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Review Article

A Systematic Review of the Coopetition Relationship between Bike-Sharing and Public Transit

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The sharing economy, mobile Internet, and smartphones have been widely utilized in recent years to promote the development of bike-sharing services. Bike-sharing serves as a first/last mile travel mode to connect to public transit, which improves trip efficiency, alleviates traffic problems, improves environmental quality, and promotes public health. However, the substitution of public transit by bike-sharing and the decline in public transit ridership have raised concerns among city managers regarding the coopetition between shared mobility services and public transit. To understand the impact of bike-sharing on the decline in public transit and to formulate reasonable synergistic development policies, it is crucial to identify the coopetition relationships between the two. This paper uses a combination of database search and backward snowballing to review existing research. Three research themes were identified: macrolevel studies on bike-sharing and public transit interaction, studies on actual coopetition behaviors based on bike-sharing user surveys, and studies on potential coopetition relationships based on bike-sharing transaction data. The three categories of studies reveal the effect of bike-sharing usage on public transit ridership, the emergency function of bike-sharing in the event of unexpected transit shutdowns, and the substitution and connection relationships between bike-sharing and public transit and the factors influencing them. Finally, this study suggests many directions for future research. This review helps clarify the understanding of the coopetition relationships between bike-sharing and public transit, provides theoretical support to promote the synergistic development of both, and points out ways to deepen the research on the coopetition relationship between the two.

1. Introduction

In recent years, the popularization of mobile Internet and smartphones has promoted the rapid development of shared mobility services such as bike-sharing, ride-hailing, and car-sharing. Economic, environmental, and social forces have driven shared mobility from the fringe to the mainstream, and its role in urban mobility has become a popular topic of discussion [1]. In order to facilitate the advancement of shared mobility, the United States has crafted the Shared Mobility Policy Playbook [2], which provides a compendium of resources and instruments for municipal governments and public entities to integrate and administer shared mobility services. Similarly, Europe has integrated the promotion of shared mobility into its Sustainable Urban Mobility Plans (SUMP), providing resources and tools for local governments and public agencies for the incorporation and oversight of shared mobility services [3]. In China, the Outline of Building a Powerful Transportation Country [4] has been promulgated, which advocates the accelerated development of shared mobility services. Before the advent of these novel mobility services, public transit has been perceived for a long time as a strategic measure to address urban challenges. The confluence of emerging and established transit methodologies invariably engenders a spectrum of beneficial and adverse effects. The question of whether and how shared mobility services and public transit can synergize with each other is fundamental to promoting the sustainable development of urban transportation. Meanwhile, the collaborative development of shared mobility and public transit is the key to prompting mobility as a service (MaaS) in urban areas [5].

Both bike-sharing and public transit have their advantages and disadvantages. As an integral part of shared mobility services, bike-sharing has been positioned as a green travel mode serving the "last mile" and as an efficient feeder to public transit. Simultaneously, it has played a positive role in cost-effectiveness [6], flexibility [6], improving travel efficiency [7], reducing car use [8], easing traffic congestion [9], reducing greenhouse gas (GHG) emissions [10, 11], and promoting public health [12, 13], physical health [14, 15], and mental health [13, 16]. However, shared bikes are not very suitable for long-distance travel due to physical exertion [17] and uphill cycling [17]. They are also not friendly to people with disabilities [18] and are significantly affected by adverse weather conditions [19]. On the other hand, public transit, as a sustainable mode of transportation with a large capacity, offers significant benefits in alleviating traffic congestion [20], reducing greenhouse gas emissions [20], promoting physical [21] and social health [21], addressing long-distance travel [22], accommodating travel in adverse weather conditions [23], and facilitating transportation for people with disabilities [24]. However, it often faces challenges such as being greatly affected by traffic congestion [25], having a low punctuality rate [25], long transfer distances [22], and long waiting times [26]. Therefore, the service level of the comprehensive transportation system would see significant improvement if public transit and bike-sharing could complement each other's strengths and establish a cooperative relationship rather than competing.

The competition and cooperation between bike-sharing and public transit are important research topics in the field of bike-sharing and public transit. Current research indicates that bike-sharing and public transit can be substitutes for each other for short-distance trips of 1–3 km [27, 28]. During rush hours with traffic congestion, the average speed of bike-sharing is even faster than that of public transit [29]. A survey of Hangzhou bike-sharing users showed that 58% of users substituted public transit with bike-sharing during their most recent trip in 2019 [30]. In 2016, during their most recent trip in Shanghai, 19.7% of bike-sharing users substituted the bus with bike-sharing, and 7.8% substituted rail transit with bike-sharing [31]. In 2013, 19% of users riding bike-sharing to connect to rail transit were shifted from the bus during their most recent trip in Nanjing [32]. Figure 1 displays the share of bike-sharing users who have substituted public transit with bike-sharing during their recent trips in different cities around the world. Furthermore, several major Chinese cities such as Shanghai, Beijing, Guangzhou, and Shenzhen have experienced a steady decline in bus ridership after the introduction of bike-sharing in recent years [33], and similar phenomena have been observed in several U.S. cities [34].

Although there is currently no unified definition of the coopetition relationship between bike-sharing and public transit, in our opinion, the coopetition relationship between bike-sharing and public transit is a kind of relationship driven by the microlevel travel choice behaviors of travelers. These microlevel travel choice behaviors trigger micro-interactive relationships between bike-sharing and public transit in their operation, dynamically influencing the macroridership of both systems. In detail, these microinteractive relationships are mainly reflected in the way that bike-sharing can be combined with public transit to improve travel efficiency and public transit ridership or can replace public transit, leading to a loss of public transit ridership. Clearly, the changes in microinteractive relationships directly relate to the macrolevel spatial and temporal characteristics of ridership in the bike-sharing and public transit systems.

The scientific evaluation of the coopetition relationship between bike-sharing and public transit serves as the foundation for the synergistic planning, design, operation, and management of bike-sharing and public transit systems. However, there is currently a lack of review articles that summarize the commonalities and differences in research results on the coopetition relationship between bike-sharing and public transit in different cities, along with related evaluation methods. This gap hampers the systematic understanding and scientific evaluation of the relationship between the two. Although some review articles have touched on the substitution and connection relationship between the two modes [19, 48–51] and some studies have investigated complex mode choice behaviors [52, 53] and other interrelationships [54–56] in the comprehensive transportation system, there is a notable absence of in-depth and systematic exploration of the evaluation methods and research results pertaining to the competitive and cooperative relationships between bike-sharing and public transit across different studies. Therefore, this article presents a review of studies on the definition, evaluation methods, and research results of the coopetition relationship between bike-sharing and public transit in different cities. The intention of this article is to provide a reference for a comprehensive understanding of the relationship between bike-sharing and public transit, establish a basis for the scientific formulation of synergistic development strategies, and pave the way for further research.

This paper is organized as follows: Section 1 provides the research background, Section 2 describes the research methodology, Section 3 reviews the studies on the interaction between bike-sharing and public transit at the macrolevel, Section 4 analyzes actual coopetition behaviors based on surveys of bike-sharing users, Section 5 reviews the studies on potential coopetition relationships based on bike-sharing transaction data, Section 6 presents the discussion and future research directions, Section 7 provides the conclusion, and Section 8 discusses the limitations.

2. Methods

The systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology [57, 58], which includes a checklist and a flow diagram. The flow diagram,

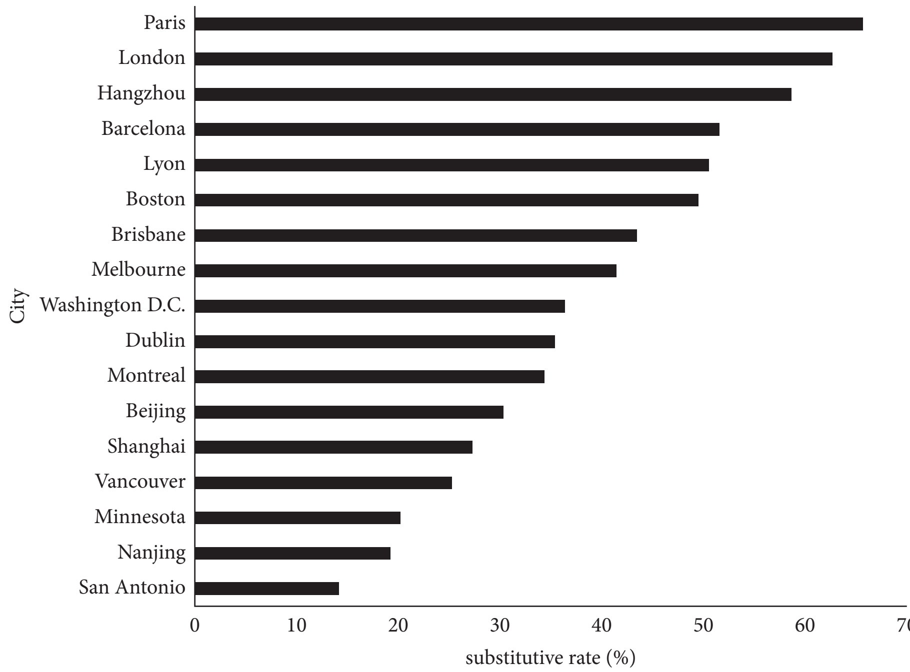

FIGURE 1: The proportion of bike-sharing users who substituted public transit with bike-sharing during their recent trips in various cities worldwide. The data source is detailed in Table 1.

TABLE 1: The proportion of bike-sharing users in various studies who substituted other travel modes with bike-sharing during their recent trips.

