss-making profit during a pandemic, but this is not easy. On the other hand, some railway companies that could cover their loss-making transportation business with profitable divisions could make profits. Improving the cost efficiency of the railways business contributes to railway companies being able to post a profit. Therefore, the second point is to clarify the cost efficiency of Japanese listed railway companies and identify the characteristics of the best-practice railway companies. Then, I analyze the factors influencing cost efficiency before and after the pandemic. No studies have analyzed the production or cost efficiency of listed Japanese railway companies since the 2010s, the factors that affect cost efficiency levels, and the impact of the COVID-19 pandemic on the cost efficiency of Japanese railway companies. I intend to add knowledge about the cost inefficiency of Japanese listed railway companies.

1.3 Objectives

The objectives of this study are sixfold. In the first part of the profitable and business model analysis, (1) This study examines the impact of the COVID-19 pandemic on the loss of revenue to these companies and the changes in their profit structure. Based on Japanese railway companies' investor relations (IR) information from 2017 to 2021, all of which are listed on the Tokyo Stock Exchange. (2) It uses text analysis of the IR information of countermeasures of the pandemic and after the pandemic to show the differences in management strategies between profitable and loss-making companies. The results of these analyses relate to the characteristics of the profit structures and management strategies of private railway companies that would be sustainable after the COVID-19 pandemic. (3) The study also discusses new business models and future challenges for railway companies after the pandemic. (4) The study verifies that the diversified business of railway companies will help them avoid the management risks of the pandemic. Given these results, profitable companies can cover the losses in their transportation business with profits from profitable businesses, so to operate sustainably, it is necessary to strengthen the profitable business and increase the efficiency of the loss-making transportation business to minimize the losses. In the latter part of cost efficiency analysis, (5) I examine the cost efficiency of listed Japanese railway companies by applying stochastic frontier analysis (SFA) to data from 2005 to 2020 when the COVID-19 pandemic began to influence the world. (6) I identify the characteristics of best-practice railway companies and examine the drivers of their cost efficiencies. I also analyze the impacts of and differences from the crises that occurred before the COVID-19 pandemic, such as the financial crisis and the Great East Japan Earthquake, in terms of cost inefficiency. Finally, based on the empirical results, I discuss the sustainable business practices required by railway companies to survive after the COVID-19 pandemic.

1.4 Research Question

In setting the research question for this study, I referred to the following existing studies. Alvesson and Sandberg (2011) propose the gap-finding approach and the evidence-from-practice approach as methods for problematizing research question setting. This thesis consists of two research by following analyses.

Profitability and business model analysis

Analysis 1-1: Operational data analysis based on company groups from cluster analysis

In Analysis 1-1, there are two research questions based on a gap-finding approach and they are as follows:

(1) How much is the decrease in the number of railway passengers and the company's revenue?

(2) What business segment is affected and unaffected by the COVID-19 pandemic?

Analysis 1-2: Analysis of management strategies to countermeasure the COVID-19

The research question for Analysis 1-2 is based on the evidence-from-practice approach and the questions are as follows:

(1) What is the difference in the feature of management strategy to countermeasure the COVID-19 pandemic between profitable companies and loss-making companies?

I examine existing empirical analyses that provide a theoretical foundation for the research questions in this study and verify their consistency.

Cost efficiency analysis for railway (Stochastic Frontier Analysis)

Analysis 2: Cost efficiency analysis for railway

The research question for analysis 2 is based on a gap-finding approach or the evidence-from-practice approach and the questions are as follows:

(1) How much is the cost efficiency of listed Japanese railway companies and how much is affected by the COVID-19 pandemic? (gap-finding approach)

(2) What are the characteristics of best-practice Japanese railway companies? (evidence-from-practice approach)

1.5 Contributions

The centerpiece of this doctoral thesis is founded on the fact that no analysis of changes in passenger numbers, revenues, the profit structure of diversified businesses, and the cost efficiency of railway business for railway companies before and after the COVID-19 pandemic has been found in previous studies. The contributions of this doctoral thesis include the following theoretical, practical, and academic contributions. Theoretical contributions are as follows:

(1) Construction of a method to quantitatively evaluate changes in the number of railway passengers and revenues and cost efficiency from IR information

(2) Construction of a method for quantitative analysis of business segments affected or unaffected by pandemics based on IR information

(3) Construction of a method for qualitative analysis of management strategies of companies that generate profitable/loss-making from IR information by text analysis

(4) Proposal of a new framework (Fig. 20) for the overall cost efficiency analysis of private railway companies by combining traditional methods in the cost efficiency analysis of private railway companies.

Practical contributions are as follows:

(1) Quantifying the degree of decline in railway passengers and revenues due to the COVID-19 pandemic

(2) Specific business segments that are affectable or unaffectable by the COVID-19 pandemic

(3) Indicate the specific characteristics of the management strategy of the profitable companies after COVID-19 (whether the management strategy formulated was as intended or not)

(4) Indicate the characteristics of best-practice railway companies by the results of the cost efficiency

(5) Indicate the cost efficiency of private railway companies and the relationship between efficiency improvement measures and investments.

Therefore, the academic contribution of this doctoral thesis is to propose a framework that integrates quantitative and qualitative analysis, which can be used to efficiently assess current conditions and formulate management strategies in the event of sudden changes in the business environment, such as pandemics and disasters. Since the data used for analysis is publicly available, anyone can use this framework for analysis. The content of this thesis is fully understandable for people involved in the railway company. These insights are useful from the perspective of improvement of cost efficiency for sustainable operations after the COVID-19 pandemic. Therefore, managers of railway operators or public sector policymakers can use the results of this study to quantitatively analyze the reduction in railway passengers, revenues, and profits affected by the COVID-19 pandemic. The findings from the management strategy can also provide a reference for what to keep in mind when reviewing the management strategy in the event of social changes such as a pandemic or disasters that may lead to a change in people's behavior worldwide.

Even in countries other than Japan, the analytical methods of this study can be used to conduct country-specific analyses. Data can also be easily collected using IR information and publicly available data such as the number of railway passengers, railway transportation revenues, and management strategies. In the public sector, the business segment can be replaced by other sectors to provide support to railway operators and provide clues for non-railway policy making.

1.6 Structure of the Thesis

The remaining thesis is structured as follows. Chapter 2 is “Profitable and business model analysis”. Section 2.1 reviews the literature on the impact of the COVID-19 pandemic on public transportation, from the perspectives of financial and theory of transportation business. Section 2.2 describes the methodology employed in this study. Section 2.3 presents Analysis 1: Operational data analysis based on company groups from cluster analysis and includes methodology, results, and empirical analyses. Section 2.4 presents Analysis 2: Analysis of the Japanese railway companies’ management strategies after the COVID-19 pandemic and includes methodology, results, and empirical analyses. In Chapter 2, cluster analysis is used to divide companies into groups with similar net income to sales ratio trends. The results of Chapter 2 show that the transportation business would be in the loss-making during a pandemic. Railway companies need to minimize this loss-making in the transportation business profits, and the railway business's cost efficiency needs to be improved. Therefore, this cost-efficiency analysis is conducted in the next Chapter. The analysis of the cost efficiency of the railway business is carried out on a company-by-company basis. Chapter 3 is “Cost efficiency analysis (Stochastic Frontier Analysis). Section 3.1 reviews previous studies that empirically analyze the efficiency of railway companies using SFA. Section 3.2 describes the data and methodology used in this study. Section 3.3 presents the results and discusses the implications for railway business and operations. Chapter 4 discusses the results of these studies and Chapter 5 concludes with the main findings and implications.

Chapter 2 Profitability and business model analysis

This chapter is based on Endo and Goto (2024a), with additional post-pandemic analysis and discussion.

2.1 Literature Review

2.1.1 COVID-19 impact study on transportation and related businesses

The research question of analysis 1-1 is on the impact of the COVID-19 pandemic on railway passengers. Previous studies have focused on changes in railway passengers. There are existing studies of cases in the European Union (EU), Switzerland, Spain, New York, Chicago, Turkey, China, and Hong Kong.

Aloi *et al.* (2020) analyzed the impact of the quarantine imposed in March 2020 on urban mobility in the city of Santander in Spain to reveal an overall decline of 76% in mobility, while public transport users dropped by 93% in relative terms. Shakibaei *et al.* (2021) investigated the impacts of the pandemic on travel behavior in Istanbul, Turkey, through a longitudinal panel study conducted in three phases during the early stages of the pandemic; they show a decline in the utilization of all major public transportation modes and an increase in the use of private cars. Molloy *et al.* (2021) analyzed the impact of Switzerland's strict measures on mobility behavior based on a GPS tracking panel of 1439 Swiss residents and found a reduction of approximately 60% in the average daily distance traveled, and over 90% for public transport.

Zhang *et al.* (2021) analyzed the changes in the local travel behavior of various population groups in Hong Kong, between 1 January and 31 March 2020, by using smartcard data from the Mass Transit Railway Corporation system. They observed that during the pandemic, the daily commute flow decreased by 42%. Local trips to shopping areas, amusement areas, and borders decreased by 42%, 81%, and 99%, respectively. Using the Bayesian structural time series model, Hu and Chen (2021) analyzed the 20-year daily transit ridership data in Chicago to gauge the impact of COVID-19 on ridership. Their results showed that the pandemic had exerted significant effects on 95% of transit stations, leading to an average 72.4% drop in ridership. Xin *et al.* (2021) analyzed the impact of COVID-19 on the daily ridership of urban rail transit using the Synthetic Control Method in 11 cities in Asia and found that most Chinese cities had experienced about a 90% reduction in ridership.

Rajput *et al.* (2022) attempted to identify the impact of the pandemic and the effectiveness of government policies on human mobility by analyzing multiple datasets available at both macro and micro levels for New York City. Their study showed a drop of about 80% in people's mobility in the city; the movement to and from Manhattan showed the most disruption for both public transit and road traffic. Grechi and Ceron (2022) investigated the decrease in the number of passengers based on six Lombard/ Piedmont lines in North-West Italy by using official data from Trenitalia and Trenord; their analysis verified the impact of a substantial reduction in passenger numbers by 40-60%.

Thus, while there have been previous studies focusing on changes in the number of railway passengers, there have been no previous studies of revenue changes from the perspective of railway operators. In this study, this research gap is analyzed in analysis 1.

Regarding the analysis method, since it is not efficient to study all companies individually, companies with similar characteristics are grouped and analyzed. In existing studies by Le *et al.* (2022) and Miki and Ieda (2020), cluster analysis was used to group and analyze similar companies. Therefore, I have applied cluster analysis in this study.

Table 6 shows the position of analysis 1-1 in existing studies.

Table 6 The position of analysis 1-1 in existing studies

Analysis 1-1 : COVID-19 impact study on transportation and related businesses		
Research questions	**(1) How much is the decrease in the number of railway passengers and the company's revenue?**	**(2) What business segment is affected and unaffected by the COVID-19 pandemic?**
Exsiting studies	Changes in the number of railway passengers during the COVID-19 pandemic. Italy : Grechi and Ceron (2022) Switzerland : Molloy *et al.* (2021) Spain : Aloi *et al.* (2021) New York : Rajput *et al.* (2022) Chicago : Hu and Chen (2021) Turkey : Shakibaei *et al.* (2021) China : Xin *et al.* (2021) Hong Kong : Zhang *et al.* (2021)	No research in railway business
Analysis method	Cluster analysis : Le *at el.* (2022), Miki and Ieda (2020)	

2.1.2 Theory on Transportation Business

The research question of analysis 1-2 was set by a problematization method of the evidence-from-practice approach (Alvesson and Sandberg, 2011). As a practical empirical analysis, it is intended to provide insights for railway operators and public sector policymakers on issues related to the stability of railway operations. The hypothesis for the research question of this study is to test the consistency of the theoretical and empirical results of the foundational previous studies based on Locke and Golden-Biddle's (1997) method of clarifying theoretical contributions. I list the existing empirical studies that served as the foundation for the theory of this study.

Mogaji and Nguyen (2021) reviewed that in the concept of subjective well-being (Diener *et al*., 2018), transportation and travel experiences contribute to an individual's subjective well-being (Singleton, 2019; Lorenz, 2018), and that travel satisfaction and increased stress (Mokhtarian and Pendyala, 2018), and correlation between travel satisfaction and vulnerability, particularly vulnerability of people with disabilities, between travel satisfaction and willingness to relocate and even willingness to change jobs (Farinloye *et al.*, 2019). They found that there is a lack of knowledge on the vulnerability of people with disabilities in developing countries regarding their commuting travel experiences and satisfaction levels. They showed that the Nigerian transportation system is yet to meet the expectations of people with disabilities.

Raghavan *et al.* (2021) showed that the COVID-19 pandemic changed the way organizations and employees behaved with digital and teleworking and that it is irreversible. In Japan, the pandemic is now under control, but the number of railway passengers has not recovered to pre-pandemic levels.

Kot and Dragon (2015) analyzed business risk management models in international energy companies through a literature review. Unstable financial markets and ever-changing business environments have shown that organizations operating in international markets cannot function effectively and be competitive without continually recalculating risk. Companies, especially those operating in different social, political, and legal conditions on different continents, have developed specific mechanisms and tools to effectively estimate risk. Then, they showed that by identifying and assessing risks that may prevent a company from achieving its goals, it can determine how to handle the risks and develop its mitigation strategies.

Makkawi (2021) showed through his article review that risk management does indeed contribute to improved business performance, measured as increased corporate profits, reduced business costs, and ultimately increased economic proficiency. The study suggested that risk management has a positive impact on the quality of business, which is embodied in improved financial conditions, increased profits, and reduced costs for the company.

Chan *et al.* (2022) used content analysis methods to obtain survey data from internet news media and official company websites from eight different companies (manufacturing, tourism, transportation, technical services, catering, retail, airlines, and accommodation) and different industry sectors from December 2019 to December 2021. Then they analyzed how global companies adopt a proactive risk management approach. The findings confirmed that proactive risk management not only helped companies maintain sustainable operations during the epidemic but could also lead to excess earnings.

Rodrigues *et al.* (2021) conducted a content analysis of the documents and qualitative data using MAXQDA software through a literature review. In the COVID-19 pandemic, small to medium enterprises (SMEs) that transitioned to new ways of doing business in creativity, entrepreneurship, digitization, new management of human resources, including labor flexibility, and open innovation adapted to changing consumer behavior by gaining liquidity flows. Then they suggested that the company might survive this crisis by adopting corporate and individual social responsibility.

Gorzelany (2021) showed from a literature review and questionnaire survey that companies disrupted by the COVID-19 pandemic were more innovative in terms of products and management than their unaffected counterparts. Baryshnikova *et al.* (2021) assessed changes in the economic behavior of companies in the context of the pandemic and analyzed business practices in adapting functional strategies to new risks. The results showed that pandemics have a significant impact on the economic behavior of companies. Specifically, the companies changed not only their tactics but also their strategies, using remote work formats, digitization of processes and tasks, and new approaches in management, showing that those that adapted to the prevailing conditions were the most successful in adapting to unexpected threats.

As for the analysis method, previous studies by Shin *et al* (2021) and Lee and Rha (2018) used a text analysis method based on the network text analysis technique, which is used in this study. Table 7 shows the position of analysis 1-2 in existing studies.

Table 7 The position of analysis 1-2 in existing studies

Analysis 1-2: Theory on transportation businesses	
Research question	**What is the difference of the feature of management strategy between profitable companies and loss-making companies?**
Exsiting empirical studies	・Transportation satisfaction of disabled passengers: Evidence from a developing country: Mogaji and Nguyen (2021) ・Business Risk Management in International Corporations. Procedia Economics and Finance: Kot *et al.* (2015) ・The role of risk management in increasing business performance: Makkawi (2021) ・COVID-19 and the New Normal of Organizations and Employees: Raghavan *et al.* (2021) ・Reviewing COVID-19 Literature on Business Management: What It Portends for Future Research? : Rodrigues *et al.* (2021) ・COVID-19: Business Innovation Challenges: Gorzelany (2021) ・Enterprises' strategies transformation in the real sector of the economy in the context of the COVID-19 pandemic: Baryshnikova *et al.* (2021) ・Risk and Financial Management of COVID-19 in Business, Economics and Finance: Chan *et al.* (2022)
Analysis method	Network text analysis: Shin *et al.* (2021), Lee and Rha(2018)

Based on the literature review, I outline a two-fold original contribution of this study. First, in existing studies, Japanese cases are added. As a novelty of my research, I propose a method to quantitatively analyze the revenue and profit of railway companies by business segment due to the COVID-19 pandemic from IR information. Then, I add the knowledge of business segments that are more or less likely to be affected by the pandemic. I add knowledge about the company's risk aversion measures for unexpected situations, such as a pandemic in a railway company.

Second, I group companies into profitable and loss-making companies and then analyze them by text analysis. I propose one method for qualitatively analyzing whether the management strategies formulated by that management did or did not go as they intended. It also indicates that the profitable real estate business of a railway company is due to the management strategy and not to the economic trends. In addition, instead of using interview methods for management strategy, I use IR information, (i.e., public information from management to stakeholders). This allows for qualitative analysis using objective data that does not rely on the subjectivity of the interviewer.

2.2 Methodology and Data

This study conducts the following two empirical analyses of the impact of the COVID-19 pandemic on the profits of Japanese railway companies. Fig. 1 shows the structure of the empirical analyses.

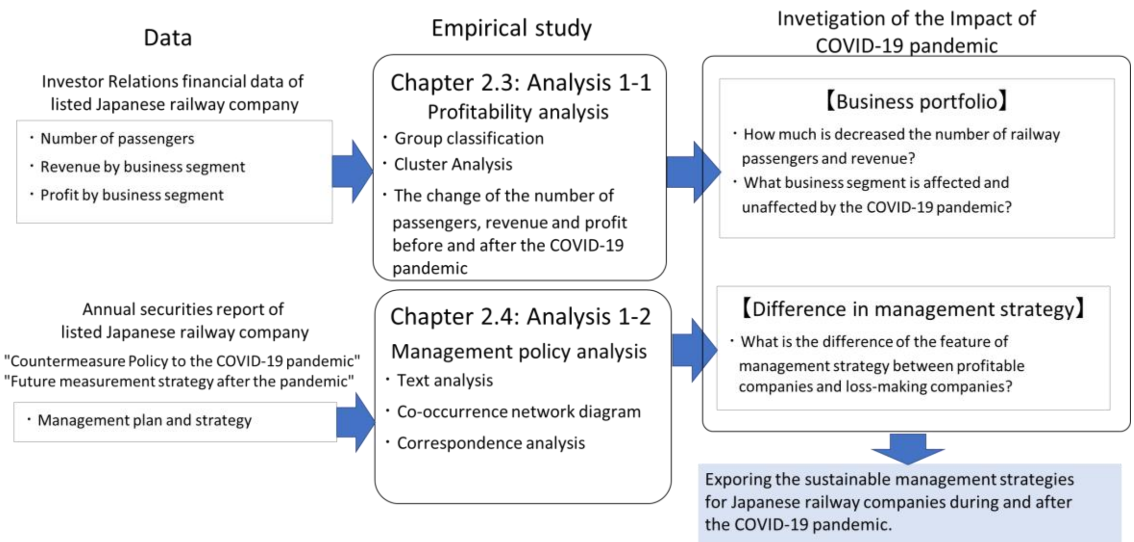


Fig. 1 Research flow of Profitability and business model analysis

The first Analysis is a cluster analysis of the profit structure using financial data to classify the railways affected by the COVID-19 pandemic into profitable and loss-making companies and show the characteristics of their earnings structure. This analysis consists of the following two parts.

The first part is a quantitative evaluation of the number of railway passengers and revenue changes. Since it is not efficient to analyze each of the targeted railway companies individually, the companies are grouped together for analysis. The reason for using cluster analysis is to objectively analyze the characteristics of a company's management, not merely its profitability or loss-making, and to group companies with similar characteristics. This is to prevent the researcher from missing objective facts due to their subjectivity.

The indicator used in the cluster analysis is the ratio of net income to sales. This is characteristic of railway companies, which have a large number of fixed assets such as land, railway facilities, and rolling stock. For this reason, I used return on sales, a measure of the final profit from corporate activities, to capture the impact of the COVID-19 pandemic, including gains from the sale of securities, land, and businesses. In order to allow companies of different sizes to be analyzed on the same scale, changes in the number of railway passengers and railway revenues are measured on a year-to-year basis. There is no need to stick to year-to-year, and the financial year (FY) for comparison can be varied depending on the subject of the study. Since this study employs a before, during, and after the COVID-19 pandemic comparison, FY2021 and FY2023 are compared to FY2019, and not to FY2020 and FY2022 (i.e., the year-to-year comparison).

The second part is to quantitatively assess businesses that are more or less susceptible to the pandemic. I analyze the percentage of each business segment's revenue or profit in the total business segment, thereby providing a quantitative view of which business segments are less likely to be affected by the COVID-19 pandemic and which are more likely to be affected.

The second analysis is a text analysis of management policies after the COVID-19 pandemic for profitable and loss-making companies to identify the characteristics of sustainable profit-making strategies even during and after the pandemic. I use text analysis to qualitatively analyze the business strategies of companies that generate profit and those that post a profit or loss. The management strategies referred to here are those for responding to the pandemic and for maintaining sustainable railway company management even after the pandemic. For this reason, I collect text data on "Countermeasure policy to the COVID-19 pandemic" and “Future measurement strategy after the pandemic” from IR information. These response policies are limited to pandemic response policies such as financial responses, asset management reviews, and business reviews. For this reason, I think that it is appropriate to analyze the impact of the COVID-19 pandemic on railway company’s management strategies. Here, I attempt to qualitatively analyze the characteristics of a company from its management strategy, which cannot be analyzed by quantitative evaluation alone. The reason is that a company's business strategy is characterized by its corporate culture and management level, which is derived from employees.

First, I classify the companies as either profitable or loss-making. Then, by conducting a text analysis of the management strategies of each group of companies, I propose a method for analyzing the characteristics of management strategies found in groups of profitable and loss-making companies.

Theoretically, I use the method by co-occurrence network diagrams and correspondence analysis. I show trends found in profitable and loss-making companies by analyzing frequent terms and their connections in management strategy texts.

The data are obtained from IR information published by each railway company on its website; this includes annual securities reports, financial statements, financial results presentation materials, fact sheets, and monthly transportation revenues. The data are collected during the period from Q1 FY2017 (April-June) to Q3 FY2021 (October-December) and Q3 FY 2023 (October-December) to compare the performance before, during and after the COVID-19 pandemic.

2.3 Analysis 1-1: Operational data analysis based on company groups from cluster analysis

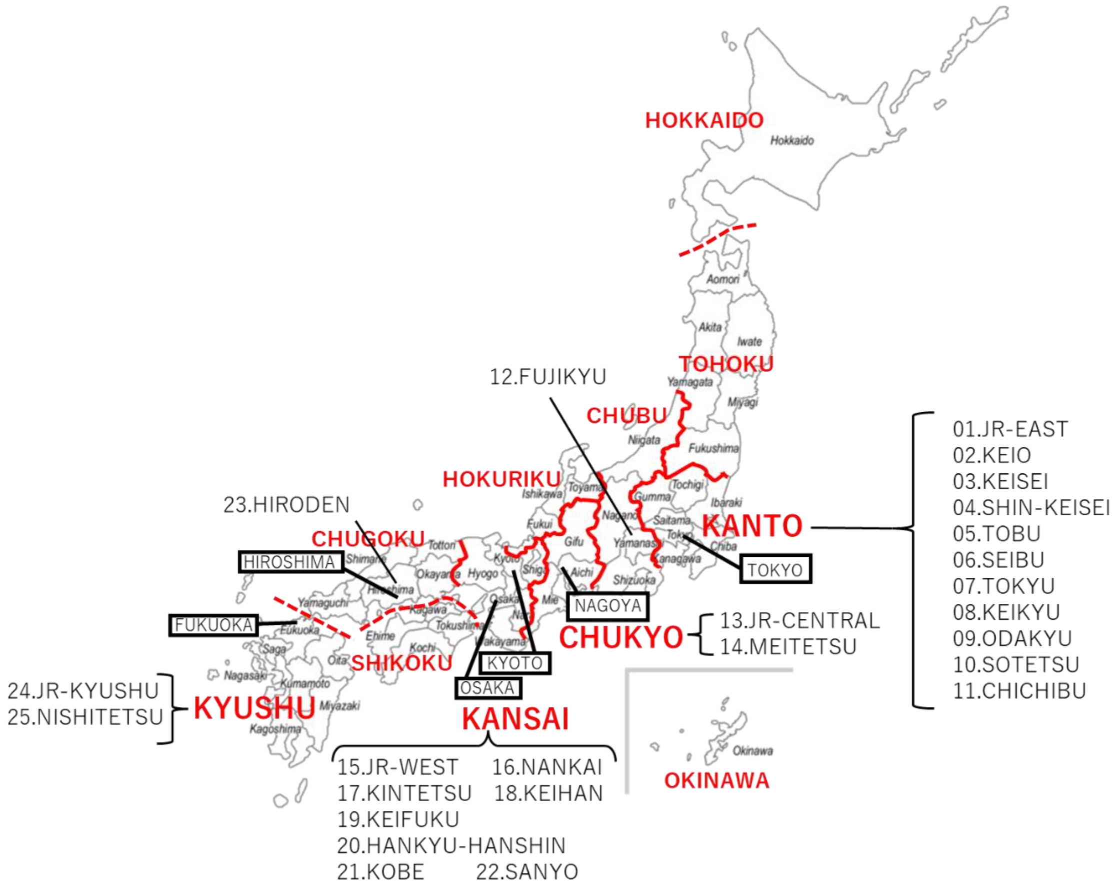
2.3.1 Characteristics of Japanese Railway Companies

Japanese railway companies operate through diverse business models centered on the transportation business. Table 8 gives the names and other details of the 25 Japanese railway companies in this study. They are listed on the Tokyo Stock Exchange. Fig. 2 shows the business areas of the Japanese railway companies shown in Table 8.

Table 8 The 25 listed railway companies in Japan that were studied

No.	Company name	Business type	Service area	Business segment (Main business in 3Q FY21: Underlined business segment)
01	JR-EAST	JR	KANTO, TOHOKU, CHUBU(YAMANASHI, NIGATA, NAGANO, SHIZUOKA)	Transportation, Retail, Real Estate
02	KEIO	OPR	KANTO(TOKYO)	Transportation, Retail, Real Estate, Leisure
03	KEISEI	OPR	KANTO(TOKYO, CHIBA)	Transportation, Retail, Real Estate, Leisure, Construction
04	SHIN-KEISEI	OPR	KANTO(CHIBA)	Transportation, Real Estate
05	TOBU	OPR	KANTO(TOKYO, SAITAMA, GUNMA, TOCHIGI, CHIBA)	Transportation, Retail, Real Estate, Leisure, Construction
06	SEIBU	OPR	KANTO(TOKYO, SAITAMA)	Transportation, Real Estate, Leisure, Construction
07	TOKYU	OPR	KANTO(TOKYO, KANAGAWA)	Transportation, Retail, Real Estate, Leisure
08	KEIKYU	OPR	KANTO(TOKYO, KANAGAWA)	Transportation, Retail, Real Estate, Leisure
09	ODAKYU	OPR	KANTO(TOKYO, KANAGAWA)	Transportation, Retail, Real Estate
10	SOTETSU	OPR	KANTO(KANAGAWA)	Transportation, Retail, Real Estate, Leisure
11	CHICHIBU	OPR	KANTO(SAITAMA)	Transportation, Real Estate, Leisure, Bus
12	FUJIKYU	OPR	CHUBU(YAMANASHI)	Transportation, Real Estate, Leisure
13	JR-CENTRAL	JR	KANTO(TOKYO, KANAGAWA), CHUBU(SHIZUOKA,NAGANO, YAMANASHI), CHUKYO(AICHI, GIFU, MIE), KANSAI(SHIGA,KYOTO,OSAKA)	Transportation, Retail, Real Estate
14	MEITETSU	OPR	CHUKYO(AICHI, GIFU, MIE)	Transportation, Retail, Real Estate, Leisure, Logistics, Aviation service
15	JR-WEST	JR	CHUBU(NIGATA,NAGANO),HOKURIKU, KANSAI, CHUGOKU,KYUSHU(FUKUOKA)	Transportation, Retail, Real Estate
16	NANKAI	OPR	KANSAI(OSAKA, WAKAYAMA)	Transportation, Retail, Real Estate, Leisure, Construction
17	KINTETSU	OPR	KANSAI(OSAKA, KYOTO, NARA), CHUKYO(AICHI,MIE)	Transportation, Retail, Real Estate, Leisure
18	KEIHAN	OPR	KANSAI(OSAKA, KYOTO)	Transportation, Retail, Real Estate, Leisure
19	KEIFUKU	OPR	KANSAI(KYOTO), HOKURIKU(FUKUI)	Transportation, Real Estate, Leisure
20	HANKYU-HANSHIN	OPR	KANSAI(OSAKA, KYOTO, HYOGO)	Transportation, Real Estate, Leisure, Travel, ICT, Entertainment, International Transportation
21	KOBE	OPR	KANSAI(HYOGO)	Transportation, Retail, Real Estate
22	SANYO	OPR	KANSAI(HYOGO)	Transportation, Retail, Real Estate, Leisure
23	HIRODEN	OPR	CHUGOKU(HIROSHIMA)	Transportation, Retail, Real Estate, Leisure, Construction
24	JR-KYUSHU	JR	KYUSHU	Transportation, Retail, Real Estate, Construction
25	NISHITETSU	OPR	KYUSHU(FUKUOKA)	Transportation, Retail, Real Estate, Leisure, Logistics

Note: OPR and JR represent the Original Private Railway and Japan Railway, respectively. Service area refers to the areas served (see Fig. 2). The bold and italics business segment indicates the main business of a company.



Note: Source (Endo and Goto 2024a)

Fig. 2 Map of Railway service areas in Japan

According to the annual financial reports of the 25 listed railway companies that I reviewed for the period of Q1 FY2017 to Q3 FY2021, the main business segments of railway companies are classified into six categories (1) to (6). Here, Q stands for the quarter of a year and FY stands for the fiscal year. The Japanese fiscal year begins in April and ends in March, for example, Q1 indicates from April to June, and Q3 indicates from October to December. I use these acronyms hereafter (Endo and Goto, 2024a). (1) Transportation business sector: Railways, bus, taxi, ship, cableway, airport operation, and so on; (2) Retail business sector: Department store, shopping center, supermarket, convenience store, restaurant, credit card, wholesale, and so on; (3) Real estate business sector: Real estate lending, real estate sales, real estate subdivision, real estate management, and so on; (4) Leisure business sector: Hotel, travel, leisure-related facility, leisure service, amusement park, zoo, aquarium, souvenir sale, bowling, sport, golf, skiing, outdoor activity, boat racing facility rental, restaurant, entertainment, cinema, and so on; (5) Construction business sector: Construction, civil engineering and building construction, telecommunications engineering, construction consultant business, and so on; (6) Other businesses sector: IC card, information, credit card, financial business, vehicle maintenance, accounting agency, human resource operations agency, temporary staffing business, insurance agency, car rental, trading, and so on.

Japan has a well-established railway system that can be classified into two types based on how the companies were historically established: type 1 with Original Private Railway (OPR) companies, and type 2 with the Japan Railway (JR) companies (Endo and Goto, 2024a). They have different business characteristics, associated with higher and lower diversified business models.

The OPR companies acquired large areas of land along the railway lines before their construction and developed and sold residential areas after the railway began to operate. This ensured that the commercial railway transportation business became profitable when land prices went up after the start of the railway services and the demand for railway transportation increased after the people moved into these residential areas. In addition, as retail businesses such as department stores and shopping centers came up at station terminals, the railway companies reaped the advantage of lower initial costs because the land and buildings were owned directly by them or by real estate companies within the railway corporate group.

In addition, OPR companies developed leisure businesses in the suburbs to meet the needs of passengers who traveled in the opposite direction during rush hour or of the excess transportation capacity on weekends and holidays. In densely populated urban areas, demand for railway transport through the development along railway lines resulted in a high proportion of non-transportation revenues. Thus, the OPR companies are characterized by diversified businesses and revenues, with a high percentage of revenues coming from the associated real estate, retail, and leisure service industries and a low percentage of revenues from transportation compared to JR companies.

JR companies, in contrast, are characterized by a higher proportion of revenues accruing from the transportation business. This is because they were established, through privatization and divestiture in 1987, by Japan National Railways (JNR), which specialized in the transportation business, including railway and bus services. Since privatization, all JR companies have promoted diversified management but have not been able to develop large-scale railway lines as the OPR companies did. Thus, even as the JR companies strive for diversification, including real estate development around the stations and their land, businesses at stations, electronic payment systems using IC cards, and railway car manufacturing business, they still heavily rely on the railway business for their revenues. Thus, the JR companies are characterized by railway-centered businesses and lower diversification.

Other than the railway sector, airline and bus companies have not diversified their business with other transportation businesses because they do not have this background. The diversified bus companies are either part of a group of railway companies or companies that used to operate railway services but have now been out of the railway business.

2.3.2 Methodology and Data

The study applied cluster analysis using the crucial performance indicator, net income to sales ratio, from 1Q FY2017 through 3Q FY2021. The reason for using this indicator is that railway companies are characterized by a large number of fixed assets, such as railway land, railway facilities, and rolling stock, and to ascertain the impact of the COVID-19 pandemic, such as gains from the sale of securities, land, and businesses, I used the net income to sales ratio, which is an indicator of final profits from corporate activities, to determine. The groups are defined as those with similar time-series changes from Q1 FY2017 before the pandemic to Q3 FY2021 during the pandemic. I use the hierarchical cluster analysis in which the square Euclidean distance is used to measure the distance between individuals in a cluster (Endo and Goto 2024a). The square Euclidean distance is an effective method for measuring the distance between individuals, defined by Equation (1) as:

$$\boldsymbol{d_{ij} = \sum_{k=1}^{m}\left(x_{ki} - x_{kj}\right)^2}\ , \tag{1}$$

where x_{ki} and x_{kj} are arbitrary individuals i and j $(i, j = 1, \dots, n)$ in a cluster with k dimensions $(k = 1, \dots, m)$.

The Ward method is used to measure the distance between clusters. This method creates clusters based on the criterion of minimizing the sum of squares within two clusters. When using the Ward method, the square Euclidean distance is used to measure the distance between individuals.

The distance between cluster r and cluster s is defined as d_{rs} in Equation (2) as follows.

$$\boldsymbol{d_{rs} = \frac{n_p + n_s}{n_r + n_s} d_{ps} + \frac{n_q + n_s}{n_r + n_s} d_{qs} - \frac{n_s}{n_r + n_s} d_{pq}} \tag{2}$$

where d_{ps} is the distance between cluster p and cluster s, d_{qs} is the distance between cluster q and cluster s, and d_{pq} is the distance between cluster p and cluster q. n_p, n_q, n_r, n_s are the numbers of individuals belonging to clusters p, q, r, s $(p, q, r, s = 1, \ldots, N)$, respectively, that is, $n_p, n_q, n_r, n_s = 1, \ldots, n$. This study uses IBM SPSS ver. 28 for the cluster analysis.

Next, the following two analyses are performed for each group classified by the cluster analysis.

(i) Analysis of changes in the number of railway passengers and railway transport revenues before and after the COVID-19 pandemic

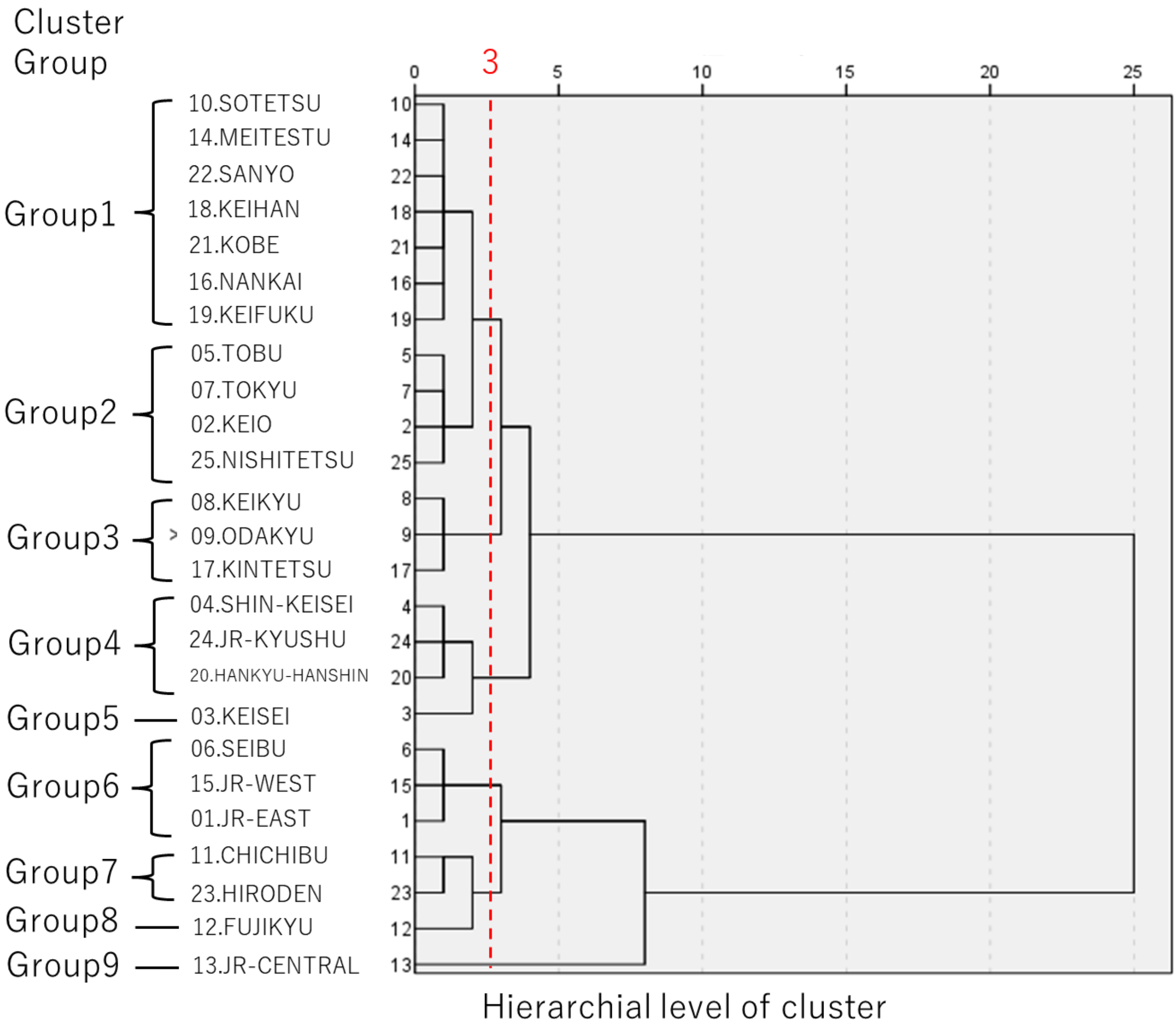
Panel data on the number of railway passengers and railway transport revenues before and after the COVID-19 pandemic are used to analyze the characteristics of each group. I use data for 3Q FY2021 as a steady-state value for forecasting transportation passenger numbers.

(ii) Analysis of the changes in revenue and profit structure by business segment before, during, and after the COVID-19 pandemic

Using panel data on revenue and profit composition by business segment from IR information, I analyze the characteristics of each group in terms of changes in revenue and profit structure by business segment before, during, and after the COVID-19 pandemic. The analysis is conducted using the data from 3Q FY2019 to 3Q FY2021 and 3Q FY2023 to cover pre- and post-pandemic periods.

