Citation: QUAN Yongshen, PAN Zhaoyu, MA Yilin. Evolution of Urban Transportation System and Change Thinking [J]. Urban Transport of China, 2021 (4): 1–9, 18.

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Evolution of Urban Transportation System and Change Thinking

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Abstract: China is in a critical period of economic and social transformation, and the external ecological environment on which the urban transportation system depends for development has undergone significant changes. By the analysis of the internal and external dynamics of urban transportation system evolution and specific cases of urban transportation, this paper summarizes the system properties of the urban transportation system, including openness, complexity, and nonlinearity, as well as the characteristics such as the far-from-equilibrium state, internal interaction and balance, and self-organization. The paper proposes that the strategic orientation of urban transportation in the new era should change from pursuing the balance of supply and demand to adapting to the continuous evolution of the urban functional system. In addition, the goal orientation and planning-thinking method of the urban transportation system should be adjusted. Finally, this paper analyzes the major issues such as the capacity and intelligence of the urban transportation system and put forward suggestions. **DOI:** 10.13813/j.cn11-5141/u.2021.0401-en

Keywords: urban transportation; system evolution; strategic thinking; transportation planning

China is in a critical period of economic and social reform and transformation. The urban development model, the social and economic growth model, the social governance model, and the technology development model are all undergoing changes [1]. The common ground of reform and transformation lies in the adherence to the principle of putting people front and center, the attention paid to the harmonious human-nature and human-society development, the highlight of innovation-driven and high-quality development, and the emphasis of the decisive role of the market in resource allocation. All these reforms that conform to the laws of social evolution will inevitably promote new advancements in society. As the urban transportation system is a subsystem in the large urban economic and social system, its survival and development are closely related to the evolution process of the large system, and there certainly exists an evolutionary law that is in line with the evolution process of the large system.

1 Evolutionary trend and mechanism of urban transportation system

1.1 Evolutionary characterization and trend of urban transportation system

According to system science theory, a system always evolves in the direction of adapting to the changes in the survival and development environment. The evolution of the urban transportation system is mainly characterized by its adaptation to and coordination with the urban development model, the urban functional structure, and the changes in the external environment. Due to the influence of the changes in urban spatial patterns and the interaction between social and natural factors, the external environment of the urban transportation system is constantly evolving. It is under the joint actions of both the interaction with the external environment and the system's intrinsic self-organization functions that the urban transportation system achieves the upgrade and evolution of its internal functional structure and organizational collaboration function while expanding its scale.

The evolution of the urban transportation system is reflected in the following aspects: 1) The dependence of the survival and development of the system on external material resources is gradually weakened as it turns to rely more on the information and intellectual support; 2) compared with the scale effect of denotation expansion, the structural effect of the system's internal collaboration is more prominent; 3) For the adaptation to the evolution of urban economic and social forms and patterns, the boundary constraints of the urban transportation system become weakened, and the transportation networks of different space-time domains and different service models are highly integrated. The evolution of the urban transportation system is not only a match between system scale and urban space, but also a reflection of

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Received: 2020-08-10

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the adaptation of the hierarchical structure, resource allocation, factor combination, and operation model of the system functional units (subsystems and their constituent factors) to the changes in the external supply and demand environment. Certainly, the most direct manifestation of the evolution of the urban transportation system is the optimization of passenger and freight transportation services, which is reflected in the update and evolution of service equipment, service types, and service models.

1.2 Evolutionary mechanism of urban transportation system

Similar to the evolution of other systems, the evolution of the urban transportation system also goes through a spiral upward process of "the negation of negation" and is the result of joint actions of the external environment and various internal factors.

1) External driving force for the evolution of urban transportation system

The urban transportation system is a dynamic and open system that constantly exchanges material, energy, and information with the outside world. Within the space-time domains of different levels, the urban transportation system is always in a non-homogeneous and unbalanced state. Meanwhile, the law of entropy increase determines that the process of system operation is inevitably accompanied by internal consumption and functional decline (such as aging infrastructure, outworn organization and administration systems, and decline in the innovation of information technology), and the consumption or decline causes the system to tend to chaos and disorder, i.e., the tendency of entropy increase. Therefore, the urban transportation system must maintain active two-way information feedback with the external environment and rely on the trigger and the empowerment mechanisms for the changes in the external environment to continuously absorb the "negative entropy flow" composed of external materials, energy, and information. In this way, the "entropy increase" of the system itself can be canceled out, and thereby the system is allowed to maintain a spiral evolution process of "order-disorder- higher-level order …." It is self-evident that system evolution is to counter entropy increase by introducing negative entropy from the outside of the system for survival and development.

