1 Introduction

1.1 Research Motivation

1.1.1 The leading national highway passenger transport company is facing a life-or-death crisis and a structural crisis.

In the past, intercity bus services in Taiwan undertake a heavy responsibility for intercity transportation. However, in recent years, the entire industry has faced a severe structural crisis. Chen, Hung-Chieh (2005) pointed out that since the opening of intercity bus services to private ownership, competition has been fierce. However, due to the disadvantage of lacking dedicated right-of-way, the industry faces problems of shrinking market size and internal friction. According to an empirical analysis of an official report from the Transportation Research Institute of the Ministry of Transportation, the total passenger volume of Taiwan's highway bus services had already shrunk by as much as 23.2% between 2016 and 2019, before the outbreak of the COVID-19 pandemic, making it highly susceptible to being replaced by rail transportation, which has the advantage of shorter travel times (Tsai Chin-Tung and Chen Chi-Hua, 2023). In addition, the global environment, including a declining birth rate and welfare conditions, has led to a severe shortage of bus drivers. The traditional operating model of intercity bus services is now facing a life-or-death test.

1.1.2 The North-Keelung Commuter Corridor: The Lifeline and Challenges of Kuo-Kuang Bus

Amidst a general decline in passenger numbers, intercity bus services rely heavily on a few routes with "rigid commuting demand" to maintain cash flow, with the "North-Keelung Commuter Corridor" being one of Kuo-Kuang Bus's most vital lifelines. However, this golden corridor is facing unprecedented challenges. With the Executive Yuan's implementation of the "TPASS Commuter Monthly Pass," price differences between various modes of transportation have been eliminated, leading many long-distance commuters to switch to Taiwan Railways for punctuality.

To retain passengers, bus operators often maintain a high density of bus stops at urban terminals. However, research by (Liang, Li-shuang, 2003) shows that improperly designed or excessively circuitous bus routes can lead to significant increases in vehicle wear and tear and travel time, resulting in unreasonable hidden operating costs. Chen (Chen, Zhicheng; Zhang, Yafu; Zeng, Qingzhi, 2022) further pointed out in their analysis of the production efficiency of Kuo-Kuang Bus after its privatization that if resources are not concentrated on efficient travel distances, simply increasing the number of vehicles and drivers can lead to a decline in pure technical efficiency and scale efficiency. This means that frequent urban stops and road congestion on the Taipei-Keelung route are constantly consuming scarce driving labor, trapping operators in a vicious cycle of "lower service levels → reduced demand" (Wang, Junwei, 2012).

1.1.3 Exploring Solutions to Route Operation Challenges Based on Official Data

In conclusion, the operational difficulties of the Kuo-Kuang

Bus's commuter corridor in northern Taiwan are not isolated incidents, but rather a systemic consequence of "route fragmentation" and "capacity misallocation." This study aims to directly utilize official data from the government's "Transport Data eXchange" open-data source platform (Ministry of Transport, 2026) to quantitatively analyze the current situation of excessively dense station spacing on Kuo-Kuang Bus's northern Taiwan routes. Simultaneously, by combining a system dynamics perspective with interviews with frontline drivers, it delves into the causal structure between traffic congestion, labor shortages, and operational decline, hoping to provide concrete suggestions with both theoretical basis and empirical evidence for the route restructuring and capacity optimization of intercity buses.

1.2 Research Objective

(1) The big data system was used to quantitatively analyze the "station density" and capacity waste of commuter routes in Taipei and Keelung.

(2) Through in-depth interviews with frontline drivers, we uncovered the hidden operating costs arising from congestion and frequent stops.

(3) Assess the impact of the TPASS monthly pass on the price advantage of national highway passenger transport and the loss of long-distance passenger traffic.

(4) By constructing system fundamental models using system dynamics, the systemic structure of labor shortages, traffic congestion, and passenger transport decline can be clarified.

(5) Based on a comprehensive quantitative and qualitative analysis, specific recommendations were formulated for the integration of national highway passenger transport routes and the separation of long and short-distance travel.

2 Literature Review

2.1 Structural decline and competition from rail transport facing national highway passenger transport

Before discussing the capacity issues of individual operators, it is essential to clarify the changes in the overall passenger transport environment. Tsai Chin-Tung and Chen Chi-Hua (2023) empirically analyzed official research on highway public transport passenger volume from 2017 to 2021, indicating that total highway passenger volume had already experienced a severe decline of 23.2% between 2016 and 2019, before the outbreak of the pandemic. Furthermore, key routes along the Taipei-Keelung corridor (such as routes 1813 and 1800), which are the focus of this study, also faced significant volume declines. The official report further analyzes that passenger transport is easily replaced by rail transport with dedicated right-of-way (such as Taiwan Railways, High Speed Rail, and the MRT), and its most critical weakness lies in the lack of a "travel time advantage." This literature finding directly confirms the hypothesis of this study: once the TPASS commuter pass eliminates the fare differences between modes of transportation, if Kuo-Kuang Bus continues to be constrained by urban congestion and frequent stops, resulting in a significant increase in travel time, its main long-distance commuter customer base will inevitably be lost to Taiwan Railways at an accelerated pace.