Serial number	Walking (%)	Private bike	Bus	Rail	Private car (%)	Taxi	New trips	Other modes	Sample size	City
1	49	23%	17%	3%	3	2%	—	3%	117	Beijing [23]
2	27	26%	22%	8%	6	10%	—	1%	167	Beijing [23]*
3	47	9%	19%	8%	7	7%	2%	1%	670	Shanghai [31]
4	47	15%	19%		15	4%	—	—	168	Nanjing [32]
5	19	10%	58%		8	5%	—	—	275	Hangzhou [30]
6	31	6%	45%		7	6%	4%	2%	5287	2011 Washington D.C. [35]
7	38	5%	44%		4	6%	3%	1%	2809	2013 Washington D.C. [36]
8	37	5%	40%		6	6%	3%	3%	4287	2014 Washington D.C. [37]
9	39	3%	14%	21%	5	16%	2%	—	5832	2016 Washington D.C. [38]
10	31	5%	15%	34%	3	4%	4%	4%	191	Boston [39]
11	38	8%	20%		19	3%	9%	3%	N	Minnesota [40]
12	7	14%	14%	—	21	0%	36%	7%	14	San Antonio [39]
13	18	24%	50%		8	0%	—	—	2502	2009 Montreal [41]
14	21	22%	41%		10	6%	—	—	2509	2010 Montreal [41]
15	25	28%	34%		2	8%	3%	—	1432	2010 Montreal [42]
16	38	6%	18%	7%	6	3%	18%	5%	4533	Vancouver [43]
17	29	5%	23%	38%	1	4%	1%	1%	1199	London [44]
18	45	—	26%	9%	20	—	—	—	360	Dublin [45]
19	54	12%	31%		3	—	—	—	237	Dublin [46]
20	20	—	65%		8	5%	—	2%	N	Paris [47]
21	37	4%	50%		7	—	2%	—	N	Lyon [47]
22	27	9%	41%		19	2%	1%	1%	N	Melbourne [40]
23	23	8%	43%		21	3%	1%	1%	N	Brisbane [40]
24	26	6%	51%		10	—	—	7%	N	Barcelona [47]

Note. "—" indicates that there is no consideration of this substitutive travel mode in the survey; "*" indicates a survey on electric bike-sharing; "N" indicates no mention in the original literature; the values corresponding to the same city represent the results of studies conducted in different years or by different scholars in the same year.

illustrated in Figure 1, aims to depict the process of creating the systematic review dataset for further analyses. The PRISMA checklist follows a structured format with sections such as title, abstract, introduction, methods, results, discussion, and funding, specifying information that each section should include [58]. While PRISMA 2020 provides a template indicating where information might be located, the suggested location should not be seen as prescriptive; the guiding principle is to ensure the information is reported [58]. Therefore, to enhance the organization of this article, the suggested location of some information may be reorganized.

2.1. Literature Search and Filtering Method. This study employed a three-stage literature collection method to obtain research on the competition and cooperation relationship between bike-sharing and public transit. Seventy-one high-quality pieces of literature relevant to the topic were ultimately retained, and the literature search and filtering process is illustrated in Figure 2. Firstly, we searched Google Scholar, Web of Science, Scopus, and Baidu Scholar databases for all literature that contains terms with the same meaning as bike-sharing and public transit simultaneously in the title, abstract, and keywords. Given that bike-sharing-related studies started to appear after 2010, the literature period was set from 2010 to 2022. This search resulted in an initial collection of 1177 articles, comprising 1158 peer-reviewed journal articles and 19 industry reports on bike-sharing (grey literature). Secondly, the titles and abstracts of the collected literature were reviewed. Articles with research objectives covering bike-sharing and public transit, along with research content related to the interrelationship between the two, were retained. Using the backward snowballing method, 21 papers related to the topic were retrieved from the cited papers. Together with the previously identified articles, this made a total of 344 papers. In the third step, after reading the full text of the literature retained in the second step, a total of 71 representative studies related to the coopetition relationship between bike-sharing and public transit were kept. Table 2 presents the distribution of these 71 studies by year.

2.2. Literature Analysis Method. In terms of literature analysis methods, we initially categorized the articles by conducting a detailed review. This categorization was based on the definition, evaluation metrics, and quantification methods of the coopetition relationship between bike-sharing and public transit. Subsequently, we summarized and reviewed the evaluation methods, evaluation results, and research shortcomings within each category. Finally, we identified the strengths, weaknesses, and potential improvement directions for each evaluation method.

After sorting and analyzing the final 71 papers, we divided the current research on the coopetition relationship between bike-sharing and public transit into the macro- and micro-categories based on the data granularity used in the study, as shown in Figure 3. Macrostudies use data on bike-sharing rides and public transit ridership at the station, route, or city level, while the microstudies use survey data on users travel behaviors or bike-sharing transaction data. Within the macrostudies, based on the definition, evaluation metrics, and quantification methods of the coopetition relationship, they can be classified into studies on the impact of bike-sharing facilities or ridership on public transit ridership, studies on the effects of public transit facilities or ridership on bike-sharing ridership, and studies on the influence of a sudden shutdown of public transit on bike-sharing ridership. Microlevel studies can be classified into studies on actual coopetition behaviors based on bike-sharing user behavior surveys and studies on potential coopetition relationships based on bike-sharing transaction data. Studies based on user surveys include studies on the substitution and connection behaviors of shared bikes and public transit, as well as studies on factors influencing shared bikes to substitute for or connect with public transit. Studies on potential coopetition relationships based on bike-sharing transaction data mainly include analyses of the potential substitution, connection, and complementation relationships between shared bikes and public transit, along with their spatiotemporal characteristics. The paper summarized and reviewed the evaluation methods, evaluation results, and research shortcomings for each category in Sections 3–5. Finally, the strengths, weaknesses, and improvement directions of each evaluation method are discussed in the Discussion section.

3. The Macro-Coopetition Relationship Based on Public Transit Ridership and Shared Bike Ridership

Since the advent of bike-sharing, factors influencing its ridership and its impact on public transit ridership have been primary concerns for operating companies and government agencies. These considerations are beneficial to operators in site selection, scheduling operations, and vehicle deployment. Simultaneously, these considerations also help government agencies in planning and deploying bike-sharing and public transit systems, preventing overlapping and competing services.

Given the above issues, three main types of studies have been conducted. (1) The impact of bike-sharing on public transit ridership: this type of study attempts to quantify the extent to which the usage of bike-sharing increases and decreases public transit ridership. These studies argue that when public transit ridership decreases, the two modes form a competitive relationship, and vice versa, a cooperative relationship. (2) The impact of public transit on bike-sharing ridership: this analysis explores how public transit facilities' density, ridership, and service level influence bike-sharing ridership in different spatiotemporal scenarios. Studies in this category consider that the two modes form a cooperative relationship when they are significantly positively correlated and a competitive relationship when they are significantly negatively correlated. (3) The impact of public transit shutdowns on bike-sharing ridership: this type of study focuses on answering how bike-sharing compensates for the decline in public transit service level and enhances urban resilience under unexpected events.

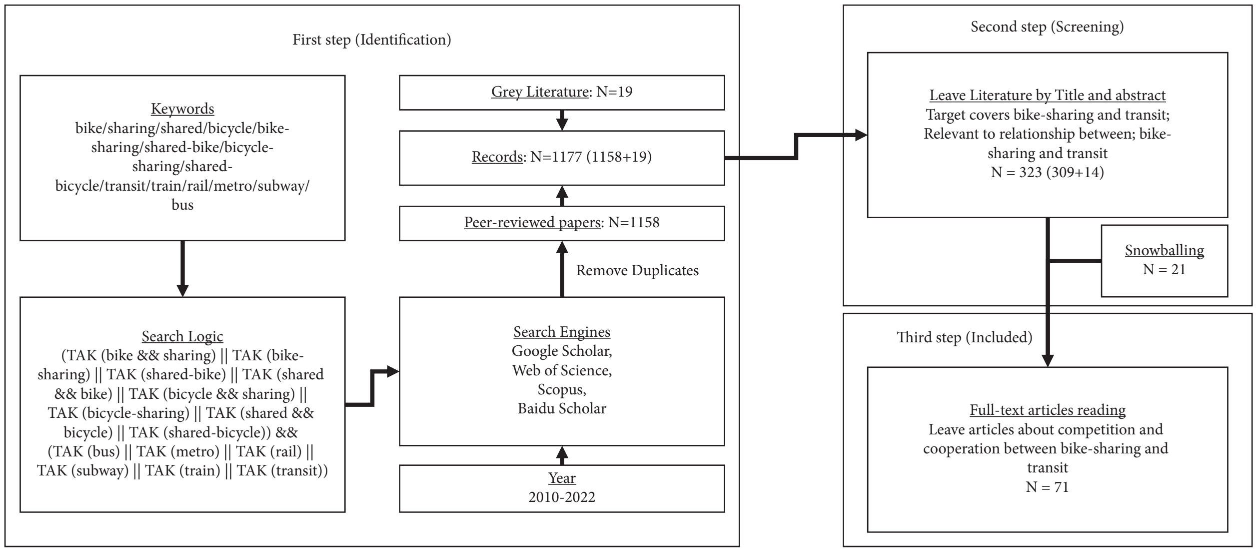

Figure 2: The flowchart of the literature search and filtering process. TAK refers to title, abstract, and keywords; || refers to or; *N* refers to sample.

Table 2: Distribution of the 71 studies by year.

Year	Number of studies	Percentage (%)
2010	1	1
2011	2	3
2012	4	6
2013	2	3
2014	5	7
2015	2	3
2016	3	4
2017	5	7
2018	4	6
2019	7	10
2020	12	17
2021	14	20
2022	10	14

3.1. The Impact of Bike-Sharing Facilities and Ridership on Public Transit Ridership. The main research contents, methods, and conclusions of representative research results are shown in Table 3. This kind of research primarily employs statistical, econometric, and deep learning models, including the difference-in-difference (DID) model, linear regression model, synthetic control method, and random forest, to analyze the impact of the introduction of bike-sharing on public transit ridership based on bike-sharing transaction data and data on urban public transit stations or route passenger volume.

These studies have observed that bike-sharing weakens bus ridership while boosting rail transit ridership [59, 60, 62]. Shi et al. [59] found a significant positive correlation between the introduction of bike-sharing and rail transit ridership while a negative correlation between the introduction of bike-sharing and bus ridership. This suggests that shared bikes may substitute for buses as feeders to the subway, leading to a decline in bus ridership and an increase in rail transit ridership. Campbell and Brakewood [60] discovered that for every 1000 shared bike stocks near public transit lines, bus ridership decreased by 2.4%, without controlling for the variable of bicycle lane facilities. However, when controlling for the variable of bicycle lane facilities, bus ridership decreased by 1.69%, indicating that the combined layout of shared bikes and bicycle facilities intensified the weakening effect on bus ridership.