2) System self-organization functions as the internal driving force for evolution of urban transportation system

The self-organization function of a system means that driven by the internal collaboration mechanism of the system, the subsystems and even the components within a subsystem (functional units and constituent factors) constantly regulate its own organizational structure and operation model and improve the ability to adapt to the environment, so as to adjust to the overall requirements of the large system. The regulation and ability improvement are realized by following a mutually tacit agreement rule and taking the manner of cooperation or competition. In this way, the dynamic evolution of the system from a low level to a high level and from disorder to order is automatically achieved. On the one hand, the characterization of system self-organization is the perception and self-adjustment toward the external environment by each subject within the system; on the other hand, the nonlinear interaction among subjects within the system results in the multiplication effect. Throughout the historical process of the evolution and development of the urban transportation system, it can be easily found that the self-organization function, either on the demand side or on the supply side of the system, has played a huge and dynamic role in achieving the match between the supply and demand models of the system, the adjustment of the functional gradation structure, and the optimization of organizational models. Undoubtedly, it is by the rule of survival of the fittest as well as the intrinsic competition-cooperation interaction and collaboration mechanism of the system that self-organization becomes the internal driving force for the constant evolution of the system to adapt to the external environment.

2 Intrinsic system properties determining the evolution of urban transportation

Since Qian et. al [2] developed the open complex giant system theory [2] 30 years ago, this theory has been applied to multiple professional fields such as medicine, finance, social management, corporate training, and tourism and has produced profound impacts. The urban transportation system exhibits open, multi-component, and multi-level properties. Intricate nonlinear interactions between different components and levels do exist, and they are always in a non-equilibrium and constantly changing state in dimensions of time, space, or function, i.e., the far-from-equilibrium state. These intrinsic system properties fully conform to the typical characteristics of dissipative structure. In recent years, some researchers have introduced the dissipative structure theory and synergistic theory into the planning and governance of transportation systems [3–5].

2.1 Openness and "far-from-equilibrium state" of urban transportation system

The urban transportation system is an open system, and both the objects receiving transportation services and the subjects of service providers can autonomously intervene in the system. The external environment of the urban transportation system is also open and has a strong correlation and interaction with the subsystems of human settlement, the economy and society, and the ecological environment, with all the subsystems belonging to the large urban functional system.

Participants in the urban transportation system include both the planning, construction, and operation and maintenance managers on the supply side and the transportation service objects on the demand side. They are not only the internal constituent factors of the system but also the external factors that intervene in the system, changing their functional roles in different space-time environments. The individual behavioral decision of system participants is subject to both objective constraints and subjective randomness, and it is undoubtedly a complex random process for the transportation system. On the demand side, even if the space-time distribution and the model choice for the requirements of basic daily traveling (the so-called "rigid demand") have a certain pattern, they will still witness random fluctuations due to the influence of multiple objective factors. The fluctuations, together with the mutual superposition of a large quantity of "elastic demand" coexisting with the "rigid demand", cause loads of various subsystems of urban transportation to be in an uncertain and fluctuating state in dimensions of time and space.

Due to the restriction of intrinsic defects of information asymmetry and cooperative operation mechanisms of feedback, the supply side composed of different operating service subsystems can hard maintain the space-time balance in service resource allocation and cannot achieve a precise matching with demand. Moreover, any subtle change in social and economic reforms and technology trends will lead to changes in the supply model and the state of the urban transportation system. For example, the Beijing municipal government used to exert all its strength and wisdom to reverse the continuous shrinking trend of bicycle travel under the conventional government-centered supply model, but it failed after several years of efforts; however, the chronic diseases that had been difficult to cure for many years have been "cured immediately" after introducing a bicycle-sharing system with the involvement of social capital, and the proportion of bicycle travel has increased significantly (see Fig. 1).