*2.3.3 Results*Note: Source (Endo and Goto 2024a)

Fig. 3 shows the results of the cluster analysis of return on sales (net income to net sales ratio) from Q1 FY2017 to Q3 FY2021. In Fig. 3, the vertical axis indicates the group of companies and the horizontal axis indicates the hierarchical level of clusters. The smaller the hierarchy on the horizontal axis, the more similar the characteristics of the clusters. The results of the cluster analysis at level 2 classify them into nine groups as follows; Group 1 (seven companies): SOTESTU, MEITETSU, SANYO, KEIHAN, KOBE, NANKAI, and KEIFUKU; Group 2 (four companies): TOBU, TOKYU, KEIO, and NISHITESTU; Group 3 (three companies): KEIKYU, ODAKYU, and KINTETSU; Group 4 (three companies): SHIN-KEISEI, JR-KYUSHU, and HANKYU-HANSHIN; Group 5 (one company): KEISEI, Group 6 (three companies): SEIBU, JR-EAST, and JR-WEST; Group 7 (two companies): CHICHIBU and HIRODEN; Group 8 (one company): FUJIKYU; and Group 9 (one company): JR-CENTRAL. Level 2 divided the respondents into nine groups, but because some of these groups showed similar trends, the analysis was conducted at level 3 in order to efficiently analyze the groups with more distinct differences in characteristics. This analysis is conducted at level 3 (six groups) rather than level 2 (nine groups). Ultimately, I analyze the above six groups ("Groups 1 & 2", Group 3, "Groups 4 & 5", Group 6, "Groups 7 & 8", and Group 9) reduced from the nine groups.



Note: Source (Endo and Goto 2024a)

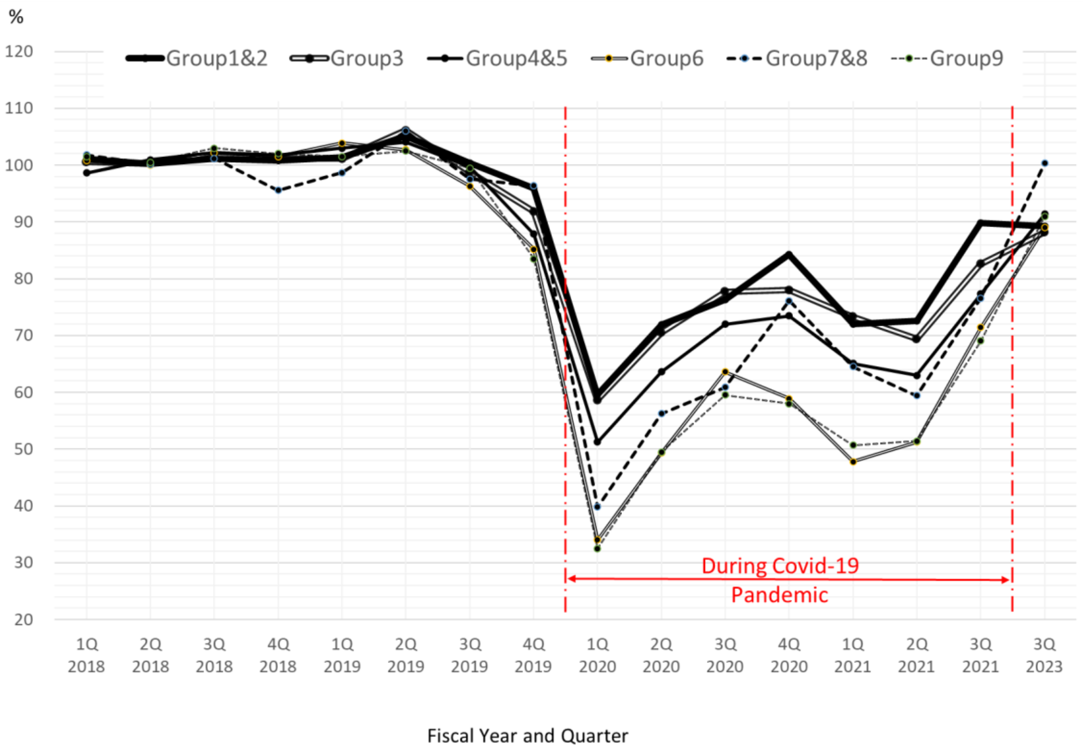
Fig. 3 Results of the Cluster Analysis for Net Income to Net Sales Ratio (Q1 FY2017-Q3 FY2021)

In this subsection, I examine the characteristics of each group from various operational aspects (A-D) and provide a discussion (Chapter 4).

A. Changes in the number of railway passengers

First, I analyze the changes in the number of people transported by railway. Fig. 4 shows the group-averaged growth rates from previous years. Note that FY2021 and FY2023 shows the comparison to FY2019 because it compares before the pandemic in

FY2019.



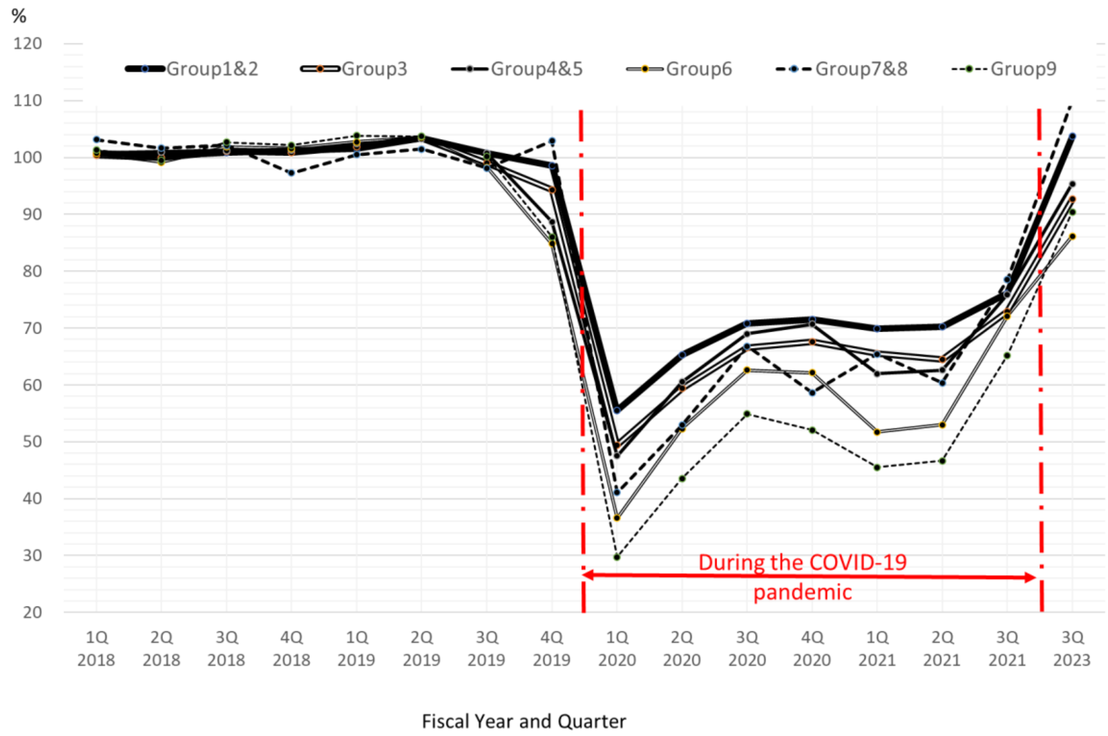
Notes 1: FY2021 and FY2023 shows the comparison to FY2019. 2: JR-CENTRAL of FY2023 compared to FY2018

Fig. 4 Group-averaged growth rates from previous years of the number of railway passengers

The overall trend in the number of railway passengers shows a drastic drop from 4Q FY2019 to 1Q FY2020, hitting the lowest in 1Q FY2020, followed by an increase and a decrease in 1Q and 2Q FY2021 respectively, then returning to an increase. All groups are at their lowest in 1Q FY2020 after the drastic decline from 4Q FY2019; the number of railway passengers is approximately 32% for the worst (most damaged) group and 62% for the best (relatively less damaged) group in 1Q FY2020 compared to the previous year. After the drop, Groups 1 & 2 recorded the highest increase in 4Q FY2020, recovering to about 85% compared to the previous year, while the other groups presented the highest in 3Q FY2021. In 3Q FY2021, the growth rate of the number of railway passengers is

70% for the worst (most damaged) group and 82% for the best (relatively less damaged) group. The other groups recorded approximately 70-80% in the order of Groups 4 & 5, Groups 7 & 8, Group 6, and Group 9. After the pandemic in 3Q FY 2023, the growth rate of the number of railway passengers in 88% for the worst and 100% for the best group at Groups 7 & 8. The other groups recorded approximately 90 %.

B. Changes in railway transportation revenues



Note: FY2021 and FY2023 shows the comparison to FY2019

Fig. 5 Group-averaged growth rates from previous years of railway transportation revenues

Fig. 5 shows the group-averaged growth rates in railway transportation revenues from previous years. The overall trend of railway transportation revenues shows a similar trend to that of number of passengers; it is the lowest in 1Q FY2020 after the drastic drop from 4Q FY2019, followed by an increase and a decrease in 1Q and 2Q FY2021, returning to an increase in 3Q FY2021. All groups are at their lowest in 1Q FY2020, the growth rate of railway transportation revenue is approximately 30% to 56%. After the large drop, all groups fare the best in 3Q FY2021, when railway transportation revenues are approximately 65% to 78%. Groups 7 & 8 record the best at 78%, followed by Groups 1 & 2, Groups 4 & 5, Group 3, Group 6, and Group 9.

I consider the factors that are related to the impact of the COVID-19 pandemic presented in these results. In 1Q FY2020, the Japanese government declared a state of emergency, and railway transportation was affected by the restrictions on the movement of people. Groups 6 and 9 are low in value because these groups are JR companies, which were affected by the decline in the number of passengers of express trains and high-speed trains. In 3Q FY2021, the Japanese government did not declare a state of emergency or restrict the movement of people. The numbers in 3Q FY2021 indicate the standard value after the COVID-19 pandemic. After the pandemic in 3Q FY 2023, the growth rate of railway transportation revenue is 86% for the worst of Group 6 and 110% for the best group of Groups 7 & 8. The other groups recorded approximately 90% to 103% in order of Group 9, Group 3, Groups 4 & 5 and Groups 1 & 2.

C. Changes in revenue structure

Fig. 6 shows the group-averaged revenue composition in percentage by business segment between 3Q FY2019 (upper panel), 3Q FY2021 (middle panel), and 3Q FY2023 (lower panel).

Here, the definitions of Transportation-related and Non-transportation businesses are clarified. For the purposes of this study, I define it from the perspective of railway users. I define Transportation-related business as a business that occurs when railway users move, and Non-transportation business as one that can be established even when railway users do not move. For example, retail and leisure are Transportation-related businesses because they are business segments generated by the transportation of railway users. Logistics is defined as a Non-transportation business because it is a segment that does not involve the movement of railway users.

A texture legend with horizontal or vertical lines indicates Transportation-related business segments, such as Transportation (B1), Retail (B2), and Leisure (B4), while the filled legend indicates Non-transportation business segments such as Real estate (B3), Construction (B5), Logistics (B7), and Information and Communication Technology (ICT) (B8). Groups 1 & 2, Group 3, and Group 6 show a minor change in their revenue structure from 3Q FY2019 to 3Q FY2021, whereas Groups 4 & 5, 7 & 8, and 9 show almost no change. For Groups 1 & 2, Retail (B2) decreased from 28.5% to 21.4% (-7.1%), and Real estate (B3) increased from 16.4% to 22.5% (+6.1%). For Group 3, Real estate (B3) increased from 11.8% to 21.0% (+9.2%) and Leisure (B4) decreased from 16.9% to 10.9% (-6.0%). For Group 6, Leisure (B4) decreased from 16.8% to 9.7% (-7.1%).

After the pandemic in 3Q FY2023, Group 3, Groups 4 & 5, and Group 6 show a major change in their revenue structure from 3Q FY2021 to 3Q FY2023. For Group 3, Retail (B2) decreased from 26.4% to 19.5% (-6.9%), Real estate (B3) decreased from 21.0% to 13.9% (-7.1%) and the new business segment of Logistics (B7) increased from 0% to 14.5%. For Groups 4 & 5, Transportation (B1) decreased from 43.0% to 37.0% (-6.0%), Retail (B2) increased from 7.9% to 10.0% (+2.1%), Leisure (B4) increased from 3.3% to 9.8% (+6.5%) and ICT (B8) decreased from 4.2% to 2.1% (-2.1%). For Group 6, Transportation (B1) increased from 45.3% to 51.1% (+5.8%), Leisure (B4) increased from 9.7% to 19.0% (+9.3%), Construction (B5) changed no business segment and Others (B6) decreased from 15.6% to 7.2% (-8.4%).

In 3Q 2023, Groups 1 &2 and Group 9 returned to their before the COVID-19 pandemic in 3Q FY2019 revenue structures, while Group 3, Groups 4 & 5, Group 6, and Groups 7 & 8 had changed their revenue structure before the pandemic in 3Q FY2019.

As there have been significant changes in the revenue composition of Group 3, I analyze the changes in the revenue structure of Group 3. Fig. 7 shows Group 3 revenue composition in 3Q FY2019, 3Q FY2021, and 3Q FY2023. Group 3 comprises KEIKYU, ODAKYU, and KINTETSU. Fig. 7 shows that KINTETSU's revenue structure changed in 3Q FY2023, with an increase in revenue from logistics. In Group 3, the impact of the increase in revenue from the logistics business of one KINTETSU company could be observed.

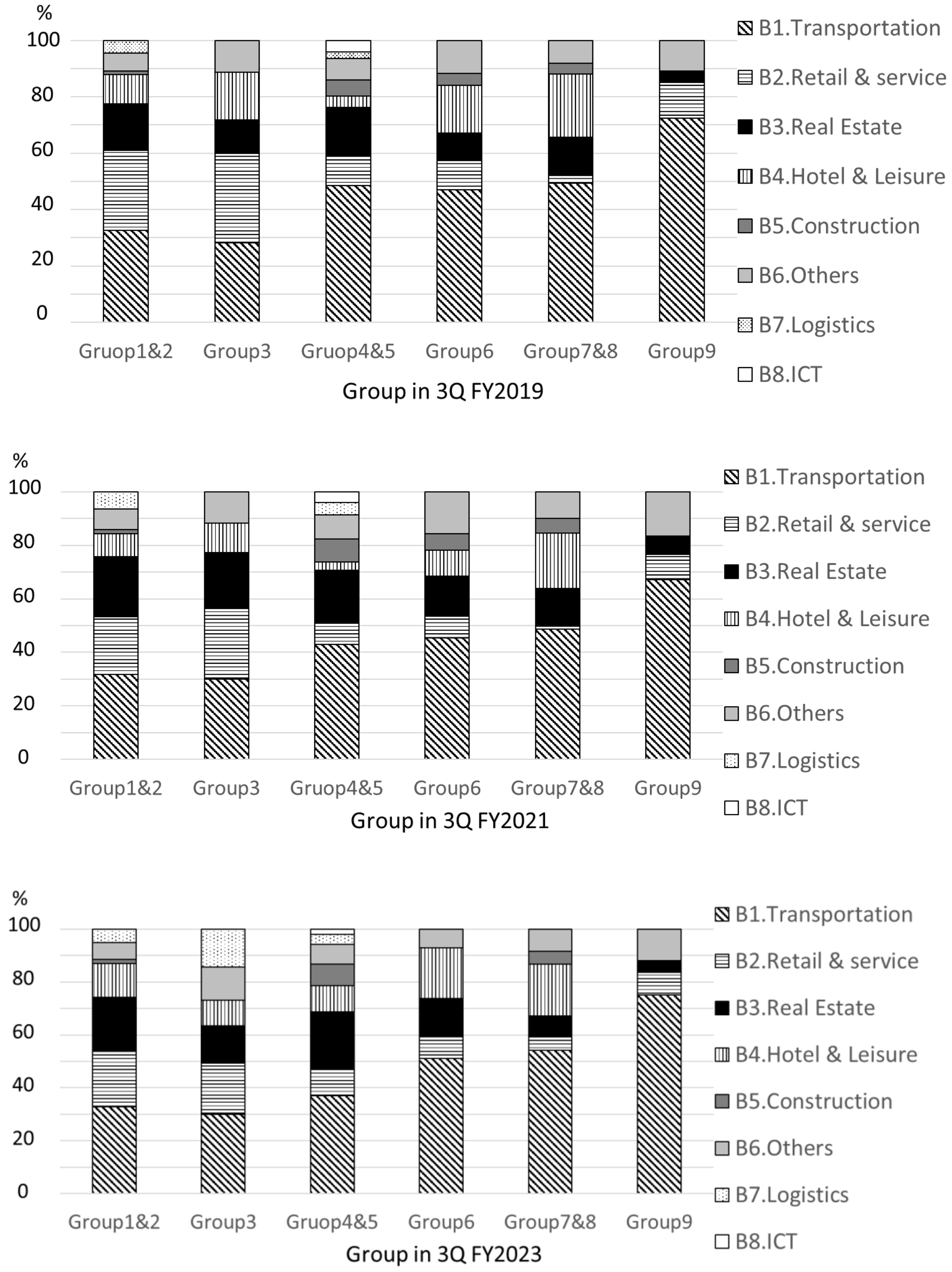


Fig. 6 Group-averaged revenue composition by business segment in 3Q FY2019, 3Q FY2021 and 3Q FY2023

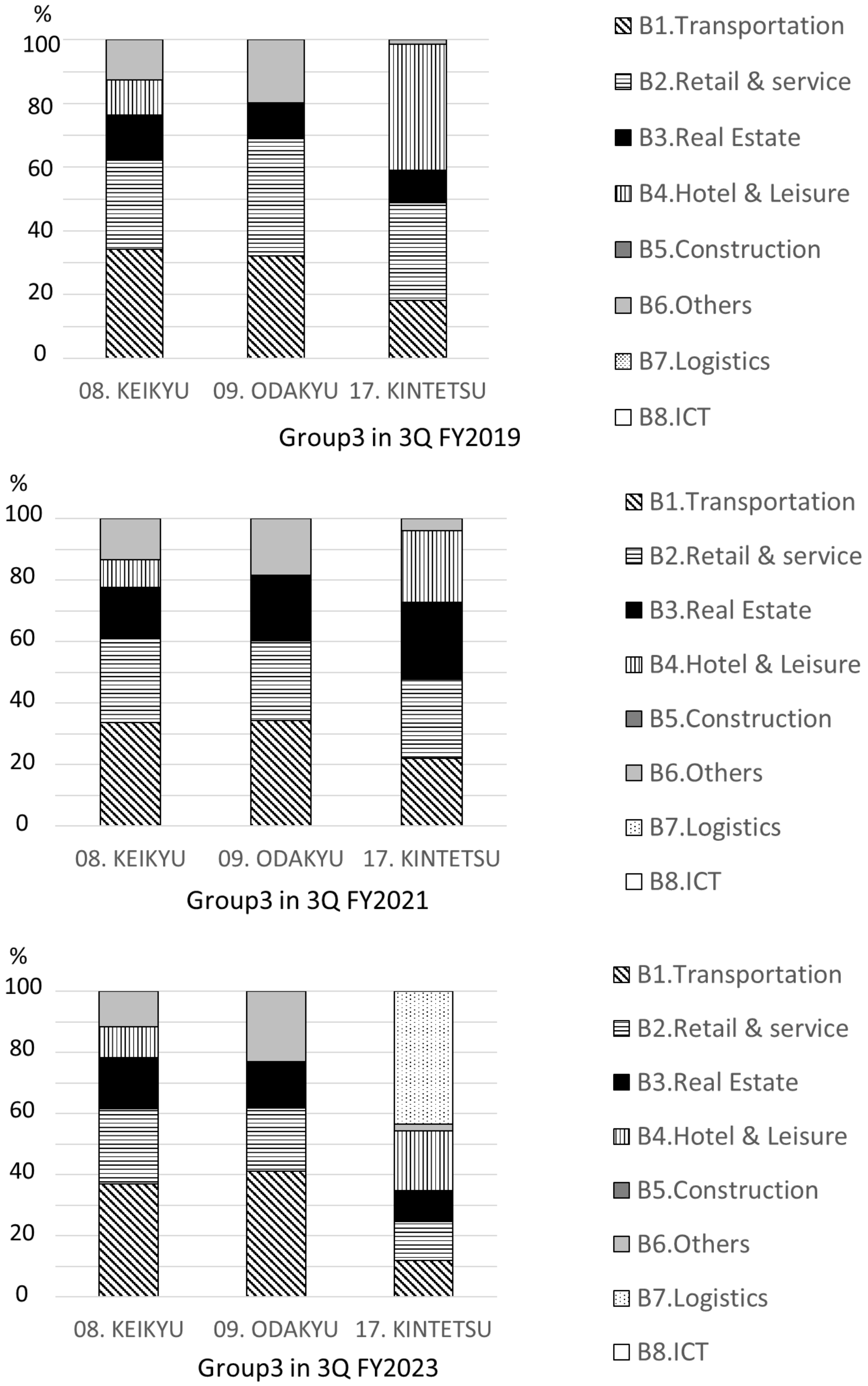


Fig. 7 Group 3 revenue composition in 3Q FY2019, 3Q FY2021 and 3Q FY2023

D. Changes in profit structure

Fig. 8 shows the group-averaged profit composition by business segment for 3Q FY2019 (upper panel), 3Q FY2021 (middle panel), and 3Q FY 2023 (lower panel). In 3Q FY2019, all groups were profitable in most business segments but, interestingly, by 3Q FY2021, all groups had significantly changed their profit structure. All groups except for Groups 7 & 8 and Group 9 changed their largest profitable business segment from Transportation (B1) to Real estate (B3). In 3Q FY2021, Groups 1 to 8 had the largest share of the real estate profits (B3) as follows: Group 1 & 2: 35% to 50% (+15%), Group 3: 20% to 60% (+40%), Group 4 & 5: 40% to 30% (-10%), Group 6: 35% to 20% (-15%), Group 7 & 8: 70% to 30% (-40%), Group 9: 5% to 25% (+20%).

In addition, all groups have a loss-making business segment in 3Q FY2021 as follows: Group 1 & 2: Retail (B2) -25% and Transport (B1) -5%; Group 3: Retail (B2) -30%, Group 4 & 5: Transportation (B1) -35% and Retail (B2) -5%; Group 6: Transportation (B1) -30% and Retail (B2) -25%; Group 7 & 8: Transportation (B1) -50%; and Group 9: Retail (B2) -10%.

In Groups 1 & 2, 3, 4 & 5, and 9, the profitable business segment is larger than the loss-making business segment because these companies have made enough profit in Real estate (B3) to cover for the loss made in Transportation (B1) and Leisure (B4). Groups 6 and 7 & 8 cannot cover the loss from Transportation (B1) and other businesses, resulting in a net loss. Group 9 has a unique profit structure, with Transportation (B1) the most profitable business segment. It records 95% of its revenues and 60% of its profits from Transportation (B1). Group 9 is JR-CENTRAL with a high-speed railway line (Tokaido–Shinkansen) from TOKYO to OSAKA via NAGOYA and KYOTO, which transports many passengers and runs at high frequency. This suggests that transportation services such as high-speed railway lines can be a sustainable profit source.

After the pandemic in 3Q FY2023, Group 9 in 2023 returned to its before the COVID-19 pandemic in 3Q FY2019 profit structures, while other groups had changed their profit structure before the pandemic in 3Q FY2019. The ratio of Transportation-related businesses such as Transportation (B1), Retail (B2), and Leisure (B4) to Non-transportation businesses such as Real estate (B3), Construction (B5), and Logistics (B7)in 2019 and 2023, Groups 1 & 2 changed from 60%: 40% to 53%: 47%, Group 3 changed from 75%: 25% to 56%: 44%, Groups 4 & 5 changed from 57%: 43% to 42%: 58%, Group 6 changed from 76%: 24% to 74%:26% and Groups 7 & 8 changed from 24%: 76% to -54.6%: 87.8% and Group 9 changed from 96%: 4% to 95%: 5%.

Based on the above discussion, I find that owing to the restrictions on the movement of people in Japan during the state of emergency, Japanese railway companies faced reduced revenues and profits in Transportation (B1), Retail (B2), and Leisure (B4). Their profitable business segments changed from Transportation-related sectors such as Transport (B1), Retail (B2), and Leisure (B4) to Non-transportation ones such as Real estate (B3), Construction (B5), and Logistics (B7). Profitable companies recorded a changing profit structure in favor of Non-transportation business segments.

Here, only in Groups 7 and 8, the transportation business is still in loss-making after the pandemic. Group 7 is CHICHIBU and HIRODEN, and Group 8 is FUJIKYU. These groups are not because of the pandemic but because of changes in Japan's social structure, such as population decline and labor shortages in local areas.

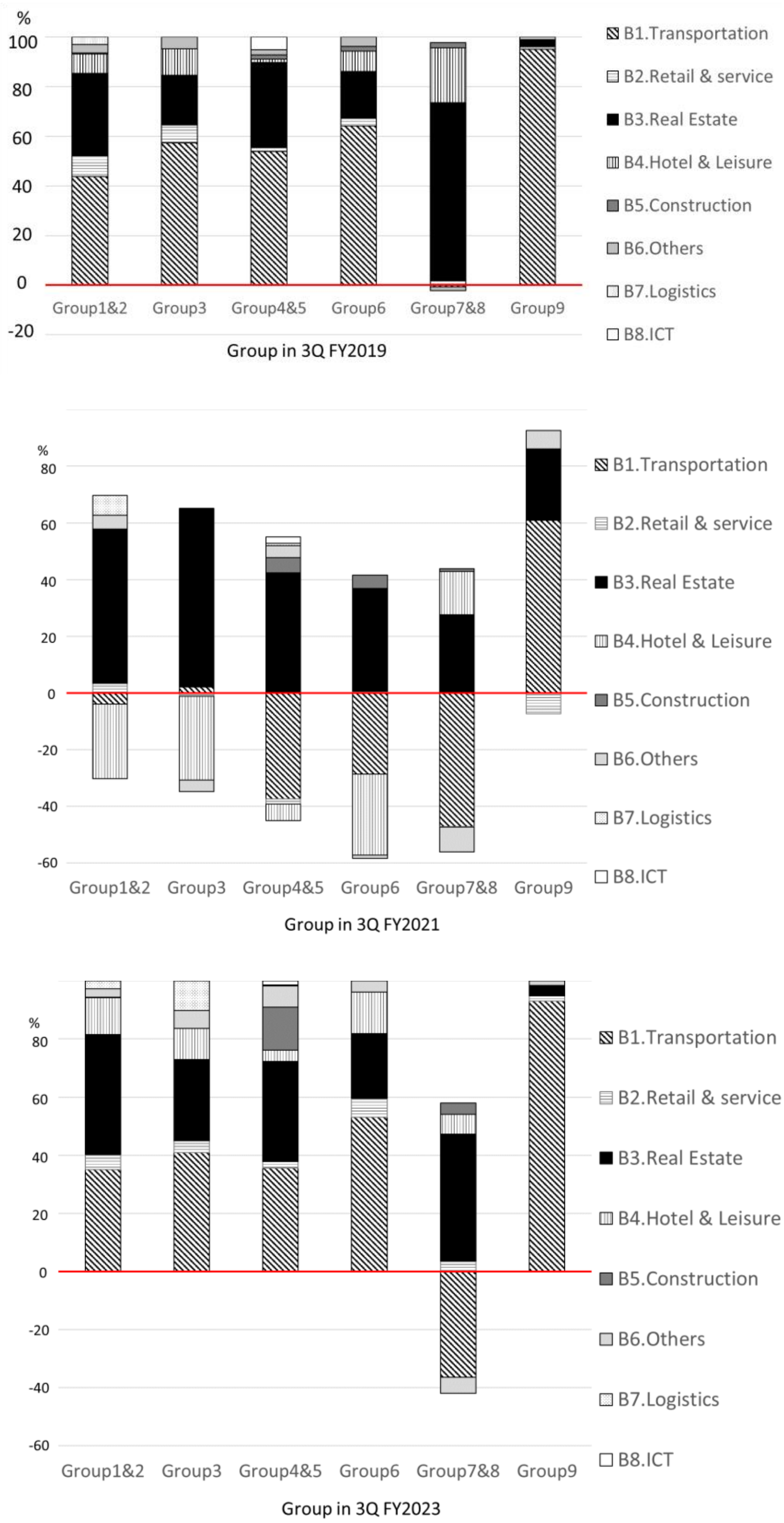


Fig. 8 Group-averaged profit composition by business segment in 3Q FY2019, 3Q FY2021 and 3Q FY2023

2.4 Analysis 1-2: Analysis of the Japanese railway companies' management strategies to countermeasure the COVID-19 pandemic

2.4.1 Methodology and Data

I first extracted the qualitative information related to management strategy against the COVID-19 pandemic and future management strategy after the pandemic from the 25 railway companies' IR information (financial results briefing material or annual securities reports) not including analyst assessments. For this purpose, I collect the text of the 'Countermeasure Policy to the COVID-19 Pandemic' and 'Future Management Strategy after the Pandemic' from these sources to analyze what management strategies are developed in response to the pandemic and the characteristics of the result in profitable/loss-making companies. I created text data for each company, which were combined to create integrated text data. The integrated text data were analyzed using morphological analysis and text mining tools. This study's language is Japanese; as the original IR information is in Japanese, the text analysis is conducted in Japanese, and then the analysis results are translated into English for presentation.

This study uses KH-Coder (http://khcoder.net/dl3.html) for text mining analysis, a popular free software for text analysis originally developed and published in Japanese. In morphological analysis, this study uses MeCab (http://taku910.github.io/mecab/#download) including KH-Corder for the morphological analysis tool, a popular free software originally developed and published in Japanese. In dictionaries, this study uses IPA dictionary (Mecab-ipadic) (https://drive.google.com/uc?export=download&id=0B4y35FiV1wh7MWVlSDBCSXZMTXM). I used the morphological analysis engine that incorporates dictionaries, such as word lists, to allow documents to be segmented into morphemes and parts of speech identified. Words that have a similar pattern of occurrence in a sentence, that is, words with a strong degree of co-occurrence, can be drawn in a network diagram with lines connecting them, called a co-occurrence network diagram. By analyzing the co-occurrence network diagram, I extract keywords commonly used in the management strategies of railway companies.

In the aggregation by attribute (correspondence analysis), the relationship between the extracted words is plotted on a bubble plot on a scatter diagram to express "the relationship between two indicators" in two dimensions, on the x-axis and y-axis; the size of the bubble also expresses the number of occurrences of the words. The results of the analysis show that the further away the words are from the origin, the stronger their feature. Words plotted near the origin indicate that the elements are general words with no features. Also, strongly related words are plotted near each other and weakly related words are plotted farther apart.

In addition, I drew co-occurrence network diagrams from the text mining results to analyze the relevance of keywords and conducted correspondence analysis to analyze the trend of keywords that appear in management strategies. I also qualitatively analyzed the management strategies of the sustainable railway company business after the pandemic by classifying the keywords separately for profitable and loss-making companies in 3Q FY2021. The reason for analyzing these two groups separately is to analyze what management strategies have resulted in a profit/loss-making in response to the deteriorating performance of the pandemic in FY2019 to FY2020, as a countermeasure to the COVID-19 pandemic.

2.4.2 Results

To analyze the management strategies after the pandemic, I compare the characteristics of the management strategies of positive net-profit (profitable) and negative net-profit (loss-making) companies in 3Q FY2021, the last period of the data set. Here, the validation of the adequacy of the management strategy against the COVID-19 pandemic is assessed in terms of net profit for 3Q FY2021, where a positive result indicates that the strategy was adequate and a negative result indicates that the strategy was not adequate. The reason for using net income is that the policy for dealing with the pandemic in the short term includes the disposal of properties and other financing aspects. However, to verify the performance of the core business, I also examine operating profit for 3Q FY2021.

Table 9 shows the category of positive and negative net-profit companies in 3Q FY2021. The reason for showing the overall co-occurrence network diagram here is to analyze the differences in the emergence tendency of profitable and loss-making companies for the clusters that appear and to analyze the characteristics of profitable and loss-making companies in comparison to the overall 25 Japanese railway companies.

Table 10 shows Japanese 25 listed railway companies with operating profit and net profit in profitable/loss-making in 3Q FY2021. The reason for presenting Table 10 is that net income does not capture what a company earns in its core business, so I analyze operating profit profit/loss-making. Here, I survey whether the operating profit and net profit of each company is in the profit or in the loss-making. I extract companies that are in the profit on one side (operating profit or net profit) and in the loss-making on the other, and investigated the detailed reasons that resulted in this outcome. As a result of the survey, two companies, KEIKYU and JR-CENTRAL, are identified.

Table 10 identifies the impact of special profit. KEIKYU recorded a loss in operating profit, but a profit in net profit for the year. KEIKYU recorded a positive net profit for the year due to an extraordinary gain on the sale of fixed assets. JR-CENTRAL recorded a profit in operating profit but a loss-making in net profit. This is because operating profit had not reached a level at which a profit could be recorded in net profit for the year.

The other railway companies have confirmed that their operating profit and net profit/loss-making are in line with their operating profit and net profit for the year.

Table 9 Positive and negative net profit companies in 3Q FY2021

Positive Net profit Companies (Profitable Companies) (18 companies)	Negative Net profit Companies (Loss-making Companies) (7 companies)
02.KEIO, 04.SHIN-KEISEI, 05.TOBU, 07.TOKYU, 08.KEIKYU, 09.ODAKYU, 10.SOTESTU, 12.FUJIKYU, 14.MEITETSU, 16. NANKAI, 17.KINTETSU, 18.KEIHAN, 19.KEIFUKU, 20. HANKYU-HANSHIN, 21.KOBE, 22.SANYO, 24. JR-KYUSHU, 25. NISHITETSU	01.JR-EAST, 03.KEISEI, 06.SEIBU, 11.CHICHIBU, 13.JR-CENTRAL, 15. JR-WEST, 23.HIRODEN

Note: Source (Endo and Goto 2024a)

Table 10 Japane’s 25 listed railway companies with operating profit and net profit in profitable/ loss-making in 3Q FY2021

No.	Company name	Operating profit	Net profit
01	JR-EAST	***Loss-making***	***Loss-making***
02	KEIO	Profit	Profit
03	KEISEI	***Loss-making***	***Loss-making***
04	SHIN-KEISEI	Profit	Profit
05	TOBU	Profit	Profit
06	SEIBU	***Loss-making***	***Loss-making***
07	TOKYU	Profit	Profit
08	KEIKYU	***Loss-making***	Profit
09	ODAKYU	Profit	Profit
10	SOTETSU	Profit	Profit
11	CHICHIBU	***Loss-making***	***Loss-making***
12	FUJIKYU	Profit	Profit
13	JR-CENTRAL	Profit	***Loss-making***
14	MEITETSU	OPR	OPR
15	JR-WEST	***Loss-making***	***Loss-making***
16	NANKAI	Profit	Profit
17	KINTETSU	Profit	Profit
18	KEIHAN	Profit	Profit
19	KEIFUKU	Profit	Profit
20	HANKYU-HANSHIN	Profit	Profit
21	KOBE	Profit	Profit
22	SANYO	Profit	Profit
23	HIRODEN	***Loss-making***	***Loss-making***
24	JR-KYUSHU	Profit	Profit
25	NISHITETSU	Profit	Profit

Fig. 9, Fig. 10, and Fig. 11 show the co-occurrence network diagram of 25 Japanese listed railway companies, profitable companies, and loss-making companies (in Table 9). First, I analyze the co-occurrence network diagram from 25 Japanese listed railway companies' management strategies overall. The diagram shows groups of strongly connected words and their frequency of occurrence. Words connected by a line indicate the strength of the word-to-word connection, indicating co-occurrence in a sentence. In the diagram, the legend of the community shows a group of related words (co-occurrence network). The size of a word bubble indicates the number of times the word appears. The larger the bubble, the more often the word appears, and vice versa. Overall, categories are divided into 12 groups, as shown in Fig. 9. The following 12 categories are identified.

Financial, Innovation, Business model, Management strategies, How to conduct business, Future prospective, Business resources, COVID-19 measures, Social environment, Administrative measures, Government policy (Go to travel, etc.), and Inbound.

Then, I analyze the co-occurrence network diagram from the perspective of both profitable and loss-making companies' management strategies to examine the types of strategies. To organize it more clearly, I categorize the groups of words in these diagrams into four categories based on the overall 12 classifications: Financial Strategy, Business Strategy, Brand Strategy, and Business Environment. Table 11 shows the Correspondence of the categorization of group keywords between overall (Fig. 9) and profitable/loss-making companies (Fig. 10 and Fig. 11).