By modeling for each bus line and the entire bus network, Godavarthy et al. [62] found that while bike-sharing ridership reduced bus ridership at the network level, individual line analysis revealed that night operations and long-distance bus lines were not significantly affected by bike-sharing ridership. This might be attributed to unsafe night-time riding and the physical limitations of long-distance riding. Ma et al. [61] discovered that bike-sharing significantly contributed to bus ridership on weekdays but had a minor effect on weekends. These findings highlight substantial spatial and temporal heterogeneity in the impact of bike-sharing on public transit. Besides the heterogeneity due to lines with different operating patterns and weekdays/weekends, other factors such as whether urban cores and suburbs contribute to differences in the impact of bike-sharing on the bus ridership are also worth exploring in future research.

Unlike buses, rail transit significantly benefited from bike-sharing [8, 59, 63, 64]. Shi et al. [59] confirmed that the introduction of bike-sharing boosted rail transit at the city level, based on the DID model. Fan and Zheng [8] further validated these results at the rail line level. Furthermore, they observed that lines with high cycling intensity, defined as the number of daily trips of shared bikes starting or ending within 600 meters of rail transit stations, had significantly higher ridership than those with low cycling intensity. However, having more bike-sharing rides around rail lines may not always be advantageous, as this could offset the benefits for rail transit with negative effects on bus ridership [59]. More specifically, Fan and Zheng [8] found more substantial boosts on weekdays than on weekends. In

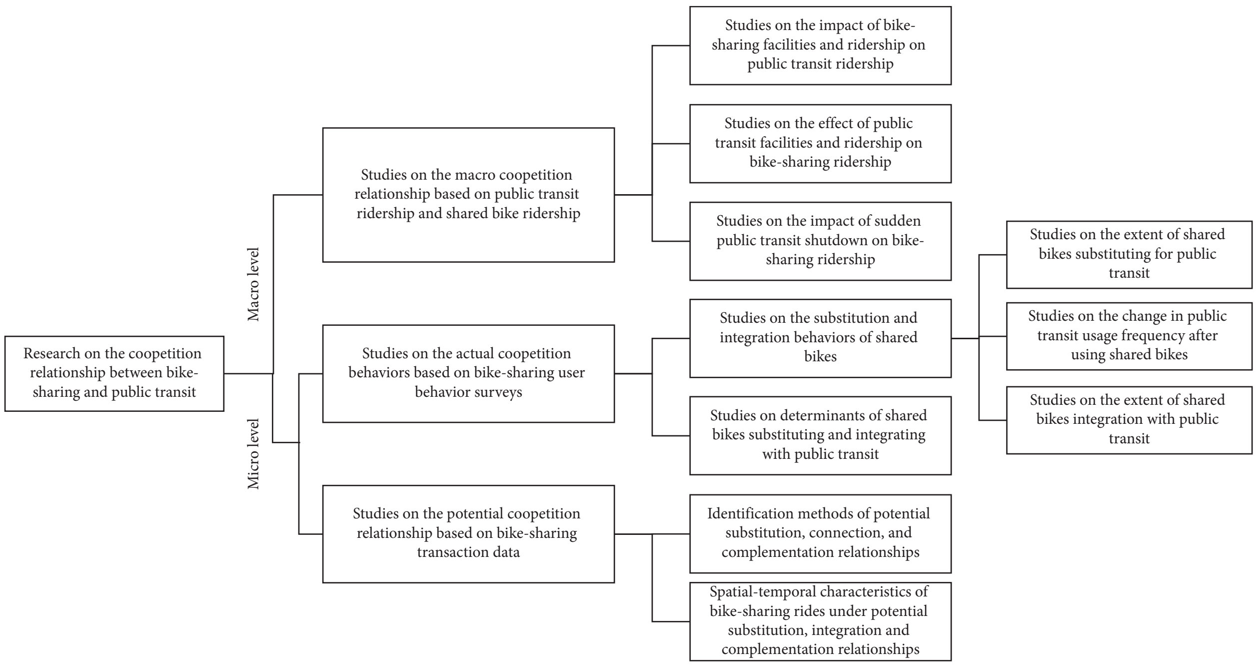

Figure 3: Summary of research on the coopetition relationship between bike-sharing and public transit.

contrast to studies based on large cities, Li et al. [64], focusing on a small city (Tucson, Arizona), found that the bike-sharing system did not significantly impact bus and bus rapid transit (BRT) systems but significantly boosted tram ridership. The authors suggested that this might be due to the relatively low coverage of shared bikes around bus and BRT routes. Few studies have revealed the evolutionary characteristics of the impact of bike-sharing facilities and ridership on public transit over a long-term scale. This involves exploring how the marginal degree of impact of bike-sharing on public transit ridership changes over time.

3.2. The Effect of Public Transit Facilities and Ridership on Bike-Sharing Ridership. Some studies use facility density, ridership, and service level of public transit as independent variables and bike-sharing ridership as a dependent variable to develop statistical models to infer the effects of the independent variables on the dependent variable under different spatial and temporal scenarios.

Bike-sharing ridership is generally significantly related to public transit ridership and the density of public transit facilities [46, 65–70]. Bike-sharing ridership is positively correlated with rail station density and negatively correlated with distance from the rail station, implying that the level of public transit service is positively associated with bike-sharing ridership [66, 68–70]. However, a study by Sun et al. in Chicago found a significant negative correlation between bike-sharing ridership and subway departure frequency [65]. This could be because areas with dense public transit facilities and close proximity to public transit facilities have higher travel demand, resulting in crowded carriages and long waiting times, which lead travelers to opt for bike-sharing.

The relationship between bus and bike-sharing ridership exhibits significant variation between cities. In Melbourne, bike-sharing ridership is higher in areas with low bus accessibility, suggesting potential cooperation between bike-sharing and buses in areas with limited bus accessibility [66]. In Seoul, the density of bus stops during morning rush hours is positively associated with bike-sharing departure ridership but negatively associated with bike-sharing arrival ridership [67]. Furthermore, the study in Seoul also found that bike-sharing ridership for distances less than 10 km was positively correlated with travel duration and transfer duration of public transit.

While most studies considered the effect of public transit on bike-sharing ridership as a linear effect, Wang et al. [71] constructed a random forest model and discovered a nonlinear effect of the distance between bike-sharing stations and subway stations on bike-sharing ridership. The bike-sharing ridership reaches its highest value at a distance of 200–300 meters from metro stations. Furthermore, the distance threshold corresponding to the peak in ridership exhibits significant regional heterogeneity.

The above research reveals the spatial-temporal correlation between bike-sharing and public transit but does not precisely illustrate the competition and cooperation relationship. In our opinion, the main reason is the lack of consideration of the relationship between bike-sharing ridership and the supply-demand situation of the public transit system. Current studies usually focus on the relationship between bike-sharing ridership and the supply situation of the public transit system, such as the density of public transit stations and the frequency of public transit departures. Specifically, when bike-sharing ridership is positively correlated with the density of public transit stations, it may indicate that shared bikes serve travel needs that

Table 3: Research summary on the impact of bike-sharing on public transit ridership.

Serial number	Research objective	Research method	Key results	Source
1	The impact of bike-sharing's emergence on bus and rail transit ridership across 273 cities in China from 2004 to 2017	The difference-in-difference (DID) model	(i) The emergence of bike-sharing decreased bus ridership by 17% in cities across China (ii) The emergence of bike-sharing increased rail ridership by 146% in cities across China	Shi et al. [59]
2	The influence of bike-sharing ridership on rail transit ridership in Beijing in 2017	DID model	(i) Every increase of 10,000 in bike-sharing ridership around one metro line increased rail ridership by 10% (ii) Every increase of 10,000 in bike-sharing ridership connecting to the metro around one metro line increased rail ridership by 16%	Fan et al. [8]
3	The impact of the advent of bike-sharing on bus use in New York between 2012 and 2014	DID model	(i) The emergence of bike-sharing weakened bus ridership, with every 1,000 rides resulting in a 1.69% reduction in ridership for each bus route	Campbell and Brakewood [60]
4	The influence of the advent of bike-sharing on bus ridership in Chengdu between 2016 and 2017	DID model	(i) Each shared bike increased bus ridership by 4.23 person-times per day on weekdays at the bus route level (ii) Each shared bike reduced bus ridership by 0.56 person-times per day on weekends at the bus route level	Ma et al. [61]
5	The impact of bike-sharing ridership on bus ridership in the area around North Dakota State University in 2015	Linear regression model considering error autocorrelation	(i) Every 100 bike-sharing rides reduced bus ridership by 44 person-times per day	Godavarthy et al. [62]
6	The impact of bike-sharing on rail transit ridership in Washington, D.C., in 2013	OLS model	(i) Every 10% increase in the number of shared bike rides resulted in a 2.8% increase in metro station ridership	Ma et al. [63]
7	The impact of a small-scale bike-sharing system on public transit ridership in Tucson in 2019	Synthetic control method	(i) Every increase of 1 trip in bike-sharing resulted in an increase of 0.55 trips for trams	Li et al. [64]

public transit cannot meet due to saturation, which can be viewed as cooperation. However, if shared bikes take passengers who could be served by public transit, this can also be viewed as competition.

3.3. The Impact of Sudden Public Transit Shutdown on Bike-Sharing Ridership. These studies concentrate on the complementary role of bike-sharing to public transit when public transit shuts down. Table 4 shows representative studies, including objectives, methods, and results. These research efforts primarily employ complex network and regression models, such as the disruption time series model, the Bayesian structural time series model, and the OLS linear regression model, to explore the distinctions in bike-sharing riding patterns during public transit shutdowns compared to those before the events.

When the urban public transit system shuts down, bike-sharing becomes a crucial alternative mode of travel, significantly contributing to the resilience of integrated urban transportation systems. Studies generally indicate that when urban rail transit shuts down for a full day or temporarily for a few hours, the use of shared bikes increases. Furthermore, the use of shared bikes shows significant spatial and temporal heterogeneity [72–76]. In terms of spatial heterogeneity, Yang et al. [72] and Jia et al. [73] found the most significant increase in bike-sharing ridership in areas near disrupted rail lines. Klingen [75] and Saberi et al. [76] observed that bike-sharing stations located near disrupted rail stations experience a significantly higher increase in ridership compared to other areas, and this increase decreases with distance from the disrupted rail stations. This implies that bike-sharing effectively supplements travel service capacity when public transit is out of service.