2.2 Production efficiency and capacity waste after the privatization of Kuo-

Kuang Bus Company

Faced with declining passenger numbers and operational pressure, the effective input of resources (vehicles and drivers) has become crucial for the survival of the passenger transport industry. Chen, Zhicheng; Zhang, Yafu; Zeng, Qingzhi (2022) used the data envelope method and tracking data model to analyze the production efficiency of Kuo-Kuang Bus after its privatization. Their research results raise an important warning: among the production inputs of passenger transport, increasing "total driving distance" and "market share" helps improve technical efficiency, but simply and excessively increasing "number of vehicles" and "number of drivers" will have a significant negative impact on pure technical efficiency and scale efficiency. This academic empirical evidence provides the core methodological support for this study: the current Taipei-Keelung commuter corridor routes are overly fragmented due to urban stops, resulting in the continuous consumption of scarce driver labor in ineffective short-distance stops and traffic jams, which is a standard example of "scale inefficiency" and capacity misallocation. Without route consolidation, simply adding extra services will not save revenue.

2.3 Relationship between route design characteristics and operating cost rationality

Regarding the operational burden arising from route fragmentation, (Liang, Li-shuang, 2003) proposed in her research on the reasonable route costs of bus transportation that the cost structure of passenger transport not only includes capital costs but is also heavily influenced by the operating environment. The study pointed out that improper route design (such as excessive detours or overly dense stops) directly leads to abnormally high costs for fuel, tire wear, vehicle depreciation, and maintenance materials, and these costs are often not accurately reflected in the ticket revenue of that route. This literature perfectly echoes the concept of "hidden costs" that this study aims to explore through long-distance interviews with frontline drivers: when Kuo-Kuang Bus Company stops and starts in urban areas to cater to a small number of short-distance passengers, the resulting increased fuel consumption and vehicle wear and tear are the hidden killers dragging down the company's finances.

2.4 Vicious cycle caused by inefficient fragmentation routes

When resources are misallocated to inefficient and fragmented feeder lines, it will have a profound impact on the sustainable operation of enterprises. Wang, Junwei (2012) in evaluating the performance of subsidies for remote highway passenger routes, pointed out that if public transportation lacks proper planning, it is very easy to fall into a vicious cycle of "reduced demand → reduced revenue → lower service levels → reduced demand". This literature emphasizes that if inefficient, low-load-rate routes are forcibly maintained, it will not only consume the company's cash flow, but may even put operators in a predicament of being overworked but unable to achieve substantial transportation benefits. This theory coincides with the "poisoned chalice" system model constructed in the system dynamics of this study, and strongly supports the necessity of "removing unreasonable short-distance feeder lines of Kuo-Kuang Bus" proposed in this study.

2.5 Solutions to fragmentation: Constructing a hub-and-spoke road network and transfer mechanisms

To overcome the aforementioned predicament and capacity loss, transforming the road network structure and seeking cooperation are imperative solutions. Regarding road network structure, Lin, Chih-Yuan (2004)'s research supports transforming the public transport route network into a "linear hub-and-spoke network." Empirical results show that by setting up connecting transfer stations and changing direct routes to trunk line transfers, although the number of transfers for passengers slightly increases, it can significantly reduce the "total vehicle-kilometers" of bus operators by 30% to 40%. In terms of cross-industry cooperation, Chen, Hung-Chieh (2005), in his research on strategic alliances for national highway passenger transport, further suggests that national highway passenger transport should focus on "medium- and long-distance transportation" and form transfer alliances with regional passenger transport operators. By returning the responsibility for short-distance urban connections to city buses or the MRT, national highway passenger transport can reduce the time cost of traveling on urban roads, effectively improve vehicle turnover, and alleviate the time pressure on drivers. The discovery of these two documents provides a solid theoretical basis and feasibility verification for the specific recommendations finally formulated in this study, such as "implementing direct trunk line access" and "promoting the control of long-distance and short-distance diversion stations".

2.6 Application of system dynamics to complex operational problems

Faced with the overlapping challenges of labor shortages, passenger loss, and capacity misallocation in the passenger transport industry, traditional linear thinking (such as reducing shifts or raising prices to cover losses, or simply increasing wages to address labor shortages) often only alleviates superficial symptoms and may even have the opposite effect, making it difficult to cope with the highly dynamic and complex system of transportation. Yang Chao zhong et al. (2007) pointed out in their book "System Dynamics: Thinking and Application" that system dynamics is a discipline that explores the dynamic behavior of complex systems. Its core advantage lies in its ability to clarify the "positive and negative feedback mechanisms" and "time lag effects" between variables within the system through "causal loop diagrams".

This study will use this as its core methodology, and by constructing a systemic model, break the one-way linear myth of "treating the head when the head aches and the foot when the foot aches," accurately depict the true nature of the interaction between Kuo-Kuang Bus's internal operations and the external environment, and then find the fundamental structure that has caused the company to be trapped in the quagmire of "Fixes that Fail" and "Limits to Growth," and based on this, deduce a transformation strategy with long-term sustainability.

Based on the comprehensive literature review above, it is clear that the predicament faced by Kuo-Kuang Bus in the Taipei-Keelung commuter corridor is not simply due to poor business management, but rather stems from multiple structural constraints, including "overall industry contraction," "deteriorating cost structure," "misaligned spatial hierarchy," and "insufficient traditional subsidy incentives." The high-density stops implemented by bus operators to attract passengers not only violate the spatial hierarchy principles of intercity transportation and TOD (Transit-Oriented Development), but also create serious "ineffective capacity" in the context of labor shortages.