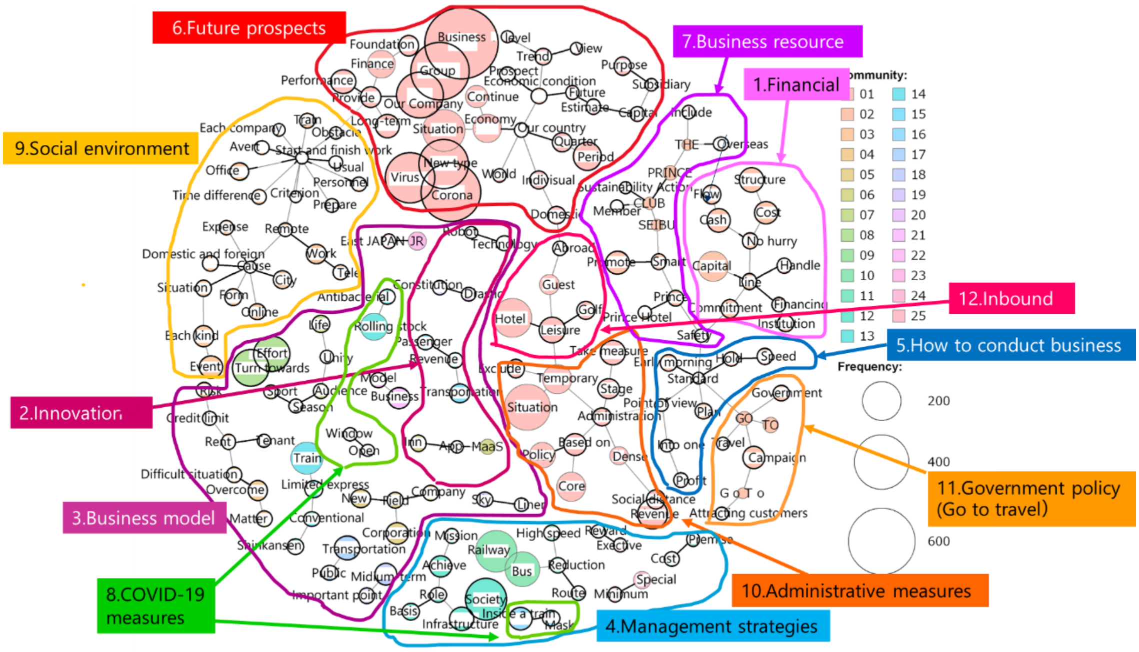


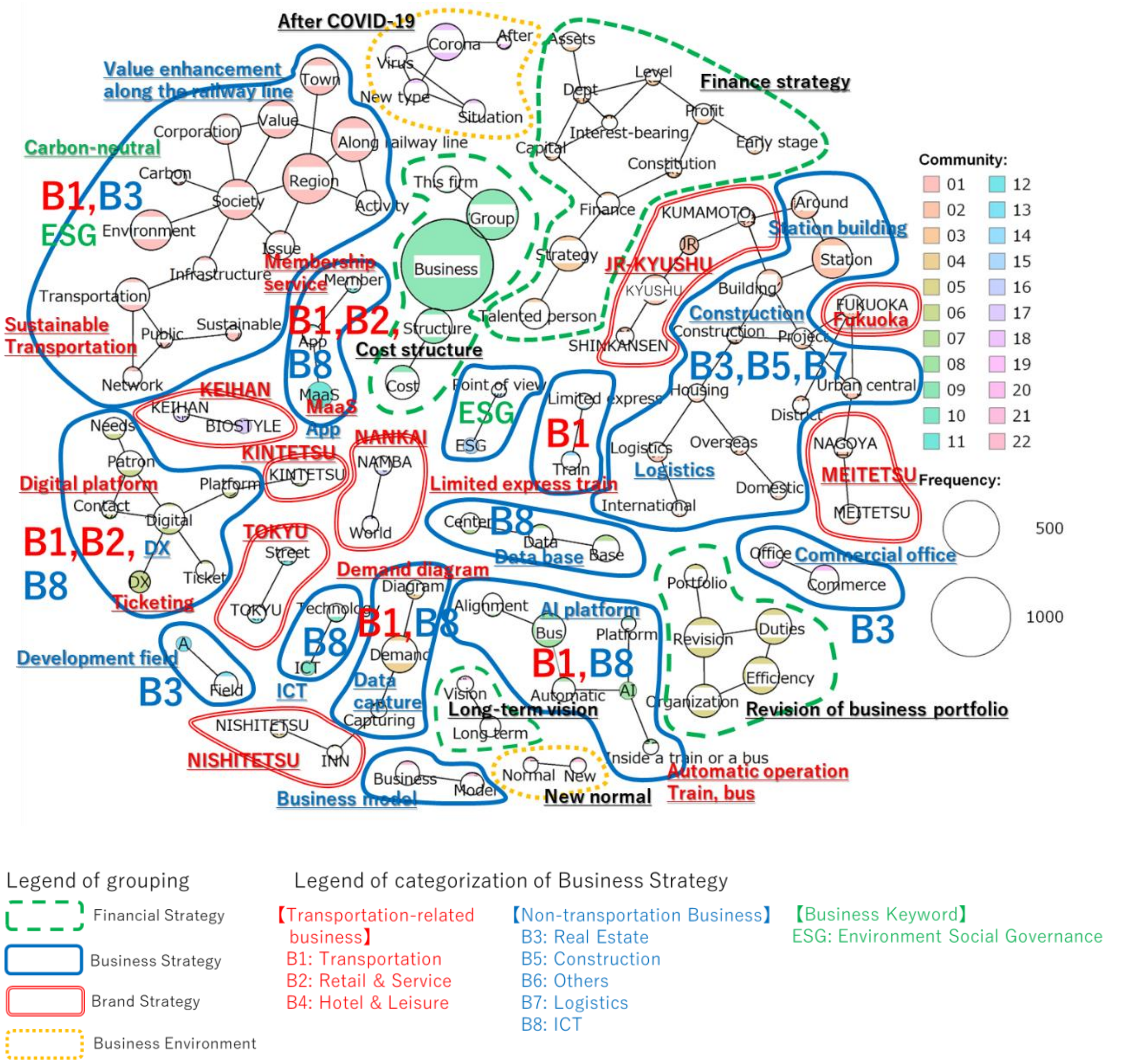
Fig. 9 The Co-occurrence network diagram for overall 25 Japanese listed railway companies

Table 11 Correspondence of the categorization of group keywords between overall

(Fig.9) and profitable/loss-making companies (Fig.10 and 11)

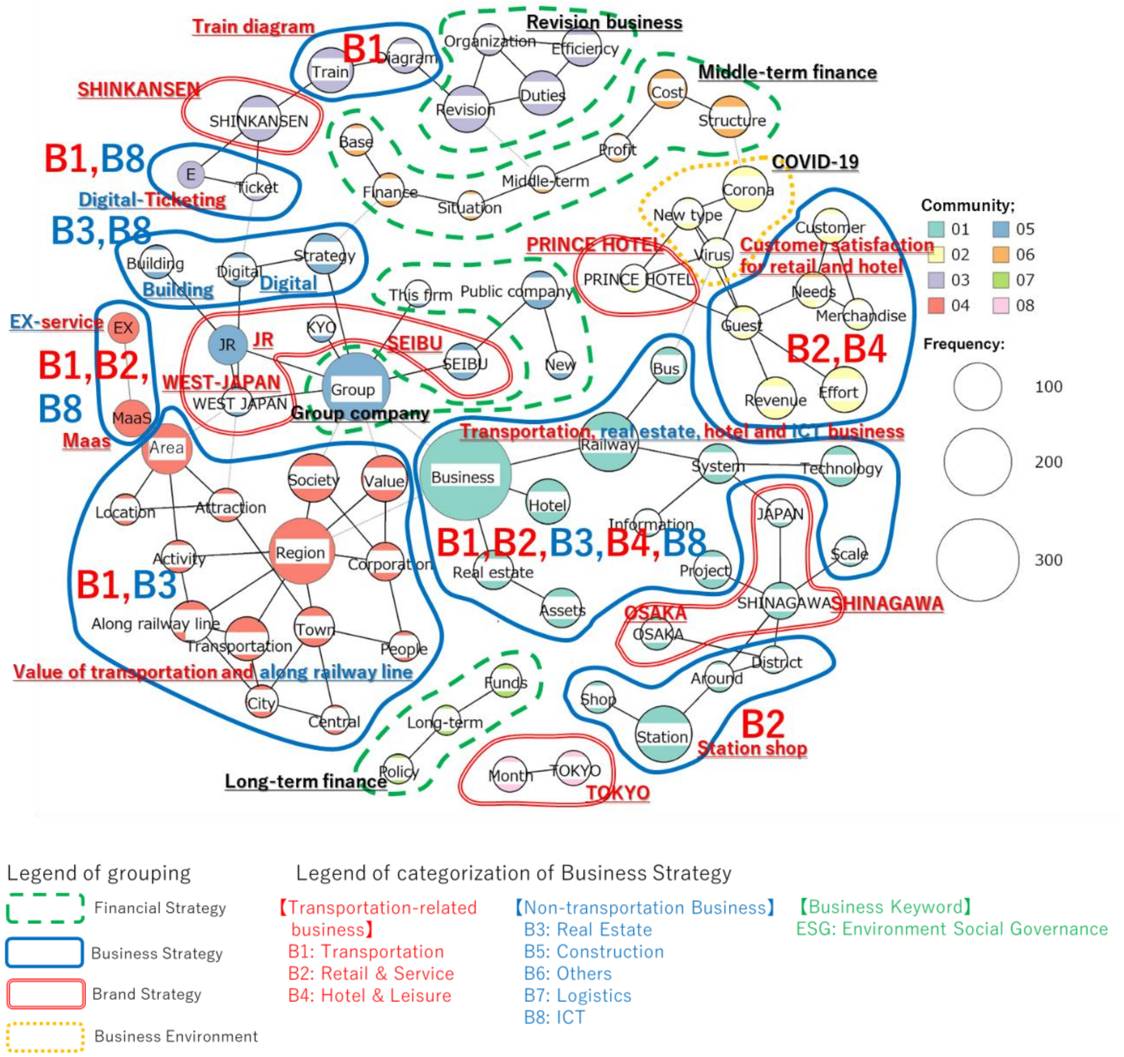
Overall (Fig.9)	Categories of Plofitable companies (Fig.10)/ Loss-making companies (Fig.11)	Plofitable companies (Fig.10)	Loss-making companies (Fig.11)
1. Financial	Financial Strategy	･Financial strategy ･Revision of business portfolio ･Lomg-term vision ･Cost structure	･Long-term finance ･Middle-term finance ･Revision business ･Group company
2. Innovation 3. Business model 4. Management strategies 5. How to conduct business 6. Future prospect	Business Strategy	【Transportation-related business】 ･Sustainable transportation (B1) ･Limited express (B1) ･Ticketing (B1) ･Demand diagram (B1) ･Automatic operation train, bus (B1) ･Digital platform (B1, B2) 【Non-transportation business】 ･Commercial office (B3) ･Station building (B3) ･Development field (B3) ･Value enhancement along the railway line (B3) ･Construction (B5) ･Logistics (B7) ･ICT (B8) ･DX (B8) ･Apps (B8) ･Data capture (B8) ･IT platform (B8) ･Business model 【Business Keyword】 ･ESG ･Carbon-neutral	【Transportation-related business】 ･Transportation (B1) ･Value of transportation (B1) ･Ticketing (B1) ･Train diagram (B1) ･Service (B1, B2) ･MaaS (B2) ･Station shop (B2) ･Customer satisfaction for ･Retail and hotel (B2, B4) ･Hotel and business (B4) 【Non-transportation business】 ･Real estate (B3) ･Building (B3) ･Along railway line (B3) ･ICT (B8) ･EX (B8) ･Digital (B8)
7. Business resource	Brand Strategy	･TOKYU ･MEITETSU ･NANKAN ･KINTETSU ･KEIHAN ･JR-KYUSHU ･NISHITETSU ･Fukuoka	･JR ･SEIBU ･PRINCE HOTEL ･WEST-JAPAN ･SHINKANSEN ･Tokyo ･Shinagawa ･Osaka
8. COVID-19 measures 9. Social environment 10. Administrative measures 11. Government policy (Go to travel etc.) 12. Inbound	Business Environment	･After COVID-19 ･New normal	･COVID-19

To examine the relationship between revenue composition and profit composition, I classify Business Strategy into three segments in correspondence with the eight business segments in Subsection 2.3.3, namely, Transportation-related business, Non-transportation business, and Business keywords. Transportation-related business is classified into Transportation (B1), Retail (B2), and Leisure (B4). Non-transportation business is classified into Real estate (B3), Construction (B5), Others (B6), Logistics (B7), and ICT (B8). The business keyword has only one segment – ESG.



Note: The size of the bubble indicates the frequency of the words' appearance. Source (Endo and Goto 2024a)

Fig. 10 The Co-occurrence network diagram for the profitable railway companies



Note: The size of the bubble indicates the frequency of the words' appearance. Source (Endo and Goto 2024a)

Fig. 11 The Co-occurrence network diagram for the loss-making railway companies

I compare the co-occurrence network diagrams for profitable (Fig. 10) and loss-making companies (Fig. 11) and list the common features of the business strategies. First, (B1, B8) indicate the use of ICT in the Transportation business. Second, (B1, B2, B8) indicate common applications (APP) used for Transportation and Retail businesses. Third, (B1, B3) indicates real estate development mainly along the railway lines.

Meanwhile, I find different features between profitable and loss-making companies.

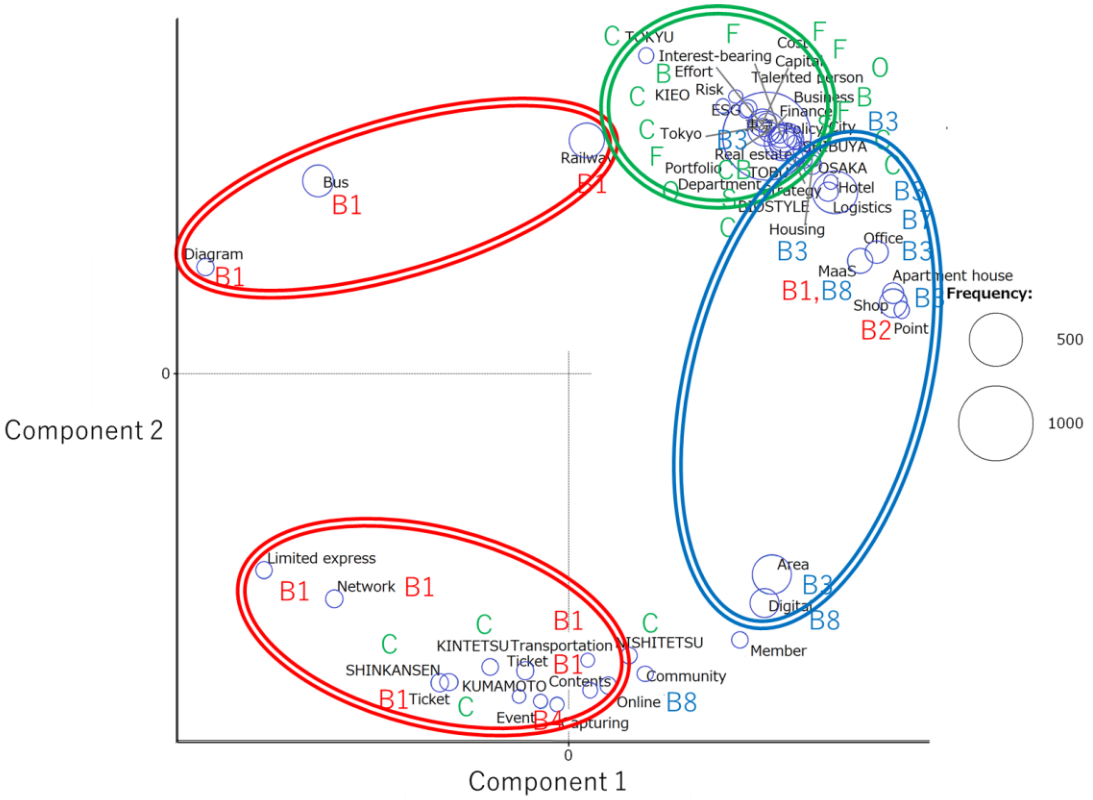
In profitable companies (Fig. 10), business strategies of the Non-transportation business segment such as (B3), (B3, B8), and (B3, B5, B7) are focused and often appear as related keywords. In contrast, in loss-making companies (Fig. 11), business strategies of Transportation-related business segments, such as (B2), (B2, B4) are centered. In particular, (B1, B2, B3, B4, and B8) are typically OPR-type business segments. In Fig. 10, financial strategies are expressed in detail and appear in the words of ESG management, but not in Fig. 11.

Table 11 shows the keywords that appear in Fig. 9, Fig. 10, and Fig. 11. Table 11 shows that, compared to the loss-making companies, the profitable companies were characterized by fewer Transportation-related businesses, more Non-transportation businesses, the appearance of business keywords not seen in the loss-making companies, and the appearance of words related to after COVID-19 in the Business Environment category.

The results show that the profitable companies shift to the Non-transportation business segment to reduce the impact of the COVID-19 pandemic, whereas the loss-making companies focus on business strategies of the traditional OPR-type businesses, that is, Transportation-related businesses including Retail and Leisure. Further, profitable companies show some evidence of strategic management for corporate sustainability, such as financial strategies and ESG management.

I then analyze the relationship between extracted words by using the correspondence analysis diagram. Fig. 12 and Fig. 13 show the correspondence analysis of profitable and loss-making railway companies. The diagram plots the similarity and relatedness of words on the horizontal and vertical axes, and I need to analyze the meaning of the horizontal (component 1) and vertical (component 2) axes in this arrangement. The diagram also shows that the more distinctive words are further away from the origin, the more strongly related words are placed closer, and the less related words are placed farther apart. The size of the bubble indicates the frequency of the word's appearance. I classify these words into Business Strategies in correspondence with the eight business segments in Subsection 2.3.3. This business segment was broadly classified into three groups, Transportation-related business, Non-transportation business, and Business keywords, which are represented by Corporate brands, Organization, Finance, Business, and Strategy. I integrate Fig. 12 and Fig. 13 into Fig. 14 for visual convenience and compared profitable (Fig. 12) and loss-making companies (Fig. 13).

First, I examine the horizontal axis (Component 1) in Fig. 14. Transportation-related business segment and Non-transportation business segment are placed closer and mixed near the horizontal between a profitable (Fig. 12) and a loss-making company (Fig. 13). In Fig. 14, the locations of Transportation-related business and Non-transportation business are near profitable company and loss-making company, respectively. I consider that the horizontal axis (Component 1) indicates Transportation-related business or Non-transportation business segments. The left side of the axis indicates the "Transportation-related business segment" and the right side indicates the "Non-transportation business segment". Second, I examine the vertical axis (Component 2) in Fig. 14. I find that the positions of the Business keywords are reversed between a profitable company and a loss-making company. The profitable companies are placed in the above Business keywords, and the loss-making companies are placed lower. Since I consider the frequency of appearance and the meaning of the words, I think that the vertical axis (Component 2) indicates "the importance of the business strategy." The upper part of the vertical axis indicates higher importance, and the lower part indicates lower importance.



【Transportation-related business】

B1: Transportation
B2: Retail & Service
B4: Hotel & Leisure

【Non-transportation business】

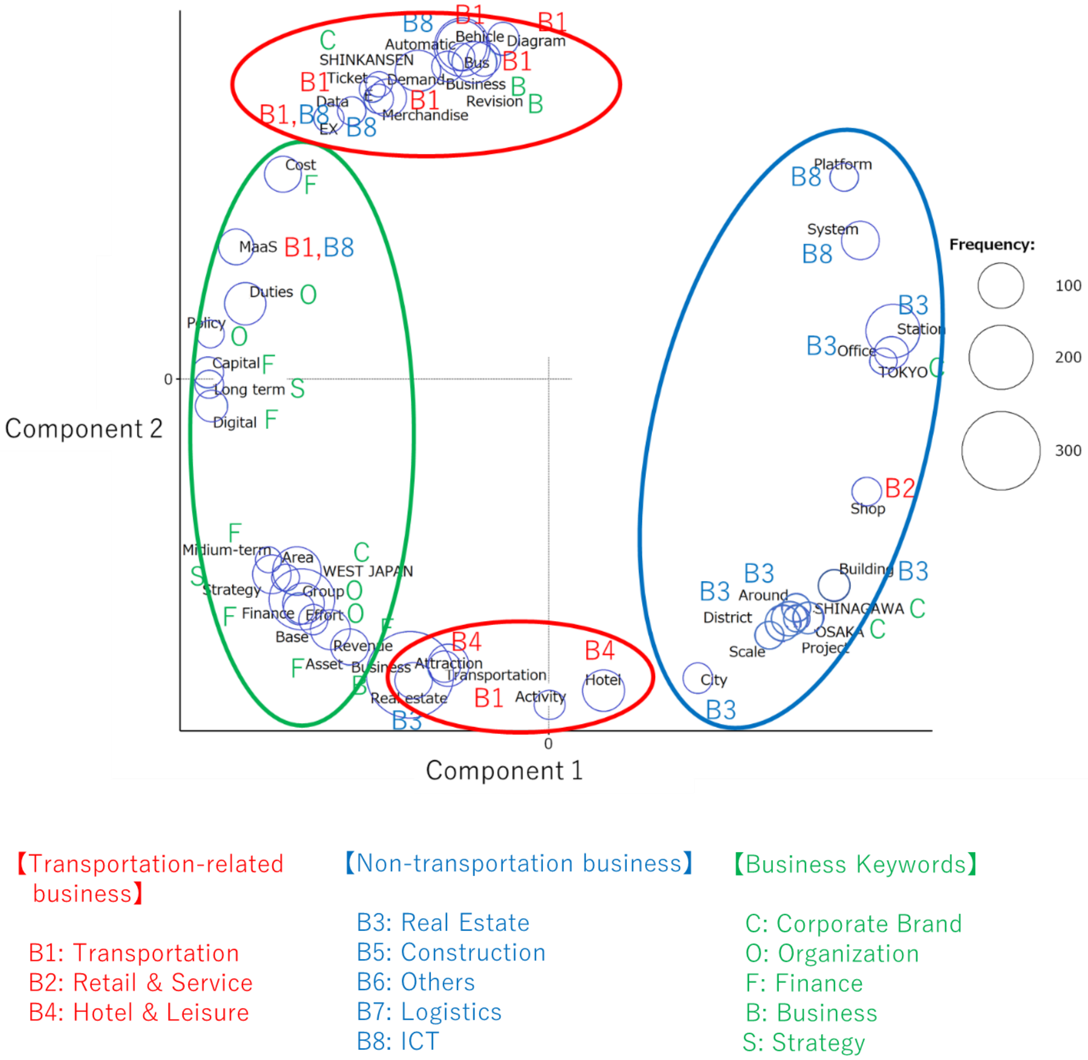
B3: Real Estate
B5: Construction
B6: Others
B7: Logistics
B8: ICT

【Business Keywords】

C: Corporate Brand
O: Organization
F: Finance
B: Business
S: Strategy

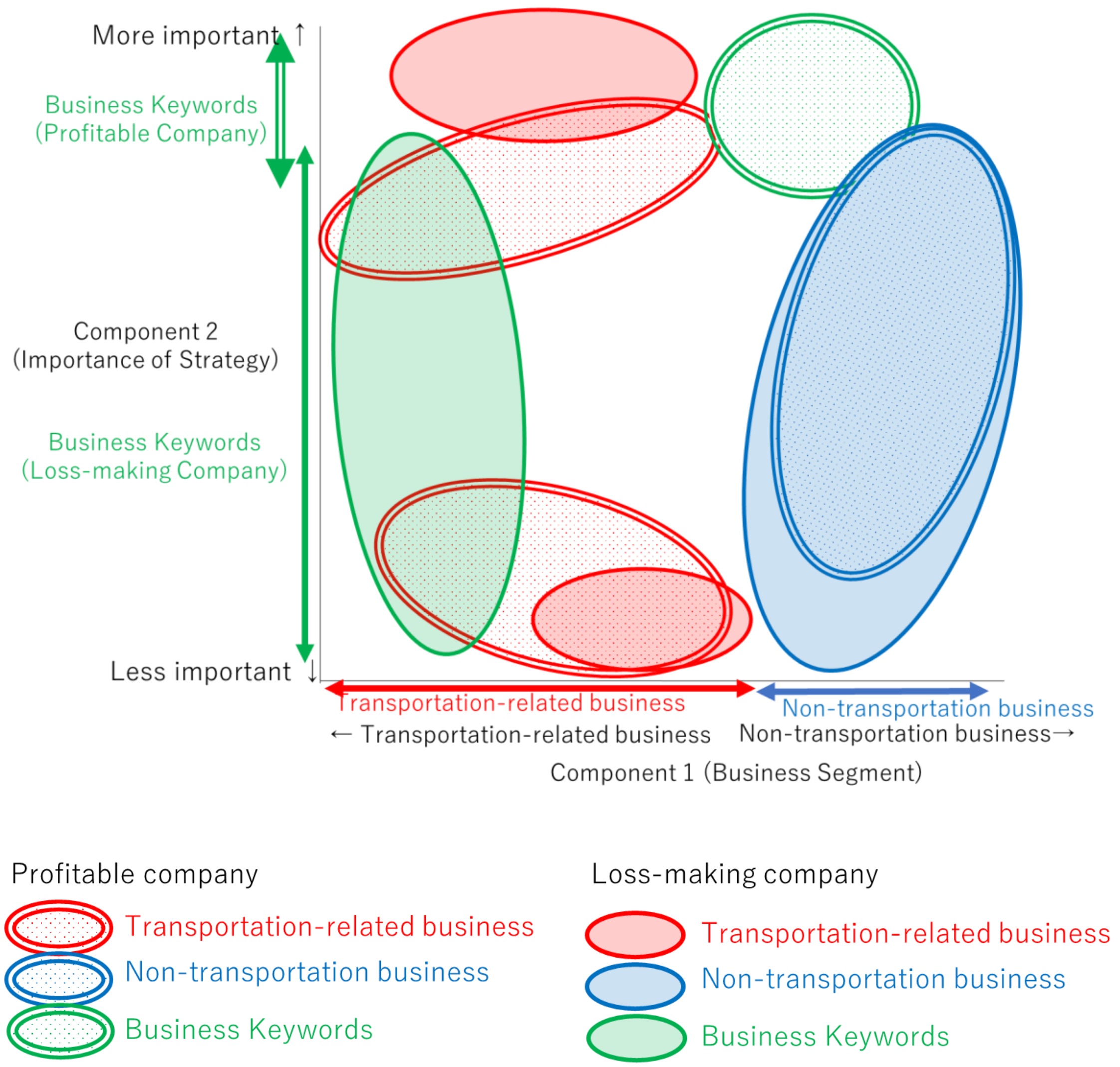
Note: Source (Endo and Goto 2024a)

Fig. 12 The correspondence analysis diagram for the profitable railway companies



Note: Source (Endo and Goto 2024a)

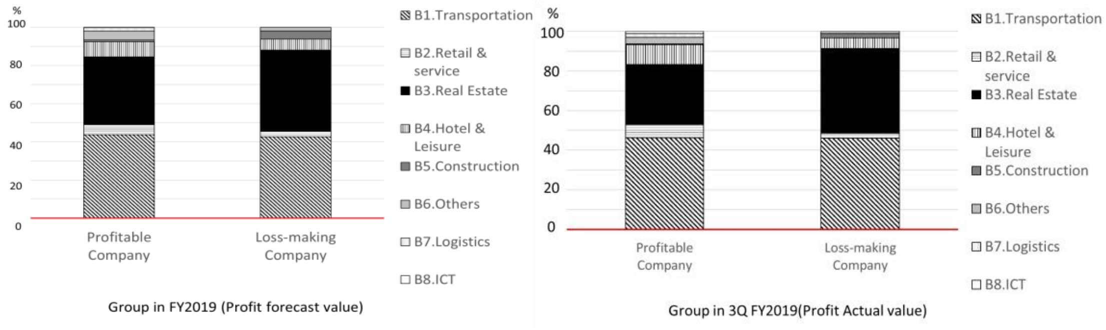
Fig. 13 The correspondence analysis diagram for the loss-making railway companies



Note: Source (Endo and Goto 2024a)

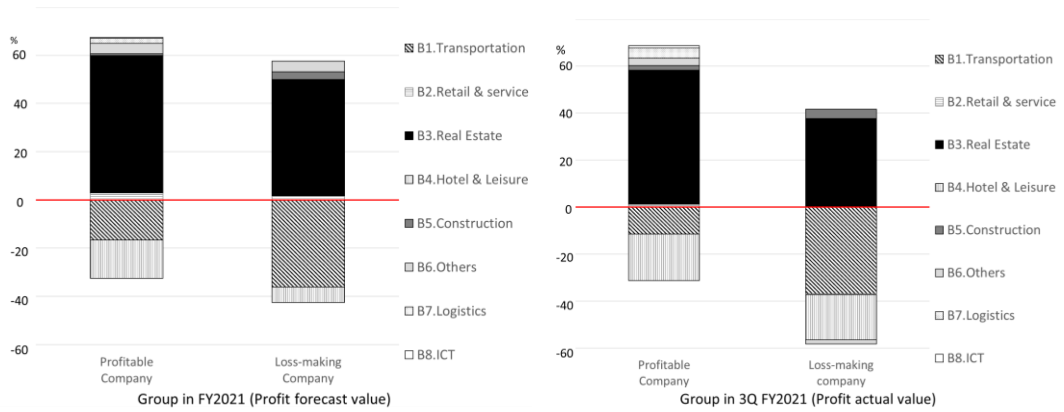
Fig. 14 A comparison of the correspondence analysis diagram between profitable (Fig.12) and loss-making companies (Fig.13)

Next, in order to quantitatively evaluate the management strategy before and after the pandemic, I compare the forecasted and actual performance of profit by business segment that was formulated as the management strategy. Fig. 15-Fig. 17 shows a comparison of forecasted and actual earnings by business segment for profitable and loss-making companies. Fig. 15 shows a comparison of 3Q FY2019, Fig. 16 shows 3Q FY2021, and Fig. 17 shows 2Q FY2022. In both figures, the left-hand side shows forecasted profit and the right-hand side shows actual profit.



Note: Source (Endo and Goto 2024a)

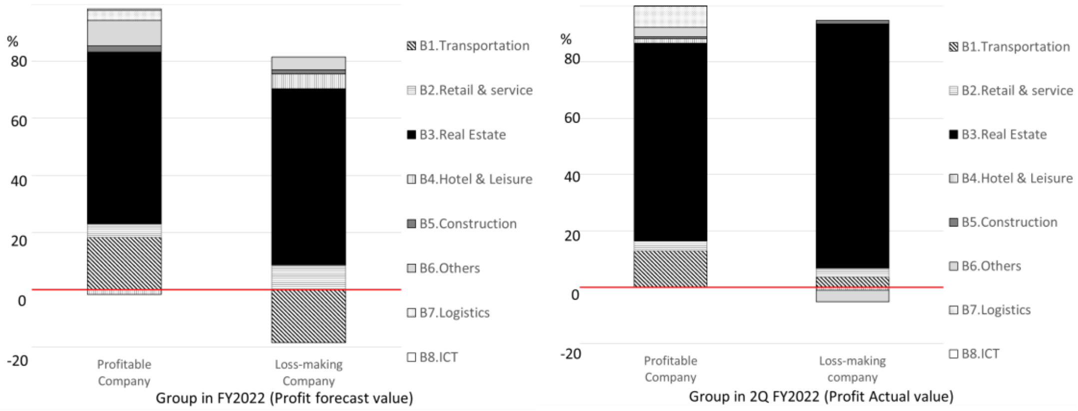
Fig. 15 The comparison of the profit forecast value and actual value between profitable and loss-making companies in 3Q FY2019



Note: Source (Endo and Goto 2024a)

Fig. 16 The comparison of the profit forecast value and actual value between profitable and loss-making companies in 3Q FY2021

In FY2019, there was no significant difference between forecasted and actual profits for both profitable and loss-making companies. In FY2021, profitable companies posted an overall profit within the forecasted range as an overall profit/loss ratio because the actual profit/loss-making ratio of (B2) was higher than the forecasted value and the actual profit/loss ratio of (B1) was lower than the forecasted value. In contrast, loss-making companies posted an overall loss because the actual profit/loss ratio in (B2) was higher than the prospected performance, and the actual profit in (B3) was lower than the prospected performance.



Note: Source (Endo and Goto 2024a)

Fig. 17 The comparison of the profit forecast value and actual value between profitable and loss-making companies in 2Q FY2022

In FY2022, the forecasted and actual earnings values are almost the same for the profitable companies, while the loss-making companies forecasted (B1) profit or loss in the actual forecast, but in the actual results, (B1) posted a profit and (B3) posted a larger proportion of actual profit than in the forecast, resulting in overall profits. This result suggests that profitable companies are accurate in forecasting the variable components of their earnings estimates. In other words, loss-making companies are less accurate in forecasting the variable components of their earnings estimates.

Table 12 Japanese real gross domestic product (GDP) by industry in FY2019 to

FY2021

Percent changes from previous year (%)

Items (Real Gross Domestic Product)	Related business segment	Business Type A:Transportation B:Non-transportation	2019	2020	2021
1. Agriculture, forestry and fishing			4.3	-7.5	3.3
2. Mining			-5.3	-4.9	-5.2
3. Manufacturing			-1.8	-6.0	7.5
4. Electricity, gas and water supply and waste management service			-2.1	-4.0	1.7
5. Construction	B5.Consteruction	B	-0.9	-0.6	-2.8
6. Wholesale and retail trade			-3.1	-4.3	6.9
7. Transport and postal services	B1.Transportation	A	-0.7	-27.5	2.1
	B7.Logistics	B			
8. Accommodation and food service activities	B2.Retail & service	A	-6.2	-35.7	-11.1
	B4.Hotel & Leisure	A			
9. Information and communications	B8.ICT	B	1.0	0.7	3.0
10. Finance and insurance	B6.Others	B	-1.4	4.8	8.1
11. Real estate	B3.Real Estate	B	1.0	-0.6	-0.9
12. Professional, scientific and technical activities			1.4	-1.1	1.4
13. Public administration			0.7	0.5	0.5
14. Education			0.4	-0.7	-0.4
15. Human health and social work activities	B6.Others	B	2.0	0.1	4.3
16. Other service activities	B6.Others	B	1.2	-12.1	-0.1
Sub-total			-0.6	-4.8	3.1
Taxes and duties on imports			-0.8	-1.3	0.7
(less) Consumption taxes for gross capital formation			-1.3	-7.6	2.1
Gross domestic product (not including statistical discrepancy)			-0.6	-4.7	3.1
Statistical discrepancy			-	-	-
Gross domestic product			-0.4	-4.3	2.1

Note: Source Cabinet Office, Government of Japan (2022a)