Regarding temporal heterogeneity, Yang et al. [72] found a modest increase in morning peak ridership but a significantly higher rise in other periods when rail transit was shut down throughout the day in London. This is likely due to the tighter commute schedules during the morning peak, making it challenging to use a more physically demanding and low-speed alternative like bike-sharing than rail transit. A study by Klingen [75] on the impact of temporary rail shutdowns in Paris found that bike-sharing ridership reached its maximum at 40 minutes of shutdown, and total ridership stopped changing after one hour due to supply saturation. Yang et al. [72] also confirmed that rail shutdowns accelerate the saturation of bike-sharing stations, suggesting that operators need to enhance scheduling efficiency to maximize the complementary capacity of bike-sharing to public transit during unexpected events.

When rail transit was shut down, bike-sharing substituted for some short-distance rail transit trips and significantly increased travelers' tolerance for longer rides. The average duration of bike-sharing rides increased from 23 minutes to 42 minutes after a rail shutdown in London [76]. In contrast, a rail shutdown in Washington, D.C., did not significantly increase ride length [73]. Further research is needed to understand why these differences occurred among cyclists using shared bikes in different countries. This variation may be related to factors such as riding culture, facility density, and the service level of the bike-sharing system.

When rail transit was shut down, studies based on the complex network approach found changes in the network structure of bike-sharing system. In detail, not only did ridership between the original origin-destination (OD) pairs increase, but new OD pairs of bike-sharing trips were also generated [72, 73, 76]. Saberi et al. [76] observed that the new OD pairs did not alter the original community structure, indicating the importance and centrality of the complex network established based on bike-sharing stations and the ridership between them. Yang et al. [72] found that the new cycling OD pairs mainly occurred on weekdays rather than weekends, suggesting that these new OD pairs mainly originated from the original rail transit commuting trips, which may be related to the rigidity of commuting demand. Additionally, Jia et al. [73] found that cycling intensity between central and peripheral areas increased after the rail transit shutdown.

Typically, shared bikes are used for short-distance travel, while buses cater to short-to-medium distance travel. Optimizing the deployment of these two modes to address the reduced passenger capacity resulting from rail transit shutdown is a topic deserving of future research. Considering the inherent challenge of quicker saturation of shared bike stations during rail line disruptions, it is essential to study how the bike-sharing systems should respond promptly.

In summary, at the macrolevel, the introduction of bike-sharing boosts ridership for rail transit but decreases it for buses. Rail transit facility density and ridership show a significant positive correlation with bike-sharing ridership. However, the relationship between bus facility density, ridership, and bike-sharing ridership varies significantly by region. Bike-sharing plays an essential alternative role when rail transit is out of service. This section synthesizes the literature about the relationship between bike-sharing and public transit systems from a macroscopic perspective, while the next section will delve into synthesizing the behavioral choice mechanism involved.

4. The Actual Coopetition Behaviors Based on Bike-Sharing User Behavior Surveys

The previous section reviews the research on the coopetition relationship from a macroperspective, which is driven by individual travel behavior. Travelers shifting from using public transit to using bike-sharing will lead to a decline in public transit ridership. Conversely, travelers using bike-sharing to connect with public transit, thereby replacing cars or other non-public transit modes, will increase public transit ridership. Therefore, it is generally accepted that bike-sharing substituting for public transit forms a competitive behavior, while bike-sharing connecting to public transit forms a cooperative behavior. As travelers' decisions generate substitution and connection behaviors, this review terms them the actual coopetition behavior, distinguishing them from potential coopetition relationships in the next

Table 4: Research summary on the impact of public transit shutdowns on bike-sharing usage.

Serial number	Research objective	Research method	Key results	Source
1	The impact of four full-day tube shutdowns in London on the characteristics and behavior of bike-sharing use	Graph-based data analysis and visualization techniques	(i) A network-level weekday disruption resulted in an 88% increase in bike-sharing trip volumes throughout the day, while weekend disruptions led to a 52% increase in trip volumes (ii) The number of stations under saturation pressure doubles during the weekday morning peak (iii) The number of new bike-sharing OD pairs increased by 80% during weekday strike events and by 38% during weekend strike events	Yang et al. [72]
2	The impact of the metro shutdown on the spatial and temporal characteristics of different bike-sharing users in Washington, DC.	Spatial-temporal analysis and statistical inference methods based on complex networks	(i) The metro shutdown resulted in a 12% increase in bike-sharing trips by members and a 191% increase in trips by casual users per day (ii) For members, the average trip duration increased by 22% from 12.5 to 15.3 minutes, and the trip distance increased by 16% from 1.85 to 2.14 kilometers; however, the variation in trip duration and distance for casual users was not significant (iii) Bike-sharing stations in central traffic analysis zones (TAZ) and in TAZs within 2 km of metro lines experienced an increased number of trips during shutdowns (iv) The node degree of the bike-sharing network on metro shutdown days averaged 46.09, compared to 40.51 on normal days	Jia et al. [73]
3	The impact of the Philadelphia public transit workers' strike on bike-sharing use	Interrupted time series models and Bayesian structural time series models	(i) During the strike period (a week) in Philadelphia, the public transit strike caused an average increase of 86 to 92 trips per 100,000 population, with member ridership increasing by 41 trips and non-member ridership by 49 trips, respectively	Fuller et al. [74]
4	The impact of temporary metro disruptions in Paris on demand for shared bikes	Fixed-effects and one-difference regression models	(i) The difference between the net bike-sharing checkout volume and the normal state net checkout volume reaches its peak 40 minutes after a subway disruption, and this difference tends to zero after 1 hour (ii) Temporary subway disruptions increase the likelihood of encountering an empty station more than usual, from approximately 13% to 15%	Klingen [75]

Table 4: Continued.

Serial number	Research objective	Research method	Key results	Source
5	The impact of rail disruption on bike-sharing usage patterns in London	Complex network theory approach	(i) London rail disruptions led to an 85% increase in total bike-sharing rides (ii) London rail disruptions resulted in an 88% increase in average ride length, with significantly longer ride lengths observed in suburban areas compared to urban areas (iii) There was a more significant growth in ridership in areas close to tube stations compared to other areas (iv) Rail disruptions increased the connectivity of the bike-sharing travel network by 88% (v) Neither the importance nor the centrality of the original bike-sharing stations in the network has changed	Saberi et al. [76]

section. Concerning actual coopetition behavior, the extent to which bike-sharing substitutes for or integrates with public transit, as well as the determinants underlying such coopetition behavior, was analyzed mainly based on user surveys.

4.1. The Substitution and Connection Behaviors of Shared Bikes. The questionnaire-based study on the extent of bike-sharing and public transit substitution and connection focused on three questions: (1) How many bike-sharing rides were shifted from public transit, and how many were shifted from other modes? (2) How did people's usage frequency of public transit change after using bike-sharing for the first time? (3) How many bike-sharing rides were integrated with public transit or other modes?

4.1.1. The Extent of Shared Bikes Substituting for Public Transit. The extent to which bike-sharing is used as a substitute for public transit was investigated by asking bike-sharing users about the type of travel mode they substituted the last time they rode a shared bike. The current publicly available research results are mainly from cities in China, the United States, Canada, the United Kingdom, France, Australia, and Spain (Table 1). However, independent surveys conducted across cities have led to inconsistent data statistical standards. Some surveys do not distinguish between bus and rail transit, and some do not consider that bike-sharing may induce new trips [23, 30, 32, 41, 45–47]. Additionally, some surveys categorize modes such as car-sharing and getting a ride from others as individual motorized travel modes, while others classify them as other types [30, 32, 41, 42, 45–47]. Furthermore, surveys in different cities also differed slightly in their questioning methods, with some studies asking, "How did you complete your last bike-sharing trip before the advent of bike-sharing?," while others asked, "How did you complete your last bike-sharing trip when bike-sharing was not available?" or "What travel mode did you usually use before you first used bike-sharing?" In short, these studies have similar objectives but differ in questionnaire design and questioning style. Consistency in data collection is a matter of concern for the future to ensure the comparability of findings.

The visualization of Table 1 is presented in the box plot shown in Figure 4. Shared bikes are predominantly an alternative to green travel modes, with a limited ability to replace cars. Figure 4 illustrates that 30–50% of bike-sharing trips are shifted from public transit trips, 22–44% from walking trips, and only 14% from trips by car or taxi, including ride-hailing. However, a comparison of the results from surveys in Washington [35–38] and Montreal [41, 42] over consecutive years reveals a decreasing trend in the replacement of public transit and an increasing shift towards individual motorized travel modes, including private cars and taxis.

The variance in the substitution rate of bike-sharing for public transit across cities primarily arises from the variance in the substitution rate for rail transit. Figure 4 indicates that the variance of the substitution rate for buses is slight, concentrated around 20%, whereas the substitution rate for rail transit fluctuates between 6% and 28%. These substitution rate results are based on aggregated data from different studies. Thus, there is a lack of explanation for the variance in the substitution rate for rail transit. This systematic review suggests that one possible reason is the relatively well-established scale of the bus system in each city compared to the wide variation in rail transit coverage. Fishman et al. [40] speculate that the high rate of bike-sharing substitution for public transit (61%) and the low rate of substitution for cars (5%) in London may be related to London's low modal share of cars and high public transit usage.

Campbell et al. [23] conducted a stated preference (SP) survey of Beijing residents to investigate potential changes in travel modes with the advent of bike-sharing and e-bike-sharing. This study found that shared e-bikes had higher substitution rates for public transit and cars than shared bikes, primarily due to the lower walking substitution rates of shared e-bikes. Furthermore, the study revealed that travelers who previously used sheltered travel modes (such as cars, buses, and other travel modes providing shelter from wind and rain) and those who traveled longer distances tended to shift to shared e-bikes compared to shared bikes [23].