Given that traditional unidirectional linear solutions can no longer reverse this trend, this study will build upon the aforementioned theoretical foundation and conduct empirical research in subsequent chapters: First, the reasonable walking distance between TOD stations will be used as a test standard, and big data will be combined to quantify the severity of capacity misallocation; then, system dynamics will be introduced as the core analysis tool to construct a causal loop diagram, thereby breaking the myth of "treating the symptoms but not the root cause" and sorting out a fundamental transformation strategy with long-term sustainability for national highway passenger transport.

3 Research Methods

3.1 Literature analysis method

This study first uses literature analysis to collect and organize relevant domestic and international literature on the development of the highway passenger transport industry, the labor structure of large buses, and the application of system dynamics in recent years. The main data sources include official government statistical reports (such as the Transportation Research Institute of the Ministry of Transportation), academic journal articles (such as the productivity analysis of Academia Sinica), and credible news reports. By integrating the above secondary data, the overall economic background of Kuo-Kuang Bus's current deep losses is clarified, and key variables such as the "TPASS policy impact" and "driver shortage" are extracted as the theoretical basis and verification evidence for the subsequent construction of a system dynamics causal loop diagram.

3.2 Data and empirical analysis

Transport Data eXchange " (Ministry of Transport, 2026). To overcome the limitations of raw data, this study further integrates the Streamlit Web Framework (Khorasani et al., 2022; Sapkota et al., 2025) in order to develop and build a "National Highway Passenger Transport Operation Analysis System." Through this visual web platform, key routes with "dense urban stop characteristics" (As shown in Figure 1 the inter-urban bus named routes' number 1800, 1802, 1813D, and 1815) in the Taipei-Keelung commuter corridor can be dynamically and accurately identified. Quantitative analysis indicators include "station spacing density analysis" (using the semi-sine formula to calculate the physical distance between stations to verify station fragmentation) and "ineffective capacity analysis."

Figure 1 Photos of the inter-urban bus named routes

Source: Taiwan Bus Cultural on Facebook

3.3 Practical In-Depth Interview Method

To address the hidden operational costs that pure data analysis cannot reveal, this study employed a semi-structured, in-depth practical interview method. Interviewees were frontline bus drivers with actual driving experience along the Taipei-Keelung corridor. The core focus was on how road congestion and frequent stops reduce drivers' "ineffective standby time," and the hidden internal friction caused by "vehicle mechanics and fuel consumption."

3.4 Theoretical Model Construction - Introduction to System Dynamics

3.4.1 Introduction to System Dynamics

Modeling through System Dynamics is a methodology for exploring the dynamic behavior of complex systems (Chen, 2009; Tao, 2016). It clarifies the positive and negative feedback mechanisms and time delay effects of various variables within the system through causal loop diagrams (Coyle, 1997; Kleiner et al., 2011; Senge, 1994). This study breaks away from the linear thinking of previous studies on single variables (such as ticket prices or labor shortages) in the passenger transport industry (Jifeng et al., 2008). It uses system fundamental modeling to connect phenomena such as "TPASS policy," "urban station spacing," "capacity loss," and "labor shortage" in order to seek a fundamental solution to the operational difficulties of national highway passenger transport.

3.4.2 Introduction to Causal Cycle Diagrams

This study used Vensim system dynamics software to draw causal loop diagrams (Coyle, 1997; Senge, 1994; Sterman, 2001). A positive correlation between A and B, that is, A is the cause and B is the effect. When A increases, B will also increase. A negative correlation between C and D, that is, when the quantity of C increases, D will decrease.

Furthermore, the variables form a loop and present a positive cycle, the variables will continue to increase. When there is more E, there will be more F, and more F will also make more E, so the variables will increase more and more. If the variables form a loop and present a negative cycle, when there is more G, there will be less H, and less H will make less G, so the variables will make each variable present a stable state.

3.5 Application of System Dynamics in the Analysis of Operational Dilemmas of Kuo-Kuang Bus

System dynamics is particularly well-suited for handling complex management issues involving "time delay" and "nonlinear feedback"(Coyle, 1997). Applying it to the analysis of Kuo-Kuang Bus Company's operational difficulties effectively overcomes the blind spots of focusing on single variables (such as simply discussing fares or labor shortages). This study, through a macroscopic perspective of system dynamics, connects seemingly independent phenomena such as "TPASS policy," "urban station density," "capacity loss," and "driver shortages" into a dynamic structure with causal relationships, thereby uncovering the root causes of the company's continued losses.

3.6 System Basic Model

Scholars have pointed out that system archetypes are the most basic form of problem exploration (Coyle, 1997; Senge, 1994; Sterman, 2001). Therefore, this study uses system archetypes for analysis and discussion based on the aforementioned literature.

3.6.1 System Basic Model (I): Fixes that Fail

This schema describes how decision-makers, when faced with systemic problems, often tend to adopt "quick and easy-to-implement short-term solutions" (such as passenger transport operators trying to maintain a high density of urban stops to attract passengers) (Coyle, 1997; Jifeng et al., 2008). However, this approach, which only addresses the symptoms and not the root cause, will generate more serious "side effects" after a period of delay (such as causing chaos in short-distance travel, driver fatigue, and increased vehicle maintenance rates), which will worsen the original loss problem and ultimately plunge the system into a vicious cycle from which it cannot extricate itself (Kleiner et al., 2011; Senge, 1994; Sterman, 2001).