Table 13 Prefectural real gross domestic product (GDP) by industry in FY2019 to

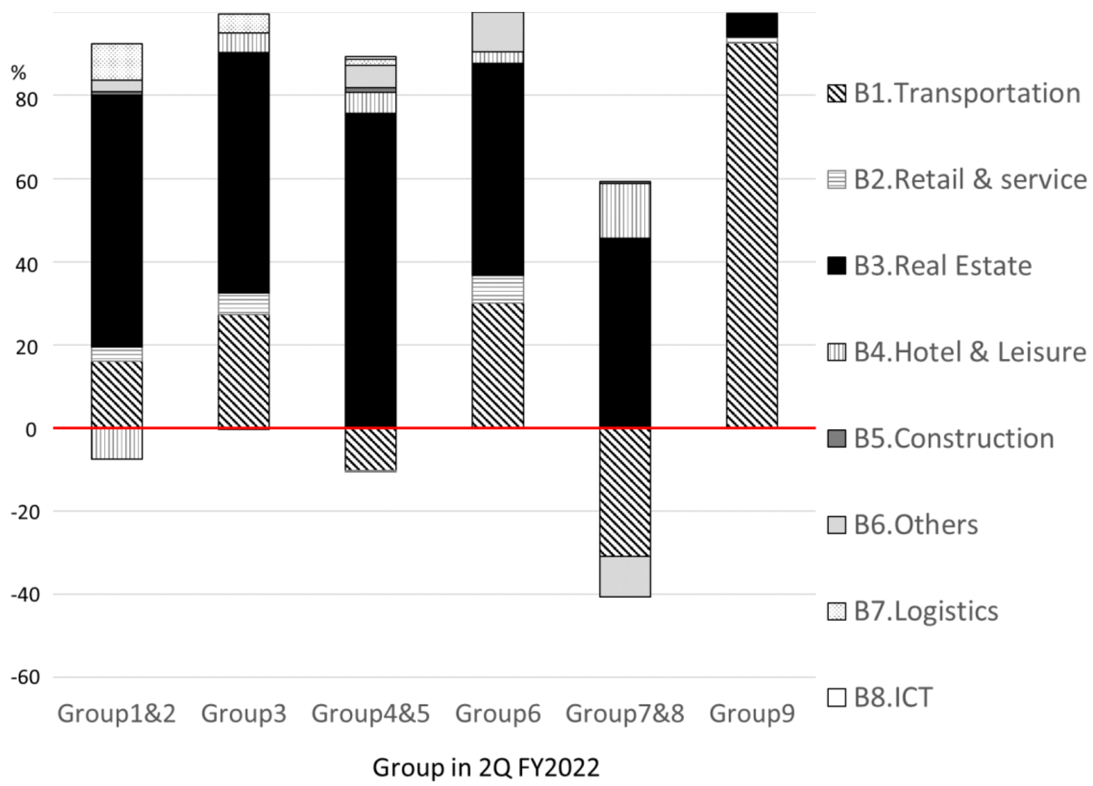
FY2021

Prefecture	5.Construction			7.Transport and postal service			8.Accomodation and food service activities			9.Information and communications			10.Finance and insurance			11.Real Estate			15.Human health and social work activities			16.Other service activities		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
All JAPAN	-0.9	-0.6	-2.8	-0.7	-27.5	2.1	-6.2	-35.7	-11.1	1.0	0.7	3.0	-1.4	4.8	8.1	1.0	-0.6	-0.9	2.0	0.1	4.3	1.2	-12.1	-0.1
TOHOKU	-6.9	7.2	-18.7	-0.6	-16.8	-0.7	-10.3	-42.9	-0.1	-1.7	3.1	0.2	-10.3	4.0	10.7	0.4	-0.0	-0.8	1.7	-0.4	3.4	-0.8	-11.7	2.8
AOMORI	8.0	6.6	-9.0	-0.0	-15.3	-1.3	-11.3	-41.7	0.8	-2.9	5.5	5.8	-2.0	-4.7	5.5	-0.5	3.1	-1.1	1.0	-0.4	2.6	-1.2	-10.4	4.7
IWATE	-10.8	-2.4	-28.3	-1.9	-20.0	-4.7	-9.6	-44.5	0.7	-1.4	2.7	0.3	-4.7	-0.9	3.0	1.1	-0.2	-0.4	1.1	0.0	3.1	0.4	-10.6	3.3
MIYAGI	-15.3	2.2	-18.5	-1.3	-22.4	2.2	-9.2	-39.5	0.8	-1.4	1.6	-0.9	-8.9	3.1	11.9	1.2	0.1	-0.1	3.5	0.7	4.1	0.2	-10.9	4.5
AKITA	7.1	1.7	-8.2	-1.1	-13.6	20.6	-10.9	-44.3	-3.5	-3.8	4.0	-0.1	-0.6	-2.5	5.1	1.4	0.1	-0.3	0.3	-2.4	3.4	-1.3	-13.3	0.3
YAMAGATA	-5.3	11.8	-6.4	-0.1	-18.6	6.8	-11.4	-44.4	0.8	-1.8	2.7	0.6	-1.4	-2.0	7.8	-3.1	-3.0	-2.8	1.2	-1.8	3.2	-1.4	-12.9	2.6
FUKUSHIMA	-4.5	20.8	-24.3	1.0	-8.2	-11.2	-10.6	-45.1	-1.2	-0.6	4.4	-1.6	-31.0	27.3	22.6	0.6	-0.4	-1.2	1.4	-0.2	3.6	-2.2	-12.6	0.1
KANTO	-3.1	1.1	-1.4	-2.5	-27.0	8.2	-6.2	-32.6	-6.0	1.2	0.0	4.4	-3.6	4.0	7.7	1.6	0.3	-0.3	3.1	-1.1	7.1	-1.4	-13.5	4.4
IBARAKI	5.9	3.1	11.1	-1.2	-16.6	0.2	-7.8	-37.0	-0.3	-2.0	1.8	1.9	-7.8	4.6	10.6	1.5	0.3	1.0	2.8	-0.5	5.7	-0.5	-12.0	3.8
TOCHIGI	-1.2	11.7	-5.3	-0.3	-3.6	6.3	-9.5	-40.8	-0.9	-3.1	4.9	0.3	-11.8	8.8	10.7	-0.1	-1.1	-2.4	3.0	-0.3	5.5	-2.4	-14.1	2.4
GUNMA	-3.9	-5.3	-3.0	-4.7	-14.3	5.9	-10.2	-41.7	-4.9	-0.7	1.0	-1.9	-0.4	0.8	8.8	1.0	0.0	-0.5	1.9	-1.1	5.5	-2.4	-13.1	-0.7
SAITAMA	-7.5	-0.2	-3.2	-0.7	-22.5	4.4	-9.0	-32.8	-1.1	-0.8	4.7	0.4	-2.6	2.5	6.0	-1.3	-1.8	-1.6	1.9	-1.2	7.3	-2.8	-11.8	3.1
CHIBA	-6.2	1.9	2.3	-1.9	-30.8	13.9	-7.4	-38.1	-3.5	-0.1	-0.2	-1.9	-24.3	21.6	17.0	3.1	-1.7	-0.4	3.7	0.1	7.3	-0.5	-14.2	1.7
TOKYO	-5.0	1.3	-1.0	-3.6	-33.3	9.1	-3.5	-28.5	-10.2	1.9	0.2	6.3	-1.3	2.8	6.3	2.6	1.9	0.2	3.0	-1.7	7.3	-1.7	-12.8	4.3
KANAGAWA	4.0	-0.8	-7.2	-2.3	-22.1	8.7	-9.1	-36.3	1.1	-0.9	-2.9	-2.6	-7.0	4.8	12.7	0.3	-0.8	-0.8	4.2	-0.9	7.3	-0.6	-16.3	8.9
CHUBU	-1.3	10.4	-4.5	-0.7	-28.3	8.9	-10.7	-44.0	1.5	-1.8	3.0	2.1	-1.9	2.2	7.7	0.3	-0.6	-0.8	3.0	-0.3	3.7	-1.6	-11.5	3.7
NIGATA	-9.3	6.5	-2.2	-0.4	-19.7	9.6	-11.5	-42.7	-0.4	-2.0	2.9	0.5	-0.6	-2.3	6.3	1.0	-0.7	-1.8	1.8	-0.2	3.2	-2.3	-12.3	1.5
YAMANASHI	-6.4	-2.4	-0.3	0.4	-21.0	9.8	-10.0	-45.9	0.9	-0.1	4.5	2.2	2.1	2.4	9.0	1.9	0.7	-1.0	1.5	-1.9	4.9	-0.9	-12.8	2.7
NAGANO	1.3	25.1	-7.3	0.4	-19.8	-1.0	-12.1	-47.7	-0.8	0.6	3.3	3.8	-7.9	6.6	9.3	1.8	-0.7	-0.6	4.6	-0.8	2.4	-1.5	-11.3	2.1
SHIZUOKA	4.9	8.5	-5.2	-1.3	-36.0	12.7	-9.4	-41.5	4.1	-3.6	2.6	2.1	-0.2	2.4	7.4	-1.2	-0.9	-0.2	3.2	0.3	4.6	-1.3	-10.7	6.1
HOKURIKU	4.3	6.5	1.0	-0.2	-18.2	4.8	-7.8	-40.5	-2.3	-3.4	5.4	3.5	1.7	2.4	8.0	0.8	-0.1	-0.6	1.6	-0.6	4.7	0.0	-8.7	3.0
TOYAMA	0.8	6.2	5.1	-2.3	-10.5	-1.9	-8.8	-39.2	-4.6	-0.8	5.0	3.8	1.1	-0.8	8.9	2.0	-0.6	1.2	2.2	-0.9	4.8	0.3	-10.0	-1.3
ISHIKAWA	-6.5	2.8	0.5	0.4	-24.9	-1.4	-7.7	-42.0	-3.7	-6.8	5.6	2.1	1.4	2.0	8.3	1.1	0.2	-2.7	0.8	0.1	4.1	-2.0	-8.9	6.6
FUKUI	18.0	9.5	-1.6	1.9	-19.6	21.4	-6.8	-39.6	2.3	-1.0	5.5	5.3	2.9	7.2	6.6	-1.7	-0.1	0.4	2.0	-1.2	5.3	2.5	-6.8	3.3
CHUKYO	0.1	2.3	4.8	-1.0	-30.1	10.1	-9.3	-36.5	-1.9	-1.9	0.2	1.7	3.0	2.2	6.8	1.4	0.6	-0.2	2.8	0.8	5.3	-0.8	-11.2	2.8
GIFU	2.2	13.1	1.3	3.1	-32.7	15.7	-10.2	-39.9	-4.9	-5.3	2.8	-0.5	5.2	0.3	5.3	0.8	-0.9	-1.7	2.6	-0.7	5.2	-1.6	-13.7	-0.6
AICHI	1.6	0.7	5.1	-2.5	-31.3	9.9	-9.2	-34.9	-0.9	-1.3	-0.8	2.4	2.0	2.9	6.5	1.8	1.2	0.3	2.9	1.7	5.6	-0.6	-10.7	4.5
MIE	-8.2	-3.6	8.5	2.5	-22.7	6.5	-9.1	-39.1	-2.8	-3.1	5.0	-1.1	5.2	0.9	9.6	-0.4	-1.5	-1.4	2.8	-0.8	4.1	-1.0	-10.3	-0.4
KANSAI	1.3	10.0	-2.7	-2.2	-32.5	4.7	-10.3	-38.3	5.1	-2.7	2.7	3.1	3.1	3.2	10.0	2.3	-0.4	-1.1	3.4	-0.8	4.6	-1.8	-12.6	4.0
SHIGA	7.0	11.0	-9.7	-1.0	-23.0	6.9	-11.1	-41.7	-0.5	-2.0	5.2	0.7	10.2	1.0	6.0	2.0	0.5	0.5	2.3	-1.0	7.9	-2.8	-13.4	2.2
KYOTO	1.5	-0.8	-5.9	2.3	-38.9	11.4	-7.7	-39.7	32.9	-1.0	2.9	7.7	12.3	5.4	10.0	-0.0	-1.1	-1.8	2.9	-0.5	3.4	0.9	-10.7	2.7
OSAKA	2.0	10.5	0.4	-3.8	-37.3	1.1	-11.1	-36.9	0.0	-3.4	1.0	2.9	-1.3	3.1	10.8	3.6	-0.7	-2.1	3.2	-0.9	4.8	-2.8	-13.9	4.3
HYOGO	-2.7	16.2	-3.9	-2.8	-23.7	9.6	-10.2	-38.9	2.1	-1.0	6.1	2.7	5.0	2.6	9.0	1.8	0.7	0.1	4.6	-1.2	4.5	-1.5	-13.0	6.0
NARA	-6.8	10.3	-9.5	5.2	-29.0	-9.6	-12.7	-40.3	-8.4	-3.1	11.6	-1.9	3.2	2.9	10.6	0.3	-0.9	-0.7	3.2	-1.1	4.7	-1.4	-9.1	-1.4
WAKAYAMA	9.3	6.2	-1.2	3.6	-25.0	7.7	-8.4	-37.8	3.1	-2.0	12.0	1.4	25.2	5.7	9.8	1.0	-3.1	2.4	2.3	1.4	1.8	-0.6	-5.8	4.6
CHUGOKU	-1.0	4.4	0.0	-2.5	-20.8	-0.5	-12.2	-39.2	-3.0	-4.4	2.4	1.7	4.2	1.3	9.3	-0.7	1.0	0.4	1.8	-0.7	3.6	-1.8	-11.1	1.3
TOTORI	-11.7	3.2	8.4	-3.6	-25.8	19.6	-16.7	-37.9	-4.2	-2.1	3.4	0.8	-2.4	1.7	5.1	0.3	-1.6	-1.6	1.0	-0.8	2.2	-1.4	-11.6	0.2
SHIMANE	15.5	6.3	-5.7	-1.5	-13.1	6.5	-10.6	-42.1	0.9	-2.1	9.3	-4.0	-1.7	-0.0	8.3	0.3	0.0	-0.9	2.2	0.7	2.6	0.6	-8.5	1.3
OKAYAMA	4.8	1.3	-6.2	-2.6	-16.6	-9.7	-11.0	-37.2	0.7	-2.3	2.7	-0.2	12.2	1.3	11.5	-0.8	0.6	-0.1	2.6	-1.0	3.7	-0.7	-8.2	5.5
HIROSHIMA	-0.5	8.3	-7.0	-1.2	-28.5	2.9	-12.5	-38.7	-6.4	-7.1	-0.6	4.9	4.2	2.9	8.7	-2.7	2.4	1.9	1.5	-0.8	4.3	-2.9	-12.9	-1.3
YAMAGUCHI	-11.5	-0.6	23.9	-4.6	-13.4	-0.4	-11.8	-41.7	-2.1	-3.0	5.4	1.0	-0.2	-1.8	9.6	2.4	0.3	-0.2	1.3	-0.8	3.2	-2.6	-12.4	1.1
KYUSHU	-3.2	3.2	5.1	-0.1	-23.6	5.2	-9.7	-40.0	-0.0	-0.3	3.2	0.7	1.0	-7.4	14.3	1.4	0.3	-0.3	2.3	-0.7	4.0	-1.7	-13.1	1.5
FUKUOKA	5.9	-10.8	16.9	-0.9	-24.2	4.9	-9.7	-36.2	-0.2	-1.8	1.2	1.4	1.5	-3.6	12.5	1.0	0.6	-0.5	2.3	-1.1	5.6	-2.7	-13.4	0.7
SAGA	1.1	5.4	5.8	-0.2	-23.2	5.7	-10.1	-39.5	-0.6	-0.5	6.7	1.2	-8.0	4.6	-5.3	-0.3	-1.4	-1.6	1.7	-0.9	4.1	-1.7	-12.2	0.1
NAGASAKI	-8.0	27.8	-9.1	-1.9	-26.0	0.4	-8.5	-42.3	-0.9	-0.9	8.4	-0.4	-2.7	-12.9	24.2	2.2	1.1	0.3	2.0	-1.0	3.1	-1.3	-13.1	0.3
KUMAMOTO	-6.1	-1.7	1.2	4.8	-36.2	7.5	-7.4	-42.9	2.1	12.3	5.4	0.8	0.1	-20.7	33.4	-0.2	-0.5	-0.5	2.6	0.3	2.7	1.9	-13.3	5.1
OITA	-10.0	7.4	3.8	0.7	-18.8	5.2	-11.5	-44.5	-1.2	-1.2	1.0	-1.3	0.8	-4.4	6.1	5.5	0.9	0.4	2.1	-0.9	3.1	-2.6	-13.3	0.6
MIYAZAKI	-8.3	10.2	4.3	1.1	-19.9	11.3	-13.1	-42.5	1.0	-4.1	4.7	0.1	6.8	-6.2	0.7	-0.0	-0.7	-0.1	1.6	-0.5	2.2	-3.0	-13.7	0.5
KAGOSHIMA	-9.8	16.8	-0.8	-1.0	-14.6	4.0	-9.5	-42.1	-0.4	-0.4	7.1	-0.6	4.2	-10.3	20.2	2.1	0.4	-0.1	2.7	0.2	2.8	-0.8	-12.1	2.8

Note: Source Cabinet Office, Government of Japan (2022b)

Then, I analyze the overall recovery of the Japanese economy and the underlying performance of the railway companies. The reason for using real GDP is to verify that the profits recorded in Non-transportation businesses are corporate business strategies but to rule out the possibility of a faster macroeconomic recovery from the pandemic in these industries. Table 12 and Table 13 show All of Japan and Prefectural real Gross Domestic Product (GDP) by industry as a percentage of the year over year from FY2019 to FY2021. In all of Japan's GDP, Transport and postal service (7), Accommodation and food service activities (8) related to the Transportation-related business segments (B1) (B2) (B4) fell sharply in FY2020 and (8) related to (B2) (B4) continued to decline in FY2021. This result is also shown to be relevant in Table 12. Real estate (11) related to (B3), the Non-transportation business, declined slightly in both FY2020 and FY2021 for the Japanese economy. Japanese railway companies strengthen the profitability of their real estate business through management strategies and change their profit structure into Non-transportation business segments such as real estate. Next, in prefectural GDP, Transport and postal service (7) is -27.5% in all regions in FY2020; +2.1% nationally in FY2021, while the regions with negative GDP are -0.7% in the TOHOKU region and -0.5% in the CHUGOKU region. Accommodation and food service activities (8) is -35.7% in all regions in FY2020; -11.1% nationally in FY2021, while the regions with positive GDP are +1.5% in the CHUBU region and +5.1% in the KANSAI region. Real estate (11) is -0.6% for all regions in FY2020, but the regions with positive GDP are +0.3% in the KANTO region, +0.8% in the CHUKYO region, +1.0% in the CHUGOKU region and +0.3% in the KYUSHU region; -11.1% for the whole country in FY2021, but the region with positive GDP is +0.4% in the CHUGOKU region. Although regional differences can be seen, this level of increase does not indicate that the Japanese economy is recovering after the pandemic, and the profitable real estate sector can be attributed to the management strategy of the railway companies.

Here, even though GDP by province was negative from a macro trend, an increase or decrease was confirmed for each region from a micro trend. For example, in the Kanto region of real estate, Tokyo, Ibaraki, and Gunma showed positive growth, suggesting that Tokyo was affected by the Olympic and Paralympic events or return to the city. In contrast, Ibaraki and Gunma were affected by the COVID-19 pandemic, which caused people to move from urban to suburban areas. In this analysis, real estate showed the same trends the six groups analyzed, but if a different trend emerged for a particular group, examining prefectural real GDP is very useful for analysis in detail.



Note: Source (Endo and Goto 2024a)

Fig. 18 Group-averaged profit composition by business segment in 2Q FY2022

Finally, I examine the shift in management strategy to Non-transportation businesses. Fig. 18 shows Group-averaged profit composition by business segment in 2Q FY2022. In Groups 1 & 2 through 7 & 8, a Non-transportation business accounts for a larger share of profits than a Transportation-related business. Only in Group 9, JR-CENTRAL, the Transportation-related business accounts for nearly 90% of the total. This is due to transportation revenues from the Tokaido Shinkansen. The results indicate that with the exception of JR-CENTRAL, profit-generating business segments have shifted to Non-transportation businesses.

Chapter 3 Cost efficiency analysis for railway

This chapter is based on Endo and Goto (2024b), with additional discussion of firms with low efficiency.

3.1 Literature Review

The profitability and business model analysis results in Chapter 2 show that profitable railway companies can cover losses in the transportation business with profits in the Non-transportation business. Analysis of management strategies showed that diversified companies were able to avoid risk exposure to pandemics by generating profits from Non-transportation businesses. Furthermore, for a railway company to operate sustainably, the loss-making profit in the transportation business needs to be minimized. Therefore, it is necessary to increase the efficiency of the railway business. To this end, Chapter 3 presents a railway business cost efficiency analysis.

This section reviews previous related studies by classifying them into five groups. The first group is SFA analysis methods, which include the Battese and Coelli model used in this study and other recent analysis methods. The second group includes studies that analyzed the efficiency of the railway sector, and the third group includes studies that analyzed the efficiency of transport sectors other than the railway sector. I focus on SFA for the third group, but the second group also includes other methodologies, such as data envelopment analysis (DEA). Both methodologies are popular in efficiency analysis, and the same trend applies to the railway sector. Catalano *et al.* (2019) surveyed efficiency analysis methods used in previous studies with respect to passenger railway services. They found that three main methods were used: regression-based, parametric frontier (e.g., SFA), and nonparametric frontier methods (e.g., DEA). Similarly, Holvad (2020) conducted a literature review of efficiency analysis methods in the railway sector, focusing on frontier-based methods, including both parametric and nonparametric methods, and presented the characteristics of each analysis. The fourth group includes the impact of the COVID-19 pandemic and Digital Transformation (DX) on companies and businesses. The fifth group includes methods to improve efficiency in enterprises and businesses.

3.1.1 Stochastic Frontier Analysis (SFA)

This study applies SFA to data from Japanese railway companies to measure their cost inefficiencies. The reason for using SFA is that it takes into account the error term, which makes it less susceptible to the effect of data observation errors on efficiency values and easier to test hypotheses compared with DEA. SFA was introduced by Aigner *et al.* (1977) and Meeusen and Van Den Broeck (1977). Subsequently, several researchers developed various types of models and applications using these models. For instance, Battese and Coelli (1995) proposed a model to measure technical efficiency using a stochastic frontier production function based on panel data, while Battese and Coelli (1996) measured the technical inefficiency of Indian paddy farmers by applying the model to data collected over 10 years.

In this study, the SFA model of Battese and Coelli (1995) is applied. This model has strengths in analyzing efficiency using panel data and is a very popular and well-established method often used in empirical studies these days. Recent studies on technical efficiency using Battese and Coelli's (1995) model include, for example, the following studies. Tsukamoto (2019) applied it to manufacturing data for 47 prefectures in Japan from 2002 to 2014; Khetrapal (2020) applied it to electricity distribution business data in India from 2006 to 2013; Zhang (2021) applied it to bus services data in the USA from

2008 to 2017; and Amornkitvikai *et al.* (2024) applied it to data from the manufacturing industry in Thailand from 2007 to 2017. Srivastava *et al.* (2024) applied it to data from 2009 to 2019 for commercial banks in India to analyze profit efficiency; Jarboui and Alofaysan (2024) applied it to data from 2010 to 2019 for the top 20 global oil and gas companies by market capitalization and analyzed the impact of the energy transition on environmental and operational efficiency, applied to data from 2010 to 2019.

In addition, recent studies of SFA methods include, for example, Wheat *et al.* (2019), who proposed a new Student's t-distribution for the error term and applied it to the analysis of the efficiency of highway maintenance in England; a study that proposed a new multi-product production function using a Multifactor model and applied it to the analysis of financial efficiency in Russian companies (Mitsel *et al.* 2021); a study proposing a semi-parametric model for estimating a stochastic frontier model with a single index structure, with an unknown link function and a linear index, and applied this to the analysis of the total energy demand of American states (Forchini and Theler 2023); a new proposal for a dependency between two error components using the Copula function and the application of asymmetry in random errors assigning a generalized logistic distribution, applied to the estimation of the production frontier of the Italian airport system and the cost efficiency of the Italian banking sector (Bonanno and Domma 2022); and a newly proposed Spatial Durbin Stochastic Frontier Model (SDF-STE) introducing spillover effects as determinants of technical efficiency which applied this to the analysis of efficiency in the Italian accommodation industry (Galli 2023).

Although this study does not propose a new analytical method as described above, its contribution is that it quantitatively assesses the efficiency of Japanese railway companies using recent data and identifies the characteristics and management measures of efficient companies, thereby providing suggestions for improving efficiency. Another contribution of this study is that it proposes a new framework for the entire series of analyses of railway companies by combining conventional methods.

3.1.2 Efficiency analysis of the railway sector

Couto and Graham (2009) examined the performance of European railways from 1972 to 1999 using a stochastic cost frontier approach with the Translog function from 1972 to 1999. They found that inefficiencies were essentially explained by the excess capacity and overemployment of labor inputs. Asmild *et al.* (2009) examined railway operations in 23 European countries between 1995 and 2001 to determine whether railway policy reforms improved railway system efficiency. Specifically, they used a multidirectional efficiency analysis to investigate how railway reforms affected the efficiency of specific cost factors. In their study, the outputs included passenger train-kilometers and freight train-kilometers, while the discretionary inputs included staff costs and material costs, and the non-discretionary inputs included route length. The dummy variables of the reform were used, including accounting separation; complete separation; independent management from government; competitive tendering for passenger services; and market opening for freight transport. They indicated that these reforms generally improve efficiency, and in particular, accounting separation contributes to increased technical efficiency.

Friebel *et al.* (2010) assessed changes in technical efficiency as a result of the European railway reform using a stochastic production frontier with the Cobb–Douglas functional form, with a focus on passenger transport. They found that the reform positively affected output. Their study thus claimed that the railway sector seems to be sensitive to changes in the regulatory framework and to the way in which reforms are implemented.

The following studies analyzed the efficiency of Japanese railway operators. Mizutani *et al.* (2009) investigated the effectiveness of yardstick regulations by estimating variable cost frontier functions using a dataset of Japanese railway companies. In the variable cost functions, the estimated coefficient on the yardstick regulation dummy and the competitive pressure from outside the industry was statistically significant and negative, indicating that the introduction of yardstick regulations and competition tends to reduce railway companies' variable costs. Fukui and Oda (2012) argued that the privatization of the JNR was a success for some JR companies (JR-EAST, JR-CENTRAL, and JR-WEST) but not for others (JR-HOKKAIDO, JR-SHIKOKU, and JR-KYUSHU). Their study also pointed out that adjusting to regional profit disparities was challenging for both the JR companies and the government. Furthermore, one of the most serious flaws of the JNR reform was the lack of a concrete plan for the abolition of financially loss-making local lines. As such, while the JNR reform has been successful, continuing efforts are necessary to adapt to the changing social circumstances surrounding Japanese railways, such as the declining local area population.

Song and Shoji (2016) estimated a quantitative model to examine the relationship between diversification and transport investment for Japanese private railway companies. They revealed that investment in railway operations is influenced by diversification and that internal capital is likely to be used to invest in diversified operations, as well as transport operations. Le *et al.* (2022) analyzed the operational, cost, and revenue efficiencies of 18 lines operating in a Japanese metropolitan area using DEA. The quality of service for railway operations is reflected by operational efficiency by incorporating in-vehicle congestion into the efficiency assessment. The results indicated that a higher in-vehicle congestion rate leads to lower cost efficiency but higher revenue efficiency. This implies that lines with high in-vehicle congestion rates may not necessarily exhibit high financial performance. Kuramoto and Hirota (2008) analyzed the efficiency of third-sector railways using SFA as well as temporal changes in technical inefficiency using Battese and Coelli's (1995) time-varying model. They found that the greater the proportion of private sector investment, the more efficient the management.

Wiegmans *et al.* (2018) analyzed the efficiency of road and railway freight networks in Canada, Europe, and the USA from 2000 to 2012 using SFA. They found that roads were more efficient than railway freight, suggesting that the liberalization of rail freight transport had no impact on efficiency and that the efficiency of the companies using the infrastructure had a significant impact. Whitmore *et al.* (2022) assessed the economic viability of public transport with shared automated mobility. Using Allegheny County, Pennsylvania, as a case study, the cost efficiency analysis compared the direct operating costs of shared automated vehicles and automated shuttles with conventional transit buses, suggesting that they could be feasible at a lower cost than buses, on average.

3.1.3 Efficiency analysis of public transport other than the railway sector

Holmgren (2013) analyzed the operational efficiency of public transport in Sweden by SFA using annual data from 1986 to 2009 for 26 counties. They indicated that the average cost efficiency decreased from 85.7% in the 1980s to 60.4% between 2000 and 2009, owing to the increased importance of route density and the stricter environmental and safety requirements. Filippini *et al.* (2015) directly compared the impact of competitive tendering and performance-based contract negotiations with the cost efficiency of Swiss bus services in 2009 using SFA. Their results indicated that the difference in cost efficiency between the two contracting regimes is not significant.

Vigren (2016) measured the cost efficiency of public transport in Sweden using SFA and analyzed how different contracting factors affect cost efficiency. They found that service provision in densely populated areas is associated with lower cost efficiency and efficiency is also lower when a contract is awarded directly to a public transport operator. Holmgren (2018) examined how the output variables of public transportation should be defined and measured in efficiency studies. He compared the Cobb–Douglas production function with the three Translog functions by SFA using data from 1986 to 2015 in Sweden. He suggested that the choice of output variables is important when undertaking efficiency analysis and that a combination of both supply-oriented (vehicle kilometers) and demand-oriented (passenger kilometers) indicators should be used when analyzing public transport performance. Bergantino *et al.* (2021) applied the spatial stochastic frontier approach (SSFA) to analyze the impact of geographical distances of airports on technical efficiency. Data from 206 airports worldwide were used for the data. The results detected different effects on the efficiency levels of airports depending on the geographical distance. Karanki and Lim (2021) used two stochastic variable cost frontier models, the Battese and Coelli model (1995) and the True Random-Effects model (TRE) to measure the impact on the cost efficiency of airports. The analysis suggested that US airports could reduce operating costs by an average of 2.7%. Krljan *et al.* (2021) used the stochastic production frontier with control input variables in Cobb–Douglas and logarithmic function forms to analyze the technical efficiency of the North Adriatic Ports Association (NAPA), presenting that the technical efficiency of medium sized NAPA terminals ranged from 65.24% to 93.92%, with a global average of 78.49. Chung and

Chiou (2023) analyzed the technical efficiency of 20 bus companies and 890 route-year observations in Taiwan using stochastic meta-frontier models. They found that most bus routes were efficient in providing bus services but less so in attracting passengers, which indicates insufficient incentive designs in Taiwan's current subsidy scheme. Bourjade and Muller-Vibes (2023) used the stochastic frontier approach proposed by Kumbhakar and Lovell's model (2000) using annual data from 134 airlines worldwide for the period 2007–2019) to analyze cost efficiency. The results indicated that airline leasing plays a strategic role in improving the operational efficiency of airlines after the COVID-19 pandemic.

3.1.4 The Impact of the COVID-19 Pandemic and Digital Transformation

Yin *et al.* (2021) described the characteristics of the COVID-19 epidemic and identified vulnerabilities in preventing and containing the spread of the epidemic in the railway transport system. They showed that measures to prevent the spread included passenger services, information, staff, and equipment. Kawaguchi *et al.* (2022) analyzed the impact of the crisis on firms' sales, employment, and working hours per employee for Japanese firms during the COVID-19 pandemic, and the role of the work-from-home system in mitigating the negative impact. The study found that adapting to the pandemic by increasing the number of remote-working employees helped companies moderate the negative impact on sales. Maharjan and Kato (2023) conducted semi-structured interviews with five Japanese companies between November 2020 and February 2021 to understand the impact of the COVID-19 pandemic on different aspects of logistics and supply chain activities and the resilience strategies implemented. The results showed that the interviewed companies experienced both positive and negative impacts of the pandemic on their logistics and supply chain activities, and levels of resilience preparedness, response, and future planning differed between companies with different attributes, such as industry sector and organizational size.

Lee and Eom (2023) systematically reviewed the evidence on transportation responses to the COVID-19 pandemic and identified research trends. They indicated a strong relationship between the pandemic and mobility, with significant impacts on overall mobility decline, significant reductions in transportation use, changes in travel behavior, and improvements in transportation safety. Faber *et al.* (2023) estimated the relationship between telecommuting and travel behavior using panel data from the Netherlands Mobility Panel through 2017-2021. They found that working from home had a negative effect on commute travel time before and during the pandemic and a positive effect on leisure travel time only before the pandemic. Chauhan *et al.* (2024) conducted a nationwide online longitudinal survey of behavior during the COVID-19 pandemic in the United States. Survey items included commuting, long-distance travel, telecommuting, online learning, online shopping, pandemic experiences, attitudes, and demographic information. The survey was conducted three times with the same respondents to observe how their reactions to the pandemic changed over time. The survey results indicated that attitudes toward stay-at-home home and business shutdowns declined over time. Vašaničová and Bartók (2024) analyzed the relationship between the share of tourism in employment (TTEMPL) and the share of tourism in gross domestic product (TTGDP) between 2019 and 2021. They proposed a model for 117 countries using quantile regression (QR). The results of the QR showed that individual percentiles of TTGDP are more affected by TTEMPL than other percentiles of TTGDP, which is reflected in the changes in the regression coefficients. Furthermore, the COVID-19 pandemic showed that the tourism recession had a negative impact on TTEMPL and TTGDP.

Magoutas *et al.* (2024) analyzed how rapid progress in information and communications technology (ICT) is associated with economic growth in the European Union (EU). They conducted their analysis using structural equation modeling, utilizing data sets from the Digital Economy and Society Index 2022 (DESI), the Statistical Office of the European Union (EUROSTAT), and the Organization for Economic Cooperation and Development (OECD) for all 27 European Union member states. The results showed a positive correlation between ICT development and Gross Domestic Product (GDP) indices. They indicated the need to strengthen human capital and promote the growth of e-government technology. They suggested that this is crucial to strengthening the infrastructure that supports citizens and public enterprises in European countries. Lastauskaite and Krusinskas (2024) analyzed the impact of production digitalization investments on the financial performance (operating revenue) of European companies from 2013 to 2021. They conducted a fixed-effects panel regression analysis using a sample size of 5706 records from the Orbis database, covering 30 countries and 634 business units. The results suggest that Eastern European firms benefit more from production digitization than Western European firms. The results showed a tendency for firm costs of employees and intangible fixed assets to increase as investment in production digitization expands. It also indicated that larger firms tend to benefit more from these investments than smaller firms. Hussain *et al.* (2024) investigated the effects of transportation infrastructure, income inequality, and information and communication technology on transportation-oriented household expenditures. They selected a dataset covering 1997–2021 for 24 OECD countries and analyzed it using a cross-sectional autoregressive distributed lag (CS-ARDL) approach.

They showed a convex relationship between income inequality and household expenditures. The magnitude of information and communication technology (ICT) is negative and significant. They suggested that ICT reduces Transportation-related household expenditures by allowing people to access real-time information and choose destinations and modes of travel from the comfort of their homes.

3.1.5 The method to improve cost efficiency

Keuchel (2020) conducted an analysis of the ongoing process of traveler digitalization in Blumenberg. The study said the digitalization of the transport system results in the digitalization of transport information, reservations, and pricing, as well as the automated operation of vehicles, leading to an increase in the number of users, improved transport conditions, and safer transport. Zhang and Wu (2023) proposed a framework for examining the operation performance of public transport using traffic data, e.g., smart card data, bus basic operation data, traditional transportation survey data, and geographical data. They presented that the framework of these traffic data can improve public transportation systems and provide a method for further efficient operation. Altieri *et al.* (2022) examined the impact of railway business strategy on the growth of the population. Their results presented the lagged influence of business strategies concerning the expansion of the railway network on the growth of the population in the Tokyo Metropolitan Area from 1970 to 2015. In particular, they found that the growth of population was positively associated with private sector, diversified businesses, and third sector railways, while it was negatively associated with public sector railways. This is because the private railway companies have positively influenced the population growth along the railway line as they jointly conducted railway deployment with urban development through business strategies from the 1970s to the 1990s. Meanwhile, public railways (Japanese National Railways and Subway: Teito Rapid Transit Authority) were not involved in urban development until the privatization of the Japanese National Railways in 1987 and therefore did not influence population growth along the railway lines.

Jansson *et al.* (2023) considered the challenges that the railway sector may face if automatic train operation is introduced on mainline railways. Automatic train operation enables unmanned operation, which reduces the number of crew members and reduces operating costs. They identified six categories of required driver action, illustrated some of the challenges of unmanned or undermanned train operations, and suggested the need to develop strategies not only for the operational aspects but also for technical operational management.

Fraczek and Urbanek (2021) discussed the reason for the digital payment development in public transportation and identified the influencing factors for the degree of digital ticketing and digital payments in the railway. They used a macroeconomic approach, which was applied to total data for European Union countries. The results from the regression analysis revealed the factors influencing digital payments in passenger transport and indicated that the degree of digital payments in passengers depends on the degree of mobile device, as well as the degree of the provided electronic banking services. Chiscano and Darcy (2022) examined measures against COVID-19 for Spanish urban public transport, which should ensure safe journeys by intensifying the digitalization of services. They applied the method of service-dominant logic co-creation process for disabled persons via a comparative approach. They suggested that disabled persons are able to improve their experiences of public transport through a suitable combination of digital and non-digital resource allocation.

Erdei *et al.* (2023) proposed an operational concept that enables flexible transport concepts to meet ad hoc passenger demand, which is made more efficient by combining the travel demands of individual passengers. Bulková *et al.* (2023) proposed measures to improve the quality and efficiency of transport processes in railway passenger transport during a potential pandemic. They showed that introducing modern passenger equipment systems in rail passenger transport through process automation and digitalization will streamline and improve the quality of transport processes. Varotsis (2022) conducted a comprehensive review and identified six key factors influencing digital entrepreneurship and creative industries in tourism, such as the economic, socio-psychological, and other aspects of tourism.

3.1.6 Position of this study

Considering the efforts and achievements of previous studies, my study makes the following original contributions to the literature. First, to the best of my knowledge, few studies have hitherto analyzed the production or cost efficiency of listed Japanese railway companies since the 2010s, as well as the impact of the declining population and the deteriorating efficiency of local lines. An exception is Tomikawa and Goto (2022), who analyzed four types of efficiency measures using recent data; however, their study did not include OPR but only JR.

Second, few previous studies have examined the factors that affect the cost efficiency levels of railway companies excepting, e.g., Asmild *et al.* (2009). In particular, this study uses variables such as the percentage of local lines, population density, railway usage rate, and number of transformer substations to explain inefficiency. Furthermore, I use dummy variables to identify the different impacts on efficiency caused by the individual characteristics of service areas, regional core cities, and local areas. These examinations identify correlations between demographics along railway lines, the railway infrastructure of substations, and cost inefficiency.

Third, few previous studies have analyzed the impact of the COVID-19 pandemic on the cost inefficiency of Japanese railway companies. This study thus provides useful insights for policymakers and railway company managers from the perspectives of cost inefficiency and sustainable operations against business uncertainties, such as that posed by the COVID-19 pandemic. By comparing the results with those of other railway companies, the corporate leaders of Japanese railway companies can identify the best-practice peers from which they can obtain hints to improve their management, not only under typical but also in critical business situations.

3.2 Methodology and Data

3.2.1 Methodology

In this study, I use the stochastic frontier cost function approach that is based on Battese and Coelli (1996), which is one of the most popular models in empirical studies of SFA due to its characteristics with robust mathematical background and flexible capability for panel data applications (Endo and Goto 2024b). The model is described by Equation (3):

$$\boldsymbol{C_{it}} = \boldsymbol{f}(\boldsymbol{x_{itm}})\boldsymbol{V_{it}}\boldsymbol{U_{it}}, \qquad (3)$$

where C_{it} is the cost for period t $(t = 1, \dots, T)$ of firm i $(i = 1, \dots, N)$, x_{itm} is the production factor m ($m = 1, \ldots, M$) in period t of firm i, V_{it} is the error term, and U_{it} is the inefficiency term.

Following Battese and Coelli's (1996) model, time-varying cost inefficiency term U_{it} is described by Equation (4):

$$\boldsymbol{U_{it}} = \boldsymbol{f}(\boldsymbol{z_{it}}), \qquad (4)$$

where z_{it} represents the factors that explain firm i's inefficiency in period t. I use three input factors such that m in Equation (3) represents labor, fuel, and capital, and the variables in the estimation model are logarithmic.

The cost frontier function is formulated as a Cobb-Douglas type, according to Coelli (1996), and Equation (3) becomes Equation (5):

$$\ln\left(\frac{C_{it}}{R_{it}}\right) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} \ln \boldsymbol{Q_{it}} + \boldsymbol{\beta_2} \ln\left(\frac{W_{it}}{R_{it}}\right) + \boldsymbol{\beta_3} \ln\left(\frac{E_{it}}{R_{it}}\right) + \boldsymbol{V_{it}} + \boldsymbol{U_{it}}, \qquad (5)$$

where the explanatory variable are passenger kilometers for output Q_{it} and the prices of production factors for labor (W_{it}), fuel (E_{it}), and capital (R_{it}). Labor price W_{it} is calculated from wages divided by the number of employees, capital price R_{it} is the depreciation cost divided by the fixed assets, and fuel price E_{it} is the electricity cost divided by the number of car-kilometers. Explained variable C_{it} is railway operating expenditure. V_{it} is a random error term with a distribution of *i.i.d.* $N(0, \sigma_v^2)$ and U_{it} represents cost inefficiency, which is a random variable following a non-negative truncation of normal distribution $N^+(\mu_{it}, \sigma_u^2)$. Note that the cost function is assumed to satisfy first-order homogeneity with respect to input prices, so that it is divided by capital price.

The estimation model for the average cost inefficiency is specified in Equation (6):

$$\boldsymbol{\mu_{it}} = \boldsymbol{\delta_0} + \sum_{j=1} \boldsymbol{\delta_j Z_{jit}}. \qquad (6)$$

Z_{jit} is the j th variable $(j = 1, \ldots, J)$ representing the characteristics of firm i in period t and δ is the vector of estimated coefficients. The concrete cost inefficiency equation estimated in this study is described by Equation (7):

$$\begin{aligned}
\boldsymbol{\mu_{it}} &= \boldsymbol{\delta_0} + \sum_{j=1} \boldsymbol{\delta_j Z_{ji}} \\
&= \boldsymbol{\delta_0} \\
&\quad + \boldsymbol{\delta_1}(\boldsymbol{Percentage\ of\ local\ lines\ operating\ kilometers})_{\boldsymbol{it}} \\
&\quad + \boldsymbol{\delta_2}(\boldsymbol{Number\ of\ transformer\ substaions})_{\boldsymbol{it}} \\
&\quad + \boldsymbol{\delta_3}(\boldsymbol{Population\ density\ of\ railway\ operating\ area})_{\boldsymbol{it}} \\
&\quad + \boldsymbol{\delta_4}(\boldsymbol{Railway\ usage\ rate})_{\boldsymbol{it}} \\
&\quad + \boldsymbol{\delta_5}(\boldsymbol{Dummy\ of\ regional\ core\ city}) \\
&\quad + \boldsymbol{\delta_6}(\boldsymbol{Dummy\ of\ local\ areas}). \qquad (7)
\end{aligned}$$

The estimated parameters and variables for inefficiency in Equation (7) are as follows (Endo and Goto 2024b):

(i) δ_1 (percentage of local lines' operating kilometers): to examine whether inefficiency increases with a higher percentage of local routes and fewer users.

(ii) δ_2 (number of transformer substations): to examine whether the cost of operating equipment represented by transformer substations, including overhead line facilities and other ground infrastructure required for electric railways, affects inefficiency.

(iii) δ_3 (population density of railway operating areas: to examine whether population density in relation to the number of railway passengers affects inefficiency.

(iv) δ_4 (railway usage rate): to examine whether railway usage rate affects inefficiency.

(v) δ_5 (dummy variable of regional core city) and δ_6 (dummy variable of local areas): to examine whether there are differences in inefficiency according to city size and location.

The parameters in the cost frontier model were then obtained using maximum likelihood estimation. Cost inefficiency measure μ_{it} ranges as $1 \leq \mu_{it}$, where 1 represents the status of full efficiency. If μ_{it} is larger than 1, it indicates inefficiency. The larger the value, the more inefficient the system is.

3.2.2 Data

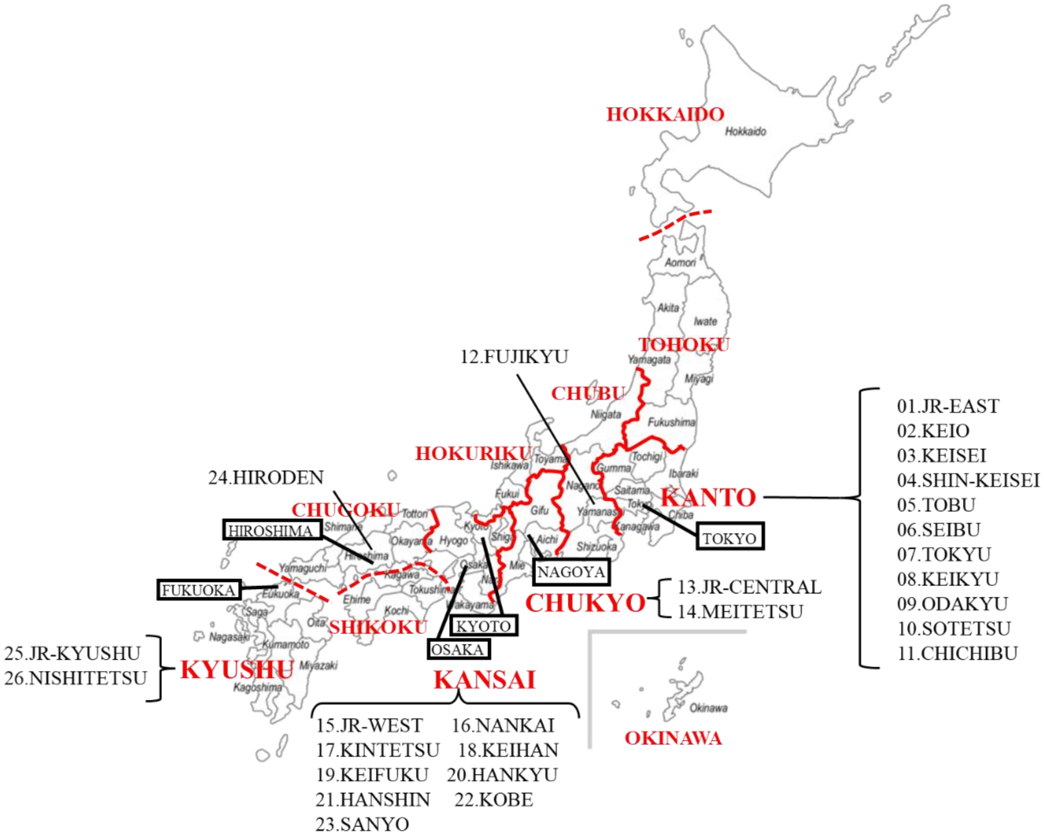
This study examined 26 listed Japanese railway companies. Table 14 summarizes the 26 listed railway companies in Japan and Fig. 19 shows a map of service areas for each company.