The substitution of bike-sharing for public transit does not necessarily mean that bike-sharing competes directly with public transit. Susan et al. [36] found that bike-sharing was a dominant alternative to public transit for commuting trips but a dominant alternative to walking for noncommuting trips, based on a survey of bike-sharing users in Washington, D.C. McKenzie [29] found that bike-sharing was more time-efficient than buses or ride-hailing during congested rush hours in Washington, D.C. These studies suggest that bike-sharing can play an essential role in reducing traffic congestion and improving the efficiency of commuting trips. Therefore, it is one-sided to completely define the mutual substitution of shared bikes and public transit as competition at present research and requires further exploration. In fact, bike-sharing and public transit form a cooperative relationship when the time required for a shared bike trip is significantly shorter than that for public transit, especially during rush hour. In this case, bike-sharing can help compensate for the low level of service on public transit.

Bike-sharing can impact public transit not only through substitution but also through connection. By using bike-sharing in combination with public transit to replace private car trips, public transit ridership can be promoted. Therefore, relying solely on surveys that measure the substitution rate can overestimate the reduction in public transit usage. To address this issue, surveys should also examine changes in travel mode chains.

4.1.2. The Change in Public Transit Usage Frequency after Using Shared Bikes. The previous section shows that bike-sharing has both substitution and integration effects on public transit, which can affect the frequency of public transit usage. Questionnaires were used to investigate changes in public transit usage frequency among bike-sharing users after their first use of shared bikes. The

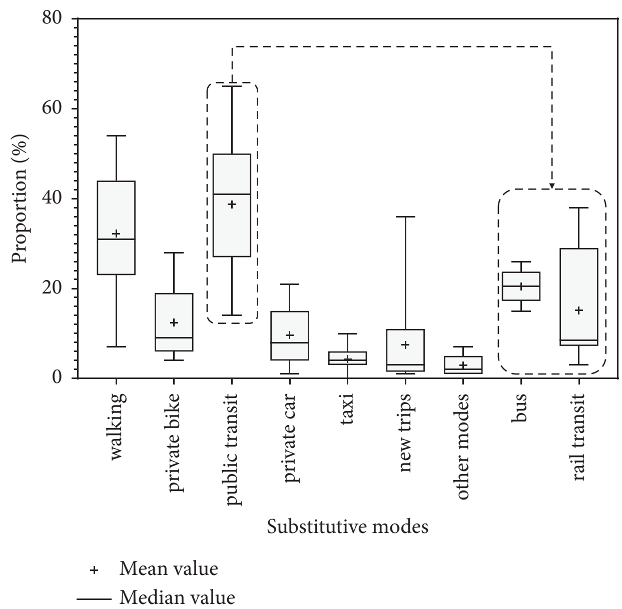

FIGURE 4: Distribution of substitution rates for various travel modes. The substitution rate for bus and rail transit represents the overall substitution rate for public transit; the figure excludes data on shared electric bikes; when multiple studies have been conducted on the same city, only the earliest research results are used as samples; the box plot representing walking is based on 17 sample percentages from the "walking" column in Table 1. Each percentage in every cell of Table 1 represents an individual sample.

results showed that in most cities, more users decreased their bus usage frequency than increased it (Table 5), supporting the macrolevel finding that bike-sharing generally weakens bus ridership. Surprisingly, a greater proportion of users in most cities decreased their rail usage frequency than increased it (Table 5). This contrasts with the macrolevel finding that bike-sharing predominantly promotes rail transit ridership. This review suggests that users who increase their rail transit usage after using bike-sharing may do so to a greater extent than those who decrease their usage.

4.1.3. The Extent of Shared Bikes' Integration with Public Transit. Bike-sharing plays a crucial role in providing transportation for the "last mile" of a journey. A survey conducted in the Spanish province of Malaga showed that 79.6% of bike-sharing trips were single-mode trips, with 10.7% connecting to buses, 3.4% connecting to rail, and only 6.3% connecting to other modes [78]. In Dublin, 39% of bike-sharing trips were combined trips, 14% of which were integrated with buses and 22% with rail [45]. In Shanghai, bike-sharing feeder rides accounted for 51.2% of total rides, with 50.2% integrated with public transit and only 1% integrated with other modes of travel [31]. Although the proportion of bike-sharing integration rides varies across cities, public transit is typically the primary travel mode integrated with bike-sharing.

Despite the increasing popularity of bike-sharing, there remains a notable gap between bike-sharing ridership and public transit ridership, with walking continuing to serve as the primary feeders for public transit. For example, Ji et al. [79] conducted a random intercept survey at Nanjing subway stations to inquire about the feeder mode of rail transit travelers. They found that 44% of respondents opted for walking as their integration mode, while 29% used the bus, with shared bikes, private bikes, and private cars each accounting for 9%. In a similar study conducted by Guo and He [80] on the feeders of rail transit commuters in Shenzhen, approximately 75% of users relied on walking for integration, 15% used shared bikes, and 10% preferred buses.

Theoretically, combining shared bicycles with public transit can serve as a viable alternative to cars. However, research shows that bike-sharing predominantly functions as an alternative to walking and bus when used as a feeder. For example, a study based on intercepted surveys conducted at subway stations in Nanjing found that 47.6% of bike-sharing users combined it with rail transit for commuting, replacing walking as a connection to the rail. Additionally, 18.9% used it to replace buses, and 14.8% used it to replace private bikes when connecting to the rail [32]. Surprisingly, only 15.4% of users who combined bike-sharing with rail transit used it to replace private cars for their entire journey [32]. Addressing this issue and improving the substitution of car trips with the combination of shared bikes and public transit is crucial for enhancing bike-sharing's role in alleviating traffic congestion and addressing environmental concerns in the future.

4.2. Determinants of Shared Bikes Substituting and Integrating with Public Transit. While the previous section reviewed the extent to which bike-sharing substitutes for and integrates with public transit, this section delves into the research on the factors influencing these outcomes. In other words, this section aims to understand why travelers use bike-sharing in place of or in combination with public transit. In addition to scrutinizing the relationship between bike-sharing and public transit, scholars have also explored how other travel modes interact with public transit. Consequently, this section includes an analysis of various travel modes.

These studies typically rely on surveys, including both revealed preference (RP) surveys and stated preference (SP) surveys. These surveys aim to collect data on travelers' choices and intentions regarding the use of bike-sharing as an alternative or in integration with other travel modes across various scenarios. The questionnaires typically include determinants such as personal profiles, travel characteristics, travel habits, travel attitudes, satisfaction with bike-sharing, bike-sharing accessibility, and usage characteristics of bike-sharing. Furthermore, researchers sometimes consider indicators related to the built environment, land use, and the natural environment in urban areas as other determinants. Subsequently, researchers construct a relationship model between these determinants and mode choice, aiming to identify the significant factors influencing travelers' decisions to use bike-sharing as an alternative or a feeder to other travel modes. The most common models employed for this analysis are discrete choice models, including the binomial logit model, the multinomial logit model, and the hybrid logit model.

Table 5: Changes in bus and rail transit use frequency by shared bike users after first using shared bikes.

Serial number	Frequency of bus use increasing (%)	Frequency of bus use with no change (%)	Frequency of bus use decreasing (%)	Frequency of rail use increasing (%)	Frequency of rail use with no change (%)	Frequency of rail use decreasing (%)	City
1	4	58	38	5	74	21	Vancouver [43]
2	3	45	52	4	35	61	Washington D.C. [36]
3	7	56	38	9	48	43	Montreal Toronto Washington, D.C. [39]
4	14	69	17	15	83	3	Twin Cities [77]
5	16	63	18	11	85	2	Twin Cities [39]
6	8	76	4	14	79	7	Salt Lake City [39]
7	6	37	56	7	34	57	Montreal [39]
8	3	55	39	8	41	49	Toronto [39]
9	20	44	34	13	67	17	Mexico City [39]

Note. Three cities in one cell represent three city aggregate statistics.

4.2.1. Determinants of Bike-Sharing Substituting for Other Travel Modes. Not all travelers choose to use a shared bike after its introduction, and even those who do may not use it all the time. People typically select travel modes based on factors like travel distance, travel purpose, and personal habits. City managers hope that bike-sharing will substitute for cars and complement public transit. Therefore, it is crucial to understand the mechanisms and factors that facilitate bike-sharing substituting for and integrating with other travel modes.

Travel characteristics, natural environment, and psychological factors influence whether travelers abandon their original travel mode in favor of bike-sharing. Ye et al. [81] constructed a mixed multinomial logit model based on SP survey data from docked bike-sharing users in Nanjing city. The analysis found that scenarios such as sunny weather, rush hours, short travel distance, and commuting trip purposes were the main situations that promoted bike-sharing as an alternative to the original travel mode. Given the differences in function, user, and usage characteristics between docked and dockless bike-sharing [17, 82], the determinants that affect the use of shared bikes as an alternative travel mode differ between the two systems. A study in Delft found that users who were accustomed to combining travel modes during commuting were more likely to use dockless shared bikes [83]. In contrast, users who enjoy public transit concessions were more inclined to use docked shared bikes, possibly because public transportation companies operate docked shared bikes in Delft. In addition, the psychological perception of not having to worry about theft and damage and the lower price are the main incentives for dockless bike-sharing users to abandon their original travel mode. Conversely, docked bike-sharing users value the quality of the bicycle more.

What travel mode the shared bike substitutes for depends on the travelers' profile, travel characteristics, built environment, psychological factors, and usage characteristics of the shared bike. Bartling [84] explored the determinants of docked shared bikes as a substitute for different travel modes by residents in Chicago's Lincoln Park neighborhood based on a binomial logit model. They found that psychological factors significantly influenced the propensity to use shared bikes to substitute for different original travel modes. The attitude that shared bikes are low cost promotes their substitution for rail transit, and the attitude that travelers want to exercise promotes substitution for the car. Interestingly, the environmental protection factor for cycling was insignificant, which may be because it is not the first consideration for people to choose to ride a bike [85]. Chen et al. [86] constructed a multinomial logit model based on a dockless bike-sharing case in Beijing to compare the determinants of different travel modes replaced by shared bikes under various travel scenarios, including commuting, sports and leisure, grocery shopping, and recreational activities. They found that the determinants vary across different travel scenarios. In the case of public transit, the availability of public transit in the commuting scenario inhibits its substitution by bike-sharing. However, the availability of public transit in sports and leisure scenarios promotes its substitution.