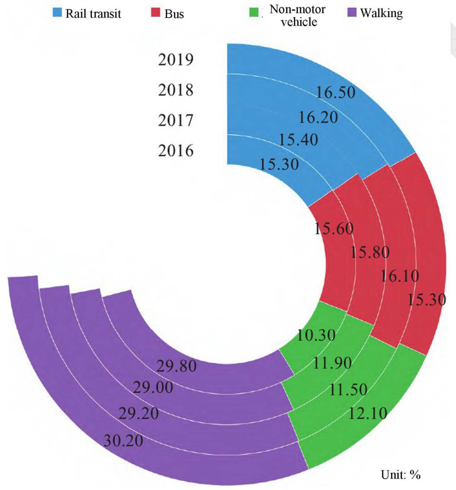


Fig. 1 Changes in the green travel mode share in the central urban area of Beijing

Source: Literatures [6–7].

As mentioned above, the urban transportation system is in a course of endless dynamic evolution on both the demand and supply sides. Apparently, the multi-dimensional "balance of supply and demand" that matches time-space distribution and patterns is only likely to occasionally occur in a moment of the microscopic locality. It is undoubtedly far from the equilibrium state as far as the macroscopic integrity of the system is concerned.

2.2 Complexity and the internal interactive checks and balances of urban transportation system

On the one hand, the complexity of the urban transportation system lies in the non-equilibrium of system constitution, structural hierarchy, and the nonlinear interaction between subsystems as well as between their basic functional units (or functional factors); on the other hand, it lies in the system's dynamic evolution.

An urban transportation system is subordinate to the giant urban functional system and exhibits a two-way collaborative feedback interaction with the external environment. Its interior is a multi-level structure composed of many mutually independent functional primitives (constituent factors), where there exist complex checks and balances between various levels as well as between the constituent primitives of each level. The system structure is shown in Fig. 2.

The complexity of the urban transportation system is also reflected in the typical characteristics of "fluctuation" and "emergence" (i.e., from an unstable and disordered state to a new higher-level and ordered-structure state) [8]. Under the joint action of external and internal factors, subsystems often exhibit some randomly fluctuating perturbations. Such perturbations at the microscopic level of the system will gradually attenuate and subside in most cases, failing to affect the macroscopic state of the system. This is termed "fluctuation" in dissipative structure theory. In the vicinity of the critical point for the phase transition of the system, the change in the system's overall macrostate, i.e., the system's phase transition (termed "emergence" in dissipative structure theory), will be triggered when the accumulation of fluctuations reaches a certain threshold. For example, the activities such as changes in urban population, fluctuations in economic development, expansion and transformation of transportation infrastructure, and participation and withdrawal of novel technologies and new business forms (car-hailing, bicycle-sharing, etc.) will all cause the fluctuations of some subsystems. The evolution of "order-disorder- higher-level order …" for the state of the urban transportation system is achieved by means of the continuous accumulation and superposition of random fluctuations.

The evolution of urban transportation modes is taken as an example. Although the strategy of the public-transit-priority has been implemented over the past two decades, and the fluctuations of various subsystems (such as public traffic, car traffic, walking, and bicycle traffic systems) never cease, the overall macrostate of transportation modes has not changed as expected. Indeed, the completion of large-scale urban rail transit in recent years has increased the proportion of rail transit in the public transportation system. However, the dominant position of public transportation in an urban travel system has not been truly established, and the demand for car travel has not been suppressed as expected. On the contrary, the travel proportion of walking and bicycles continues to shrink (see Table 1). The root of the problem is that the evolution of urban transportation modes is not only limited to the public transport subsystems but also subject to the interaction between multiple other subsystems (such as the car traffic subsystem, travel subsystem by foot and bicycle, and demand management subsystem). Apparently, the dependent variable of transportation modes is determined by the nonlinear interaction relationship comprised of multiple independent variables, and it will not be given a unique solution by a single independent variable (such as the level of public transportation service); instead, it is uncertain with multiple solutions.