Table 14 Summary of 26 Japanese listed railway companies

No.	Company Name	Business Type	Service Area
01	JR-EAST	JR	KANTO, TOHOKU, CHUBU (Yamanashi, Nigata, Nagano, Shizuoka)
02	KEIO	OPR	KANTO (Tokyo)
03	KEISEI	OPR	KANTO (Tokyo, Chiba)
04	SHIN-KEISEI	OPR	KANTO (Chiba)
05	TOBU	OPR	KANTO (Tokyo, Saitama, Gunma, Tochigi, Chiba)
06	SEIBU	OPR	KANTO (Tokyo, Saitama)
07	TOKYU	OPR	KANTO (Tokyo, Kanagawa)
08	KEIKYU	OPR	KANTO (Tokyo, Kanagawa)
09	ODAKYU	OPR	KANTO (Tokyo, Kanagawa)
10	SOTETSU	OPR	KANTO (Kanagawa)
11	CHICHIBU	OPR	KANTO (Saitama)
12	FUJIKYU	OPR	CHUBU (Yamanashi)
13	JR-CENTRAL	JR	KANTO (Tokyo, Kanagawa), CHUBU (Shizuoka, Nagano, Yamanashi), CHUKYO (Aichi, Gifu, Mie), KANSAI (Shiga, Kyoto, Osaka)
14	MEITETSU	OPR	CHUKYO (Aichi, Gifu, Mie)

15	JR-WEST	JR	CHUBU (Nigata, Nagano), HOKURIKU, KANSAI, CHUGOKU, KYUSHU (Fukuoka)
16	NANKAI	OPR	KANSAI (Osaka, Wakayama)
17	KINTETSU	OPR	CHUKYO (Aichi Mie), KANSAI (Osaka, Kyoto, Nara)
18	KEIHAN	OPR	KANSAI (Osaka, Kyoto)
19	KEIFUKU	OPR	HOKURIKU (Fukui), KANSAI (Kyoto)
20	HANKYU	OPR	KANSAI (Osaka, Kyoto, Hyogo)
21	HANSHIN	OPR	KANSAI (Osaka, Hyogo)
22	KOBE	OPR	KANSAI (Hyogo)
23	SANYO	OPR	KANSAI (Hyogo)
24	HIRODEN	OPR	CHUGOKU (Hiroshima)
25	JR-KYUSHU	JR	KYUSHU
26	NISHITETSU	OPR	KYUSHU (Fukuoka)

Notes 1: Service areas are described by combinations of regions, such as KANTO and TOHOKU, and the prefectures in the region are shown between parentheses, such as Tokyo and Chiba. 2: The reason for the 26 listed Japanese railway companies in Chapter 3 is that in Chapter 2, the HANKYU-HANSHIN group was counted one company, but in Chapter 3, the HANKYU-HANSHIN groups were counted two companies in order to investigate the efficiency of each railway company. The total number of Japanese listed railway companies in Japan is 26.



Note: Source (Endo and Goto 2024b)

Fig. 19 Map of service areas of the 26 Japanese listed railway companies

This study uses a panel dataset comprising 26 Japanese companies from 2005 to 2020 (Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan 2005-2020). For analysis, I used Japan's fiscal year from April to March. This period includes several events that deteriorated the business environment, such as the financial crisis from 2007 to 2008 and the Great East Japan Earthquake of 2011, and we compare those impacts with those of the COVID-19 pandemic after 2020.

The sources of the data used in this study are the "Annual Report on Railway Statistics" and "Inter-Regional Travel Survey in Japan" published by the Ministry of Land, Infrastructure, Transport and Tourism, Japan; the "National Census" by the Ministry of Internal Affairs and Communication; and the annual securities reports of each railway company. The variables used for the inefficiency factors are as follows (Endo and Goto 2024b):

(i) Percentage of operating kilometers of local lines: I used data from the Annual Report on Railway Statistics. Specifically, this is the ratio of all local lines' operating kilometers, calculated as an average daily transit capacity (transit density) of local lines with less than 2,000 passengers/day to the total operating kilometers. Here, the limit of 2,000 passengers/day is determined by Japan National Railways as a guideline for discontinuing railway lines.

(ii) Number of transformer substations: I used data from the annual securities reports of each railway company. This number represents the total number of traction substations owned by each railway company.

(iii) Population density of railway operating areas: I used census data for the population and the area of each prefecture. As the census is conducted every 5 years, the most recent census data are used for several years. For example, 2005 data were used from 2005 to 2009 and 2010 data were used from 2010 to 2014. Specifically, I used the population density of the prefecture in which each railway company operates. If the operating area extended over several prefectures, the population density was calculated using the average value.

(iv) Railway usage rate. I used data from the inter-prefectural passenger table of the Inter-Regional Travel Survey in Japan. However, as I could not access data on private car use, I used the percentage of railway users relative to that of the entire public transport system. Specifically, I calculated the rate for the four JR companies (JR-EAST, JR-CENTRAL, JR-WEST, and JR-KYUSHU) and for the OPR companies using Equation (8):

$$\textit{Railway usage rate (JR or OPR)} = \frac{\sum(\textit{Total number of JR or OPR passengers in each prefecture of operating area})}{\sum(\textit{Total number of public transport passengers in each prefecture of operating area})} \dots (8)$$

(v) Dummy of regional core city: It takes 1 if the operating area includes an ordinance-designated city, excepting three metropolitan areas (Tokyo, Kanagawa, Saitama, Chiba, Osaka, Kyoto, Hyogo, Nara, Wakayama, Aichi, Gifu, and Mie prefectures), that is, Fukuoka, Kumamoto, Hiroshima, Okayama, Shizuoka, Hamamatsu, Niigata, or Sendai City, and 0 otherwise.

(vi) Dummy of local areas: It takes 1 if the three metropolitan areas and regional core city are not included in the operating area, and 0 otherwise.

The software used for the analyses was FRONTIER Version 4.1 for the SFA and IBM SPSS Ver. 29 for the descriptive statistics.

3.2.3 Flow of analysis

I can summarize the flow of the analyses in this study as follows. Fig. 20 shows the methodology flow. First, I measured the cost efficiencies of railway companies from 2005 to 2020 by estimating the stochastic frontier cost function and identified the railway companies with the best and worst cost efficiency. Here, high or best cost efficiency (low cost inefficiency) is defined as a small cost efficiency value, i.e., a cost efficiency value closer to 1. Low or worst cost efficiency (high cost inefficiency) is defined as a large cost efficiency value, i.e., a cost efficiency value larger than 1. Then, I examined the differences in the cost efficiency of each railway company between 2019 and 2020, that is, before and after the start of the COVID-19 pandemic. Second, I rank listed Japanese railway companies based on cost efficiency and profile characteristics of the companies with the best efficiency (best practice). Third, I compared the cost efficiency between the best practice railway companies in 2019 and 2020, that is, before and after the start of the COVID-19 pandemic. Fourth, I examined the relationship between cost efficiency and the implementation of efficiency measures for each railway company. This is because it is important to examine what efficiency measures influence costs in companies to improve cost efficiency.

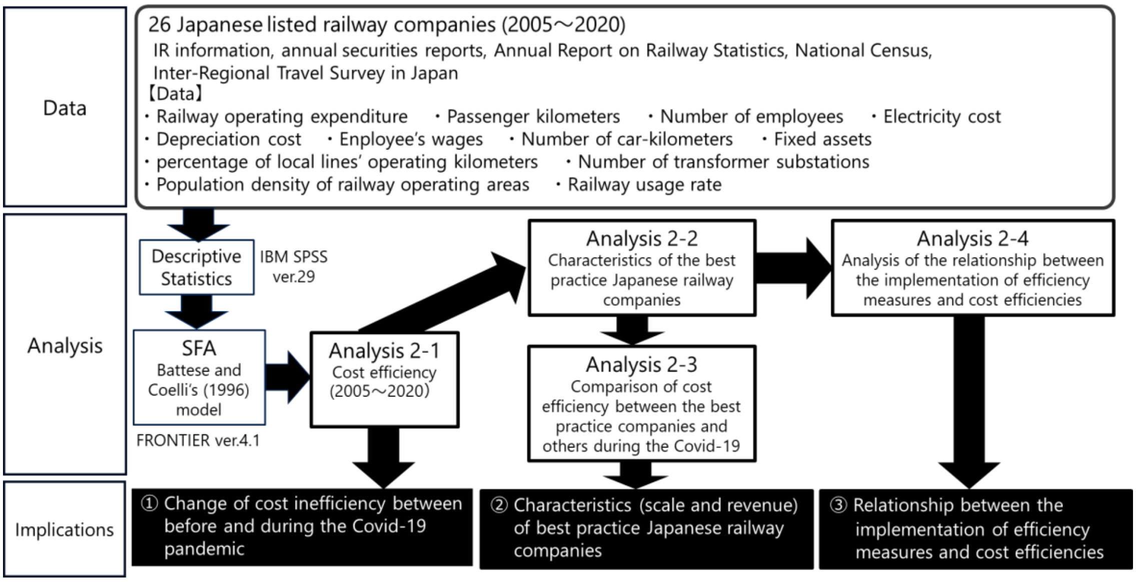


Fig. 20 Methodology flow of Cost efficiency analysis

3.3 Results

3.3.1 Analysis 2-1 Estimation results for stochastic cost frontier function

Table 15 shows the descriptive statistics of 26 Japanese listed railway companies to better understand their characteristics. The effective data size is 416, as the data covers 26 companies over 16 years in the form of balanced panel data.

Table 15 Descriptive statistics for the 26 Japanese listed railway companies (from 2005 to 2020)

Variable Name	Minimum Value	Maximum Value	Average Value	Standard Deviation
Railway operating expenditure (million yen)	1147	1,715,178	170,278	348,194
Passenger-kilometer (million passenger kilometers)	18	137,598	13,406	26,987
Labor price	1194	9905	5577	1533
Capital price	0.01	36.86	0.15	1.80
Fuel price	16.70	65.63	33.99	9.29
Number of personnel	97	54,697	5680	10,535
Power cost (million yen)	46	71,577	8167	14,380
Depreciation cost (million yen)	105	298,807	34,033	66,131
Salary cost (million yen)	262	297,516	32,717	58,231
Car kilometer (million passenger kilometers)	0.89	2343	275	509
Percentage of local lines operating kilometers	0.00	0.54	0.07	0.14
Number of substations	1	339	43.92	74.07
Population density	181	6403	1824	1662
Railway usage rate	0.06	0.66	0.48	0.14
Dummy of regional core city	0.00	1.00	-	-
Dummy of local areas	0.00	1.00	-	-

Note: Source (Endo and Goto 2024b)

Table 16 presents the results of the stochastic cost frontier function estimation.

Table 16 Estimation results for the stochastic frontier cost function of the 26 Japanese listed railway companies (from 2005 to 2020)

	Variable	Coefficient	Standard Error	*t*-Value
β0	Constant term	0.0155	0.1153	0.1344
β1	Passenger-kilometers	0.2477 ***	0.0378	6.5461
β2	Labor price/Capital price	0.7876 ***	0.0362	21.7366
β3	Fuel price/Capital price	0.8416 ***	0.0532	15.8068
δ0	Constant term	0.2795 ***	0.093	3.0052
δ1	Percentage of local lines operating kilometers	−0.0001	0.0003	−0.4658
δ2	Number of substations	−0.0001 ***	0.0000	−15.145
δ3	Population density	−0.6801 ***	0.2457	−2.7674
δ4	Railway (JR/OPR) usage rate	0.2107 ***	0.0538	3.914
δ5	Dummy of regional core city	−0.3352 ***	0.0731	−4.5863
δ6	Dummy of local areas	0.4352 ***	0.0743	5.851
	lnsigma2	0.0317 ***	0.0547	5.7998
	Γ	0.8396 ***	0.0350	23.9845
	loglikelihood	411.9217	-	-
	Number of observations	416	-	-
	LR test of the one-sided error	213.8084	-	-

Notes: 1: lnsigma2 stands for $ln\, ln\, \sigma^2 = ln\, ln\, (\sigma_u{}^2 + \sigma_v{}^2)$, where $\sigma_u{}^2$ is the variance of the cost inefficiency term and $\sigma_v{}^2$ the variance of the random error term. γ represents the proportion of the cost inefficiency to the whole error term in the variance. 2: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Source (Endo and Goto 2024b)

The estimated parameters of the stochastic cost frontier function (β), are all positive and significant at the 1% level, which is consistent with the monotonicity condition of the cost function for input prices. Meanwhile, the estimated parameters of inefficiency (δ) indicate that cost inefficiency increases if the parameter is positive and decreases if it is negative.

The estimated coefficients for the cost frontier function, passenger kilometers, railway operating expenditure, labor price, and fuel price are positive and significant at the 1% level. For the inefficiency term, the number of substations, population density, railway (JR/OPR) usage rate, the dummy of the regional core city, and the dummy of local areas were significant at the 1% level, whereas the percentage of local lines operating in kilometers was not significant. Of the significant variables, the number of substations, population density, and the dummy of the regional core city had negative coefficients, while the railway (JR/OPR) usage rate and the dummy of local areas had positive ones.

Because cost inefficiency decreases when the number of variables with significant and negative estimated coefficients increases, I expect that an increase in the number of substations, population density, and dummy variables of the regional core city would decrease cost inefficiency. Intuitively, an increase in the number of substations would lead to a larger cost inefficiency, owing to operating and maintenance costs; however, in this study, it contributes to reducing cost inefficiency, which probably represents a greater increase in outputs. For example, from 2005 to 2020, some railway companies increased the number of transformer substations by opening new lines or increasing transport capacity, which may have positively affected reducing cost inefficiency by increasing the output values of passenger kilometers. Meanwhile, I can intuitively understand that cost inefficiency decreases as population density increases because of the economies of scale.

3.3.2 Analysis 2-2 Estimation results of cost efficiency of Japanese railway companies

Table 17 presents the cost efficiencies of railway companies measured based on the estimated stochastic cost frontier functions. Bold italics indicate the most cost-efficient (lowest cost inefficiency) railway company in each year and the average one. KEIO presents the most cost efficiency during 2005-2008 and 2010-2018, SOTETSU in 2009, and TOKYU in 2019 and 2020. On average, from 2005 to 2020, KEIO had the most cost efficiency (1.019), indicating there is still room for a 1.9% cost reduction compared with the least inefficiency with a unity measure. In terms of annual averages for all companies, the most cost efficiency was recorded in 2014 at 1.0555, and the worst efficient year with the largest cost inefficiency was 2020 at 1.2094. In addition, cost inefficiency significantly worsened by 0.1412 points before the COVID-19 pandemic (1.0682) in 2019 compared with that during the pandemic (1.2094) in 2020.

The second worst cost efficiency was 1.0953 in 2009, a year affected by the financial crisis. In 2011, the cost efficiency was 1.0816, which is better than the 2010 value of 1.0901; thus, this can be seen as a relatively mild impact of the Great East Japan Earthquake. This is because the areas directly affected by the Great East Japan Earthquake were limited to the TOHOKU region and JR-EAST was the only railway company affected. In other words, the earthquake did not have a significant impact on the operations of the other railway companies.

Table 17 Cost efficiency from the stochastic cost frontier functions of railway companies (from 2005 to 2020)

No	Company	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
	Event				Financial crisis	Financial crisis		Great East Japan Earthquake								Before COVID-19	During COVID-19	
1	JR-EAST	1.0796	1.0968	1.0780	1.0524	1.0556	1.0495	1.0491	1.0413	1.0373	1.0380	1.0536	1.0591	1.0530	1.0447	1.0504	1.1949	1.0646
2	KEIO	***1.0155***	***1.0164***	***1.0173***	***1.0178***	1.0251	***1.0216***	***1.0197***	***1.0168***	***1.0145***	***1.0138***	***1.0147***	***1.0180***	***1.0173***	***1.0155***	1.0159	1.0434	***1.0190***
3	KEISEI	1.0405	1.0408	1.0407	1.0317	1.0451	1.0527	1.0522	1.0422	1.0331	1.0320	1.0383	1.0477	1.0441	1.0361	1.0426	1.2047	1.0515
4	SHIN-KEISEI	1.0269	1.0275	1.0288	1.0271	1.0365	1.0357	1.0308	1.0233	1.0192	1.0181	1.0204	1.0265	1.0254	1.0236	1.0251	1.0834	1.0299
5	TOBU	1.0354	1.0356	1.0360	1.0320	1.0255	1.0430	1.0360	1.0299	1.0214	1.0202	1.0223	1.0276	1.0263	1.0234	1.0324	1.0880	1.0334
6	SEIBU	1.0315	1.0251	1.0280	1.0241	1.0318	1.0288	1.0263	1.0182	1.0161	1.0163	1.0177	1.0220	1.0206	1.0185	1.0211	1.0732	1.0262
7	TOKYU	1.0255	1.0324	1.0269	1.0266	1.0403	1.0327	1.0354	1.0259	1.0220	1.0192	1.0201	1.0283	1.0247	1.0223	***1.0141***	***1.0386***	1.0272
8	KEIKYU	1.0213	1.0213	1.0244	1.0213	1.0327	1.0306	1.0303	1.0248	1.0196	1.0190	1.0204	1.0283	1.0264	1.0210	1.0242	1.0964	1.0289
9	ODAKYU	1.0288	1.0274	1.0277	1.0248	1.0374	1.0326	1.0277	1.0208	1.0179	1.0165	1.0182	1.0248	1.0223	1.0203	1.0212	1.0762	1.0278
10	SOTETSU	1.0304	1.0300	1.0339	1.0286	***1.0135***	1.0279	1.0273	1.0209	1.0183	1.0182	1.0209	1.0262	1.0239	1.0214	1.0200	1.1153	1.0298
11	CHICHIBU	1.0540	1.0492	1.0458	1.0352	1.0462	1.0397	1.0395	1.0326	1.0287	1.0258	1.0301	1.0414	1.0372	1.0345	1.0365	1.1493	1.0454
12	FUJIKYU	1.1173	1.1389	1.1115	1.0781	1.1257	1.1085	1.0944	1.0620	1.0479	1.0589	1.0790	1.1203	1.1153	1.1266	1.2375	1.6133	1.1397
13	JR-CENTRAL	1.0796	1.0854	1.0832	1.0791	1.1284	1.1137	1.0897	1.0759	1.0473	1.0421	1.0449	1.0558	1.0460	1.0371	1.0491	1.3425	1.0875
14	MEITETSU	1.1182	1.1235	1.1372	1.1163	1.1543	1.1383	1.1148	1.0978	1.0848	1.0623	1.0709	1.0954	1.0775	1.0638	1.0564	1.2413	1.1096
15	JR-WEST	1.0760	1.0845	1.0884	1.0749	1.1079	1.0982	1.0888	1.0781	1.0550	1.0499	1.0570	1.0691	1.0583	1.0579	1.0447	1.1337	1.0764
16	NANKAI	1.0465	1.0709	1.0743	1.0747	1.1196	1.0982	1.0979	1.0884	1.0527	1.0492	1.0479	1.0607	1.0609	1.0869	1.0989	1.2808	1.0880
17	KINTETSU	1.0723	1.0598	1.1335	1.1257	1.1500	1.1456	1.1340	1.1117	1.0772	1.0688	1.0718	1.0910	1.0798	1.0812	1.0873	1.2979	1.1117
18	KEIHAN	1.0381	1.0414	1.0442	1.0435	1.0518	1.0534	1.0500	1.0467	1.0314	1.0282	1.0285	1.0313	1.0291	1.0360	1.0278	1.0745	1.0410
19	KEIFUKU	1.0369	1.0358	1.0476	1.0348	1.0414	1.0384	1.0390	1.0389	1.0346	1.0353	1.0337	1.0483	1.0521	1.0535	1.0566	1.2368	1.0540
20	HANKYU	1.0304	1.0356	1.0357	1.0307	1.0416	1.0406	1.0364	1.0321	1.0225	1.0212	1.0214	1.0238	1.0239	1.0290	1.0325	1.1303	1.0367
21	HANSHIN	1.0458	1.0828	1.0763	1.0739	1.1172	1.1207	1.1006	1.0880	1.0612	1.0440	1.0455	1.0478	1.0444	1.0566	1.0345	1.1345	1.0734
22	KOBE	1.0609	1.0741	1.0746	1.0646	1.0831	1.0725	1.0587	1.0622	1.0410	1.0382	1.0420	1.0531	1.0523	1.0572	1.0519	1.1765	1.0664
23	SANYO	1.1793	1.1678	1.1723	1.1409	1.1720	1.1172	1.1068	1.1240	1.0564	1.0538	1.0632	1.0864	1.0699	1.0734	1.0931	1.1961	1.1170
24	HIRODEN	1.5361	1.5372	1.5750	1.5197	1.5978	1.5986	1.5677	1.5770	1.5630	1.5448	1.5907	1.6176	1.5878	1.6036	1.5201	2.1363	1.6046
25	JR-KYUSHU	1.0822	1.0500	1.0783	1.0647	1.0902	1.0875	1.0631	1.0809	1.0515	1.0482	1.1075	1.0366	1.0338	1.0303	1.0308	1.1050	1.0650
26	NISHITETSU	1.0493	1.0551	1.0956	1.0958	1.1058	1.1165	1.1045	1.0905	1.0606	1.0608	1.0649	1.0821	1.0728	1.0597	1.0495	1.1813	1.0841
	Average	1.0753	1.0787	1.0852	1.0746	1.0953	1.0901	1.0816	1.0750	1.0590	1.0555	1.0633	1.0719	1.0664	1.0667	1.0682	1.2094	1.0823

Note: Bold italics indicate the most efficient railway company. Source (Endo and Goto 2024b)

In Table 17, many KANTO region railway companies, as classified in Table 14, ranked higher in terms of cost efficiency. This is consistent with the hypothesis that the densely populated areas of the KANTO region, particularly Tokyo, have high railway usage rates. Specifically, KEIO ranks best in terms of cost efficiency (lowest cost inefficiency) because its operating area covers only Tokyo, which provides the benefit of an efficient railway business in the most densely populated area. However, in Table 17, the reason for the lower cost efficiency (higher cost inefficiency) of the four JR companies can be attributed to the fact that these companies also own local lines in rural areas, which makes them less efficient than OPR companies operating in the three metropolitan areas.

Next, I examine the major external factors (financial crisis, Great East Japan Earthquake, and COVID-19 pandemic) that greatly influenced the business environment and cost inefficiency of railway companies. Table 18 presents the best and worst cost efficiency measures (the lowest and highest inefficiency) and the corresponding years for each company from 2005 to 2019; the worst cost efficiency (highest inefficiency) during the entire period (2005 to 2020) is concentrated in 2020, and the average cost efficiencies for the entire period (2005 to 2020) for each railway company are also shown.

Table 18 Lowest and highest cost efficiencies for each company from 2005 to 2020

No	Company	Region	"FY 2005–FY 2019"				FY 2020	Average Value for "FY 2005–FY2020"	Order
			Best Cost Efficiency	Fiscal Year	Worst Cost Efficiency	Fiscal Year	Worst Cost Efficiency During Whole Period		
1	JR-EAST	TOHOKU KANTO CHUBU	1.0373	(2013)	1.0968	(2006)	1.1949	1.0646	14
2	KEIO	KANTO	1.0138	(2014)	1.0251	(2009)	1.0434	1.0190	1
3	KEISEI	KANTO	1.0317	(2008)	1.0527	(2010)	1.2047	1.0515	12
4	SHIN-KEISEI	KANTO	1.0181	(2014)	1.0365	(2009)	1.0834	1.0299	7
5	TOBU	KANTO	1.0202	(2014)	1.0360	(2007)	1.0880	1.0334	8
6	SEIBU	KANTO	1.0161	(2013)	1.0318	(2009)	1.0732	1.0262	2

7	TOKYU	KANTO	1.0192	(2014)	1.0403	(2009)	1.0386	1.0272	3
8	KEIKYU	KANTO	1.0190	(2014)	1.0327	(2009)	1.0964	1.0289	5
9	ODAKYU	KANTO	1.0165	(2014)	1.0374	(2009)	1.0762	1.0278	4
10	SOTETSU	KANTO	1.0135	(2009)	1.0339	(2007)	1.1153	1.0298	6
11	CHICHIBU	KANTO	1.0258	(2014)	1.0540	(2005)	1.1493	1.0454	11
12	FUJIKYU	CHUBU	1.0479	(2013)	1.2375	(2019)	1.5977	1.1397	25
13	JR-CENTRAL	KANTO CHUBU GHUKYO KANSAI	1.0371	(2018)	1.1284	(2009)	1.3425	1.0875	20
14	MEITETSU	CHUKYO	1.0564	(2019)	1.1543	(2009)	1.2413	1.1096	22
15	JR-WEST	HOKURIKU KANSAI CHUGOKU KYUSHU	1.0447	(2019)	1.1079	(2009)	1.1337	1.0764	18
16	NANKAI	KANSAI	1.0479	(2015)	1.1196	(2009)	1.2808	1.0880	21
17	KINTETSU	KANSAI	1.0598	(2006)	1.1500	(2009)	1.2979	1.1117	23
18	KEIHAN	KANSAI	1.0278	(2019)	1.0534	(2010)	1.0745	1.0410	10
19	KEIFUKU	KANSAI HOKURIKU	1.0337	(2015)	1.0476	(2007)	1.2368	1.0540	13
20	HANKYU	KANSAI	1.0212	(2014)	1.0416	(2009)	1.1303	1.0367	9
21	HANSHIN	KANSAI	1.0345	(2019)	1.1207	(2010)	1.1345	1.0734	17
22	KOBE	KANSAI	1.0382	(2014)	1.0831	(2009)	1.1765	1.0664	16
23	SANYO	KANSAI	1.0538	(2014)	1.1723	(2007)	1.1961	1.1170	24
24	HIRODEN	CHUGOKU	1.5201	(2019)	1.5978	(2009)	2.1363	1.6046	26
25	JR-KYUSHU	KYUSHU	1.0303	(2018)	1.0902	(2009)	1.1050	1.0650	15
26	NISHITETSU	KYUSHU	1.0495	(2019)	1.1165	(2010)	1.1813	1.0841	19
	Average		1.0513		1.1038		1.2088	1.0823	

Note: Source (Endo and Goto 2024b)

Furthermore, Table 19 shows the number of companies in each year that recorded the best and the first and second worst cost efficiencies (the lowest and the first and second highest inefficiency) from 2005 to 2020.

Table 19 Distribution of the number of railway companies from 2005 to 2020

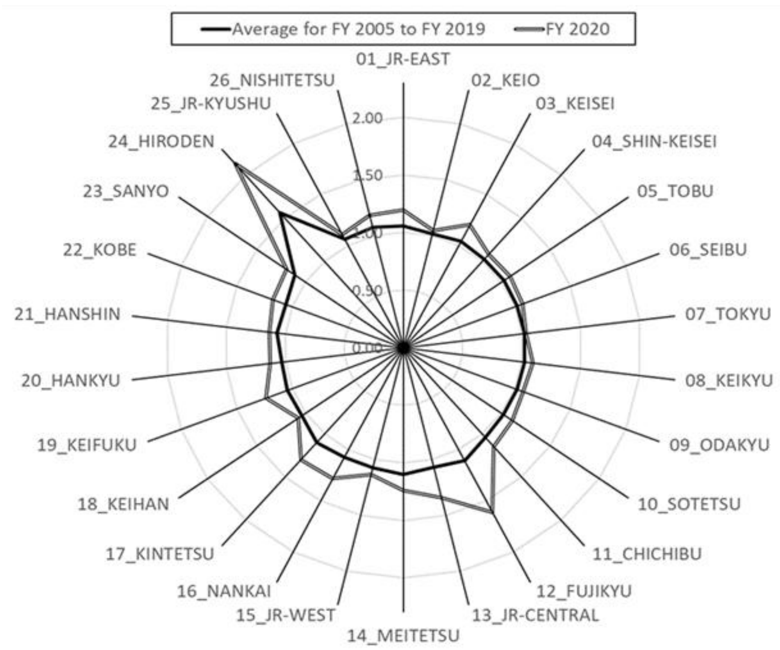
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
The best efficiency value	0	1	0	1	1	0	0	0	3	11	3	0	0	2	5	0
The second-worst efficiency value	1	1	5	0	14	4	0	0	0	0	0	0	0	0	1	0
The worst efficiency value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26

Note: Source (Endo and Goto 2024b)

Table 19 presents two findings. First, eleven companies recorded the best cost efficiency (lowest inefficiency) in 2014 and five companies did so in 2019. This can be partly explained by the influence of fare revisions following the consumption tax increase from 5% to 8% in 2014 and the additional increase to 10% in 2019. Second, 14 companies recorded the second worst cost efficiency (second highest inefficiency) in 2009. This finding suggests that cost efficiency deteriorated because of the financial crisis. The worst cost efficiency (highest inefficiency) for all companies is concentrated in 2020, suggesting that the COVID-19 pandemic has influenced the cost inefficiency of railway companies more severely compared with the financial crisis.

3.3.3 Analysis 2-3 Comparison of cost efficiency of Japanese railway companies before and during the COVID-19 pandemic

Fig. 21 shows the cost efficiency of the 26 companies before the COVID-19 pandemic (averages from 2005 to 2019) and during it (2020).



Note: Source (Endo and Goto 2024b)

Fig. 21 Cost efficiency of Japanese listed railway companies average from 2005 to

2019 and in 2020

From the figure, the value of cost efficiency is worse for all railway companies in 2020, although the level of the difference varies by company. Here, 12: FUJIKYU and 24: HIRODEN had higher values than the other companies. Because the service areas of these companies are outside the three metropolitan areas, they were mainly used by tourists of the World Heritage Sites: Mt. Fuji for FUJIKYU and Miyajima for HIRODEN. Due to the COVID-19 pandemic, the number of inbound tourists decreased sharply due to entry restrictions into Japan. These companies were greatly affected by the decline in the number of passengers and their cost inefficiency increased.

The reason for the lower efficiency of HIRODEN compared to other companies is that the study uses passenger kilometres for output production. This value represents the total passenger kilometres. HIRODEN's railway business is operated by trams, and the efficiency value is considered to be low because the unit transport volume is smaller than that of railways.

Next, I identify the characteristics of best-practice railway companies. Table 20 presents a comparison of the profiles of the top 10 railway companies (KEIO, SEIBU, TOKYU, ODAKYU, KEIKYU, SOTETSU, SHIN-KEISI, TOBU, HANKYU, and KEIHAN) and of others before and during the pandemic. I call the top 10 railway companies the best-practice railway companies. The profiles include operating kilometers, number of stations, number of rolling stocks, number of transported passengers, passenger-kilometers, car kilometers, and number of employees in the railway sector.

Table 20 Comparison of profiles for the best-practice and other railway companies

	Average of Best Practice Railway Companies	Average of the Other Railway Companies

	Before COVID-19 Pandemic in 2019	During COVID-19 Pandemic in 2020 (Year-on-Year Rate)	Growth Rate	Before COVID-19 Pandemic in 2019	During COVID-19 Pandemic in 2020 (Year on Year Rate)	Growth Rate
Operating kilometers (km)	133.6	133.6	100.0%	1140	1134	99.4%
Number of stations	83	84	100.1%	306	304	99.4%
Number of rolling stocks	1028	1022	99.5%	1984	1984	100.0%
Number of transported passengers (thousand passengers)	597,630	421,460	70.5%	710,490	505,988	71.2%
Passenger-kilometers (million passenger-kilometers)	7541	5092	67.5%	18,624	10,660	57.2%
Car kilometer (thousand kilometers)	136,728	137,251	100.4%	371,850	362,859	97.6%
Number of employees in the railway sector	2520	2535	100.6%	7204	7140	99.1%

Note: The growth rate is calculated from 2019 to 2020. Data source: "Annual Report on Railway Statistics" (2019, 2020) from the Ministry of Land, Infrastructure, Transport and Tourism, Japan. Source (Endo and Goto 2024b)

Here, I consider 2019 as the year before the COVID-19 pandemic and 2020 as the year during the COVID-19 pandemic. I found that the other railway companies had higher values than the best-practice railway companies for all variables. The significant difference between the best-practice railway companies and the other ones is observed in passenger-kilometers, which decreased by 67.5% in 2020 compared with 2019 for the former railway companies and 57.2% for the latter ones. Passenger-kilometers refer to the total length of a passenger's trip by train. This indicates that passengers made fewer long-distance trips because they refrained from inter-prefectural travel during the pandemic.

I then analyzed the changes in cost efficiency due to the COVID-19 pandemic. Table 21 shows the difference in the cost efficiency of each railway company between 2019 and 2020, corresponding to the first research concern, that is, "How much did the cost efficiency of railway companies worse during the COVID-19 pandemic?"

Table 21 Difference between the cost efficiency of each railway company in 2019 and in 2020

No	Company	The Difference in Cost efficiency between FY2020 and FY 2019	No	Company	The Difference in Cost efficiency between FY2020 and FY 2019	No	Company	The Difference in Cost efficiency between FY2020 and FY 2019
1	JR EAST	0.1445	11	CHICHIBU	0.1128	21	HANSHIN	0.1000
2	KEIO	0.0275	12	FUJIKYU	0.3758	22	KOBE	0.1246
3	KEISEI	0.1621	13	JR CENTRAL	0.2934	23	SANYO	0.1030
4	SHIN-KEISEI	0.0583	14	MEITETSU	0.1849	24	HIRODEN	0.6162
5	TOBU	0.0556	15	JR WEST	0.0890	25	JR KYUSHU	0.0742
6	SEIBU	0.0521	16	NANKAI	0.1819	26	NISHITETSU	0.1318
7	TOKYU	0.0245	17	KINTETSU	0.2106		Average	0.1398
8	KEIKYU	0.0722	18	KEIHAN	0.0467		Minimum	0.0181
9	ODAKYU	0.0550	19	KEIFUKU	0.1802		Maximum	0.6088
10	SOTETSU	0.0953	20	HANKYU	0.0978		Standard deviation	0.1240

Note: Source (Endo and Goto 2024b)

Table 21 presents the deterioration in cost efficiency (increase in values), where the minimum value was 0.0245 for TOKYU, the maximum value was 0.6162 for HIRODEN, the mean value was 0.1398, and the standard deviation was 0.1240. These results reveal the changes in the cost efficiency of Japanese listed railway companies before and during the COVID-19 pandemic and the scale of the impact on railway companies' efficiency.

A comparison was then made between the cost efficiency values of Kuramoto and Hirota (2008), on which this study is based, and the efficiency values calculated in this study. In the study by Kuramoto and Hirota (2008), the analysis focuses on third-sector railways. Third-sector railways are railway companies jointly owned by the public sector and private companies. As such, they do not include the 26 listed railway companies covered by this study. For this reason, a comparison was made with the profiles of the railway companies analyzed by Kuramoto and Hirota (2008), which are closer to the efficiency values. The results of the Kuramoto and Hirota (2008) analysis confirm the SEMBOKU: efficiency value of 1.09, TOYO-KOSOKU: efficiency value of 1.15, and OSAKA-KOSOKU: efficiency value of 1.78, which are within the range of efficiency values in this study. For ease of comparison, a simplified passenger-kilometer (a)/number of employees (b) value was calculated to calculate the output per employee (passenger-kilometers). Kuramoto and Hirota (2008) found that SEMBOKU is the most efficient third-sector railway company in their study. Table 22 shows that SEMBOKU is close to the trend in output per employee in this study, but the other third-sector railway companies do not fit the trend. This means that SEMBOKU has achieved efficiency levels close to those of private railway companies, while TOYO-KOSOKU and OSAKA-KOSOKU are not at the level of private railway companies in terms of efficiency and require further efficiency improvements.

It follows from this that the results of this study direct the analysis of Kuramoto and Hirota (2008) and confirm that the efficiency of privately listed railway companies is higher than the efficiency of third-sector railway companies.

Table 22 Comparison of the cost efficiency and profiles for this study and previous studies (Kuramoto and Hirota (2008)

Order	No	Company	Region	Cost efficiency of Average Value for "FY 2005–FY2020"	Operating Kilometers (km)	Number of Stations	Number of Rolling Stocks	Passenger-Kilometers (Million Passenger-Kilometers) (a)	Number of Employees in the Railway Sector (b)	(a)/(b)
19	26	NISHITETSU	KYUSHU	1.0841	106.1	72	311	1574	600	2.62
20	13	JR-CENTRAL	KANTO, CHUBU, GHUKYO, KANSAI	1.0875	1970.8	405	4827	63,427	18282	3.46
21	16	NANKAI	KANSAI	1.0880	154.8	100	696	3922	2195	1.78
-	-	SEMBOKU	KANSAI	1.09※	14.3	6	112	441	258	1.70
22	14	MEITETSU	CHUKYO	1.1096	444.2	275	1070	7260	4085	1.77
23	17	KINTETSU	KANSAI	1.1117	501.1	286	1933	10,590	7226	1.46
24	23	SANYO	KANSAI	1.1170	63.2	49	236	891	715	1.24
25	12	FUJIKYU	CHUBU	1.1397	26.6	18	33	48	254	0.18
-	-	TOYO-KOSOKU	KANTO	1.15※	16.2	9	110	552	304	1.81
26	24	HIRODEN	CHUGOKU	1.6046	35.1	82	300	197	1728	0.11
-	-	OSAKA-KOSOKU	KANSAI	1.78※	28.0	18	88	311	241	1.29

Note: The value of cost efficiency with ※ of SEMBOKU, TOYO-KOSOKU, and OSAKA-KOSOKU is cited from Kuramoto and Hirota (2008). Source (Endo and Goto 2024b)

3.3.4 Analysis 2-4 Measures for efficiency improvement

Here, I discuss methods to improve cost efficiencies during and after the COVID-19 pandemic. I propose the following measures to improve cost efficiency: For capital cost, companies can divest unneeded assets and business units by reviewing capital investment plans. Fuel costs can be reduced by reducing the number of railway cars while maintaining transportation capacity through efficient train operation. Labor costs can be reduced by reducing the number of staff through automation and mechanization by investing in information and digital technologies. For example, a reduction in the number of ticket counters at stations, a shift to ticketless smartphone applications (apps), online sales of travel products, and driver-only train operations can improve cost efficiency. Through these operations, railway companies need to adjust and elaborate on operating costs C_{it} and output (passenger-kilometers) Q_{it} to secure profits above the break-even point.

It should be noted that the percentage of local lines was not significant in the cost frontier estimation results in Table 16, which is probably because only four JR companies own local lines, meaning the impacts were diluted in the total average. However, issues related to local lines have become more serious, particularly since the COVID-19 pandemic. This is because JR was able to make operational profits in the railway sector through internal mutual aid among service areas, whereby the surplus in metropolitan areas covered the losses on local lines. However, after the pandemic, it became difficult for JR companies to cover the deficit on local lines with profits from metropolitan areas, as the number of passengers in metropolitan areas decreased sharply. If the number of railway users is extremely low and railway operations are inefficient for local lines, it may be effective to switch the mode of transport from transit to buses and tramcars, which can operate more efficiently in relation to the number of users.

Next, I examined the relationship between cost efficiency and the implementation of efficiency measures for each railway company. This is because it is important to examine what efficiency measures influence costs in companies to improve cost efficiency. For example, Sharma and Chauhan (2022) addressed timetable rationalization in an urban rail transit system, for which I need to consider human intervention to meet rising passenger demand in the form of ridership, and lowering the operational expenditure in terms of energy consumption during train operation. To explore the influence on cost and efficiency measures for Japanese railway companies, I surveyed IR information for each company in 2022 and organized the efficiency improvement measures into five groups (Table 23).