4.2.2. Determinants of Bike-Sharing Integrated with Public Transit. Current studies on the factors influencing bike-sharing integrated with public transit have focused mainly on bike-sharing combined with rail transit, with little research focusing on bike-sharing integrated with buses. Guo et al. [87] found that the perception of traffic safety significantly impacted the choice between the three feeder modes—walking, shared bikes, and buses—based on the study of the feeder behavior of rail transit commuters in Shenzhen. Fear of bicycle accidents significantly increased people's tendency to choose walking over the shared bikes as integration modes. In contrast, fear of car accidents significantly increased people's tendency to choose bike-sharing or buses over walking as an integration mode. The study also found that travel attitudes, travel characteristics, and travelers' profiles had significant effects on the choice of integration mode. Ji et al. [79], based on a case study in Nanjing and also using the MNL model, confirmed the significance of the above influencing factors.

The choice of feeder modes for rail transit during commuting scenarios is influenced by the natural and built environment of one's place of residence and work. Panchal et al. [88] expanded on previous studies by considering the natural environment and road conditions. Using RIDIT analysis, they identified weather conditions as the most critical factor, with the perceived safety of cycling, traffic congestion, and integration distance as secondary factors.

The impact of the objective environment on mode choice relies on people's perception, and variation in perception often leads to differences in the degree of influence on mode choice. Consequently, Guo et al. [80] employed a structural equation model to investigate the influence of both the objective built environment and subjective perception on the feeder choice behavior of rail commuters in Shenzhen. Their findings indicated that people's perception of the built environment is weak, leading some people to not adopt the habit of riding shared bikes to integrate with public transit due to reduced sensitivity to the convenient riding and integration environment around them. This underscores the importance of not only a well-designed cycling environment but also engaging in public awareness campaigns to enhance people's perception of their surroundings for effective changes in travel behavior.

Determinants such as travelers' profiles, travel characteristics, travel attitudes, and the built environment significantly affect travel behavior. However, these factors exhibit varying effects across cities, according to different natural and social environments. In a comparative study across three cities—Beijing, Taipei, and Tokyo—Lin et al. [89] explored the influencing factors affecting travelers who use shared bikes as feeders to rail transit. The findings confirmed that the determinants differ across cities. Moreover, the travel mode prediction models based on the built environment variables of each city could not be universally applied to other cities [89]. This emphasizes that cities should avoid simply replicating strategies from others to build a bicycle-friendly environment. Instead, attention should be given to local travel characteristics when developing urban infrastructure and policies.

In summary, various factors such as personal profiles, travel characteristics, travel habits, travel attitudes, satisfaction with bike-sharing, bike-sharing accessibility, bike-sharing usage characteristics, built environment, land use, and natural environment are potential influencers in the integration and substitution of public transit by bike-sharing. It is important to note that the significance of these factors may vary across regions. However, whether loyalty plays a role in influencing the substitution and connection of shared bikes with other travel modes requires further research.

5. The Potential Coopetition Relationship Based on Bike-Sharing Transaction Data

With the introduction of bike-sharing, travelers now have the option to use shared bikes to replace their original public transit mode, connect with public transit for multimodal journeys, or simultaneously replace and connect with public transit. A notable instance of the latter involves using shared bikes to connect to the subway, effectively replacing the original bus connection to the subway, as discussed in the preceding section. Bike-sharing has the potential to make certain travel scenarios more cost-effective or efficient, either by serving as a substitute for or connecting to public transit, compared to using public transit alone. Although some travelers may still not opt for bike-sharing in these situations, the consideration of using it for future trips becomes more likely. At this point, bike-sharing creates potential substitution or connection relationships with public transit. City managers must be attentive to this potential influence, as it could impact public transit ridership.

Based on the preceding consideration, studies on the potential coopetition relationship identified three potential coopetition relationships: potential substitution, connection, and complementation relationships, between bike-sharing and public transit. Furthermore, these relationships were analyzed by examining the spatiotemporal characteristics of bike-sharing rides. Typically, a potential substitution relationship is considered a potential competition relationship, while potential connection and complementation are considered potential cooperation relationships. The following sections provide a detailed review of the identification methods and the spatiotemporal characteristics associated with bike-sharing rides corresponding to these three relationships.

5.1. Identification Methods of Potential Substitution, Connection, and Complementation Relationships. If one of the starting and ending points (other than both) of a bike-sharing ride is in close proximity to a public transit station and occurs during the operating hours of public transit, there is a high likelihood of forming a connection relationship between shared bikes and public transit, indicating a potential connection relationship. If both the starting and ending points of a bike-sharing ride are in close proximity to two different public transit stations and occur during the operating hours of public transit, there is a high likelihood of forming a substitution relationship, indicating a potential substitution relationship. Finally, if both the starting and ending points of a bike-sharing ride are far from public transit stations or occur outside the operating hours of public transit, indicating bike-sharing supplements services that public transit cannot provide, there is a high likelihood of forming a complementation relationship (potential complementation relationship). These are the basic criteria for identifying the three coopetition relationships, considering only the spatial proximity of the starting and ending points of the shared bike rides to public transit stations. Based on these basic criteria, more detailed data and criteria used in the literature to identify potential coopetition relationships are shown in Table 6. The table contains four main identification methods to only identify potential connection relationship (from line 1 to line 4), as well as two identification methods used to simultaneously identify potential substitution, connection, and complementation relationships (lines 5 and 6).

Table 6 reveals that the primary data used to identify potential coopetition relationships include bike-sharing transaction data, public transit facility data, and public transit operation data. The identification method is primarily achieved by examining three types of spatial-temporal relationships between bike-sharing rides and public transit: the spatial relationship between the starting and ending points of bike-sharing rides and public transit facilities, the temporal relationship between bike-sharing rides' starting/ending times and public transit's arrival/departure times, and the relationship between the starting and ending times of shared bike rides and the number of passengers boarding and alighting on public transit (Figures 5 and 6).

It can be observed that the identification methods in Table 6 use many thresholds for examining spatiotemporal relationships between bike-sharing rides and public transit trips. Determining how to scientifically set the values of these thresholds remains a topic worth exploring. Currently, the selection of these values in studies is generally based on the researchers' experience, often varying in different city case studies and lacking unified selection criteria.

5.2. Spatial-Temporal Characteristics of Bike-Sharing Rides under Potential Substitution, Connection, and Complementation Relationships. In comparison to studies focusing exclusively on the potential connection relationship, there are a limited number of studies that explored potential substitution, connection, and complementation relationships simultaneously. Kong et al. [102] and Wu et al. [101] analyzed the three potential coopetition relationships in four U.S. cities—Boston, Chicago, Washington, D.C., and New York—and in Shanghai, China, respectively. In both national contexts, bike-sharing is predominantly characterized by connection rides on weekdays, suggesting that commuting plays a main role in these connection rides. However, there are notable differences between the cities of the two countries. Temporally, Shanghai sees a dominance of complementation rides on weekends, while substitution rides on weekends prevail in the four U.S. cities.

Table 6: Summary of methods and data used for identifying potential coopetition relationships.

Serial number	Potential relationship	Data	Identification method	Source
1	Connection	(i) Bike-sharing transaction data, including the coordinates of starting and ending points (ii) Public transit station data, including the coordinates of each station	The distance d between one (but not both) of the starting and ending points of a bike-sharing ride r_i and the nearest transit station i is no more than a threshold distance β (as per identification method 1 of connection in Figure 5)	[90–96]
2	Connection	(i) Bike-sharing transaction data, including coordinates of starting and ending points (ii) Public transit facilities data, including coordinates of each station (iii) Public transit operation data, including times of arrival and departure, and counts of boarding and alighting passengers	The distance d between one (but not both) of the starting and ending points of a bike-sharing ride r_i and the nearest transit station i is no more than a threshold distance β; the interval between the starting time T_s (or ending time T_e) of the bike-sharing ride r_i at transit station i and the arrival time t_a (or departure time t_d) of public transit at station i is no more than a time interval threshold α; there are no few than one passenger alighting (or boarding) at the transit station i during the time interval threshold t (as per identification method 2 of connection in Figure 5)	[97]
3	Connection	(i) Bike-sharing transaction data, including coordinates of starting and ending points (ii) Public station data, including coordinates of each station (iii) Area of interest (AOI) data	The distance d between one (but not both) of the starting and ending points of a bike-sharing ride r_i and the nearest transit station i is no more than a threshold distance β; neither the starting point (O) nor the ending point (D) falls within the area of interest (AOI) within the d radius of transit station i, such as coverage areas of hospitals, shopping malls, or schools (as per identification method 3 of connection in Figure 5)	[98]
4	Connection	(i) Bike-sharing transaction data, including coordinates of starting and ending points, and starting and ending times (ii) Transit smart card data with the same ID as the bike-sharing transaction data, including entry and exit station coordinates and times	The bike-sharing ride r_i has the same user ID as the public transit trip p_i; the interval between the starting time T_s (or ending time T_e) of the bike-sharing ride r_i and the exit station time t_t (or entry station time t_y) of the transit trip p_i is no more than a specified time interval threshold t; the distance d between the starting point (or ending point) of the bike-sharing ride r_i and exit (or entry) station location of trip p_i is no more than a threshold distance β (as per identification method 4 of connection in Figure 5)	[99, 100]
5	Connection Substitution Complementation	(i) Bike-sharing transaction data, including coordinates of starting and ending points, and starting and ending times (ii) Public station data, including coordinates of each station	The coopetition relationship between shared bikes and public transit is divided into five scenarios, and each scenario corresponds to one of three types of coopetition relationships, as shown in the left half of Figure 6	[101]
6	Connection Substitution Complementation	(i) Bike-sharing transaction data, including coordinates of starting and ending points, and starting and ending times (ii) GTFS data, primarily including facility coordinates and public transit operation schedules	The coopetition relationship between shared bikes and public transit is divided into twelve scenarios, and each scenario corresponds to one of three types of coopetition relationships, as shown in the right half of Figure 6	[102]