3.6.2 System Basic Model (II): Growth Cap

This basic model consists of a "reinforcing loop" that drives growth and a "regulating loop" that inhibits growth (Coyle, 1997; Senge, 1994). Initially, the system expands rapidly due to driving forces (such as the massive rigid commuting demand along the Taipei-Keelung corridor driving revenue); however, as the system operates, it inevitably encounters insurmountable "limiting factors" or "resource bottlenecks" (such as the physical limits of urban road congestion and a severe shortage of bus drivers). When the ceiling is reached, if the limiting factors are not eliminated, the system's growth will not only stagnate but will also experience a severe backlash and decline due to decreased service reliability.

4 Research Analysis and Results

4.1 Transport Data eXchange Empirical Evidence: Route Fragmentation and Capacity Consumption

4.1.1 Construction of Automated Data Acquisition and Visualization System

To accurately quantify the density and capacity consumption of urban stations, this study moves beyond the limitations of traditional manual data collection and incorporates practical concepts from commercial big data analytics. Researchers used the Visual Studio Code development environment and wrote automated web crawler scripts in Python, directly connecting to the official API of the Ministry of Transportation's Transport Data eXchange platform (Ministry of Transport, 2026). The core business objective of this program development is to quickly clean and transform massive amounts of raw data, which are difficult to interpret manually, into quantifiable indicators with operational decision-making value.

After automatically capturing and calculating the absolute physical distances between stations using the aforementioned Python program, this study further integrates the Streamlit framework to build a visual "National Highway Passenger Transport Operation Analysis System". This system allows for the one-click display of station and distance information for all branches of a specific route, providing a solid quantitative foundation for subsequent capacity misalignment analysis.

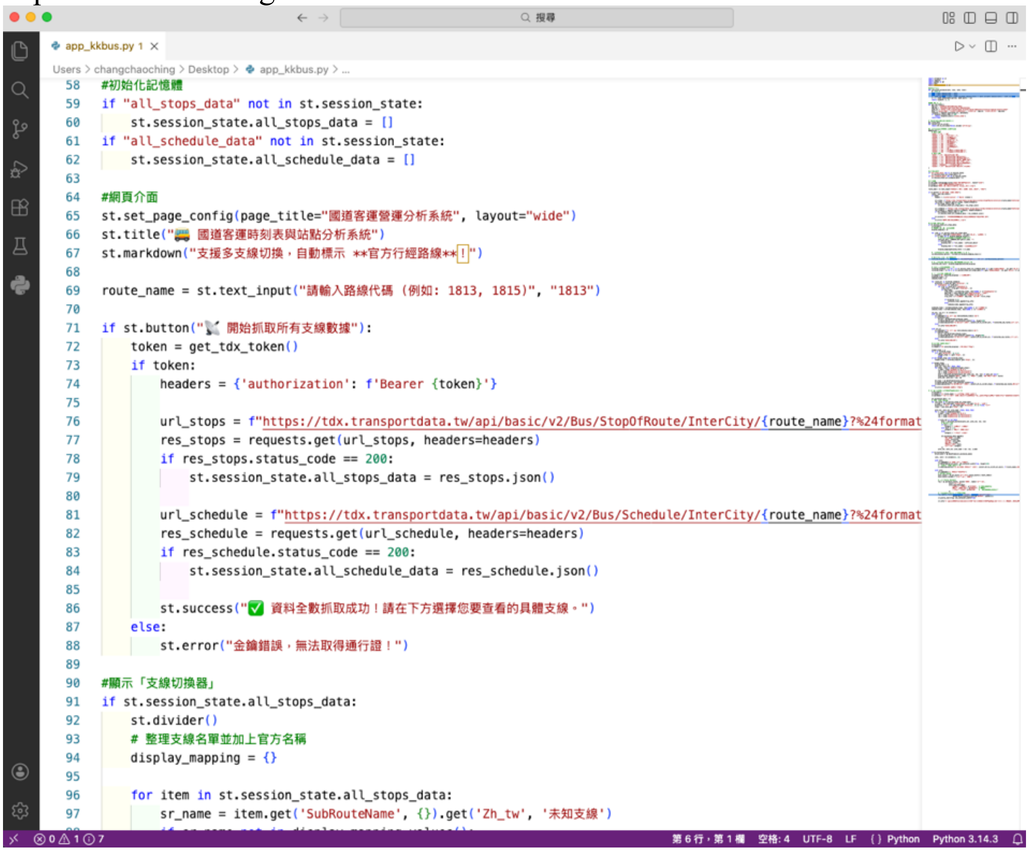
4.1.2 Basis for setting the classification threshold for station distance

To quantify the "excessive fragmentation" of Kuo-Kuang Bus routes, this study, based on empirical research by domestic scholars on the spatial structure and pedestrianization of Transit-Oriented Development (TOD) (Li Jianong and Xie Yikai, 2015), derives three station spacing classification thresholds suitable for this study:

4.1.3 Extremely short distances (less than 400 meters): Ineffective productivity of urban bus-like transit

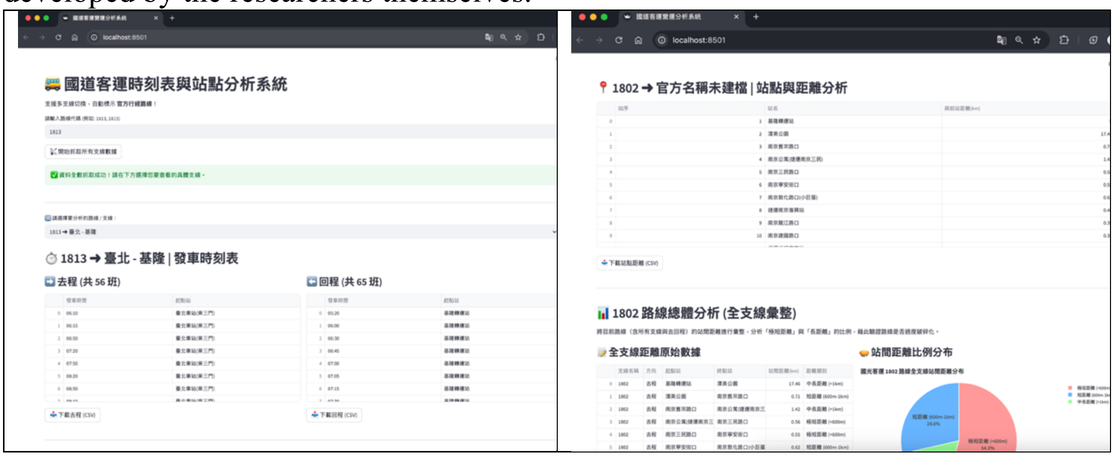
In urban planning and TOD (Transit-Oriented Development) theory, the core comfortable walking radius of public transportation stations is defined as within 400 meters (Li Jianong and Xie Yikai, 2015). When the distance between stations on national highways is less than 400 meters, it means that the stations are extremely densely packed, and the operating mode has been completely downgraded to "urban bus". Frequent starting and braking not only result in a loss of speed advantage, but are also the main culprits for increased fuel consumption and driver fatigue.

Figure 2 Screenshot of using VS Code to write a Python program that interfaces with Transport Data eXchange data.



Source: Screenshots developed by the researchers themselves.

Figure 4: The national highway passenger transport operation analysis system developed by the researchers themselves.



Source: Screenshot from a webpage developed by the researchers themselves.

4.1.4 Short distance (400 to 800 meters): Transition zone within a single walking radius

Pedestrian-friendly living circles and public transportation service radii mostly fall within the range of 400 to 800 meters (Li Jianong and Xie Yikai, 2015). This range is roughly equivalent to the average station spacing of urban rail systems such as the MRT. For intercity bus services, which should bear the heavy responsibility of rapid commuting between counties and cities, maintaining this frequency of stops "without stepping out of a single living circle" in urban areas will still be unable to compete with rail transportation, which has dedicated right-of-way, once peak traffic is encountered.

4.1.5 Medium to long distances (greater than 800 meters): Compliant with reasonable station spacing for national highway passenger transport.

The core competitiveness of highway passenger transport lies in its rapid, direct point-to-point service. A reasonable operating model should involve stopping at only a few transfer hubs in urban areas (i.e., the distance between stations should not exceed the 800-meter walking distance limit of a single TOD) before entering the highway. Therefore, based on theoretical deduction, a station distance greater than 800 meters is the true indicator of a healthy operation that can realize the high turnover rate of highway passenger transport (Li Jianong and Xie Yikai, 2015).

4.1.6 Empirical Analysis of Core Routes: Station Spacing Distribution of Branch Lines 1813 and 1815

To verify the hypothesis of capacity misallocation, this study selected the two core routes with the largest passenger volume in the Taipei-Keelung commuter corridor: 1813 (Taipei-Keelung) and 1815 (Taipei-Jinshan). The absolute physical distance of all their branch routes was calculated by the system, and the routes were classified proportionally according to the aforementioned threshold. The visualization results are shown in Figures 5 and 6.

The data in the chart below reveals a startling discrepancy: on the two main routes that should bear the heavy responsibility of rapid transportation on national highways, the proportion of stops with spacing between 400 meters and 800 meters is overwhelmingly high, while the proportion of stops with spacing greater than 1 kilometer, which is truly in line with the reasonable standard for national highway passenger transport, is severely compressed. This extremely skewed quantitative data undoubtedly serves as the most compelling evidence of the "excessive fragmentation of Kuo-Kuang Bus routes." The massive proportion of extremely short stop distances forces buses to stop and start frequently in urban areas, constantly wasting the scarce labor force of frontline drivers on ineffective stops, becoming the core cause of the company's operational capacity collapse.

4.2 In-depth practical interviews verify: Hidden costs on the front lines

To validate the macro data, this study conducted an in-depth interview with a driver surnamed Lin at the Kuo-Kuang Bus Station's Keelung Terminal in February 2026 (Driver Lin, February 21, 2026). The interview results revealed hidden operational costs that were not readily apparent.

However, this study is limited to analyzing only the two core routes of 1813 and 1815, and the interview sample consists of one chief sergeant. Future studies could expand the range of routes and interviewees to enhance the external validity of the inferences.

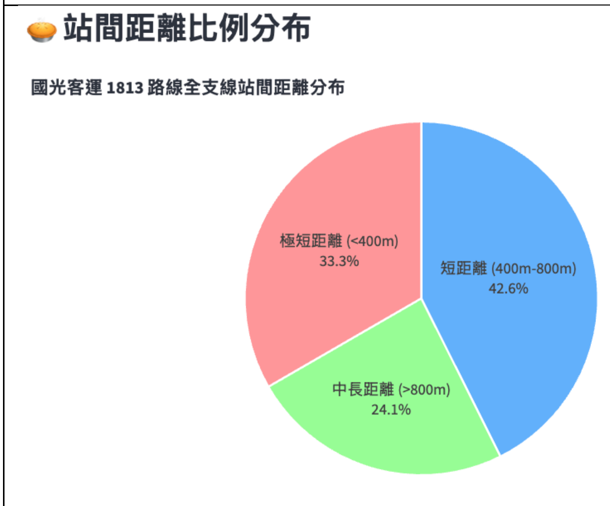
4.3 Urban congestion leads to loss of operational capacity.