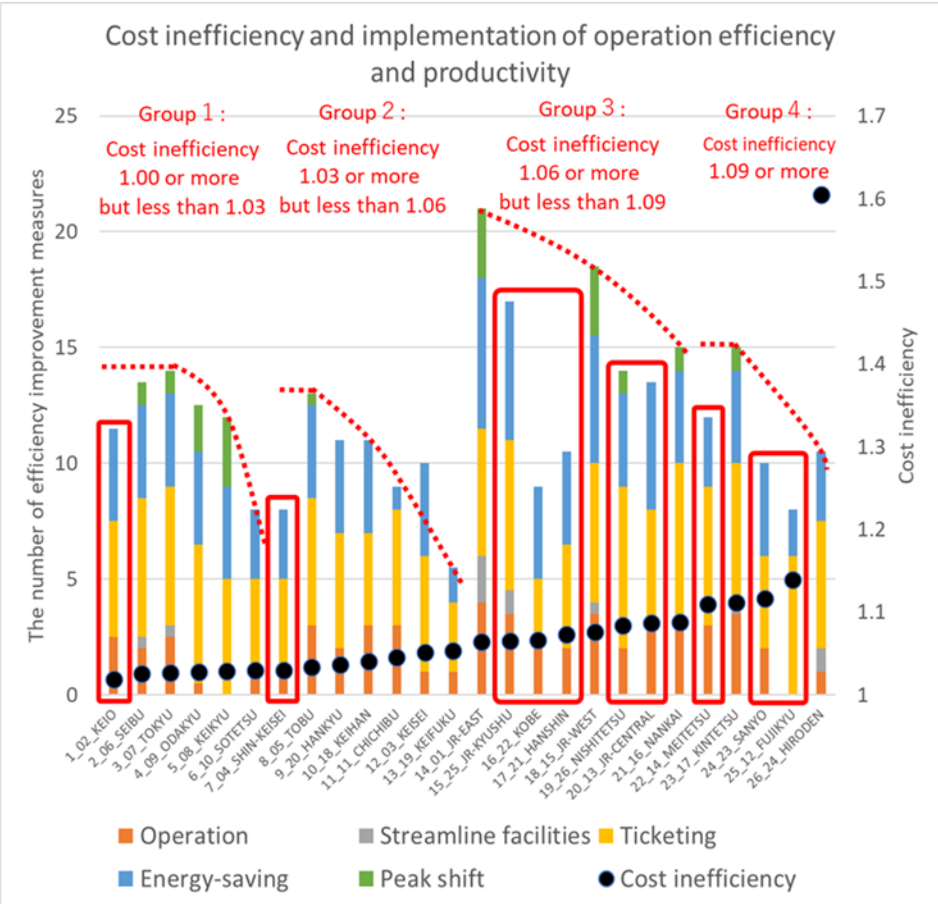
Table 23 Survey items on the efficiency improvement measures

Categorization of Efficiency Improvement Measures	Items of Efficiency Improvement Measures
Operation	• Autonomous driving • Driver-only operation (long trainset: more than three cars) • Driver-only operation (short trainset: less than two cars) • Station remote control systems (ticket counter•ticket vending machines)
Streamline facilities	• Wireless railway car control systems • Overhead contact line-less
Ticketing	• Prepaid transportation IC cards • Mobile prepaid transportation IC cards • Smartphone applications • Ticketless • QR code (payments, tickets) • Credit card payments • Electric money
Energy-saving	• Energy-saving railcars (Variable Voltage Variable Frequency (VVVF) inverter control, regenerative brake) • Battery powered railcar • Fuel cell railcar

	• Hybrid railcar (combined Internal-combustion engine and energy storage mechanism such as storage battery or flywheel or catenary and battery-powered hybrid railcar) • Energy-saving facilities (LED lighting, co-generation system, thermal barrier/insulation system, air conditioning energy-saving operation, energy-saving escalator or elevator, automatic power control by motion sensor, high-efficiency substation facilities, etc.) • Renewable energy (solar power, wind power, geothermal power, biomass, hydrogen energy, etc.) • Carbon-neutral plan
Peak shift (reduce the number of trains operating during peak periods)	• Providing information according to congestion level in real time • Commuter pass for off-peak use • Fare ticket or coupon ticket for off-peak use • Fare of off-peak use • Award points for off-peak use (each railway company's membership point service)

Note: Source (Endo and Goto 2024b)

Based on Table 23, Fig. 22 depicts the relationship between cost efficiency and the degree of implementation of efficiency improvement measures for each company.



Notes: 1: The number immediately before the company name indicates the original company list number in Table 14, and the heading number indicates the cost efficiency ranking. 2: Source (Endo and Goto 2024b)

Fig. 22 The results of a survey of each railway company's implementation of efficiency measures in 2022

The left vertical axis uses a cumulative bar graph to represent the number of efficiency improvement measures that have already been implemented, those scheduled to be implemented by the end of the fiscal year, and those undergoing demonstration testing. Specifically, the implemented items are given 1 point and 0.5 points for those currently being tested or scheduled for implementation, respectively. The cumulative bar graph comprises efficiency improvement measure categories (i.e., operation, streamlined facilities, ticketing, energy saving, and peak shift), allowing the user to visually grasp the implementation status of efficiency improvement measures for each category.

The vertical axis on the right-hand side shows cost inefficiency. On the horizontal axis, railway companies are listed from left to right in terms of decreasing cost efficiency. The cost efficiency was averaged for each railway company from FY 2005 to FY 2020.

In Fig. 22, the entire group is divided into four subgroups according to cost inefficiencies. Group 1 is defined as a cost inefficiency between 1.00 and higher but less than 1.03, Group 2 is between 1.03 and higher but less than 1.06, Group 3 is between 1.06 and higher but less than 1.09, and Group 4 is 1.09 or more.

Looking at the cost inefficiency and number of efficiency improvement measures taken by each company in a specific group, the dotted lines indicate an approximate trend from left to right for companies with the largest number of efficiency improvement measures to the smallest. This indicates that companies that implement more efficiency improvement measures have higher cost efficiency in each group. In this study, I define the dotted line connecting the values of efficiency improvement measures as the “Trend Line of the implementation of efficiency improvement Measures” (TLM).

In Fig. 22, the TLM for each group shows a decreasing trend from better efficiency (left) to worse efficiency (right), although some companies violate this trend and show much lower degrees of TLM implementation. Specifically, these companies are KEIO, SHIN-KEISEI, JR-KYUSHU, KOBE, HANSHIN, NISHITETSU, JR-CENTRAL, MEITETSU, SANYO, and FUJIKYU.

This indicates that the number of efficiency improvement measures implemented was lower than that of TLM for these companies. This suggests a favorable business environment, in which better cost efficiencies have been realized even without implementing many efficiency improvement measures. Therefore, if these companies implement more efficiency improvement measures in the future, their cost efficiency will further increase, suggesting they may belong to a higher rank or group. For example, SHIN-KEISEI (7th) and MEITETSU (22nd) could move from Group 2 to Group 1 and from Group 4 to Group 3, respectively, if they implement more efficiency increasing measures.

Furthermore, when I focus on the categories of efficiency improvement measures (operation, streamline facilities, ticketing, energy saving, and peak shift) in Fig. 22 almost all listed Japanese railway companies are implementing ticketing and promoting the digitalization of contact with customers, including the introduction of smartphone apps, ticketless service, and a variety of payment methods.

However, the measures that differ in terms of efficiency include operations, peak shifts, energy savings, and streamlined facilities. Companies that implement many of these methods tend to achieve higher efficiencies. For example, the top two companies in Group 3 are JR-EAST and JR-KYUSHU, for which many efficiency improvement measures have been implemented.

Next, I analyze the relationship between digital transformation (DX) investments and cost efficiency. According to Durand *et al.*'s (2023) investigation of the current situation and issues regarding the digitization of public transportation from the passenger's perspective, DX increasingly influences not only the public transport sector but also other sectors in various ways. Since the onset of the COVID-19 pandemic, many companies have been making efforts to transform their internal environments and business models through DX and create new value from them. Therefore, I focus on DX investments, particularly efficiency improvement investments, and examine their relationship with cost efficiencies.

Specifically, the details of each railway company's DX investment in 2022 were investigated using the following methodology. (1) From the financial results briefing materials of each railway company, I identified items related to DX among the capital investments planned by each company in 2022. I defined DX investment as items that include the keywords "DX", "Digital", "System", "Electronic", "Network", "Database", "Platform", "ICT", "MaaS", "App", "Smart", "Virtual", "Automation", "Robot", "AI", and "Remote." (2) I extracted relevant capital investments as DX investments. (3) For railway companies that did not have financial results, briefing materials, materials from general shareholders' meetings, and press releases of business plans for 2022 were used. The reason financial results briefing materials are used for (1) and (2) is that each railway company's priority capital investments are clearly described in these materials.

Table 24 shows survey items on the DX investment of Japanese listed railway companies.

Table 24 Survey items on the DX investment of Japanese listed railway companies

Categorization of DX investment	Items on the DX investment
Operation	・Autonomous driving or Driver-only operation ・Smart maintenance ・Customerservice automation ・Operational efficiency by DX ・Asset management
Streamline facilities	・Wireless railway car control systems
Ticketing	・Prepaid transportation IC cards ・Cashless ・Ticket-less or QR code ・Smart-phone payment ・Credit card touch payments
Customer database platform	・Common system Infrastructure development ・Applications ・Mobility as a Service (MaaS) ・Point service
Service	・Marketing analysis ・Travel Web reservation ・Banking services ・Real-digital hybrid shop ・EC Mall ・Digital service
New business	・Community symbiosis Business ・Digital business ・Open innovation

Note: Source (Endo and Goto 2024b)

Table 25, Table 26 and Table 27 shows the results of the survey of DX investment targets for each railway company in 2022. Measures marked with "○" indicate DX investment targets. The classification of the DX investment measures is based on Table 23. The three DX investment categories of "Operations," "Streamlines Facilities," and "Ticketing" are from the efficiency improvement measures in Table 23.

Moreover, three new categories, that is, "Customer database platform", "Service", and "New Business" are added which are deeply related to business model reform and establishment. Consequently, there are six categories. The purpose of DX investment is to provide a reasonable classification, considering its characteristics of DX investment, which serve as a foundation for companies to build new business models that adapt to future technological and social changes.

I then analyze the characteristics of DX investment targets for each of the four groups, as shown in Fig. 22. Group 1 is characterized by an even distribution of investment in operations (smart maintenance, customer service automation, operational efficiency by DX, Asset management), streamlined facilities, ticketing (cashless, ticket, smartphone payments), customer database platforms (common system infrastructure development, apps, Mobility as a Service (MaaS), point services), services (marketing analysis), and new business (regional symbiosis business, open innovation). The relatively low investment in overall services for Group 1 can be attributed to the fact that these companies have already invested in this area and are focusing on creating new services using customer databases by investing in operational efficiency and marketing.

Compared with Group 1, Group 2 shows no investment in operations (asset management) or ticketing; meanwhile, the emphasis is on investments in ticketless services and e-commerce malls. This suggests that services are still in the process of being digitized for the companies in Group 2. Compared with Groups 1 and 2, Group 3 shows more investment in ticketing (prepaid transportation IC cards), services (travel web reservation, digital service), and new business (digital business), indicating that they focus on existing services and not on marketing analysis. Group 4 shows less investment in ticketing, services, and new business than Groups 1, 2, and 3.

Considering that almost all Japanese listed railway companies have invested in customer database platforms, it can be inferred that companies with best cost efficiency (low cost inefficiency) have effectively linked their DX investments to earnings. In other words, these companies succeeded in securing profits by creating new services in cooperation with local communities. They thus effectively use their customer databases through proactive DX investments in marketing and asset management.

Table 25 DX investment items of Japanese listed railway companies in 2022 (Operation, Streamline facilities)

DX Investment Category				Operation					Streamline Facilities
Order	Group	No	Company Name	Autonomous Driving•Driver Only Operation	Smart Maintenance	Customer Service Automation	Operational Efficiency by DX	Asset Management	Wireless Railway Car Control Systems
1	1	02	KEIO		○	○		○	
2	1	06	SEIBU			○	○	○	○
3	1	09	ODAKYU	○	○			○	
4	1	08	KEIKYU			○	○	○	
5	1	05	TOBU	○		○	○		
6	1	07	TOKYU	○	○	○			○
7	1	10	SOTETSU		○	○	○	○	
8	2	04	SHIN-KEISEI						
9	2	20	HANKYU				○		
10	2	11	CHICHIBU						
11	2	18	KEIHAN	○	○	○	○		
12	2	01	JR-EAST	○	○	○	○		○
13	2	19	KEIFUKU						
14	2	03	KEISEI						
15	2	25	JR-KYUSHU	○	○	○	○	○	
16	2	15	JR-WEST	○	○	○		○	○
17	3	21	HANSHIN				○		
18	3	13	JR-CENTRAL						
19	3	22	KOBE						
20	3	16	NANKAI	○		○			
21	3	26	NISHITESU				○	○	

22		17	KINTETSU			○	○		○
23		14	MEITETSU	○	○	○		○	
24	4	23	SANYO				○		
25		12	FUJIKYU						
26		24	HIRODEN				○		

Note: Source (Endo and Goto 2024b)

Table 26 DX investment items of Japanese listed railway companies in 2022 (Ticketing, Customer database platform)

DX Investment Category				Ticketing					Streamline Facilities			
Order	Group	No	Company Name	Prepaid Transportation IC Cards	Cashless	Ticketless・QR Code	Smartphone Payment	Credit Card Touch Payments	Common System Infrastructure Development	Apps ※1	MaaS ※2	Point Service ※3
1		02	KEIO									○
2		06	SEIBU			○			○	○	○	
3		09	ODAKYU			○	○		○		○	○
4	1	08	KEIKYU		○				○		○	
5		05	TOBU			○				○	○	○
6		07	TOKYU						○	○		○
7		10	SOTETSU		○				○	○	○	○
8		04	SHIN-KEISEI							○		
9		20	HANKYU			○			○	○	○	○
10		11	CHICHIBU			○				○		
11	2	18	KEIHAN			○			○		○	○
12		01	JR-EAST	○		○			○	○	○	○
13		19	KEIFUKU		○					○		
14		03	KEISEI			○						

15		25	JR-KYUSHU			○			○	○	○	
16		15	JR-WEST	○	○		○		○	○	○	○
17		21	HANSHIN			○			○	○	○	○
18		13	JR-CENTRAL			○				○	○	○
19	3	22	KOBE									
20		16	NANKAI					○			○	○
21		26	NISHITETSU			○		○	○	○	○	
22		17	KINTETSU						○	○	○	○
23		14	MEITETSU							○	○	
24	4	23	SANYO								○	
25		12	FUJIKYU						○			
26		24	HIRODEN			○	○					

Notes: ※1: Applications (Apps). ※2: Mobility as a Service (MaaS). ※3: Railway loyalty program. Source (Endo and Goto 2024b)

Table 27 DX investment items of Japanese listed railway companies in 2022 (Service, New business)

DX Investment Category				Service						New business		
Order	Group	No	Company Name	Marketing Analysis	Travel Web Reservation	Banking Services	Real-Digital Hybrid	EC Mall	Digital Service ※4	Community Symbiosis Business	Digital Business	Open Innovation
1		02	KEIO			○				○		○
2		06	SEIBU	○						○		
3	1	09	ODAKYU	○	○					○		
4		08	KEIKYU							○		
5		05	TOBU	○				○		○		
6		07	TOKYU	○						○		○

7		10	SOTETSU						○			
8		04	SHIN-KEISEI									
9		20	HANKYU	○	○			○				
10		11	CHICHIBU									
11		18	KEIHAN	○				○		○		○
12	2	01	JR-EAST	○	○	○	○	○		○		○
13		19	KEIFUKU							○		
14		03	KEISEI									
15		25	JR-KYUSHU							○		
16		15	JR-WEST	○							○	○
17		21	HANSHIN	○	○							
18		13	JR-CENTRAL		○							
19	3	22	KOBE							○		
20		16	NANKAI		○				○	○		○
21		26	NISHITETSU					○	○	○	○	
22		17	KINTETSU		○		○		○	○	○	
23		14	MEITETSU							○	○	○
24	4	23	SANYO									
25		12	FUJIKYU									
26		24	HIRODEN									

Note: ※4: Digital service includes VR shop, Metaverse, Smart logistics. Source (Endo and Goto 2024b)

Chapter 4 Discussions

This chapter is based on Endo and Goto (2024a, 2024b), with additional analysis of other transportation sectors and a comparison and discussion of Japanese and European railway policies.

4.1 Profitability and business model analysis

The following are the answers to the research questions from this analysis.

Profitability and business model analysis

Analysis 1-1: Operational data analysis based on company groups from cluster analysis

(1) How much is the decrease in the number of railway passengers and the company's revenue?

The growth rate of the number of railway passengers in Japan in Japanese listed railway companies is at their lowest in 1Q FY2020 after the drastic decline from 4Q FY2019; the number of railway passengers is approximately 32% for the worst (most damaged) group and 62% for the best (relatively less damaged) group in 1Q FY2020 compared to the previous year. After the drop, Group 1 & 2 recorded the highest increase in 4Q FY2020, recovering to about 85% compared to the previous year, while the other groups present the highest in 3Q FY2021. In 3Q FY2021, it is 70% for the worst (most damaged) group and 82% for the best (relatively less damaged) group.

The growth rate of the number of railway transportation revenues in Japanese listed railway companies are the lowest in 1Q FY2020 after the drastic drop from 4Q FY2019, followed by an increase and a decrease in 1Q and 2Q FY2021, returning to an increase in 3Q FY2021. The growth rate of railway transportation revenue is approximately 30% to 56%. After the large drop, all groups fare the best in 3Q FY2021, when railway transportation revenues are approximately 65% to 78%.

Finally, after the COVID-19 pandemic in 3Q FY2023, the growth rate of the number of railway passengers is approximately 88% to 100% and the growth rate of railway transportation revenue is approximately 86% to 110% compared to 2019. The results indicate that this is approximately 90% of the pre-pandemic level. This figure would be the steady-state value of post-pandemic railway passengers and railway transportation revenues.

(2) What business segment is affected and unaffected by the COVID-19 pandemic?

The business segments that is affected by the COVID-19 pandemic are found to be Transportation-related businesses such as Transport (B1), Retail (B2), and Leisure (B4), the business segment that is unaffected by the pandemic are found to be the Non-transportation ones such as Real estate (B3), Construction (B5), and Logistics (B7).

Analysis 1-2: Analysis of management strategies to countermeasure the COVID-19 pandemic

(1) What is the difference in the feature of management strategy between profitable companies and loss-making companies?

I found that the profitable companies shift to the Non-transportation business segment to reduce the impact of the COVID-19 pandemic, whereas the loss-making companies focus on business strategies of the traditional OPR-type businesses, that is, Transportation-related businesses including Retail and Leisure. Further, profitable companies show some evidence of strategic management for corporate sustainability, such as financial strategies and ESG management. Additionally, I suggest that profitable companies are accurate in forecasting the variable components of their earnings estimates.

I observed minor revenue structures changing Retail, Real estate, and Leisure in Groups 1 & 2, 3, and 6, but other groups did not show significant changes in revenue structure over the study period. I expected that our revenue structure would change significantly after the pandemic, but in reality, there have been no major changes in our revenue structure. In 3Q FY2019, a majority of business segments were profitable, but in 3Q FY2021, the only profitable segment was Non-transportation businesses. Additionally, I found that the management strategy of profitable Japanese railway companies changed the revenue structure of the business to Non-transportation to adapt to the Japanese economic environment. From the above discussion, the managerial novelty is that the profit structure of railway companies cannot easily be changed solely by external factors such as a pandemic. On the other hand, in companies where changes in the profit structure were observed, the results showed that the profit structure would not change unless management decided a top-down change in management strategy and revised business segments in response to the pandemic situation.

In sum, Japanese railway companies need to shift their revenue from Transportation-related businesses to Non-transportation businesses and minimize their losses due to the COVID-19 pandemic. This business portfolio is robust against the pandemic and able to support the company. From the result of the relationship between management strategies and profits, the profitable companies had diversified their business before the pandemic and they were able to make profits in Non-transportation businesses such as real estate and construction, which covered the losses in the transportation businesses, resulting in making profits. In addition, the business segments have been reviewed and revised as appropriate to suit the business situation such as disasters and pandemics, for example by integrating less profitable business segments into more profitable business segments.

Generally, Japanese railway companies develop annual, medium-term (three to five years ahead) and long-term (ten years ahead) targeted business strategies. Unless there is a significant event, it is unlikely that there will be a sudden reorganization of business segments. Therefore, it is difficult to achieve results in FY2021 even if changes to the management strategy are launched in FY2020 due to the COVID-19 pandemic. When traditionally diversified companies restructure their business segments or carry out mergers and acquisitions, the effects may be visible in the following year, but they are emergency measures. In general, depending on the size of the business, many new business launches take several years to prepare, and many of the effects are not seen immediately in the following year. For this reason, several railway companies are reviewing their medium-term management strategies for FY2020 or FY2021.

Here, I analyze how business segments have been reorganized in major Japanese railway companies. Table 28 shows major 18 Japanese railway companies coped with the COVID-19 pandemic developed post-pandemic management strategies and reorganized business segments. Table 28 shows that during the COVID-19 pandemic, there were two main types of business segment reorganizations.

Type 1: Emergency reorganization (one company).

Type 2: During the next medium-term management plan period (five companies).

The fact that the company that made the urgent reorganization did not wait until the next medium-term management plan was formulated to reorganize their business segments suggests that the reorganization was deemed urgent. The motivation for this urgent change is thought to be a sense of urgency by management regarding the situation of the business crisis. This one company is SEIBU, whose Hawaii operations were integrated into the Hotel and Leisure business in May 2020. Type 2 is further divided into the following two categories.

Type 2 (a): The next medium-term management plan reflects the post-COVID-19 pandemic management policy (four companies).

Type 2 (b): Cancel the original medium-term management plan and formulate a new medium-term management plan (one company).

In both types, it was confirmed that the post-COVID-19 pandemic management strategy is reflected in the plan. Therefore, rather than originally intending to reorganize business segments, the intent to reorganize into more profitable business segments was confirmed as a result of the COVID-19 pandemic.

Table 28 Major 18 Japanese Railway Companies Coped with the COVID-19 Pandemic and Developed Post-Pandemic Management Strategies and Reorganized Business Segments (publicly disclosed)

Company name	Target year of long-term management plan	Medium-term management plan as of 2019	Period of first recognition of revenue loss due to the COVID-19 pandemic	Time of making public of tentative management plan	Tentative revision of the medium-term management plan	Next midium-term management plan	Time of business segment reorganization	Business segment reorganization type	Source
JR-EAST	-	2018 - 2027	4Q FY2019	Apr 2020	Sep 2020 Jan 2021 Apr 2023	-	-	-	(JR-EAST 2020a, 2021a, 2023)
KEIO	-	2015 - 2020	4Q FY2019	Jun 2020	Mar 2021	2022 - 2024	-	-	(KEIO 2020, 2021b, 2022)
KEISEI	2030	2019 - 2021	4Q FY2019	-	-	2022 - 2024	-	-	(KEISEI 2022)
TOBU	2033	2017 - 2020	4Q FY2019	Jul 2020	-	2022 - 2024	Apr 2022	Type 2 (a)	(TOBU 2020, 2022)
SEIBU	2035	2019 - 2021	4Q FY2019	May 2020	-	2021 - 2023	May 2020	Type 1	(SEIBU 2020a, 2021)
TOKYU	2030	2018 - 2020	4Q FY2019	-	-	2021 - 2023	-	-	(TOKYU 2021b)
KEIKYU	2035	2016 - 2020	4Q FY2019	Aug 2020 Feb 2021	-	2021 - 3023	-	-	(KEIKYU 2020a, 2021a, 2021b)
ODAKYU	-	2017 - 2019	4Q FY2019	-	-	2021 - 2023 2023 - 2026	-	-	(ODAKYU 2021, 2023)
SOTETSU	2030	2017 - 2019	4Q FY2019	Apr 2020 Oct 2020	-	2022 - 2024	-	-	(SOTETSU 2020a, 2020b, 2021b)
JR-CENTRAL	-	-	4Q FY2019	Oct 2020	-	-	-	-	(JR-CENTRAL 2020)
MEITETSU	2030	2018 - 2020	4Q FY2019	-	-	2021 - 2023	-	-	(MEITETSU 2021b)
JR-WEST	2032	2017 - 2022	4Q FY2019	Apr 2020	Nov 2020	2023 - 2025	Apr 2023	Type 2 (a)	(JR-WEST 2020a, 2020b, 2023)
NANKAI	2027 (- 2020) 2050 (2021 -)	2018 - 2020	4Q FY2019	May 2020 Nov 2020	-	2021 2022-2024	-	-	(NANKAI 2020a, 2020b, 2021b, 2022)
KINTETSU	2033	2019 - 2023	4Q FY2019	Nov 2020	-	2021 - 2024	May 2022	Type 2 (b)	(KINTETSU 2020, 2021b, 2022)
KEIHAN	2026 (- 2022) 2030 (2023 -)	2018 - 2020	4Q FY2019	May 2020	Nov 2020	2023 - 2025	-	-	(NANKAI 2020a, 2020b, 2023)
HANKYU-HANSHIN	2040	2018 - 2021	4Q FY2019	May 2020	-	2022 - 2025	Apr 2022	Type 2 (a)	(HANKYU-HANSHIN 2020, 2022)
JR-KYUSHU	2030	2019 - 2021	4Q FY2019	May 2020	Nov 2020	2022 - 2024	Apr 2022	Type 2 (a)	(JR-KYUSHU 2020a, 2020b, 2022)
NISHITETSU	2035	2019 - 2021	4Q FY2019	May 2020 Nov 2020 May 2022	May 2020	2023 - 2025	-	-	(NISHITETSU 2020a, 2020c, 2022b, 2023)

Note: Business segment reorganization type

Type 1: Irregular Response, Type 2: During the next mid-term management plan

Type 2 (a): The next mid-term management plan reflects the post-COVID-19 pandemic management policy.

Type 2 (b): Cancel the original medium-term management plan and formulate a new medium-term management plan.

I can conclude that while profitable companies are posting profits in their core businesses, loss-making companies are not doing so. In other words, profitable companies can generate profits from their core businesses, as they are succeeding in their businesses based on the management policies they have formulated and implemented. However, loss-making companies have not been able to generate profits as expected from their core businesses and must either strengthen their core businesses or develop new businesses to generate profits, that is, they may not be thinking beyond their existing businesses.

The results indicate that the profitable companies focused more on the Non-transportation businesses in terms of business and financial strategies, whereas loss-making companies remained focused on their strategies in the traditional Transportation-related businesses. In other words, profitable companies have changed their management strategies in response to the COVID-19 pandemic, focusing on highly profitable business segments suitable for the post-pandemic period, based on finance-based corporate management, perhaps even trying to reconsider management strategies from the perspective of the corporate brand, organization, finance, and business segments due to the COVID-19 pandemic crisis.

In terms of the response to the COVID-19 pandemic and after COVID-19, the difference was that OPR companies were able to cover their losses by strengthening Non-transportation businesses even when moving to city centers was restricted due to voluntary curfews because they were developing along railway lines, whereas JR companies were mainly developing city centers of Tokyo and hub cities (such as Yokohama, Chiba, Saitama etc.,), so they were unable to cover their losses through related businesses when travel was restricted. JR-EAST and JR-WEST are changing their business strategies significantly. For example, JR-EAST has set a goal of a 5:5 revenue ratio between transportation and Non-transportation businesses. Since the change in management strategy does not result in a drastic change in revenues, it is thought that the change in management strategy does not appear to be a change in appearance. Therefore, it is important to understand customer needs and the current situation and to formulate management strategies (e.g., promotion and investment) to close the gap between the business goal (ideal) and the business strategy.

The analysis also showed that profitable companies are characterized not only by their management strategies but also by the accuracy of their earnings forecasts for profits. This may be related to the accuracy of forecasting uncertainties in Transportation-related business due to the pandemic. The results of these analyses indicate that, as a management strategy, profitable companies structure a sustainable business portfolio that takes pandemic risk into account and forecasts earnings with a high level of accuracy.

In Japan, the following moves are being made to maintain public transportation, especially railways, after the COVID-19 pandemic:

・Reduction of railway operating costs and introduction of new technology

(Introduction of automated driving systems, ticketing systems by Information Technology (IT), diversification of payment systems)

・Shift of railway passengers during rush hours and introduction of new fare system

(Introduction of off-peak commuter passes, additional fare for enhanced barrier-free facilities)

・Small-scale logistics services on high-speed railway

・Change of transportation modes in areas with declining population (Light Rail Transit (LRT), Bus Rapid Transit (BRT), Buses, Cabs)

・Separation of infrastructure ownership in the public sector and operating railway companies

・Change of train power energy (Storage batteries, hydrogen energy)

Railway operators are required to maintain the public transportation network and compensate for the revenue decline with the Non-transportation business, which is a growth business field.

Finally, this cost and profitability analysis should be used to manage the railway company, in the event of an emergency such as the COVID-19 pandemic or disaster, it is necessary to quickly assess the current situation and minimize the impact of the revenue loss. Therefore, management needs to analyze the revenue/profit structure by business segment, strengthen profitable segments in the short term, take action to minimize the impact by considering countermeasures for profitable segments, and review management policies on a zero-based basis to achieve the ideal business goal in the medium to long term. However, since there is a gap between the ideal management strategy and reality (actual revenues), I think it is important to formulate a strategy for efficient return on investment by realizing users' well-being by providing services that match user needs through the utilization of customer information bases and asset management through the use of DX.

To evaluate the appropriateness of a decision, the profit forecasts and actual results shown in Fig. 15 and Fig. 16 are compared, and if there is no discrepancy, the decision is judged to be appropriate; if there is a significant discrepancy, the gap between the ideal and the reality is judged to have occurred. In such cases, it is necessary to identify customer needs accurately. In terms of selection and concentration of business segments, if a company is profitable in its core business (in the case of a railway company, the railway business) and is expected to grow in the future, it would be better to strengthen the core business and invest aggressively to improve services in the railway business.

However, assuming that events such as the COVID-19 pandemic that could rapidly change society will occur in the future, railway companies shouldn't concentrate solely on their core business of railway from the view of management risk. The same situation is expected to occur again. Considering business risk aversion, the composition of business segments should be considered from the following three perspectives

・Transportation-related business and Non-transportation businesses

・Real and virtual

・Urban and local area

Ideally, if one business incurs a loss, the other business should generate a level of profit that can cover the loss.

I think that the goal is to realize a business model that is geared toward the future ideal of the community and users, including after-COVID-19 well-being lifestyles, DX, and ESG management, through a management strategy that has been reviewed from the ground up. Railway companies, in particular, are closely related to people's lives. It is no exaggeration to say that they are involved in all aspects of people's lives from morning to night, including commuting to work and school, office buildings and commercial facilities in urban areas, residential land development along railway lines, supermarkets, and convenience stores. To realize the well-being of users along railway lines, the goal should be to enrich people's lives by enhancing lifestyle-related services centered on the comfortable use of railways. To realize value enhancement along the railway line through these services, an appropriate composition of Transportation-related and Non-transportation business segments will enable railway companies to run sustainable businesses. In the future, it is expected that a stronger business model will be established by developing a solid management base not only in urban areas but also in rural areas by innovating a new business model that solves regional issues by utilizing AI, DX, and automated driving technologies. Advances in DX are making local area migration possible through telework. Migrants from urban areas may use the railways to come to work in urban offices several times a month or may seek urban-like goods sales and other services while residing in local areas. There is a possibility to approach such migrants to provide urban-like services in local areas. The strength of railway companies is their ability to connect rural and urban areas by rail and their ability to approach business from both real and virtual perspectives.

In addition, railways have the advantage of transporting tourists as well as people for daily life. By building a business model that maximizes the attractiveness of cities and rural, I believe the business model can be strengthened through a more diversified and composite business model.

4.2 Cost efficiency analysis (Stochastic Frontier Analysis)

Cost efficiency analysis (Stochastic Frontier Analysis)

Analysis 2: Cost efficiency analysis

(1)How much is the cost efficiency of listed Japanese railway companies and how much is affected by the COVID-19 pandemic?

The average cost efficiency of listed Japanese railway companies from 2005 to 2021 is 1.0771. During the COVID-19 pandemic in 2020, the value of cost efficiency was lower for all railway companies, it worsened by 0.1123 points on average of listed Japanese railway companies compared to 2019. I expected that companies with larger companies and higher operating profits would be more efficient, but the results were different. I found that the increase in cost efficiency of the KANTO region's railway companies was less than other region's railway companies. In other words, this shows that the deterioration in the cost efficiency of railway companies in the Kanto region due to the effects of the pandemic was less than that of railway companies in other regions.

(2) What are the characteristics of best-practice Japanese railway companies?

The result of the analysis showed that the best practice railway company is KEIO. The characteristics of best-practice Japanese railway companies indicate they have a good business environment for example a large population along the railway. The best practice railway companies indicate that passengers made fewer long-distance trips because they refrained from inter-prefectual travel during the pandemic.

Railway companies were arranged in order of cost efficiency and divided into four groups, it was found that within each group, they were arranged in order of the number of efficiency measures implemented.

I obtained the suggestions from the analysis results of Study 2 as follows.

(1) Characteristics of best practice companies: good business environment (high population density along the railway line), large number of short-distance railway passengers, scale of the railway line (route length approximately 130km)

(2) Efficiency: railway companies that implement many efficiency measures have a higher efficiency ranking.

(3) Best practice companies invested in DX to improve cost efficiency (Customer service automation, Asset management, Common system infrastructure development, Community symbiosis business).

4.3 Comparison of other transportation

Next, I compare railways with other modes of transportation (airline and bus). The survey covered listed Japanese companies: four airline companies and six bus companies.

Table 29 summarizes the survey companies for airlines and bus companies and Fig. 23 shows a map of service areas and head office locations for each company.

Table 29 Summary of the survey for Japanese listed airline and bus companies

No.	Company name	Type	Head office location	Service area	Business segment (Main business in 3Q FY2023: Underlined business segment)
A-01	JAPAN AIRLINES (JAL)	Airline	TOKYO	Domestic (133 routes), International (66 routes)	Airline
A-02	ALL NIPPON AIRWAYS (ANA)	Airline	TOKYO	Domestic (143 routes), International (49 routes)	Airline, Travel, Trading, Related-Airline
A-03	SKYMARK AIRLINES	Airline	TOKYO	Domestic (24 routes)	Airline
A-04	STAR FLYER	Airline	KITA-KYUSHU	Domestic (5 routes), Internatinal (2 routes)	Airline
B-01	HOKKAIDO CHUO BUS	Bus	OTARU	HOKKAIDO	Bus, Real Estate, Leisure, Construction, Security
B-02	NIGATA KOTSU	Bus	NIGATA	CHUBU(NIGATA)	Bus, Retail, Real Estate, Leisure, Hotel
B-03	KANAGAWA CHUO KOTSU	Bus	HIRATSUKA	KANTO(TOKYO, KANAGAWA)	Bus, Real Estate, Automobile sales
B-04	MIE KOTSU	Bus	TSU	CHUKYO(MIE)	Transportation, Retail, Real Estate, Leisure
B-05	SHINKI BUS	Bus	HIMEJI	KANSAI(HYUGO)	Bus, Real Estate, Leisure, Travel, Automobile sales
B-06	DAIICH KOTSU SANGYO	Bus	KITA-KYUSHU	OKINAWA	Bus, Taxi, Real Estate, Finance

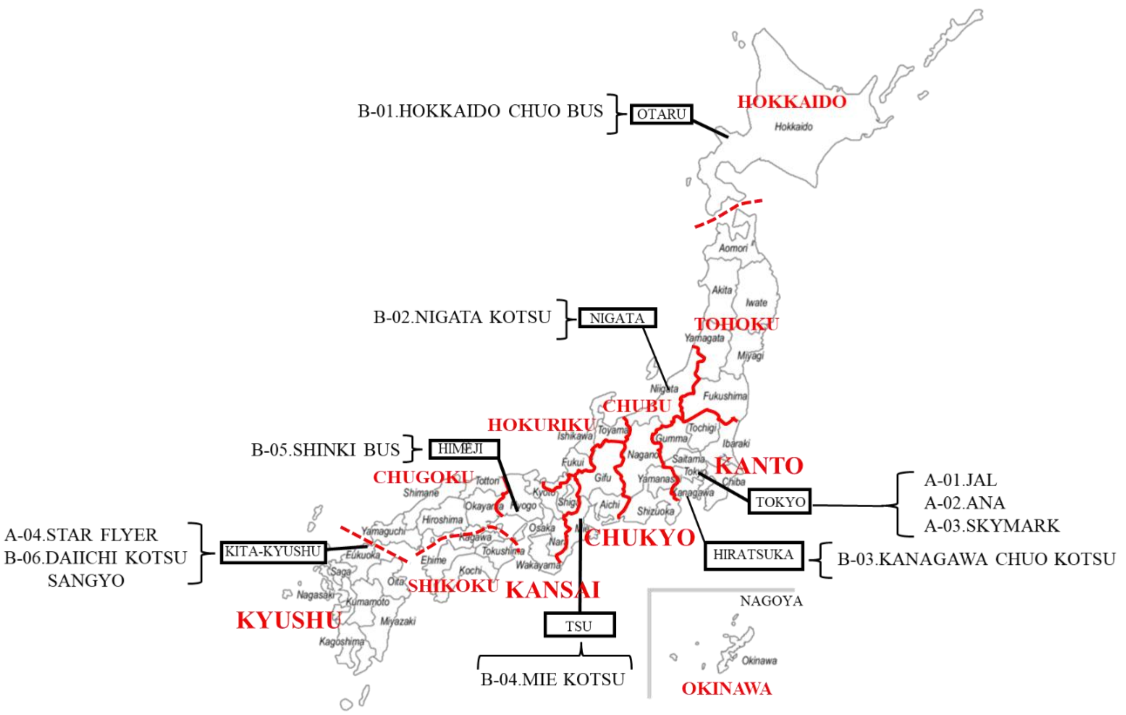
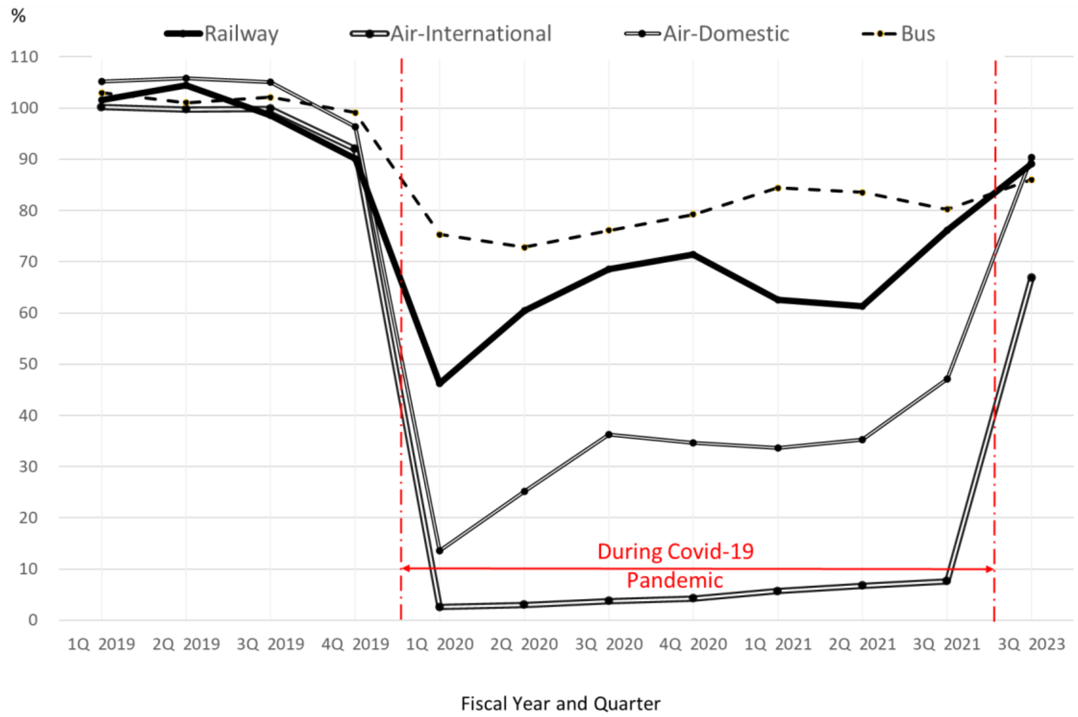


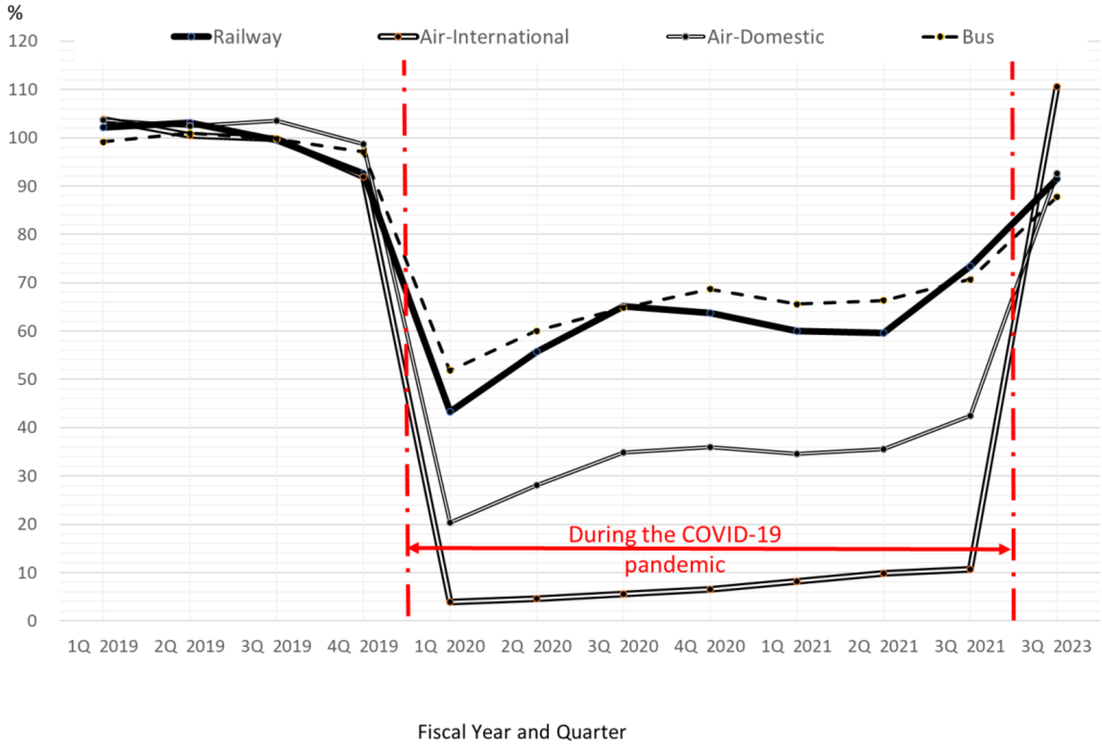
Fig. 23 Map of service areas and head office location for Japanese listed airline and bus company



Note: FY2021 and FY2023 shows the comparison to FY2019

Fig. 24 Comparison of group-averaged growth rates from previous years of the number of passengers (railway, airline, and bus)

I compared the change in the average number of people transported by railway and other railway sectors, airlines, and buses. Fig. 24 shows the comparison of group-averaged growth rates from previous years of the number of passengers. Each section figure is an averaged number of each categorized company. All sectors are at their lowest in 1Q FY2020; the number of passengers is approximately 3% for the worst sector of International airlines and 75% for the best sector for buses compared to the previous year. During the COVID-19 pandemic (from 1Q FY2020 to 3Q FY2021), international airline is approximately 3% to 8%, domestic airline is approximately 14% to 47%, bus is approximately 73% to 84% and railway is approximately 46% to 76%. Finally, after the COVID-19 pandemic in 3Q FY2023, international airline is 68%, domestic airline is 93%, bus is 86% and railway is 89%.