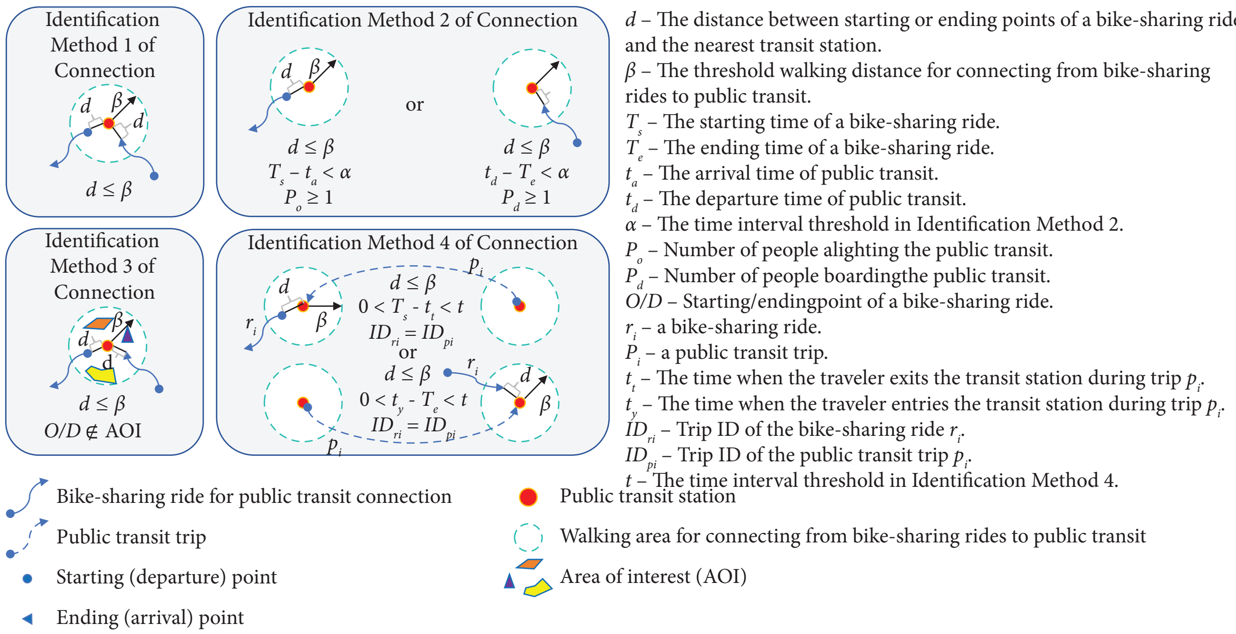

Figure 5: Potential connection relationship identification method.

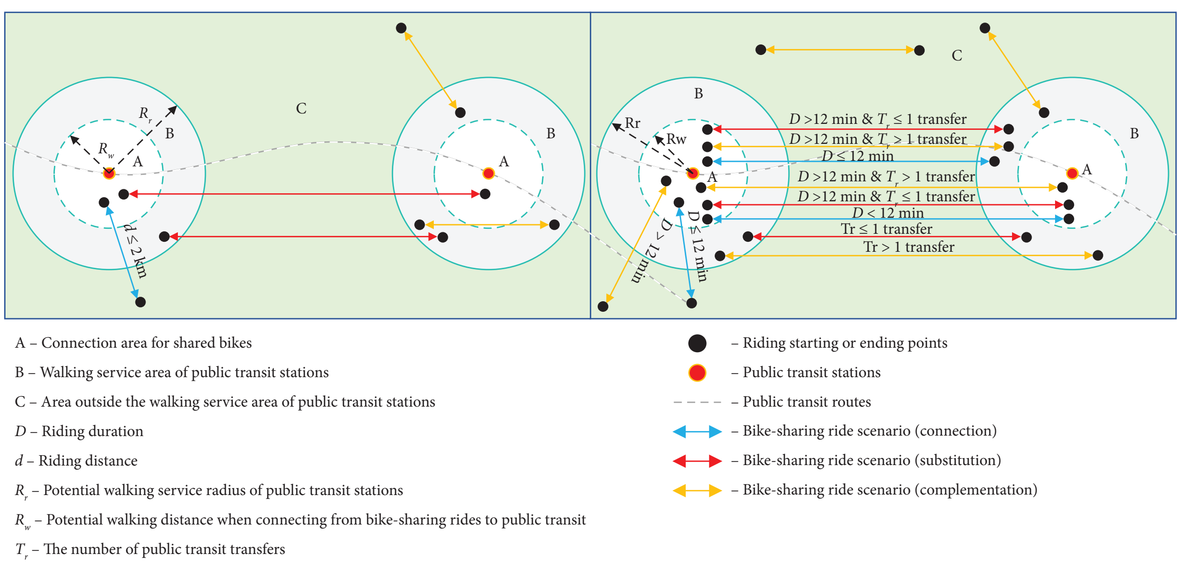

Figure 6: Potential substitution, connection, and complementation relationship identification method.

Spatially, in Shanghai, potential connection rides are concentrated in the border area between the city center and the suburbs. Potential substitution rides mostly occur near the transfer stations of transit lines leading from the suburbs to the city center, and potential complementation rides mainly occur in areas outside the coverage of public transit services. In contrast, the U.S. cities show no significant spatial differences in potential substitution and potential connection rides within bike-sharing operation zones. Interestingly, the pattern of complementation rides in the U.S. cities was similar to that in Shanghai. This divergence may be attributed to the fact that U.S. cities primarily developed bike-sharing in urban areas with well-developed public transit systems, while Shanghai deployed a large number of shared bikes in both urban and suburban areas.

Most studies focus primarily on connection rides and analyze their technical and economic characteristics, cycling temporal and spatial characteristics, cycling stability, and user profiles. Regarding technical and economic characteristics, the distance and duration of connection rides are slightly lower than those of overall rides [92, 97], typically not exceeding 2 km and less than 30 minutes [92, 94, 97, 103]. The duration of connection rides is longer during weekday morning rush hours compared to evening rush hours and longer on weekdays than on weekends [98]. Additionally, suburban connection rides tend to cover greater distances than their urban connection counterparts [98].

Regarding temporal characteristics, connection rides exhibit a higher frequency on weekdays compared to nonconnection rides [97]. The hourly distribution of connection rides and overall rides typically follows a similar pattern [97]. For instance, if there is a morning peak for overall rides, a corresponding morning peak is observed for connection rides, and the same holds true for evening peaks. Cities with distinct morning and evening peaks for weekday connection rides often show a higher proportion of connection rides during the morning peak compared to the evening peak [91, 92, 98, 100]. On weekends, there is generally no significant morning or evening peak, and the number of evening connection rides surpasses that of morning connection rides [91, 92, 98, 100]. The greater proportion of connection rides during the morning peak on weekdays may be due to time constraints for work-related travel, whereas the evening peak may coincide with times of greater flexibility for travel home from work. Furthermore, the total number of connection rides throughout the day on weekdays is typically greater than that on weekends [98]. The hourly distribution of connection rides is not significantly affected by gender but does show an age-related impact. According to Ma et al., the connection rides for minors tend to start one hour earlier in the morning than those for adults, and there are no rush hours for daytime connection rides among older adults [100].

Although connection rides exhibit commuting characteristics, they are generally casual. A study found that 66% of connection ride users have no more than three connection ride days in a half month [99]. Similarly, 60% of connection ride users have no more than two connection rides in a half month [100], which may also be related to the untimely relocation of bikes.

Regarding spatial characteristics, connection rides usually converge near interchange stations with a higher frequency of public transit departures [97]. This is because there are more transit stops and transfer stations in urban areas than in suburban areas, and the total number of connection rides tends to be higher in urban areas [91, 95–97]. In contrast, the average volume of connection rides around a single public transit station is higher in suburban than in urban areas [92]. However, some studies found the opposite result, with single transit stops in urban areas having more connection rides than those in suburban areas [99, 100].

Bike-sharing connection rides typically occur more around where people live than where they work. For example, Qiu and Chang [97] found that access rides outnumbered egress rides in the morning peak (12% vs. 7%) and vice versa in the evening peak (19% vs. 16%). Liu et al. [99] found that 75% of connection rides started in residential areas, and 72% ended in residential areas. Connection ride users are predominantly youth and middle-aged [99, 103], and commuters aged 18–30 use shared bikes for connection rides significantly more often than commuters aged 30–35 [103].

In addition, several studies have examined the role of bike-sharing in extending the accessible distance to metro stations. Lin et al. [92] divided Shanghai into four areas, ranging from the city center to the suburbs, and found that the distance of bike-sharing connecting to public transit increased gradually from the core to the suburbs. Another study compared the walking connection distance of 800 meters and found that shared bikes increased the connection area by 24%, 126%, 185%, and 104%, respectively, from the core to the peripheral areas, which means that shared bikes extend the connection distance significantly more than walking [93, 96].

The study of the potential coopetition relationships between bike-sharing and public transit cannot reflect the actual relationships of substitution, connection, and complementation. However, it can help identify potential conflict areas between the two travel modes and provide theoretical support for government decision making. In areas with a high potential for connection relationships, attention should be paid to the configuration of feeder facilities. In areas with a high complementation relationship, attention should be paid to securing the supply capacity of shared bikes. In areas with a high substitution relationship, attention should be paid to the optimal deployment of shared bikes and public transit to reduce functional conflicts.

Over time, the ridership of bike-sharing and public transit systems changes, and the spatial and temporal characteristics of the connection, substitution, and complementation relationships between the two modes also change. For example, as bike-sharing systems expand in suburban areas, they may generate more complementation trips in suburban areas where the public transit system is less developed. Tracking the evolutionary characteristics of the coopetition relationships between bike-sharing and public transit over time is a future task that will be essential for guiding the synergistic development of integrated transportation systems.