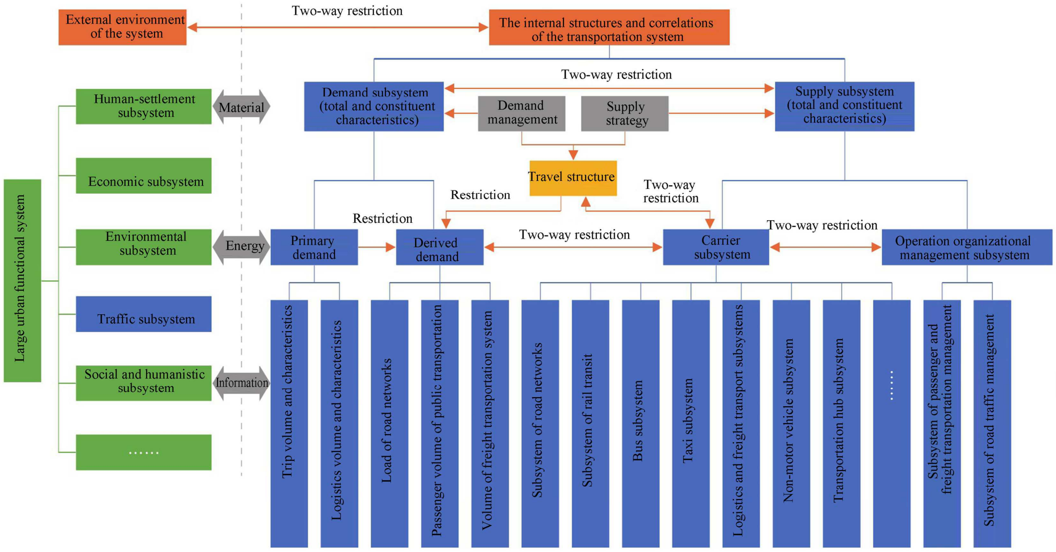


Fig. 2 “Complex giant system” of urban transportation

Table 1 Changes of transportation mode share in major cities over years %

City	Year	Transportation mode								
		Bus	Rail transit	Total of public transportation	Car	Taxi	Non-motor vehicle	Walking	Others	Total
Beijing (within the sixth ring)	2000	15.4	2.4	17.8	15.6	5.9	25.7	33.0	2.0	100.0
	2005	16.6	3.9	20.5	20.5	5.3	20.9	31.0	1.8	100.0
	2010	19.6	8.0	27.6	23.8	4.7	11.4	30.4	2.1	100.0
	2014	18.6	12.1	30.7	21.8	4.1	10.4	32.0	1.0	100.0
	2019 (central urban area)	15.3	16.5	31.8	22.6	2.5	12.1	30.2	0.8	100.0
Shanghai (downtown)	2004	20.8	4.3	25.1	13.0	9.2	22.7	28.9	1.1	100.0
	2009	17.1	8.7	25.8	18.9	8.8	19.4	26.5	0.6	100.0
	2014	13.4	15.1	28.5	19.2	7.0	16.1	24.8	4.4	100.0
	2019			33.1	20.5	6.4	16.0	24.0	0	100.0
Guangzhou (original ten districts)	2005	21.8	1.9	23.7	21.3	3.3	9.1	37.8	4.8	100.0
	2017	15.6	12.1	27.7	23.8	4.0	16.3	26.8	1.4	100.0
Shenzhen (entire city)	2010	16.5	0.2	16.7	21.1	1.6	6.0	51.0	3.6	100.0
	2016	11.7	6.8	18.5	25.0	1.5	5.0	47.0	3.0	100.0

Data sources: Brief Report of the 5th Beijing Comprehensive Traffic Survey (2016); Annual Report on Development of Beijing Transportation (2020); Brief Report of the 4th Shanghai Comprehensive Transportation Survey (2010); Brief Report of the 5th Shanghai Comprehensive Transportation Survey (2015); Shanghai Comprehensive Transportation Operation Annual Report in 2020; Brief Report of the New Round of Guangzhou Comprehensive Transportation Survey (2018); Shenzhen Resident Trip Survey and Analysis in 2016.