Note: FY2021 and FY2023 shows the comparison to FY2019

Fig. 25 Comparison of group-averaged growth rates from previous years of transportation revenues (railway, airline, and bus)

Fig. 25 shows the comparison of group-averaged growth rates from previous years of transportation revenues. All sectors are at their lowest in 1Q FY2020; the number of passengers is approximately 4% for the worst sector of international airlines and 52% for the best sector for buses compared to the previous year. During the COVID-19 pandemic (from 1Q FY2020 to 3Q FY2021), international airline is approximately 4% to 11%, domestic airline is approximately 20% to 42%, bus is approximately 52% to 71% and railway is approximately 43% to 74%. Finally, after the COVID-19 pandemic in 3Q FY2023, international airline is 113%, domestic airline is 94%, bus is 89% and railway is 92%.

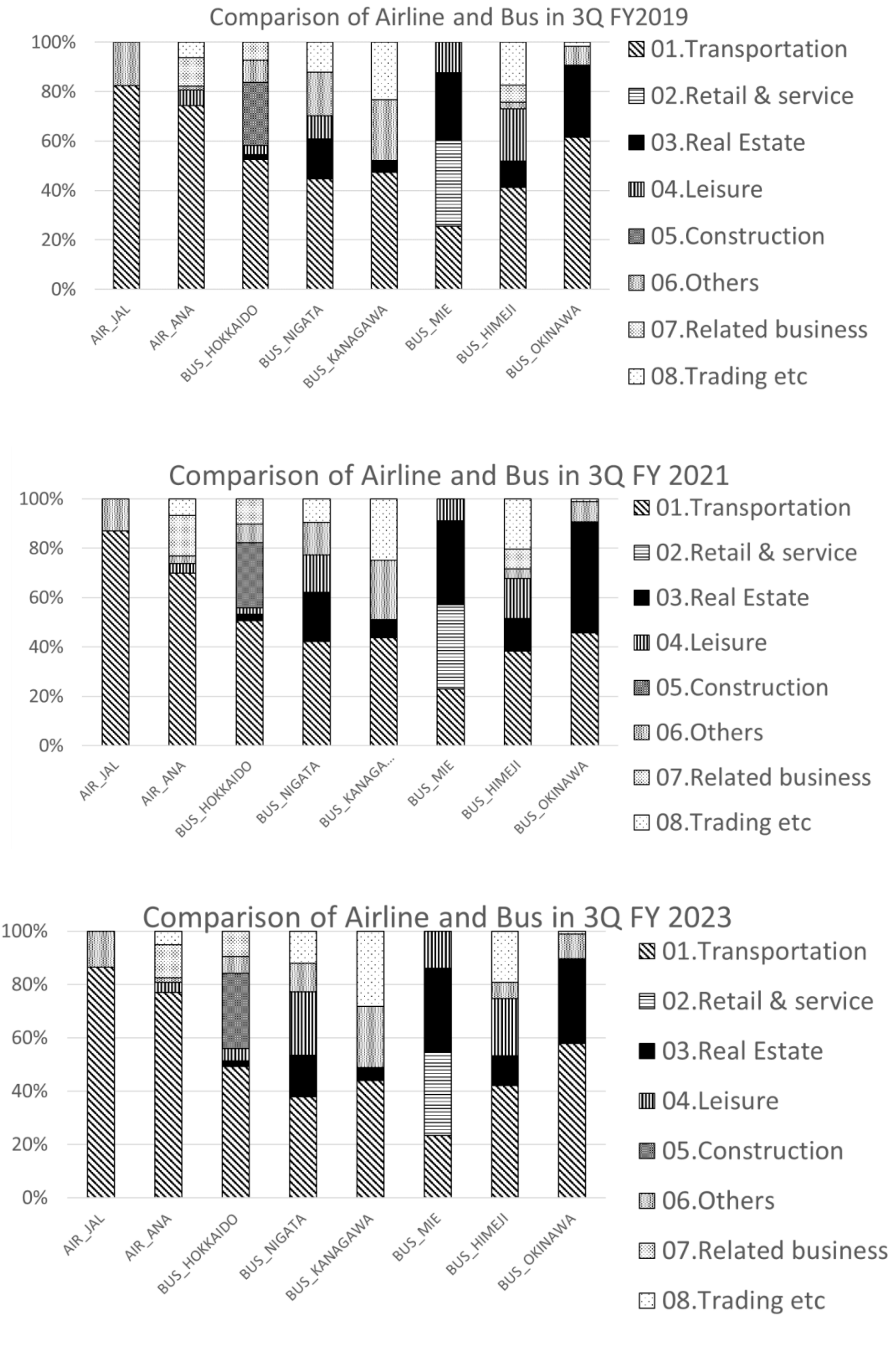


Fig. 26 Comparison of averaged revenue composition (railway, airline, and bus) by business segment in 3Q FY2019, 3Q FY2021, and 3Q FY2023

Fig. 26 shows the Comparison of averaged revenue composition (railway, airline, and bus) by business segment in 3Q FY2019 (upper panel), 3Q FY2021 (middle panel), and 3Q FY2023 (lower panel). Here, the definitions of Transportation-related and Non-transportation businesses are the same as those of railway companies. I define a Transportation-related business as one that occurs when railway users move, and a Non-transportation business as one that can be established even when railway users do not move.

A texture legend with horizontal or vertical lines indicates Transportation-related business segments, such as Transportation (B1), Retail (B2), and Leisure (B4), while the filled legend indicates Non-transportation business segments such as Real estate (B3), Construction (B5), Related business (B7), and Trading, etc (B8). All sectors show a minor change in their revenue structure from 3Q FY2019 to 3Q FY2021 and 3Q FY2023. I observed major revenue structure changes in airline and bus companies.

Fig. 27 shows a Comparison of averaged profit composition (railway, airline, and bus) by business segment in 3Q FY2019 (upper panel), 3Q FY2021 (middle panel), and 3Q FY2023 (lower panel). Before the COVID-19 pandemic in 3Q FY2019, NIGATA, and HIMEJI bus transport segments were loss-making. During the COVID-19 pandemic in 3Q FY2021, same as railway companies, Transportation-related business (B1, B2 and B4) is loss-making and Non-transportation ones (B3, B5, B6, B7 and B8) is profitable. Because airline companies don’t have a Non-transportation business, Airline companies were shown to have had difficult management during the COVID-19 pandemic. Bus companies showed almost the same trend as railway companies.

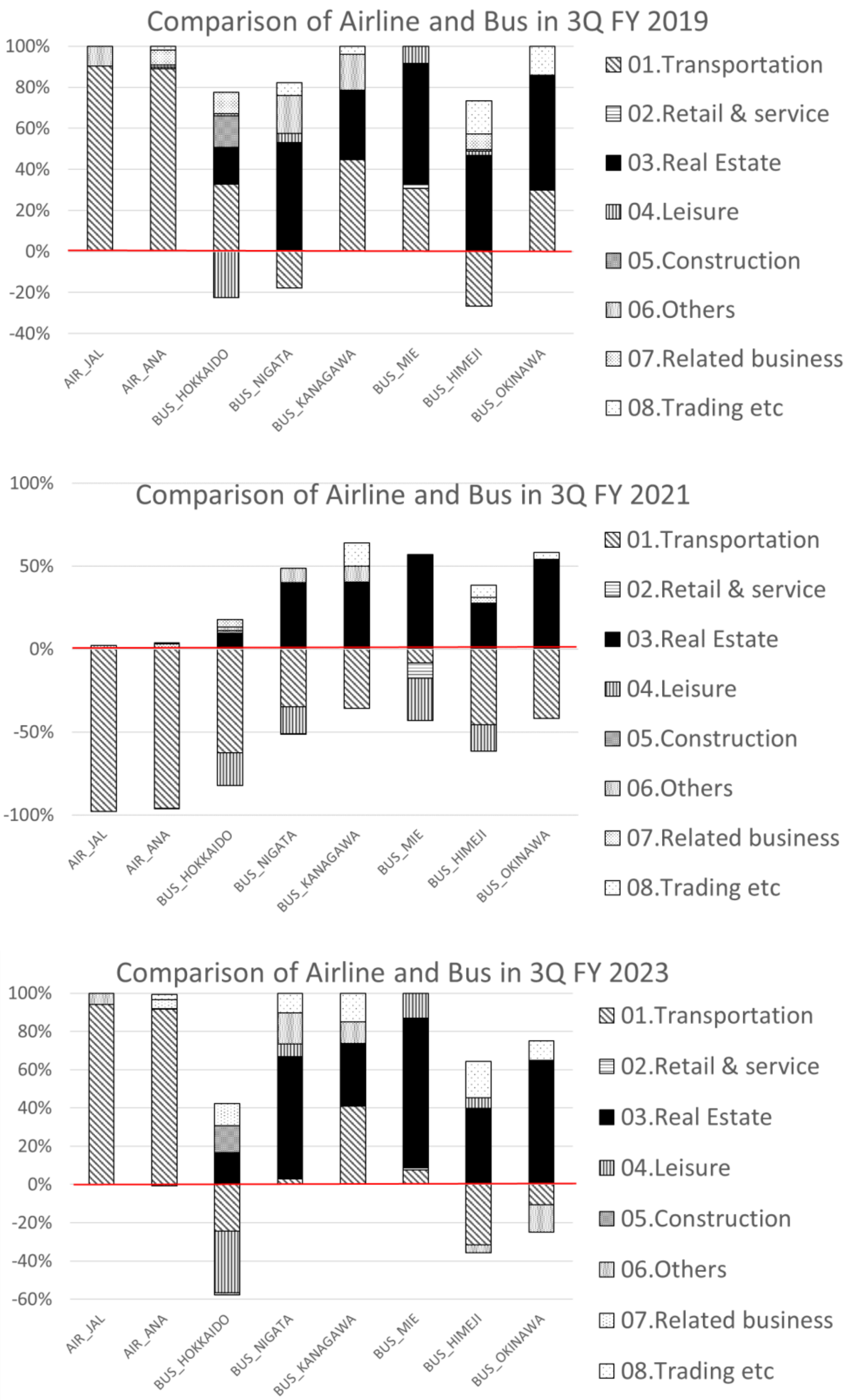


Fig. 27 Comparison of averaged profit composition (railway, airline, and bus) by business segment in 3Q FY2019, 3Q FY2021, and 3Q FY2023

After the COVID-19 pandemic in 3Q FY2023, airline and bus companies of NIGATA, KANAGAWA, MIE, and HIMEJI recovered before the pandemic level. However, the bus companies of HOKKAIDO and OKINAWA didn't recover before the pandemic level. This can be attributed to the effects of the declining population and shortage of drivers that have become apparent in Japan since the COVID-19 pandemic.

These analysis results indicate that compared with the railway sector, bus companies show similar trends in terms of the number of passengers, revenue, revenue structure, and profit structure, whereas in the airline business, profits from almost of Transportation-related businesses This indicates that if a pandemic occurs, no business segment can secure profits, and a prolonged pandemic may make it difficult for companies to survive. Airlines are not diversified in their business, and a pandemic would increase their business risk.

The results show that the railway companies had diversified their business before the pandemic and could cover the losses in the transportation business with profit from Non-transportation businesses. In addition, profitable companies have reviewed their business situation accordingly by integrating low-profit business segments into more profitable business segments. Thus, it was shown that the business diversification of railway companies also contributes to pandemic business risk avoidance.

4.4 Comparison of other countries

Next, I compare other countries. Table 30 shows a comparison of the percentage decline in railway passengers by country. It shows that passengers decreased by 70-90% for the public transport sector and by 40-60% for the railway. I assume that the proportion of decline is larger than for the railway alone because public transport includes trams, buses, and taxis other than the railway. I expected to see differences between regions but found the same overall trend. Therefore, I could not find any distinctive differences between the countries I studied and Japan in terms of the rate of decline in the number of railway passengers**.** The study also showed that the decline in the number of railway users is not a unique feature of Japan.

Table 30 Comparison of the percentage decline in railway passengers by country

Location	Period	Transportation mode	Reduction rate	Source
Spain	Mar 2020	Public transportation	93%	Aloi *et al* (2020)
Switzerland	2020	Public transportation	More than 90%	Melloy *et al* (2021)
China	2020	City public transportation	More than 90%	Xin *et al* (2021)
New York	2020	City transportation	80%	Rejput *et al* (2021)
Chicago	2020	Public transportation	72%	Hu and Chen (2021)
Northern Italy	2020	Railway	40-60%	Grech and Ceron (2022)
Hong Kong	Jan-Mar 2020	Subway (commuter)	42%	Zhang *et al* (2021)
Japan	Apr-Jun2020	Railway	54%	Fig. 24

Then, I discuss railway policy in response to the decline in railway passengers due to the COVID-19 pandemic. Table 31 shows the differences in Japanese and European railway policy since the COVID-19 pandemic

Table 31 Differences in Japanese and European railway policy since the COVID-19 pandemic

Year	Japan	Europe
2020	・Employment adjustment grants (special provisions for the impact of new coronavirus infections) ・"Go to travel" travel promotion: Distribution of coupons	
2021		・"European Year of Rail" Sustainable Mobility promotion ・New transport proposals target greater efficiency and more sustainable travel
2022	・"National travel support" Travel promotion: Distribution of coupons	
2023	・'Full implementation of "Act to amend part of the Act on the Revitalisation and Revitalisation of Regional Public Transport, etc."	・France government bans short-haul flights to cut carbon emissions ・Trans-European transport network (TEN-T): Council and Parliament strike a deal to ensure sustainable connectivity in Europe

Source: European Commission (2020),(2021),(2023), British Broadcasting Corporation (2023), Ministry of Health, Labour and Welfare, Government of Japan (2020), Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan (2020c), (2023) and Japan Tourism Agency (2022).

In Japan, employment adjustment subsidies were provided to companies that adjusted employment due to the COVID-19 pandemic for the period 1 April 2020 to 30 November 2022. This is a government subsidy to help with the impact on business caused by the declaration of a state of emergency and by people refraining from leaving their homes. The “Go to travel” campaign was launched to stimulate travel demand. Consumers who purchased a package tour were given a coupon or other incentive equivalent to half of the price of the tour, subsidized by the Government. (up to a maximum of 20,000 Yen/night per person), which started on 22 July 2020 but was suspended on 28 December 2020 due to an increase in the number of people infected with COVID-19. It was later reinstated as “National Travel Support” from 11 October to late December 2022, but the discount rate was changed to 40%, up to 8,000 Yen/night, and the coupons provided to 3,000 Yen on weekdays and 1,000 Yen on holidays. Then, the "Act to amend part of the Act on the Revitalisation and Revitalisation of Regional Public Transport, etc." came into full force on 1 October 2023. The main content is that (1) the government supports initiatives such as the “re-design” of regional public transport. (2) Local authorities or railway operators may request the Minister of Land, Infrastructure and Transport to organize a “restructuring council” to discuss the state of local railways. (3) When consultation between local stakeholders has been reached, fares can be set by notification to the Minister of Land, Infrastructure, and Transport. (4) New comprehensive social capital development grants can be used to support the construction of rail and bus facilities that are integrated with urban development. This has implications such as the expansion of the system to make it easier for local railways with fewer users to review their reorganization into other transport modes.

Meanwhile, in Europe, 2021 was the ‘European Year of Rail’ with events throughout the year to stimulate demand for railway use. One example is the ‘Connecting Europe Express’, which tours the capitals of each member state to promote the attractiveness of railway travel. In 2021, the European Commission proposed that “New transport proposals target greater efficiency and more sustainable travel”. As part of the “European Green Deal”, the decarbonization of passenger transport in scheduled services within 500 km by 2030, and the doubling and 1.5 times the current passenger and railway on the high-speed railway by 2030 and tripling and doubling respectively by 2050. In addition, the government also aims to utilize digital technology to promote the integrated use of multiple modes of transport through electronic ticketing, paperless freight transportation, and the large-scale practical application of automated driving technology by 2030. In 2023, France government banned domestic short-haul flights where train alternatives exist, in a bid to cut carbon emissions. In December 2023, the Council presidency and European Parliament's negotiators reached a provisional agreement on a revised regulation regarding EU guidelines for the development of the trans-European transport network (TEN-T). This is the TEN-T initiative, an EU-wide network of four transport networks-railway, inland waterways, short sea routes, and roads-connecting 424 major cities, ports, airports, and rail terminals, enabling travel speeds of more than 160 km/h on the main TEN-T railway network by 2040, and creating a high-speed railway network. The 424 metropolitan cities are also required to develop a Sustainable Urban Mobility Plan, which is based on zero-emission mobility and emphasizes public transportation, walking, and cycling. Thus, European railway policy is strongly oriented towards carbon neutrality in 2050 and is rational and linked not only to rail but also to environmental and transport mobility policies.

Interestingly, the government has banned short-haul air routes in France, which is considered a rational approach considering the high level of awareness of environmental issues in Europe, France's focus on the development of the SNCF high-speed rail network, and the conflicts with investment in railways.

The main difference between Japanese and European railway policy is that railway services are seen as part of the public infrastructure in Europe, whereas in Japan they are seen as a service of the railway operators. This is also the case for other modes of public transport. Therefore, as far as policies are concerned, the stance in Japan is to support railway operators and local authorities, and the "Go to travel" campaign assists with subsidies to travel-related operators and local authorities due to travel demand, and to convert local railways, whose users have decreased due to the COVID-19 pandemic, to other modes of transport. The main focus is on institutional development for this purpose. On the other hand, in Europe environmental measures are a priority and the policy is to improve the infrastructure of railways and other transportation modes, in contrast to Japan, where the goal is to improve the railway network in the future.

Japanese railway officials should learn from Europe, where policies are considered from a complex and long-term perspective from the viewpoint of energy policy and transportation infrastructure development, including aviation, shipping, roads, and logistics. Comprehensive transportation policies should be considered in collaboration between private operators and the public sector, to solve Japan's social issues, such as future population decline and maintaining rural livelihoods, food problems, and energy issues.

In Japan, on the other hand, the problems of declining population and labor shortages have been exposed after the COVID-19 pandemic. Labor shortages have also led to a reduction in the number of services due to crew shortages on local railways (Japan Broadcasting Corporation (2023)) and urban bus routes such as the KANTO region (Japan Broadcasting Corporation (2024)). Therefore, it is envisaged that sustainable operations will become difficult for railway companies to diversify their businesses alone. Efforts to improve the efficiency of transport operations will be essential in the future. In particular, the introduction of DX, such as automated driving and digitization of customer service, will be necessary to overcome labor shortages, and innovations will be required to make operations and maintenance unmanned.

In local areas where transport operations are regularly at a loss-making, there is a limit to the efficiency of private companies alone, so a future-proof comprehensive transport policy that includes not only public transport but also roads and logistics, is desirable. In depopulated areas such as local areas, due to the insufficient number of both service providers and service recipients, conflicts among railways, buses, taxis, private cars, and logistics may lead to a mutual collapse, and the area may become a transportation service-less area. If this happens, depopulation could accelerate. As a countermeasure, it is necessary to share the roles of railways, buses, taxis, private cars, and logistics so that the resources of the service providers can be utilized to the maximum extent possible, and to maintain transport services in the region sustainably.

Finally, I discuss the business and public nature of railway companies. Until now, JR and OPR companies have continued to operate local lines based on the concept of internal subsidies, in which revenue from profitable lines covers the loss-making of local lines. However, as shown in the analysis results due to the pandemic, revenue from profitable lines is now at about 90% of the pre-pandemic level, making internal subsidies difficult to provide. In addition, natural disasters such as floods and earthquakes are increasingly causing huge construction costs to restore damaged infrastructure. Under the "Act to amend part of the Act on the Revitalisation and Revitalisation of Regional Public Transport, etc." enacted in 2023, local lines with a transport density (average number of passing passengers) of less than 1,000 are allowed to discuss the continuation of their routes with the local governments along the lines, and whether or not the number of users exceeds 1,000 is the government's position on the continuation of railways. However, when considering public transportation, conversion to buses and shared cabs may not be possible due to labor shortages, and if reliance on cars and ride-sharing services becomes the norm, there will be more areas where public transportation does not exist and depopulation will increase due to transportation disparities. More efficient public transportation could be realized by using AI for transportation mode planning and operation schedule planning, and by utilizing DX such as MaaS and automated driving.

Rather than simply choosing to abolish local railways, we need to consider the continuation of railways as the main public transportation system in the region, effectively utilize railways for logistics and tourism, etc., and create a new next-generation business model that can cover the loss-making in the transportation business through the creation of compact cities centered on stations, tourism promotion, energy, agriculture, forestry, fisheries and water resource businesses, interactive businesses between urban and rural areas, etc., and logistics and DX. If this is successful, it can be fed back to urban areas.

Specifically, the following businesses could be considered

(i) Interactive businesses between urban and local areas

Agricultural and marine products from local areas are transported by railway and sold in urban areas; vice versa, products from urban areas are sold in local areas.

In addition, the development of tourism that takes advantage of the uniqueness of a region's nature, culture, and history will attract visitors from urban areas and inbound tourists.

(ii) Businesses that solve Japan's social problems by utilizing local industries

Businesses that solve issues such as food self-sufficiency, securing water resources, and energy problems through the creation of local industries.

(iii) Business to sustain local areas

To make it possible to sustainably maintain society in local areas with declining populations, AI, DX, and automation technologies will be used in businesses related to compact city development, business consolidation, and lifeline consolidation. In addition, provides a place of residence to people's targeted lifestyles through the promotion of teleworking and local areas migration through the development of DX and workcations.

If profitability is expected, the railway operator can conduct these businesses as a stand-alone business, and if profitability is difficult to secure, it can be realized by partnering with local start-up companies, investing in start-up companies, or collaborating with local governments to conduct publicly supported businesses.

I propose the possibility of a next-generation business model that aims to increase revenues in urban areas by enhancing urban value and international competitiveness, while in local areas, private operators and the public sector work together to ensure profitability through a new diversification model, rather than considering private operators' railways alone. By utilizing the framework of this study, efficiency and profitability can be efficiently analyzed. It can then be used to help consider new business models.

Chapter 5 Conclusions

Based on Japanese listed railway companies' investor relations information, in Chapter 2, I analyzed the impact of the COVID-19 pandemic on the decline in their revenues and found changes in their profit structures. I also conducted a text analysis of the differences in management strategies between profitable and loss-making companies and explored what management strategies characterize profitable companies. The companies' passenger transportation revenues showed a drastic drop from 4Q FY2019 to 1Q FY2020, hitting the lowest level, and increased thereafter. I observed a minor change in the revenue structure in business segments such as Retail, Real estate, and Leisure. Before the pandemic, all business segments were profitable, but after the pandemic, only Non-transportation businesses were profitable, and Transportation-related businesses turned loss-making. The managerial novelty is that the profit structure of railway companies and other transport companies (airlines and buses) does not easily change solely due to external factors such as a pandemic. On the other hand, the revenue structure changed company's results showed that the profit structure would not change unless management decided to change management strategy or review business segments in a top-down decision in response to the pandemic.

The findings suggest that a sustainable profit structure for private railway companies, post-pandemic, would require effectively strengthening the Non-transportation segment that generates enough revenue to compensate for the loss-making segments. This would be consistent with the diversification benefits that previous studies refer to. Furthermore, to continue running a sustainably profitable business, railway companies should review their management strategy from the perspective of the corporate brand, organization, finance, and business segments beyond existing and established ideas and patterns.

Cost efficiency analysis applied a stochastic frontier analysis using a Cobb-Douglas cost function to the data on 26 listed Japanese railway companies from 2005 to 2020 to understand their cost efficiencies before and after the COVID-19 pandemic. I also analyzed the changes in cost efficiency during the pandemic. This study aimed to provide railway company managers with a quantitative understanding of their company's management and useful information for developing management strategies to improve efficiency. To this end, the following specific analyses were conducted. (i) Quantified the deterioration in the efficiency of Japanese private railway companies due to the COVID-19 pandemic. (ii) Presented the characteristics of the size and profit status of the best-practice railway companies. (iii) Identified the relationship between cost efficiency and efficiency measures and investments by railway companies. I found that the best-practice railway companies are KEIO and TOKYU. The main reason for its good performance is that operates in and near the Tokyo metropolitan area, which is densely populated. Most Japanese railway companies showed the highest cost efficiency in 2014 and the lowest in 2020, that is, during the COVID-19 pandemic. The second-worst occurred in 2009, when affected by the financial crisis. However, I did not observe a significant impact of the 2011 Great East Japan Earthquake. This is because no railway company was influenced by the earthquake in this operating area, except for JR-EAST. The deterioration of cost efficiency due to the pandemic varied depending on the railway company. I found that highly cost efficient companies succeeded in securing profits through the creation of new services in cooperation with the local community by making effective use of customer databases through proactive DX investments in marketing and asset management.

The novelty of this research is that it established a method for quantitative analysis of revenue and profit by business segment of railway companies due to the impact of the

COVID-19 pandemic from IR information. Then, I added the knowledge of business segments susceptible/unsusceptible to the pandemic and added the knowledge of corporate risk aversion measures against unexpected situations such as a pandemic in railway companies.

The three theoretical contributions of this study are as follows:

The first is to propose a method for quantitatively evaluating changes in the number of railway passengers and revenues. The second was to propose a method for quantitatively analyzing businesses that are more or less susceptible to the pandemic. The third was to propose a method for qualitatively analyzing business strategies of railway companies that generate profits and those that post profits and losses through text analysis.

The insight of this research found that the number of railway passengers after the pandemic remained at 60-80% and has not returned to normal at 80-90% after the convergence, the composition of revenue by business segment showed little change (total amount decreased but its composition remained the same), while Transportation-related businesses (transportation, retail, and leisure) were more affected by the pandemic, while Non-transportation businesses (real estate, construction, logistics, and ICT) were less affected. The distinction between profitable and loss-making is determined by whether or not the loss-making in the Transportation-related business is covered by the profitable in the Non-transportation business.

I found that profitable companies are characterized by a shift to Non-transportation business segments, whereas loss-making companies focus on business strategies in traditional Transportation-related businesses such as retail and leisure. Furthermore, I found that profitable companies are not business-based, but rather have strategies for corporate sustainability, such as financial strategy and ESG management. In addition, I found that profitable companies were characterized by more accurate earnings forecasts. This indicates that profitable companies can generate profits from their core business because they successfully conduct their business based on the management policies they have formulated and implemented. The loss-making companies are not able to generate profits from their core business as they would like and need to either strengthen their core business or develop new businesses to generate profits, which means that they may be trapped within the confines of their existing businesses.

This thesis proposes a framework that integrates quantitative and qualitative analysis, which can be used to efficiently assess current conditions and formulate management strategies in the event of sudden changes in the business environment, such as pandemics and disasters. The framework proposed in this paper is shown in Fig. 28.

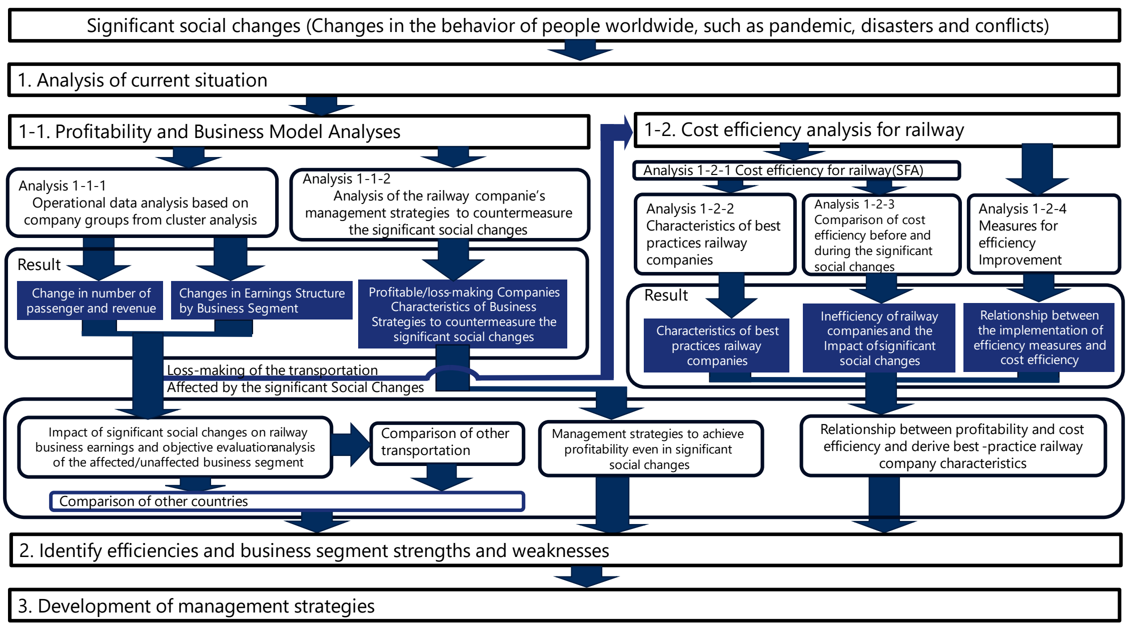


Fig. 28 The framework of evaluation of railway companies

The results of this study enable managers of railway operators or public sector policymakers to conduct quantitative analysis to assess the impact of a global pandemic, dispute, or natural disaster such as the COVID-19 pandemic on railway operations in the event of a severe impact, to examine business segment configurations to avoid risk and to estimate future railway user prosecutions. It can also be used for subsidies and other support from the public sector to railway operators as well as private railway companies, and policy development. This can be thought of as replacing the business segment with the public sector. In Europe, there have been existing studies comparing the efficiency of privatization of the railway sector (from national railways to private companies), but there have been no existing studies analyzing changes in efficiency since privatization, so I think that this research can be applied to other countries in understanding changes in efficiency since privatization and changes due to the impact of the COVID-19 pandemic. I also think that the research can be applied to the public sector in terms of changes in the efficiency of railway operations and measures to improve efficiency. In particular, by quantitatively evaluating changes in railway passengers and revenues, and using the methodology of this research to predict future changes in railway passengers and revenues, it can be used to review the profit structure of railway operators and to calculate when the public sector provides subsidies to railway operators.

In addition, this research can be used by railway company management and railway policymakers in the formulation of management strategies to improve cost efficiencies in the event of worse cost efficiencies due to a deteriorating business environment.

The limitations of this study are as follows. In Chapter 2, first, for the proposed quantitative analysis method, the suggestions obtained are limited to Japanese listed railway companies, since data from Japanese railway companies are used. Regarding text analysis, I was able to demonstrate one method of analysis, but this is not all. Other methods need to be considered. Second, the data used for the text analysis was constrained to be Japanese-language text prepared for shareholders and investors, because the data was obtained from Japanese-language IR materials. The suggestions obtained are useful for Japanese railway companies or public sector operators with multiple business segments that seek to avoid operational risks. However, they are limited to the management structure of the Japanese railway business, given the history of railway business development, and the conditions of Japanese railway policy.

Finally, Cluster analysis was conducted on panel data on return on sales from Q1 FY2017 to Q3 FY2021. This indicator shows net profit as a percentage of sales. The analysis was conducted by grouping groups with similar trends in return on sales. The average standard deviation for each group is 6.1% in terms of the growth rate of railway passengers 6.3% in terms of profit composition rate in 3Q FY2019 and 38.4% in 3Q FY2021. The after-pandemic profit composition rates have varied widely from company to company. For this reason, the analysis was based on using group averages and checking individual company data when a peculiar trend is observed.

In Chapter 3, first, the data used in this study were from railway companies in Japan. It is necessary to use other nations/areas' data to examine the generality and validity of the results of this study. Second, this study should benefit from conducting an extended factor analysis to integrate variables of efficiency measures. Third, the population density data used in this study were at the prefectural level. For a more detailed analysis, it is necessary to use data at the municipal level. Fourth, the efficiency improvement measures and DX investment survey items were obtained from a broader range of available data. More focused and appropriate evaluation items need to be selected depending on the target of the analysis. These are all future tasks of this study.

Five issues remain to be addressed in future research. First, although this study focuses on the management policies of profitable and loss-making companies, it is necessary to analyze management efficiency and productivity issues as well. Second, since the text analysis of management policies could only be conducted from a general perspective in this study, a more detailed analysis, of each business segment, may be necessary. Third, sustainable business models may be explored by conducting detailed analyses of the number of passengers and transportation revenues in the transportation business, of business activities in segments other than the transportation business, and business areas with growth potential. Fourth, I must extend the data to examine cost inefficiencies. In this study, it was not possible to analyze the correlation between operating profit and cost inefficiency for the railway sector owing to data availability, but it would be possible to analyze the correlation in more detail if cost inefficiencies from 2021 onwards could be calculated. Last issue, I must conduct an extended factor analysis of inefficiency. As some factors are not significant, I must consider other possible external factors that influence the cost efficiency of railway companies.

In concluding this doctoral thesis, I would like to point out that after the COVID-19 pandemic, Japan has entered an era of declining population, and new social issues have arisen, such as the problem of the discontinuation of local railway lines and other living infrastructure due to population decline in local areas. In this era of declining population, there is an urgent need to develop business models that can ensure profitability even in local areas. I would like to conclude with the hope that these problems will be solved through innovation and that railway companies will continue to run a sustainable business in our daily life infrastructure through new business models.

Acknowledgments

Thank you to everyone who helped, guided, and supported me during my doctoral studies. First, I would like to thank my supervisor, Professor Mika Goto, who without her assistance, patience, and support this doctoral thesis could not have been completed. I have learned a lot under her supervision, such as how academic research is done, how to summarize the results of my analysis in a paper, advice on submitting to international journals, and many other things in research throughout MOT and this doctoral studies.

I would also like to express my appreciation to the members of my research review committee, Professor Masaharu Tsujimoto, Professor Mayuko Nakamaru, Professor Eiichiro Kimura, and Professor Kazutoshi Sasahara, who kindly offered me their constructive recommendations, advice, and useful implications.

I would like to thank the members of Goto Laboratory for their useful advice and encouragement. I would also like to extend my appreciation to the members of my company for their understanding of my doctoral studies.

Finally, I would like to give special thanks to my parents, my wife, and my son for their mental support and encouragement throughout MOT and my doctoral studies. It is so appreciated, thank you.

References

Aigner, D., Lovell, C. A. K., and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models, *Journal of Econometrics*, 6(1), 21-37.

Aloi, A., Alonso, B., Benavente, J., Cordera, R., Echániz, E., González, F., Ladisa, C., Lezama, R. R., López, P. Á., Mazzei, V., Perrucci, L., Prieto, Q. D., Rodriguez, A., and Sañudo, R. (2020). Effects of the COVID-19 Lockdown on Urban Mobility: Empirical Evidence from the City of Santander (Spain), *Sustainability*, 12 (9), 3870.

Altieri, M., Raskova, E., and Costa, A. (2022). Differences in railway strategies: The empirical case of private, public-owned, and third-sector railways in Tokyo, *Research in Transportation Business & Management*, 43, 100787.

Alvesson, M., and Sandberg, J. (2011). Generating Research Questions through Problematization, *The Academy of Management Review*, 36 (2), 247-271.

Amornkitvikai, Y., O'Brien, M., and Bhula-or, R. (2024). Toward green production practices: Empirical evidence from Thai manufacturers' technical efficiency, *Journal of Asian Business and Economic Studies*, Available online: https://doi.org/10.1108/JABES-05-2023-0151 (accessed on 6 July 2024).