Interviews confirmed that densely packed city bus stops and traffic congestion are the biggest culprits for depleting passenger transport capacity. Drivers, drawing on their practical experience, pointed out that for Kuo-Kuang Bus routes 1813D and 1815, the journey from Taipei Main Station to the "Tanmei Park" stop before entering the national highway doubles from 30 minutes during off-peak hours to over 60 minutes during peak hours. More notably, even routes 1802 and 1815B, which travel along Nanjing East Road and enjoy the right-of-way of a dedicated bus lane, still experience peak-hour travel times from Sanchong to Tanmei Park that extend from 35 minutes to over 55 minutes. These extra 20 to 30 minutes spent on stop-and-go traffic in the city not only increase fuel consumption but also represent "ineffective capacity" that generates absolutely no ticket revenue.

4.3.1 Site density drags down scheduling efficiency

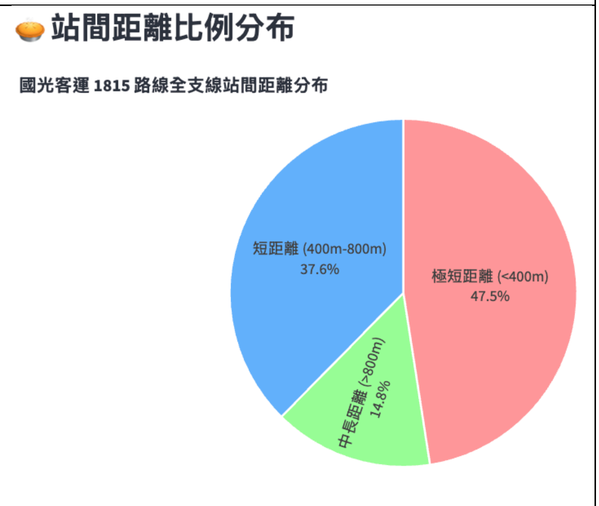
The interviewed drivers further pointed out that for routes such as 1800, 1813D, and 1815 that pass through Zhongxiao East Road: "If the buses are already full of passengers at the first few stops, they can skip the stops in the city and continue driving, which can save about 15 to 20 minutes; if they don't stop at the city hall transfer station, they can even save 25 minutes." This frontline experience fully confirms that forcing every bus to detour around the fragmented city bus stops is a huge drag on long-distance transportation.

Figure 5: Distribution of station distances along the entire branch line of Kuo-Kuang Bus Route 1813.



Source: Screenshot from a webpage developed by the researchers themselves.

Figure 6: Distribution of station distances along the entire branch line of Kuo-Kuang Bus Route 1815.



Source: Screenshot from a webpage developed by the researchers themselves.

4.3.2 Compressed rest time and chaotic short-distance travel

Regarding the phenomenon of TPASS passengers using national highway bus routes for short distances, drivers stated that vehicles still have to stop at every station as long as there are a few short-distance passengers. Furthermore, regarding urban traffic congestion, drivers explained, "If there's traffic and we get back to the station late, we don't have time to rest before we have to start again. The schedule is very tight, and there's nothing we can do about it." This situation, where rest time is compressed due to worsening traffic, overly frequent stops, and an increase in short-distance passengers, poses a hidden danger that can overload vehicles and drivers.

4.4 System Dynamics: Causal Loop Analysis of Decline

4.4.1 Growth cap system basic model

Based on data from Transport Data eXchange and in-depth interviews with frontline practitioners, while there is a huge, inelastic demand for commuting between Taipei and Keelung, the expansion of passenger transport capacity is limited by two major constraints: "urban road capacity (peak traffic congestion)" and "the number of large bus drivers (labor shortage across Taiwan)." As shown in Figure 7, this system's basic model is interwoven with a "growth-driving reinforcing loop" and a "growth-inhibiting regulating loop."

4.4.2 Enhanced loop (operational growth engine)

In the early stages of development, when commuting demand rises, passenger transport operators will increase the number of feeder routes and departures to seize market share. The increase in departures can effectively reduce passengers' waiting time, thereby driving growth in passenger numbers and revenue. The abundant revenue, in turn, will prompt operators to further expand feeder routes, forming a positive cycle that drives business growth.

4.4.3 The control loop (the ceiling of capacity and efficiency)

However, unrestricted route expansion inevitably reaches the limits of physical transportation. When there are too many branch lines, coupled with maintaining a large number of short-distance stops to cater to TPASS users, the density of stops skyrockets. Excessive stop density directly lengthens urban detour time and total travel time. With a fixed number of drivers and fixed working hours, the increased travel time per trip significantly reduces vehicle turnover, forcing an increase in actual waiting time (i.e., missed shifts or longer intervals between buses). When waiting time exceeds passenger tolerance, passenger numbers begin to decline, ultimately impacting revenue and forcing growth to stagnate or even decline.