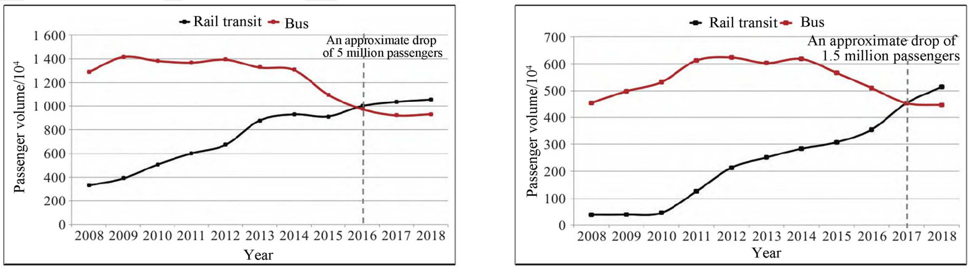
Even for subsystems of urban public transportation, there exists an interactive and mutually restricted relation between the bus system and urban rail transit system. In recent years, the volume of bus passengers in various major cities of China has generally declined (Fig. 3), which is not only due to objective reasons such as the low-quality bus service and insufficient attraction but also related to the failure of the excellent match between the expansion of urban rail transit and buses along the route. Therefore, the scale expansion of urban rail transit does not necessarily lead to an increase in the share of public transportation. Even in some cases, it may lead to the deviation from the original intention of greatly improving the operating efficiency of the entire urban transportation system.

2.3 Nonlinearity and self-organization performance of urban transportation system

As mentioned above, the urban transportation system is characterized by "fluctuation" and "emergence." It is due to the existence of a nonlinear interaction mechanism in the system and by means of coherent amplification (multiplication) effects that "emergence" is achieved by continuously accumulating "fluctuations" until reaching the critical threshold point of the phase transition. However, the motive power of the dynamic evolution is based on the nonlinear interaction between the system's internal components and the self-organization performance of positive and negative feedback mechanisms, apart from the exchange of materials, energy, and information with the outside of the system.

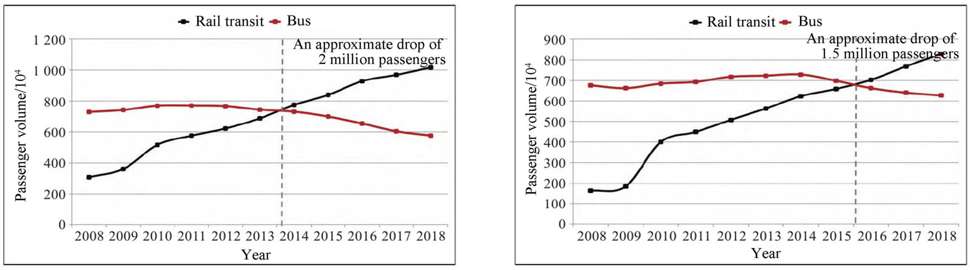
It is well known that the components in the urban transportation system do not exhibit a simple linear accumulation relationship but a nonlinear functional relationship. The change in any component is caused by the nonlinear action of other multiple factors. As mentioned previously, the optimization of transportation modes does not simply depend on the increase in the shares of public transportation, and the latter cannot be fulfilled by relying only on the scale expansion of rail transit networks. The system as a whole has properties that are not possessed by a part or the sum-of-the-parts (SOTP) of the system; that is, the whole is not equal to (or greater than, or less than) SOTP. This is because the changes in system states caused by the changes in any subsystem or component within the system are reflected not only in the scale but also in the system structure, i.e., the objective law of the joint action of the "scale effect" and "structural effect." One may make good use of the system's self-organization performance and continuously regulate the functional state of the system to adapt to environmental changes and evolve into an orderly structure only by fully understanding and respecting the nonlinear interaction patterns in the urban transportation system.

In the case of the construction of the urban road network (URN) subsystem, the carrying capacity and the operational service level of URNs do not merely depend on the scale of road networks (RNs) but are affected by multiple factors such as topological structure, functionally gradation structure, operation management, and collaborative relationship with other subsystems. The relationship between the scale expansion of RNs and the improvement of their carrying capacity is not simply linear. For instance, arbitrarily increasing the road size by 30 km does not bring about a 30% increase in the carrying capacity of RNs for an existing 100 km RN. The newly-added road may disturb the original RN structure, which produces positive or negative effects of the improvement or damage of RN functional structure. Therefore, the structural effect must not be ignored while expanding RNs.



a. Beijing

b. Shenzhen



c. Shanghai

d. Guangzhou

Fig. 3 Passenger volume changes of public transportation in major cities of China

Data source: The figures are compiled and drawn according to the data from annual urban transportation reports.

Attention should be paid to aspects including completing the RN gradation structure, optimizing the connection of nodes, and improving the right-of-way distribution, which all embody the nonlinear characteristics of the urban transportation system.