Asmild, M., Holvad, T., Hougaard, J. L., and Kronborg, D. (2009). Railway reforms: Do they influence operating efficiency?, *Transportation*, 36, 617-638.

Baryshnikova, N., Kiriliuk, O., and Klimecka, T. D. (2021). Enterprises' strategies transformation in the real sector of the economy in the context of the COVID-19 pandemic, *Production Engineering Archives*, 27 (1), 8-15.

Battese, G. E., and Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data, *Empirical Economics*, 20, 325-332.

Battese, G., and Coelli, T. (1996). Identification of factors which influence the technical inefficiency of Indian farmers, *Australian Journal of Agricultural Economics*, 40(2), 103-128

Bergantino, A. S., Intini, M., and Volta, N. (2021). The spatial dimension of competition among airports at the worldwide level: A spatial stochastic frontier analysis, *European Journal of Operational Research*, 295, 118–30.

Bonanno, G., and Domma, F. (2022). Analytical Derivations of New Specifications for Stochastic Frontiers with Applications, *Mathematics*, 10, 3876.

Bourjade, S., and Muller-Vibes, C. (2023). Optimal leasing and airlines' cost efficiency: A stochastic frontier analysis, *Transportation Research Part A*, 176, 103804.

British Broadcasting Corporation (BBC). (2023). France bans short-haul flights to cut carbon emissions. Available online: https://www.bbc.com/news/world-europe-65687665 (accessed on 16 November 2024).

Bulková, Z., Dedík, M., Lovíšek, M., Janošková, K., and Vaculík, J. (2023). Increasing the quality and efficiency of the transportation process in railway passenger transport in the case of another pandemic period, *Transport Technic and Technology*, 19, 7–12.

Cabinet Office, Government of Japan. (2022a). Gross Domestic Product classified by Economic Activities (at current prices). Available online: https://www.esri.cao.go.jp/en/sna/data/kakuhou/files/2021/2021annual_report_e.html (accessed on 15 January 2023).

Cabinet Office, Government of Japan. (2022b). Prefectural Gross Domestic Product (2011-2021). Available online: https://www.esri.cao.go.jp/jp/sna/data/data_list/kenmin/files/contents/main_2021.html (accessed on 4 November 2024).

Catalano, G., Daraio, C., Diana, M., Gregori, M., and Matteucci, G. (2019). Efficiency, effectiveness, and impacts assessment in the rail transport sector: A state-of-the-art critical analysis of current research, *International Transactions in Operational Research*, 26, 5-40.

Chan, C. L., McAleer, M., and Wong, W. K. (2020). Risk and Financial Management of COVID-19 in Business, Economics and Finance, *Journal of Risk and Financial Management*, 13, 102.

Chauhan, R., Bhagat-Conway, M., Magassy, B. T., Corcoran, N., Rahim, E., Dirks, A., Pendyal, M. R., Mohammadian, A., Derrible, S., and Salon, D. (2024). COVID Future panel survey: A unique public dataset documenting how U.S. residents' travel-related choices changed during the COVID-19 pandemic, *Transportation*. Available online: https://doi.org/10.1007/s11116-024-10479-4 (accessed on 5

June 2024).
CHICHIBU. (2022). Press Release (27 January 2022), Kumagaya: Chichibu Railway Co., Ltd. Available online: https://www.chichibu-railway.co.jp/assets/newsrelease/20220127_ICcard.pdf (accessed on 10 July 2024).
Chiscano, C. M., and Darcy, S. (2022). An accessible and inclusive public transportation management response to COVID-19 through a co-creation process with people with disability. The case of Metro Barcelona, *Research in Transportation Business & Management*, 45, 100880.
Chung, Y. S., and Chiou, Y. C. (2023). On the efficiency of subsidized bus services in rural areas: A stochastic metafrontier approach, *Research in Transportation Business & Management*, 46, 100811.
Coelli, T. (1996). A guide to FRONTIER Version 4.1: A computer program for stochastic frontier production and cost function estimation, *CEPA Working Paper,* pp.22.
Couto, A., and Graham, D. (2009). The determinants of efficiency and productivity in European railways, *Applied Economics,* 41(22), 2827–2851.
Diener, E., Oishi, S., and Tay, L. (2018). Advances in subjective well-being research, *Nature Human Behavior*, 2, 253-260.
Durand, A., Zijlstra, T., Hamersma, M., Hoen, A., van Oort, N., Hoogendoorn, S., and Hoogendoorn-Lander, S. (2023). Fostering an inclusive public transport system in the digital era: An interdisciplinary approach, *Transportation Research Interdisciplinary Perspectives,* 22, 100968.
Endo, H., and Goto, M. (2024a). The impact of the Covid-19 pandemic on the management of private railway companies in Japan: Profitability and business model analyses, *Transport Policy*, 147, 33-49.
Endo, H., and Goto, M. (2024b). Cost Inefficiency of Japanese Railway Companies and Impacts of COVID-19 Pandemic and Digital Transformation, *Economies*, 12, 196.
Erdei, L., Tamás, P., and Illés, B. (2023). Improving the Efficiency of Rail Passenger Transportation Using an Innovative Operational Concept, *Sustainability*, 15, 5582.
European Commission. (2020). Promoting Sustainable Mobility: Commission proposes 2021 to be the European Year of Rail. Available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_364 (accessed on

16 November 2024).

European Commission. (2021). New transport proposals target greater efficiency and more sustainable travel. Available online: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6776 (accessed on 16 November 2024).

European Council. (2023). Trans-European transport network (TEN-T): Council and Parliament strike a deal to ensure sustainable connectivity in Europe. Available online: https://www.consilium.europa.eu/en/press/press-releases/2023/12/18/trans-european-transport-network-ten-t-council-and-parliament-strike-a-deal-to-ensure-sustainable-connectivity-in-europe/ (accessed on 16 November 2024).

Faber, R., Hamersma, M., Brimaire, J., Kroesen, M., and Molin, J. E. E. (2023). The relations between working from home and travel behaviour: A panel analysis, *Transportation.* Available online: https://doi.org/10.1007/s11116-023-10401-4 (accessed on 5 June 2024).

Farinloye, T., Mogaji, E., Aririguzoh, S., and Kieu, T. (2019). Qualitatively exploring the effect of change in the residential environment on travel behavior, *Travel Behavior and Society*, 17, 26-35.

Filippini, M., Koller, M., and Masiero, G. (2015). Competitive tendering versus performance-based negotiation in Swiss public transport, *Transportation Research Part A: Policy and Practice*, 82, 158-168.

Forchini, G., and Theler, R. (2023). Semi-parametric modelling of inefficiencies in stochastic frontier Analysis, *Journal of Productivity Analysis*, 59, 135–52.

Fraczek, B., and Urbanek, A. (2021). Financial inclusion as an important factor influencing digital payments in passenger transport: A case study of EU countries, *Research in Transportation Business & Management*, 41, 100691.

Friebel, G., Ivaldi, M., and Vibes, C. (2010). Railway (de)regulation: A European efficiency comparison, *Economica*, 77, 77–91.

Fukui, Y., and Oda, K. (2012). Discussion paper: Who should take responsibility for unexpected interest changes? Lesson from the privatization of Japanese railroad system, *Networks and spatial economics*, 12, 263-278.

Galli, F. (2023). A spatial stochastic frontier model introducing inefficiency spillovers, *Applied Statistics*, 72, 346–67.

Gorzelany, D. M. (2021). COVID-19: Business Innovation Challenges, *Sustainability*, 13 (20), 11439.

Grechi, D., and Ceron, M. (2022). Covid-19 lightening the load factor in railway transport: Performance analysis in the north-west area of Milan, *Research in Transportation Business & Management*, 43, 100739.

HANKYU. (2021). Press Release (2 February 2021), Osaka: Hankyu Corporation. Available online: https://www.hankyu-hanshin.co.jp/release/docs/0015f1a66bbcab7d76b2eab4c826f6780b7e6f5d.pdf (accessed on 10 July 2024).

HANKYU-HANSHIN. (2020). Presentation materials of financial results (14 May 2020), Osaka: Hankyu Hanshin Holdings, Inc. Available online: https://www.hankyu-hanshin.co.jp/release/docs/b780025fb96d80688d9f95b46bf8ebb8e6f7b1eb.pdf (accessed on 31 December 2024).

HANKYU-HANSHIN. (2022). Press Release (20 May 2022), Osaka: Hankyu Hanshin Holdings, Inc. Available online: https://www.hankyu-hanshin.co.jp/release/docs/59784f37b901cb4e7c355f867f64fa76cfe5961b.pdf (accessed on 31 December 2024).

HANSHIN, (2021). Press Release (12 February 2021), Osaka: Hanshin Electric Railway Co., Ltd. Available online: https://www.hankyu-hanshin.co.jp/release/docs/f34b37234313316be2d8c0e291d103b1f84c12fb.pdf (accessed on 10 July 2024).

Holmgren, J. (2013). The efficiency of public transport operations: An evaluation using stochastic frontier analysis, *Research in Transportation Economics*, 39, 50-58.

Holmgren, J. (2018). The effects of using different output measures in efficiency analysis of public transport operations, *Research in Transportation Business & Management*, 28, 12-22.

Holvad, T. (2020). Efficiency analyses for the railway sector: An overview of key issues, *Research in Transportation Economics*, 82, 100877.

Hussain, Z., Huo, C., UI-Haq, J., Visas, H., and Umair, M. (2024). Estimating the effects of income inequality, information communication technology, and transport infrastructure on transport-oriented household expenditures, *Transportation.*

Available online: https://doi.org/10.1007/s11116-024-10486-5 (accessed on 5 June 2024).

Hu, S., and Chen, P. (2021). Who left riding transit? Examining socioeconomic disparities in the impact of COVID-19 on ridership, *Transport. Res. Part D. Transport Environ*, 90, 102654.

Ichijo, Y. (2020). JR East, JR West to start last train runs up to 30 minutes earlier, *The Asahi Shimbun.* Available online: https://www.asahi.com/ajw/articles/13697072 (accessed on 1 July 2024).

Ichijo, Y. (2021). JR East rolls out point service for commuting in off-peak hours, *The Asahi Shimbun*. Available online: https://www.asahi.com/ajw/articles/14146729 (accessed on 1 July 2024).

Ishida, M. (2020). JR Kyushu to reduce train service due to plummeting demand amid pandemic, *The Mainichi.* Available online: https://mainichi.jp/english/articles/20200827/p2a/00m/0na/008000c. (accessed on 1 July 2024).

Jansson, E., Olsson, O. E. N., and Oskar, F. (2023). Challenges of replacing train drivers in driverless and unattended railway mainline systems—A Swedish case study on delay logs descriptions, *Transportation Research Interdisciplinary Perspectives*, 21, 100875.

Japan Broadcasting Corporation (Nippon Hoso Kyokai: NHK). (2023). “20% reduction in services” - manpower shortages faced by regional railways. Available online: https://www3.nhk.or.jp/news/html/20231108/k10014249461000.html (accessed on 16 November 2024).

Japan Broadcasting Corporation (Nippon Hoso Kyokai: NHK). (2024). Why are bus routes being abolished or reduced in areas with high numbers of users? Yokohama, Tokyo's Adachi Ward, etc. What is the ‘2024 problem’ behind this? Available online: https://www.nhk.or.jp/shutoken/articles/101/008/56/ (accessed on 16 November 2024).

Japan Tourism Agency. (2022). Implementation of national travel support. Available online: https://www.mlit.go.jp/kankocho/news06_000570.html (accessed on 16 December 2024).

Jarboui, S., and Alofaysan, H. (2024). Global Energy Transition and the Efficiency of the

Largest Oil and Gas Companies, *Energies*, 17, 2271.

JR-CENTRAL. (2020). Presentation materials of financial results (29 October 2020), Nagoya: Central Japan Railway Company. Available online: https://company.jr-central.co.jp/ir/investor-meeting/2021/_pdf/settlement03.pdf (accessed on 31 December 2024).

JR-CENTRAL. (2021). Press Release (17 December 2021), Nagoya: Central Japan Railway Company. Available online: https://jr-central.co.jp/news/release/_pdf/000041637.pdf (accessed on 10 July 2024).

JR-EAST. (2020a). Presentation materials of financial results (30 April 2020), Tokyo: East Japan Railway Company. Available online: https://www.jreast.co.jp/investor/guide/pdf/202003guide1.pdf (accessed on 31 December 2024).

JR-EAST. (2020b). Press Release (21 October 2020), Tokyo: East Japan Railway Company. Available online: https://www.jreast.co.jp/press/2020/20201021_ho01.pdf (accessed on 10 July 2024).

JR-EAST. (2021a). Press Release (29 January 2021), Tokyo: East Japan Railway Company. Available online: https://www.jreast.co.jp/press/2020/20210129_ho01.pdf (accessed on 31 December 2024).

JR-EAST. (2021b). Press Release (11 May 2021), Tokyo: East Japan Railway Company. Available online: https://www.jreast.co.jp/press/2021/20210511_ho01.pdf (accessed on 10 July 2024).

JR-EAST. (2023). Press Release (27 April 2023), Tokyo: East Japan Railway Company. Available online: https://www.jreast.co.jp/press/2023/20230427_ho02.pdf (accessed on 31 December 2024).

JR-KYUSHU. (2020a). Presentation materials of finance result (12 May 2020), Fukuoka: Kyushu Railway Company. Available online: https://www.jrkyushu.co.jp/company/ir/news/__icsFiles/afieldfile/2020/05/12/9142.FY2019.4q.material.ja.pdf (accessed on 31December 2024).

JR-KYUSHU. (2020b). Press Release (4 November 2020), Fukuoka: Kyushu Railway Company. Available online:

https://www.jrkyushu.co.jp/company/ir/news/__icsFiles/afieldfile/2020/11/04/9142.FY2020.Withdrawal_Business_Plan.ja.pdf (accessed on 31December 2024).

JR-KYUSHU. (2020c). Press Release (18 December 2020), Fukuoka: Kyushu Railway Company. Available online: https://www.jrkyushu.co.jp/news/__icsFiles/afieldfile/2020/12/18/2021daiyaminaoshi_1_1.pdf (accessed on 10 July 2024).

JR-KYUSHU. (2021). Press Release (23 December 2021), Fukuoka: Kyushu Railway Company. Available online: https://www.jrkyushu.co.jp/news/__icsFiles/afieldfile/2021/12/23/211223_ekitaisei_minaoshi.pdf (accessed on 10 July 2024).

JR-KYUSHU. (2022). Press Release (22 March 2022), Fukuoka: Kyushu Railway Company. Available online: https://www.jrkyushu.co.jp/company/ir/news/__icsFiles/afieldfile/2022/03/23/220323_chuuki_keiei_keikaku2022_2024.pdf (accessed on 31 December 2024).

JR-WEST. (2020a). Presentation materials of finance results (1 May 2020), Osaka: West Japan Railway Company. Available online: https://www.westjr.co.jp/company/ir/pdf/20200501_01.pdf (accessed on 31 December 2024).

JR-WEST. (2020b). Press Release (30 October 2020), Osaka: West Japan Railway Company. Available online: https://www.westjr.co.jp/press/article/items/201030_00_minaoshi.pdf (accessed on 31 December 2024).

JR-WEST. (2020c). Press Release (16 December 2020), Osaka: West Japan Railway Company. Available online: https://www.westjr.co.jp/press/article/2020/12/page_17086.html (accessed on 10 July 2024).

JR-WEST. (2020d). Press Release (18 December 2020), Osaka: West Japan Railway Company. Available online: https://www.westjr.co.jp/info/saisyuuressya.html (accessed on 10 July 2024).

JR-WEST. (2023). Presentation materials of finance results (28 April 2023), Osaka: West Japan Railway Company. Available online: https://www.westjr.co.jp/company/info/plan/pdf/plan_2025.pdf (accessed on 31

December 2024).
Karanki, F., and Lim, H. S. (2021). Airport use agreements and cost efficiency of U.S. airports, *Transport Policy*, 114, 68–77.
Kawaguchi, D., Kitao, S., and Nose, M. (2022). The impact of COVID-19 on Japanese firms: Mobility and resilience via remote work, *International Tax and Public Finance*, 29, 1419–1449.
KEIFUKU. (2021). Press Release (12 February 2021), Kyoto: Keifuku Electric Railroad Co., Ltd.) Available online: https://www.keihan-holdings.co.jp/news/upload/2021-02-12_keifuku.pdf (accessed on 10 July 2024).
KEIHAN. (2020a). Presentation materials of financial results (13 May 2020), Osaka: Keihan Electric Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9045/ir_material_for_fiscal_ym/162013/00.pdf (accessed on 31 December 2024).
KEIHAN. (2020b). Press Release (5 November 2020), Osaka: Keihan Electric Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9045/tdnet/1898075/00.pdf (accessed on 31 December 2024).
KEIHAN. (2021). Press Release (8 Jury 2021), Osaka: Keihan Electric Railway Co., Ltd. Available online: https://www.keihan.co.jp/corporate/release/upload/2021-07-08_diagram.pdf (accessed on 10 July 2024).
KEIHAN. (2023). Press Release (30 March 2023), Osaka: Keihan Electric Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9045/tdnet/2256632/00.pdf (accessed on 31 December 2024).
KEIKYU. (2020a). Presentation materials of financial results (7 August 2020), Yokohama: Keikyu Corporation. Available online: https://ssl4.eir-parts.net/doc/9006/tdnet/1871016/00.pdf (accessed on 31 December 2024).
KEIKYU. (2020b). Press Release (27 November 2020), Yokohama: Keikyu Corporation. Available online: https://www.keikyu.co.jp/assets/pdf/20210127HP_20136EW.pdf (accessed on 10 July 2024).
KEIKYU. (2021a). Presentation materials of financial results (12 February 2021), Yokohama: Keikyu Corporation. Available online: https://ssl4.eir-parts.net/doc/9006/tdnet/1932616/00.pdf (accessed on 31 December 2024).

KEIKYU. (2021b). Presentation materials of financial results (12 May 2021), Yokohama: Keikyu Corporation. Available online: https://ssl4.eir-parts.net/doc/9006/announcement1/68669/01.pdf (accessed on 31 December 2024).

KEIO. (2020). Presentation materials of finance results (1 June 2020), Tokyo: Keio Corporation. Available online: https://contents.xj-storage.jp/xcontents/AS01800/09162e14/acef/4367/abdb/f669e5c116f6/140120200601431815.pdf (accessed on 31 December 2024).

KEIO. (2021a). Press Release (17 January 2021), Tokyo: Keio Corporation. Available online: https://www.keio.co.jp/news/update/news_release/news_release2020/nr20201118_shuden.pdf (accessed on 10 July 2024).

KEIO. (2021b). Press Release (18 May 2021), Tokyo: Keio Corporation. Available online: https://www.keio.co.jp/company/stockholder/results_briefing/pdf/2021_briefing_reference.pdf (accessed on 31 December 2024).

KEIO. (2022). Press Release (12 May 2022), Tokyo: Keio Corporation. Available online: https://www.keio.co.jp/company/stockholder/results_briefing/pdf/2022_briefing_reference.pdf (accessed on 31 December 2024).

KEISEI. (2020). Press Release (27 November 2020), Ichikawa: Keisei Electric Railway Co., Ltd. Available online: https://www.keisei.co.jp/information/files/info/20201210_093928130620.pdf (accessed on 10 July 2024).

KEISEI. (2022). Press Release (29 July 2022), Ichikawa: Keisei Electric Railway Co., Ltd. Available online: https://contents.xj-storage.jp/xcontents/AS01810/c1161707/b912/4972/8a81/72b5c68b0a06/140120220728507248.pdf (accessed on 31 December 2024).

Keuchel, S. (2020). Digitalisation and automation of transport: A lifeworld perspective of travellers, *Transportation Research Interdisciplinary Perspectives*, 7, 100195.

Khetrapal, P. (2020). Performance analysis of electricity distribution sector post the implementation of electricity act 2003: Empirical evidence from India, *Journal of Advances in Management Research*, 17, 669–96.

KINTETSU. (2020). Presentation materials of finance results (12 November 2020), Osaka: Kintetsu Railway Co., Ltd. Available online: https://www.kintetsu-g-hd.co.jp/common-hd/data/pdf/20201112-setumei20201112160216051645254.pdf (accessed on 31 December 2024).

KINTETSU. (2021a). Press Release (12 May 2021), Osaka: Kintetsu Railway Co., Ltd. Available online: https://www.kintetsu.co.jp/all_news/news_info/daiyahenkou.pdf (accessed on 10 July 2024).

KINTETSU. (2021b). Press Release (14 May 2021), Osaka: Kintetsu Railway Co., Ltd. Available online: https://www.kintetsu-g-hd.co.jp/common-hd/data/pdf/0514cyukei--20210514153416209740715.pdf (accessed on 31 December 2024).

KINTETSU. (2022). Press Release (13 May 2022), Osaka: Kintetsu Railway Co., Ltd. Available online: https://www.kintetsu-g-hd.co.jp/common-hd/data/pdf/20220513hd_kwe20220513162116524265075.pdf (accessed on 31 December 2024).

KOBE. (2021). Press Release (12 February 2021), Kobe: Kobe Electric Railway Co., Ltd. Available online: https://www.shintetsu.co.jp/release/2020/210212.pdf (accessed on 10 July 2024).

Kot, S., and Dragon, P. (2015). Business Risk Management in International Corporations. Procedia Economics and Finance, *22nd International Economic Conference - IECS 2015 "Economic Prospects in the Context of Growing Global and Regional Interdependencies", IECS 2015*, 27, 102-108.

Krljan, T., Grbˇci´c, A., Hess, S., and Grubisic, N. (2021). The Stochastic Frontier Model for Technical Efficiency Estimation of Interconnected Container Terminals, *Journal of Marine Science and Engineering*, 9, 515.

Kuramoto, T., and Hirota, H. (2008). Efficiency analysis of third sector railway, *Osaka University Knowledge Archive*, 47(4), 296-309.

Lastauskaite, A., and Krusinskas, R. (2024). The Impact of Production Digitalization Investments on European Companies' Financial Performance, *Economies*, 12, 138.

Le, Y., Oka, M., and Kato, H. (2022). Efficiencies of the urban railway lines incorporating financial performance and in-vehicle congestion in the Tokyo Metropolitan Area, *Transport Policy*, 116, 343-354.

Lee, M. S., and Rha, S. J. (2018). A network text analysis of published papers in service business, 2007–2017: research trends in the service sector, *Service Business*, 12, 809-831.

Locke, K., and Golden-Biddle, K. (1997). Constructing Opportunities for Contribution: Structuring Intertextual Coherence and "Problematizing" in Organizational Studies, *The Academy of Management Journal*, 40 (5), 1023-1062.

Lorenz, O. (2018). Does commuting matter to subjective well-being?, *Journal of Transport Geogr.*, 66, 180-199.

Magoutas, A., Chaideftou, M., Skandali, D., and Chountalas, T. P. (2024). Digital Progression and Economic Growth: Analyzing the Impact of ICT Advancements on the GDP of European Union Countries, *Economies*, 12, 63.

Maharjan, R., and Kato, H. (2023). Logistics and Supply Chain Resilience of Japanese Companies: Perspectives from Impacts of the COVID-19 Pandemic, *Logistics*, 7, 27.

Makkawi, H. (2021). The role of risk management in increasing business performance. Sciendo, *Proceedings of the 15th International Conference on Business Excellence 2021*, 15 (1), 1054-1059.

Matsumoto, S. (2023). JR East to give commuter pass discount if users avoid peak hours, *The Asahi Shimbun.* Available online: https://www.asahi.com/ajw/articles/14811739 (accessed on 1 July 2024).

Meeusen, W., and van den Broeck, J. (1977). Efficiency estimation from Cobb–Douglas production functions with composed error, *International Economic Review*, 18(2), 435-444.

MEITETSU. (2021a). Press Release (16 March 2021), Nagoya: Nagoya Railroad Co., Ltd. Available online: https://www.meitetsu.co.jp/profile/news/2020/__icsFiles/afieldfile/2021/08/11/210316_daiyakaisei.pdf (accessed on 10 July 2024).

MEITETSU. (2021b). Press Release (25 March 2021), Nagoya: Nagoya Railroad Co., Ltd. Available online: https://www.meitetsu.co.jp/profile/news/2020/__icsFiles/afieldfile/2023/05/08/210325_setsubi.pdf (accessed on 31 December 2024).

Miki, R., and Ieda, H. (2020). "Side-Business" Development in Japanese Major Private Passenger Railways:– What can we learn from their experiences?–, *ScienceDirect. World Conference on Transport Res. - WCTR 2019 Mumbai 26-31 May 2019,* 48, 187-206.

Ministry of Health, Labour and Welfare, Government of Japan. (2020). Employment adjustment grants (Special exception due to the impact of new coronavirus infections). Available online: https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/koyou_roudou/koyou/kyufukin/pageL07.html (accessed on 16 November 2024).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2005–2020). Inter-Regional Travel survey in Japan. Available online: https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00600460&tstat=000001016696&cycle=8&tclass1=000001067591&tclass2val=0

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2019a). Annual Report of Railway Statistics in Japan. Available online: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.mlit.go.jp%2Ftetudo%2Fcontent%2F001461912.xlsx&wdOrigin=BROWSELINK (accessed on 12 October 2022).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2019b). Annual Report of Railway Statistics in Japan. Available online: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.mlit.go.jp%2Ftetudo%2Fcontent%2F001577584.xlsx&wdOrigin=BROWSELINK (accessed on 9 February 2022).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2020a). Annual Report of Railway Statistics in Japan. Available online: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.mlit.go.jp%2Ftetudo%2Fcontent%2F001594348.xlsx&wdOrigin=BROWSELINK (accessed on 31 January 2023).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2020b). Annual Report of Railway Statistics in Japan. Available online:

https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.mlit.go.jp%2Ftetudo%2Fcontent%2F001584561.xlsx&wdOrigin=BROWSELINK (accessed on 31 January 2023).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2020c). White Paper on Land, Infrastructure, Transport and Tourism in Japan 2020. Available online: https://www.mlit.go.jp/hakusyo/mlit/r01/hakusho/r02/pdfindex.html (accessed on 16 November 2024).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2021a). Annual Report of Railway Statistics in Japan. Available online: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.mlit.go.jp%2Ftetudo%2Fcontent%2F001744994.xlsx&wdOrigin=BROWSELINK (accessed on 4 February 2024).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2021b). Annual Report of Railway Statistics in Japan. Available online: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.mlit.go.jp%2Ftetudo%2Fcontent%2F001744993.xlsx&wdOrigin=BROWSELINK (accessed on 4 February 2024).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2023). The revised Regional Transport Act will come into full force on 1 October - for the “re-design” (restructuring) of regional public transport. Available online: https://www.mlit.go.jp/report/press/content/001633218.pdf (accessed on 16 November 2024).

Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan. (2024). Recently Discontinued Railway Track lines (List of Discontinued railway lines in Japan since 2000). Available online: https://www.mlit.go.jp/common/001344605.pdf (accessed on 10 Jury 2024).

Mitsel, A., Alimkhanova, A., and Grigorieva, M. (2021). Advancing the multifactor model of stochastic frontier analysis, *Eastern-European Journal of Enterprise Technologies*, 3, 58–64.

Mizutani, F., Kozumi, H., and Matsushima, N. (2009). Does yardstick regulation really work? Empirical evidence from Japan’s rail industry, *Journal of Regulatory*

Economics, 36, 308-323.

Mogaji, E., and Nguyen, P. N. (2021). Transportation satisfaction of disable passengers: Evidence from a developing country, *Transport Research Part D: Transport and Environ*, 98, 102982.

Mokhtarian, P. L., and Pendyala, R. M. (2018). Travel satisfaction and well-being. In: Quality of Life and Daily Travel, *Cham: Springer*, pp. 17-39.

Molloy, J., Schatzmann, T., Schoeman, B., Tchervenkov, C., Hintermann, B., and Axhausen, W. K. (2021). Observed impacts of the Covid-19 first wave on travel behavior in Switzerland based on a large GPS panel, *Transport Policy*, 104, 43-51.

NANKAI. (2020a). Presentation materials of financial results (18 May 2020), Osaka: Nankai Electric Railway Co., Ltd. Available online: https://www.nankai.co.jp/library/ir/setsumei/pdf/setsumei_200518.pdf (accessed on 31 December 2024).

NANKAI. (2020b). Presentation materials of financial results (19 November 2020), Osaka: Nankai Electric Railway Co., Ltd. Available online: https://www.nankai.co.jp/library/ir/setsumei/pdf/setsumei_2103.pdf (accessed on 31 December 2024).

NANKAI. (2021a). Press Release (11 March 2021), Osaka: Nankai Electric Railway Co., Ltd. Available online: https://www.nankai.co.jp/library/company/news/pdf/210311_1.pdf (accessed on 10 July 2024).

NANKAI. (2021b). Press Release (30 April 2021), Osaka: Nankai Electric Railway Co., Ltd. Available online: https://www.nankai.co.jp/library/company/news/pdf/210430_2.pdf (accessed on 31 December 2024).

NANKAI. (2022). Press Release (31 March 2022), Osaka: Nankai Electric Railway Co., Ltd. Available online: https://www.nankai.co.jp/library/company/news/pdf/220331.pdf (accessed on 31 December 2024).

NISHITETSU. (2020a). Presentation materials of financial result (25 May 2020), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online:

https://www.nishitetsu.co.jp/ja/ir/i_news/inews20200525103031/main/0/link/200525.pdf (accessed on 31 December 2024).

NISHITETSU. (2020b). Press Release (28 August 2020), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online: https://www.nishitetsu.co.jp/ja/news/news20200828102928/main/0/link/20_034.pdf (accessed on 10 July 2024).

NISHITETSU. (2020c). Presentation materials of financial result (24 November 2020), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online: https://www.nishitetsu.co.jp/ja/ir/i_news/inews20201124103023/main/0/link/201124.pdf (accessed on 31 December 2024).

NISHITETSU. (2020d). Press Release (18 December 2020), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online: https://www.nishitetsu.co.jp/ja/news/news20201218103086/main/0/link/20_086.pdf (accessed on 10 July 2024).

NISHITETSU. (2022a). Press Release (17 February 2022), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online: https://www.nishitetsu.co.jp/ja/news/news20220217103067/main/0/link/21_097.pdf (accessed on 10 July 2024).

NISHITETSU. (2022b). Press Release (11 November 2022), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online: https://www.nishitetsu.co.jp/ja/ir/i_news/i_news-20221108559470/main/0/link/vision2035.pdf (accessed on 31 December 2024).

NISHITETSU. (2023). Press Release (23 March 2023), Fukuoka: Nishi-Nippon Railroad Co., Ltd. Available online: https://www.nishitetsu.co.jp/ja/ir/i_news/auto_20230323534898/pdfFile.pdf (accessed on 31 December 2024).

ODAKYU. (2020). Press Release (18 December 2020), Tokyo: Odakyu Electric Railway Co., Ltd. Available online: https://www.odakyu.jp/news/o5oaa1000001v1lj-att/o5oaa1000001v1lq.pdf (accessed on 10 July 2024).

ODAKYU. (2021). Press Release (28 April 2021), Tokyo: Odakyu Electric Railway Co., Ltd. Available online: https://www.odakyu.jp/ir/news/o5oaa1000001xacq-att/20210428_vision.pdf (accessed on 31 December 2024).

ODAKYU. (2023). Press Release (28 April 2023), Tokyo: Odakyu Electric Railway Co., Ltd. Available online: https://www.odakyu.jp/ir/news/dq40940000001y3c-att/20230428_vision.pdf (accessed on 31 December 2024).

Raghavan, A., Demircioglu, A. M., and Orazgaliyev, S. (2021). COVID-19 and the New Normal of Organizations and Employees: An Overview, *Sustainability*, 13 (21), 11942.

Rajput, A. A., Li, Q., Gao, X., and Mostafavi, A. (2022). Revealing Critical Characteristics of Mobility Patterns in New York City During the Onset of COVID-19 Pandemic. *Frontiers in Built Environ*, 7, 654409.

Rodrigues, M., Franco, M., Sousa, N., and Silva, R. (2021). Reviewing COVID-19 Literature on Business Management: What It Portends for Future Research?, *Sustainability*, 13 (11), 5995.

Rothengatter, W., Zhang, J., Hayashi, Y., Nosach, A., Wang, K., and Oum, H. T. (2021). Pandemic waves and the time after COVID-19—Consequences for the transport sector, *Transport policy*, 110, 225–37.

SEIBU. (2020a). Press Release (26 May 2020), Tokyo: Seibu Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9024/tdnet/1837713/00.pdf (accessed on 31 December 2024).

SEIBU. (2020b). Press Release (9 November 2020), Tokyo: Seibu Railway Co., Ltd. Available online: https://www.seiburailway.jp/file.jsp?news/news-release/2020/20201109_daiyakaisei.pdf (accessed on 10 July 2024).

SEIBU. (2021). Press Release (13 May 2021), Tokyo: Seibu Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9024/tdnet/1966805/00.pdf (accessed on 31 December 2024).

Shakibaei, S., de Jong, G. C., Alpkökin, P., and Rashidi, T. H. (2021). Impact of the COVID-19 pandemic on travel behavior in Istanbul: A panel data analysis, *Sustainable Cities and Society*, 65, 102619.

Sharama, M. K., and Chauhan, B. K. (2022). Timetable rationalization & Operational improvements by human intervention in an urban rail transit system: An exploratory study, *Transportation Research Interdisciplinary Perspectives*, 13, 100526.

Shin, M. M., Jung, S., and Rha, S. J. (2021). Study on Business Ecosystem Research

Trend Using Network Text Analysis, *Sustainability*, 13 (19), 10727.

Singleton, P. (2019). Validating the Satisfaction with Travel Scale as a measure of hedonic subjective well-being for commuting in a U.S. city, *Transport. Res. Part F: Traffic Psychology and Behavior*, 60, 399–414.

Song, Y. J., and Shoji, K. (2016). Effects of diversification strategies on investment in railway business: The case of private railway companies in Japan, *Research in Transportation Economics*, 59, 368-396.

SOTETSU. (2020a). Press Release (28 April 2020), Yokohama: Sagami Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9003/tdnet/1819577/00.pdf (accessed on 31 December 2024).

SOTETSU. (2020b). Presentation materials of financial results (29 October 2020), Yokohama: Sagami Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9003/tdnet/1893935/00.pdf (accessed on 31 December 2024).

SOTETSU. (2021a). Press Release (2 February 2021), Yokohama: Sagami Railway Co., Ltd. Available online: https://cdn.sotetsu.co.jp/media/2021/pressrelease/pdf/r21-07-b9h.pdf (accessed on 10 July 2024).

SOTETSU. (2021b). Press Release (25 November 2021), Yokohama: Sagami Railway Co., Ltd. Available online: https://ssl4.eir-parts.net/doc/9003/ir_material_for_fiscal_ym/109664/00.pdf (accessed on 31 December 2024).

Srivastava, B., Singh, S., and Jain, S. (2024). A frontier-based parametric framework for exploring the competition–efficiency nexus in commercial banking: Insights from an emerging economy, *Managerial Finance*, 50, 854–889.

The Asahi Shimbun. (2021). Tokyo-Area Railways to Stop Last Trains Earlier Starting Jan. 20, *The Asahi Shimbun.* Available online: https://www.asahi.com/ajw/articles/14102594 (accessed on 1 July 2024).

The Asahi Shimbun. (2022). JR East Reveals a Third of Its Rail Lines Are Bleeding Money, *The Asahi Shimbun.* Available online: https://www.asahi.com/ajw/articles/14682618 (accessed on 1 July 2024).

The Asahi Shimbun. (2023). Big Railways to Raise Fares from Spring to Cover Safety Measures, *The Asahi Shimbun.* Available online: https://www.asahi.com/ajw/articles/14843295 (accessed on 1 July 2024).

TOBU. (2020). Press Release (30 July 2021), Tokyo: Tobu Railway Co., Ltd. Available online: https://www.tobu.co.jp/cms-pdf/disclosure_documents/20200730151546Mie2btO8f3OwoJuHDqdyIw.pdf (accessed on 31 December 2024).

TOBU. (2021). Press Release (26 January 2021), Tokyo: Tobu Railway Co., Ltd. Available online: https://www.tobu.co.jp/cms-pdf/releases/20210126140455jW-dd1SriaYe3dhM3z0pXw.pdf (accessed on 10 July 2024).

TOBU. (2022). Press Release (28 April 2022), Tokyo: Tobu Railway Co., Ltd. Available online: https://www.tobu.co.jp/cms-pdf/disclosure_documents/20220428150711-udjz8jEWxdTPFS2nosCKQ.pdf (accessed on 31 December 2024).

TOKYU. (2021a). Press Release (26 January 2021), Tokyo: Tokyu Railways. Available online: https://www.tokyu.co.jp/image/news/pdf/20210126-1.pdf (accessed on 10 July 2024).

TOKYU. (2021b). Press Release (13 May 2021), Tokyo: Tokyu Railways. Available online: https://ir.tokyu.co.jp/ja/ir/news/news20210513102950/main/0/link/05_chukei_j_202105.pdf (accessed on 31 December 2024).

Tomikawa, T., and Goto, M. (2022). Efficiency assessment of Japanese National Railways before and after privatization and divestiture using data envelopment analysis, *Transport Policy,* 118, 44-55.

Tsukamoto, T. (2019). A spatial autoregressive stochastic frontier model for panel data incorporating a model of technical inefficiency, *Japan & The World Economy,* 50, 66–77.

Varotsis, N. (2022). Digital Entrepreneurship and Creative Industries in Tourism: A Research Agenda, *Economies,* 10, 167.

Vašaničová, P., and Bartók, K. (2024). Exploring the Nexus between Employment and Economic Contribution: A Study of the Travel and Tourism Industry in the Context of COVID-19, *Economies,* 12, 136.

Vigren, A. (2016), Cost efficiency in Swedish public transport, *Research in Transportation Economics,* 59, 123-132.

Watanabe, M. (2020). The COVID-19 Pandemic in Japan, *Surgery Today,* 50, 787–93.

Wheat, P., Stead, D. A., and Greene, H. W. (2019). Robust stochastic frontier analysis: A Student's t-half normal modelwith application to highway maintenance costs in England, *Journal of Productivity Analysis*, 51, 21–38.

Whitmore, A., Samaras, C., Hendrickson, T. H., Scott, M. H., and Wong-Parodi, G. (2022). Integrating public transportation and shared autonomous mobility for equitable transit coverage: A cost-efficiency analysis, *Transportation Research Interdisciplinary Perspective*, 14, 100571.

Wiegmans, B., Champagne-Gelinas, A., Duchesne, S., Slack, B., and Witte, P. (2018). Rail and road freight transport network efficiency of Canada, member state of the EU, and the USA, *Research in Transportation Business & Management*, 28, 54–65.

Yin, Y., Li, D., Zhang, S., and Wu, L. (2021). How Does Railway Respond to the Spread of COVID-19? Countermeasure Analysis and Evaluation Around the World, *Urban Rail Transit*, 7, 29–57.

Xin, M., Shalaby, A., Feng, S., and Zhao, H. (2021). Impacts of COVID-19 on urban rail transit ridership using the Synthetic Control Method, *Transport Policy*, 111, 1-16.

Zhang, F. (2021). Evaluating public organization performance under extreme weather events: Does organizational adaptive capacity matter? *Journal of Environmental Management*, 296, 113388.

Zhang, N., Jia, W., Wang, P., Dung, C. H., Zhao, P., Leung, K., Su B., Cheng, R., and Li Y. (2021). Changes in local travel behavior before and during the COVID-19 pandemic in Hong Kong, *Cities*, 112, 103139.

Zhang, X., and Wu, Y. (2023). Analysis of public transit operation efficiency based on multi-source data: A case study in Brisbane, Australia, *Research in Transportation Business & Management*, 46, 100859.