4.4.4 Basic model of the poison-quenching system

This schema vividly depicts the long-term structural disaster caused by companies adopting "short-term quick fixes" when facing operational crises. As shown in Figure 8, when passenger transport faces pressure on passenger volume and revenue, the system simultaneously contains loops attempting to address the symptoms and vicious cycles leading to serious side effects:

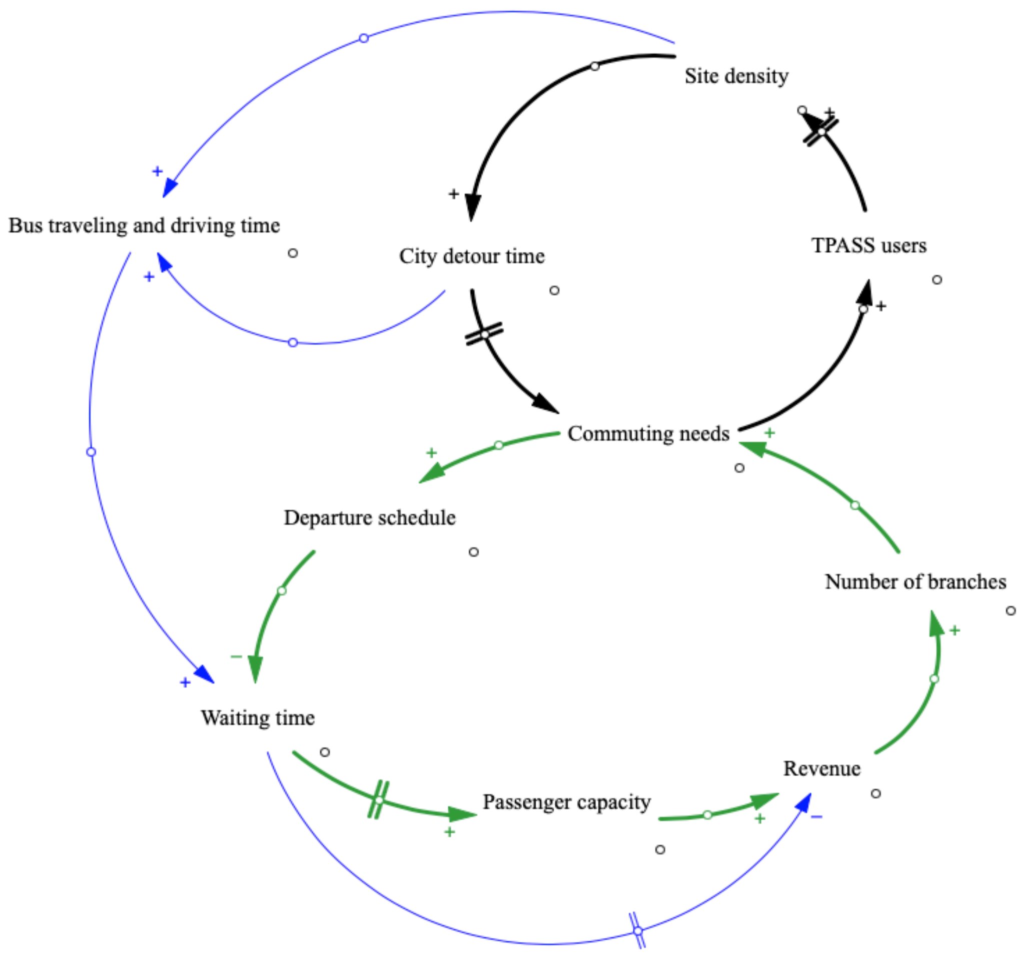
4.4.5 Short-term, quick-acting solution (a symptomatic regulatory loop)

To address the pressure of declining revenue and cater to the growing number of TPASS users, passenger transport companies have opted to maintain a high density of waiting areas and frequent departures. In the short term and superficially, this approach seems to be able to barely maintain existing passenger numbers and revenue, and is a necessary measure for companies to stem losses in a labor shortage environment.