Identical findings can be presented in urban rail transit. The passenger capacity of rail transit does not exhibit a simple additive property with increasing operating mileage of lines. The total passenger capacity of rail networks is not merely determined by a single factor of "mileage scale." Instead, many factors influence a traveler's preference for rail transit modes, such as the layout of rail transit networks, the timing of construction, the conditions of land development along the lines, the conditions of traffic connection around rail transit stations, the level of network operation organization, ticket system and fare, as well as the convenience of transfers between lines. Similarly, there also exists a complex nonlinear relationship between the passenger capacity of rail transit and many relevant factors. The objective differences in the scale benefits of different urban rail transit systems in China are the most convincing example of this "non-additivity" (see Fig. 4). The comparison of Chongqing, Shenzhen, Wuhan, Chengdu, and Nanjing, whose operating mileages of rail transit networks were all about 300 km in 2018, shows that Shenzhen has the highest passenger transport intensity of 16,000 passengers·km^{-1}·d^{-1}, followed by Chengdu (14,000 passengers·km^{-1}·d^{-1}) and Wuhan (9,000 passengers·km^{-1}·d^{-1}); both Chongqing and Nanjing have the lowest passenger transport intensity of 8,000 passengers·km^{-1}·d^{-1}, which is only half that of Shenzhen. Generally, the marginal effect of passenger flow decreases while the functional structure effect will become more prominent as the scale of rail transit networks expands. Under the long-term consistent development background of "valuing scale effect and neglecting functional structure effect" in cities of China's mainland, the functional structures of urban rail transit networks remain incomplete and unbalanced. Even in first-tier cities such as Beijing, Shanghai, Guangzhou, and Shenzhen, the focus of rail transit construction was limited to the subway networks within the central urban area for a long period of time in the past, and the construction of regional rail transit networks lags significantly behind the demand of urban agglomeration development [9]. Obviously, this kind of incomplete and unbalanced structure system will inevitably fail to achieve due input-output yields by the "structure effect". High-quality travel services cannot be provided, and the development demand of new urbanization can hardly be satisfied.

3 The reexamination of urban transportation system with a view of system evolution

Based on the studies on the patterns of urban transportation system evolution and the characteristics of system dissipative structures, it is necessary to reexamine the previous thinking methods of cognition and planning of the urban transportation system from the perspective of system evolution. Due to limited space, one or two of the topics are chosen here for a brief discussion.

3.1 Strategic orientation of urban transportation development

For a long time, urban transportation system planning has been guided by the development goal of the "balance of supply and demand", and the supply-demand balance in the transportation system is regarded as the goal and direction pursued by transportation planning. Correspondingly, the setting of specific indicators in transportation planning is often constrained by the idea of the "space-time equilibrium" for demand and supply. Apart from traditional mindsets, this is also related to the biased cognition of the attributes of the urban transportation system.

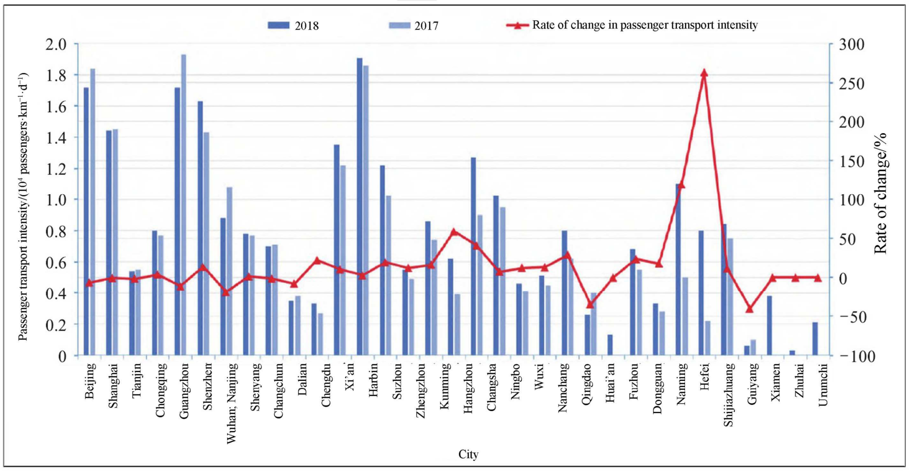


Fig. 4 Changes in passenger transport intensity of urban rail transit in major cities

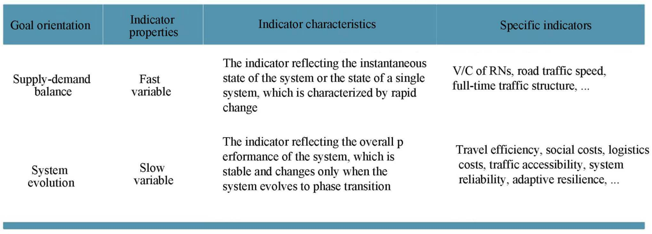
Source: Literature [10].