6. Discussion and Future Research Directions

To date, there are no uniform definitions and evaluation methods for the coopetition relationship between bike-sharing and public transit. The characteristics of the commonly used definitions and evaluation methods are summarized in Table 7. Some macrostudies consider the promotion of bike-sharing's introduction to public transit ridership as a cooperative relationship, while viewing the impact of bike-sharing on weakening public transit ridership as a competitive relationship. Other macrostudies analyze the relationship between the density of public transit facilities, ridership, and service level and bike-sharing ridership to determine the coopetition relationship, but the results are speculative. The macroscopic definition of the coopetition relationship between public transit and bike-sharing considers competition and cooperation mutually exclusive. In fact, competition and cooperation relationships coexist, as discussed in Sections 4 and 5. Microlevel studies are able to capture the competition and cooperation simultaneously, but they still have limitations. Questionnaire-based microlevel studies cannot reflect all bike-sharing trips' competition and cooperation with public transit, especially in suburban areas where bike-sharing and public transit are not well-developed, while transaction-based microlevel studies can capture all bike-sharing trips' coopetition relationships but lack actual data to verify the authenticity of the potential coopetition relationships. Therefore, an evaluation method for coopetition relationship based on combining transaction data with questionnaire data is a new direction for future research.

To the best of our knowledge, the coopetition evaluation method reviewed in this study lacks integration with collaborative optimization design for bike-sharing and public transit. The current approach for the optimal design of the combination of the two systems is to construct an operations research model with the objective of minimizing the generalized cost and determining the optimal decision variables [104–107]. Generalized costs usually include the travel costs for travelers, the operating costs of the bike-sharing and public transit systems, and the external impacts, such as traffic congestion and environmental pollution. Therefore, there is an urgent need to develop a combined system optimization model that incorporates both the degree of coopetition and generalized cost as dual objectives.

Based on the identified gaps above, this paper proposes a process that moves from micro-coopetition behaviors—i.e., the connection and substitution between bike-sharing and public transit—to constructing an operational research model with the degree of coopetition as the optimization goal. This process can be divided into four modules, named the "Coopetition Four-Part Method Framework," as shown in Figure 7. The first module involves identifying coopetition behaviors by inferring the actual connection, substitution, and complementation behaviors of each bike-sharing ride and public transit trip based on all samples of transaction data, travel behavior survey data, and public transit operation data. The second module involves assessing the degree of coopetition by evaluating the degree of competition and cooperation based on different travel scenarios. As previously mentioned, shared bikes and public transit may not necessarily be in competition with each other if shared bikes substitute for public transit but can be seen as cooperating with each other if bike-sharing significantly reduces travel time for travelers during congested rush hours by public transit. Therefore, the two key subfunctions of Module 2 are to determine the coopetition relationship and degree among substitution, connection, and complementation behaviors based on the assessment of both the utility of bike-sharing for travelers and the benefits of the public transit system. The third module involves analyzing the factors influencing the degree of coopetition. The main function of this module is to analyze the factors causing the different degrees of coopetition in different regions and cities, laying the foundation for subsequent system optimization. Finally, the fourth module is the optimization of the degree of coopetition between shared bikes and public transit systems. The main function of this module is to achieve the synergistic development of the two systems by determining the optimal values of the decision variables with the degree of coopetition as the optimization objective.

In recent years, various shared mobility services such as bike-sharing, e-bike-sharing, scooter-sharing, ride-hailing, and car-sharing have emerged and developed simultaneously. Enterprises usually possess the operational data generated by these services. However, due to issues such as commercial confidentiality and user privacy, the degree of data openness is limited. This limitation makes it challenging to explore the impact of bike-sharing on public transit ridership while excluding the effects of other service modes, potentially biasing the findings. For instance, Campbell and Brakewood [60] found that failing to control for the impact of nonmotorized facilities can lead to an overestimation of the impact of bike-sharing on public transit ridership. Therefore, with increased data openness, future studies should fully consider the implications of different shared mobility service models to enhance the study's accuracy. Meanwhile, the comparative analysis of the impact of multiple shared mobility service modes on public transit ridership is still in its early stages, holding great significance to the scientific deployment of public transit and various shared mobility services.

Bike-sharing is crucial for supplementing passenger transport capacity and promoting urban resilience, especially during unforeseen rail system shutdowns. However, such events can quickly saturate the bike-sharing system. Failing to adjust the bike-sharing system's operating strategy at this point will exacerbate the conflict between supply and demand. Therefore, studying ways to enhance the bike-sharing system's emergency response capabilities and establish linkages between bike-sharing and bus services to meet medium and long-distance travel demand is of utmost importance.

Studies on bike-sharing substitution for other travel modes have found that public transit and walking are the primary modes substituted, with a lower substitution rate for cars. Typically, these studies ask users about the travel modes replaced on their most recent trip using a shared bike. However, this approach may overestimate the negative impact of bike-sharing on public transit, as it might overlook the contribution of bike-sharing to public transit. For example, when users answer that bike-sharing replaced private cars, they may actually use a combination of bike-sharing and public transit to replace their original private cars. Therefore, future studies could benefit from employing surveys and research methodology based on travel mode chains to address this issue.

Studies on the impact of bike-sharing substituting for and integrating with public transit have used discrete choice models to demonstrate the significant effects of various factors, including the natural environment, travel characteristics, the built environment, personal profiles, psychological factors, and bike-sharing usage characteristics. With the maturity of psychological theory, the application of theories such as the theory of planned behavior and technology acceptance models in travel behavior research has gained prominence. However, the use of these theories and methods in studying bike-sharing and public transit substitution and integration behavior still needs improvement.

Table 7: The characteristics of the commonly used definitions and research methods.

Macro or micro	Evaluation methods	Specific methods	Advantages	Disadvantages
Macro	Method based on bike-sharing and public transit ridership data	(i) DID model (ii) Linear regression model considering error autocorrelation (iii) OLS model (iv) Synthetic control method (v) Random forest model (vi) Interrupted time series model (vii) Bayesian structural time series model (viii) Complex network theory approach	Ability to analyze the relationship between public transit ridership and bike-sharing ridership (or facility supply), as well as the relationship between the intensity of public transit facility supply and bike-sharing ridership, at the macrolevel	Inability to analyze the substitution, connection, and complementation relationships between bike-sharing and public transit at the microlevel of individual trip
Micro	Method based on bike-sharing user behavior surveys	(i) Statistical analysis of the proportion of connection and substitution trips (ii) Statistical analysis of the change in frequency of users' use of original travel modes before and after the emergence of bike-sharing	Ability to analyze the actual connection and substitution relationships between bike-sharing and public transit at the microlevel of individual trips	Small sample size, high survey costs, and inability to cover the trips of all individuals
		(i) Binomial logit model (ii) Multinomial logit model (iii) Hybrid logit model	Ability to identify the factors influencing the coopetition relationship between bike-sharing and public transit	The structure and assumptions of these models are different and their applicability should be examined in different research scenarios
Micro	Method based on bike-sharing transaction data	(i) Identification methods of potential coopetition relationships based on spatial-temporal relationship between bike-sharing rides and public transit	Ability to quickly obtain large or even complete samples of transaction data at low cost for analysis of coopetition relationships	Only potential coopetition relationships can be identified, and the accuracy of the identification has not yet been evaluated

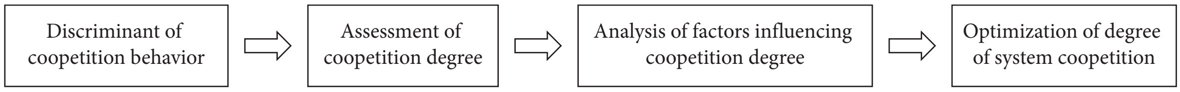

Figure 7: Four-part method framework of coopetition.

The results of consecutive years of surveys in Washington show a decreasing trend in bike-sharing replacement rates for public transit as time progresses. However, the rate of substitution for cars increases, indicating that the coopetition relationship between bike-sharing and public transit is dynamic. Future changes in the coopetition trends and how to guide people to reduce substitution for green travel modes and increase substitution for cars are also worth further exploring.

7. Conclusions

As a green travel mode suitable for connecting with public transit, bike-sharing plays a positive role in improving travel efficiency, reducing the use of cars, easing traffic congestion, reducing greenhouse gas emissions, and promoting public health. At the same time, bike-sharing can replace public transit, reducing public transit ridership and increasing the government's financial burden. Given that competition and cooperation coexist, scientific assessment of their coopetition relationship is the basis for promoting synergistic planning, design, operation, and management of integrated transportation systems. Therefore, this study reviews research on the coopetition relationship between bike-sharing and public transit.

Three types of research methods are commonly used in recent studies on coopetition relationship between shared bikes and public transit: the research method of micro-coopetition relationship based on public transit ridership and shared bike ridership, the research method of actual macro-coopetition behaviors based on bike-sharing user behavior surveys, and the research method of potential micro-coopetition relationship based on bike-sharing transaction data. Based on these methods, studies reveal that bike-sharing at all three levels—city, line, and station—boosts rail transit ridership while significantly weakening bus ridership. Bike-sharing meets people's travel needs and enhances urban transport resilience during unexpected rail transit shutdowns.

Bike-sharing predominantly substitutes for walking and public transit. While its ability to reduce traffic congestion and environmental pollution is limited, tracking studies in some cities over several years have shown an increasing trend in bike-sharing substituting for cars and a decreasing trend in substituting for public transit. In addition, the proportion of shared bike integration with different travel modes varies by city, but connecting to public transit dominates. As the bike-sharing ridership is much lower than public transit ridership, the primary integration mode of public transit is still walking. Although whether bike-sharing substitutes for or integrates with other travel modes is influenced by the natural environment, travel characteristics, the built environment, personal profiles, psychological factors, and bike-sharing usage characteristics, the determinants vary with contextual differences across cities. Therefore, each city should focus on its unique residents' travel characteristics rather than blindly copying other cities' development experiences.

Bike-sharing and public transit are mainly in a potential connection relationship on weekdays and a potential substitution relationship on weekends. This may imply that commuting rides are the primary travel scenario for combining bike-sharing with public transit. In addition, studies suggest that combining bike-sharing with public transit is an episodic behavior for individuals, implying that it is an alternative travel option for travelers to use shared bikes in integration with public transit.

8. Limitation

This paper presents a review of the research results and methods concerning the coopetition relationships between bike-sharing and public transit and points out potential research and improvement directions. Due to the speed with which bike-sharing literature has developed over the past decade and the constraints of database selection, not all papers are covered in this review, especially non-English and non-Chinese literature. The synergistic development of bike-sharing and public transit is closely related to the synergistic development of integrated transportation systems, so we expect more thought-provoking research to emerge.

Data Availability

The data supporting this systematic review are from previously reported studies and datasets, which have been cited.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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