4.4.6 The side effects of delay (a deadly vicious cycle)

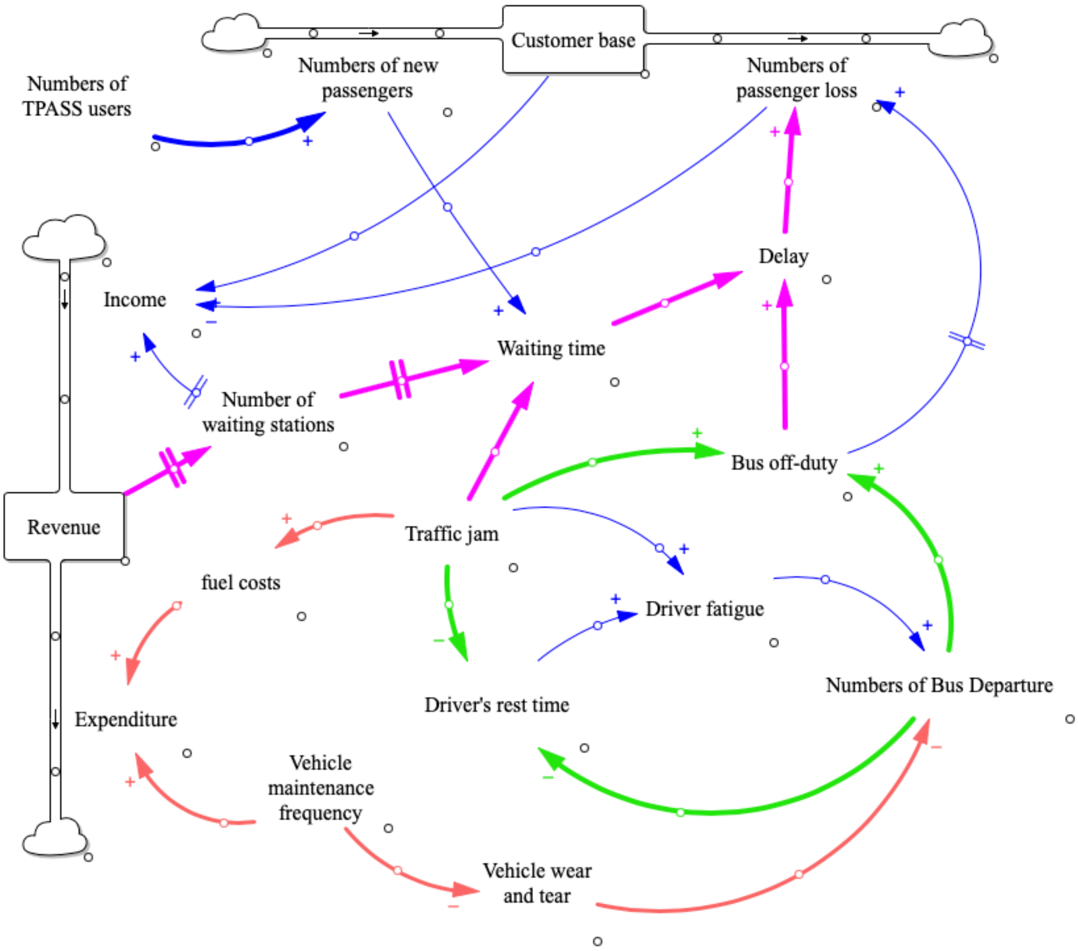
However, this practice of over-exploiting system capacity will inevitably lead to serious side effects after a period of delay. Dense urban stops coupled with traffic congestion will significantly reduce driver rest time and increase fuel costs. When drivers are chronically fatigued, coupled with increased vehicle wear and tear and maintenance frequency due to high-frequency departures, it will inevitably cause a collapse in frontline operations, resulting in severe back-to-work delays and disruptions. Back-to-work delays directly lengthen passenger waiting times, and when these waiting times exceed commuters' tolerance limits, it accelerates the increase in passenger loss. The significant loss of customers not only further depresses revenue, but the continuously increasing operating expenses exacerbate the company's financial woes, ultimately creating a vicious cycle where "the tighter the schedule, the greater the losses."

Figure 7: Causal loop diagram of the "Limits to Growth" of Kuo-Kuang Bus Operations.



Source: Drawn by the researcher.

Figure 8: The causal loop diagram of Kuo-Kuang Bus Company's "Fixes that Fail" operation.



Source: Drawn by the researcher.

5 Research Conclusions and Recommendations

5.1 Research Conclusions

Based on data from the "National Highway Bus Operation Analysis System" developed in this study, in-depth interviews with frontline drivers, and the construction of a causal model using system dynamics, the core conclusions regarding Kuo-Kuang Bus's deep-seated losses are summarized as follows:

The crisis faced by Kuo-Kuang Bus is not only affected by changes in the external environment (TPASS policy, labor shortage across Taiwan), but also by its internal "rigid operating model". Its core routes (such as 1813 and 1815) have dispersed scarce transport capacity due to "excessive fragmentation of branch lines"; at the same time, the excessively close distance between stations in urban areas has caused vehicles to get stuck in traffic jams, resulting in huge operating capacity and vehicle consumption.

According to the principles of systems dynamic, passenger transport capacity has already reached its "Limits to Growth " due to traffic congestion and labor shortages. Furthermore, the tight scheduling and high-density stops adopted by operators to maintain fragmented feeder lines have triggered a vicious cycle of short-sighted measures. These hidden costs, unseen in financial statements, lead to driver fatigue, frequent shift cancellations, and passenger loss, ultimately severely impacting passenger transport efficiency and becoming a significant factor exacerbating cash flow pressures on businesses.

5.2 Specific suggestions

5.2.1 Prioritize reviewing and consolidating inefficient branch lines, and implement "direct trunk line access".

Faced with a severe driver shortage, Kuo-Kuang Bus could prioritize evaluating and consolidating its less efficient branch lines. By focusing all its vehicles and driving resources on direct main lines connecting "end-to-end" (such as Keelung Transfer Station to Taipei Main Station), and leveraging the advantage of high-frequency service to directly compete with Taiwan Railways, Kuo-Kuang Bus could regain its lost commuter backbone.

5.2.2 Promoting station control for "separation of long and short distances"

In response to traffic congestion in urban areas and chaotic short-distance transportation, it is recommended that highway authorities allow intercity buses to implement "leapfrog stops" or "some urban stops that only allow boarding and not alighting" during peak hours. This would return the responsibility for short-distance transportation to local urban buses or subways, allowing intercity buses to focus on their core value of "medium- and long-distance rapid transportation," thereby eliminating inefficient capacity.

5.2.3 Shifting the mindset from subsidies to direct subsidies for drivers.

Faced with the predicament of "having vehicles but no drivers" in the passenger transport industry, the current government's use of "operating mileage" or "passenger volume" as the basis for loss subsidies is no longer able to fundamentally solve the labor shortage problem. The government's subsidy mindset should undergo a strategic shift, directly converting a portion of the subsidy budget into "job allowances for highway passenger transport drivers." Only by substantially improving the salary structure of frontline workers can driver turnover be effectively stopped, breaking the vicious cycle in the system where "labor shortages lead to absenteeism, and absenteeism leads to declining revenue."

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