As mentioned earlier, as the urban transportation system is an open and complex giant system, its supply and the demand are in a course of dynamic evolution with multi-dimensional interactions in time-space and mode shapes, and there does not exist an equilibrium state at the macroscopic level of the overall system. According to the theory of system evolution, a non-equilibrium state is precisely the premise of system evolution. Therefore, the concept of system planning needs to be transformed, and the goal orientation should be altered from pursuing the balance of supply and demand to adapting to the continuous evolution of the large urban functional system. In addition, we should focus on the dynamic evolution pattern of "order-disorder-higher-level order …" of the urban transportation system and build correlation analysis models related to the dynamic system evolution, such as models of "order parameters", "critical points of the phase transition", and "thresholds of control parameters."

3.2 Goal orientation of urban transportation planning

On the basis of theoretically analyzing the evolution of the urban transportation system, the goal orientation of urban transportation planning needs to be reconstructed from focusing on the variables of local subsystems to focusing on the state of the overall system. From the perspective of system evolution strategy, attention should be paid not only to the local fluctuations at the microscopic level of a certain subsystem but also to the relevance between the state parameters of various subsystems. We should discriminate between the "fast variables" (local fluctuation variables with fast attenuation) in the control parameters and the "slow variables" (i.e., "order parameters") that may induce phase transition in the critical area of the system and identify the critical threshold for the system's macroscopic state with remarkably keen insight. In the past, the specific indicators focused on by the urban transportation system were fast variables such as speed of road traffic and vehicle capacity (V/C) of RNs. Now, the focus is turned to slow variables, such as the attention to the efficiency of urban full-mode travel, social costs of travel, logistics costs, traffic accessibility, system reliability, and adaptive resilience, with the real concern over the phase transition and critical points of the system (see Table 2).

Table 2 Changes in goal orientation of urban transportation system



Goal orientation	Indicator properties	Indicator characteristics	Specific indicators
Supply-demand balance	Fast variable	The indicator reflecting the instantaneous state of the system or the state of a single system, which is characterized by rapid change	V/C of RNs, road traffic speed, full-time traffic structure, ...
System evolution	Slow variable	The indicator reflecting the overall performance of the system, which is stable and changes only when the system evolves to phase transition	Travel efficiency, social costs, logistics costs, traffic accessibility, system reliability, adaptive resilience, ...

3.3 Thinking methods of urban transportation planning

3.3.1 Static thinking and dynamic thinking

The way of thinking for recognizing and dealing with the problems of the urban transportation system needs to be adjusted. Attention should be paid to both the target level of phased planning of the system and the trend of system evolution as well as the interaction between relevant factors in the process of planning and implementation.

Firstly, the technical methods in urban transportation planning should be readjusted. The previous transportation planning analysis and forecast were to present the goals, countermeasures as well as layout plans of traffic development on the basis of considering two or three time segments of the present situation and the target year. This fails to fully consider the variability and uncertainty of relevant factors affecting traffic demand in the course of long-term implementation, which leads to a greatly reduced reliability of planning forecast and even erroneous results. Therefore, the method of planning technology should change from a thinking method of simply focusing on time segments to an analysis method of really focusing on the process. Emphasis should be put on the "fluctuation-emergence" pattern in the evolution of the urban transportation system, and an "evidence-analysis" planning model should be built on the basis of a comprehensive perception of the interactive development between traffic and cities. In this way, the uncertainty in the phase transition of the system can be effectively handled.

Secondly, the content of planning should not be limited to the final goals and facility layout within the target year of planning; furthermore, it should add control and contingency measures in planning implementation. The traditional and outdated idea of "an ultimate blueprint to determine the future" should be replaced with the new ideas of "continuous planning" and "dynamic adjustment". The conventional method and work pattern of "investigation-analysis-prediction-planning" should be reasonably discarded for specific targets [1], and great attention should be paid to the implementation process and the adaptability to achieve the planning goals.

3.3.2 Causation and correlation

While analyzing and handling the interactive correlation between components of the transportation system as well as between the system and the external environment, conventional thinking methods tend to seek causation. However, causation does not represent all correlations but is only a type of correlation with certainty (namely that the emergence or change of one factor in a system will definitely lead to the emergence or change of another factor). A correlation refers to an uncertain and quantitative dependence relationship between two or more factors, which may include causation and covariance that have not yet been known for the time being. LI [11] pointed out that for open and complex giant systems, conventional causal analysis is ineffective in that the components in a system will interact with each other, and the correlation could be causation; causation is hidden in the entire system. The transportation system is such a giant system with the characteristics of openness, complexity, nonlinearity, and self-organization. The correlations either between the system state and the internal structural factors of the system or between the system state and the various factors of the external environment are extremely complex. Admittedly, the traffic analysis models built on the basis of causation can still be used for scientific analysis and prediction, as well as the investigation of the motives promoting or impeding system evolution in some cases. The inertial thinking that has long been biased towards causation in the past should also be reexamined. Therefore, when analyzing the current state and the future trend of the evolution of the urban transportation system, we should not excessively pursue one-way, isolated, and one-sided causation but should turn to complex, multi-dimensional, and dynamic correlations.

In the case of urban transportation analysis models, great attention should be paid to the correlation pattern between traveling individuals and multiple factors, and these models should be adapted to different application scenarios in the future. For example, there are both the models for real-time operational monitoring and short-time forecasting and the multi-scenario models for planning and implementation. The model series is no longer limited to non-real-time aggregated models with activity characteristics (purpose, displacement, mode choice, etc.) of a virtual crowd in 3D physical space over a specific time period. Instead, more attention is paid to the interaction between traveling individuals as well as the cross-correlation between traveling individuals and the environment (subjective and objective) in a space-time environment combining information network space and physical space.

3.3.3 Hetero-organization and self-organization

The hetero-organization and self-organization functions are the two internal and external driving forces indispensable for sustaining system evolution. They penetrate and coordinate with each other.

So far, people are more accustomed to relying on (or even strongly preferring to) the hetero-organization function on either the supply side or the demand side: On the one hand, they continuously increase the supply of transportation facilities; on the other hand, they attempt to exhaust all means of traffic demand management and operational order management and seek, without sparing any effort, the ideal "lasting balance of supply and demand" (although this lasting balance has never been achieved). The objective reality is, however, that the supply mode often depends heavily on the driving of external resource factors (natural and social resources such as land, energy, and capital), which results in problems such as environmental degradation and resource shortage. Moreover, the understanding of the system's self-organization function and the patterns of self-adaptation and self-regulation is insufficient, and the information asymmetry between system participants and the self-interest game exists. As a result, we can avoid neither the "involution" impact on system evolution due to the blind interventions from hetero-organization behaviors nor the damage to the self-organization function of the system.

Undoubtedly, the survival and development of the urban transportation system must properly deal with the unity of opposites between hetero-organization and self-organization. In other words, we should promote the scientific level of hetero-organization means, regulate the behavior mechanisms of hetero-organization, and improve the hetero-organization function. Additionally, we should continuously strengthen the system's self-organization function and greatly reduce the excessive dependence of the system on external intervention and resource supply. The improvement of the self-organization ability of the urban transportation system is primarily achieved from the aspects including system innovation, technological innovation, and organizational model innovation. For example, for the innovation of transportation planning models, one may aim at the role of a system's self-organization function and develop models for simulating system synergistic effects on the basis of the existing research results of the theoretical "multi-agent" model [12]. In this way, it is expected to truly reflect the operation and the dynamic evolution patterns under the interactive synergism between self-organization and hetero-organization of the system and fully meet the demand of the changes in urban transportation planning in the future.

3.4 Two debatable questions

3.4.1 The "carrying capacity" of urban transportation system: a constraint condition for urban development?

The carrying capacity of the urban transportation system usually refers to the capacity [13] of the system's spatial transportation (people and objects). The definition of carrying capacity can possess practical significance only when evaluating the matching degree of the coherence between the transportation system and urban development. Thus, more precisely, the "carrying capacity" is the level of adaptation that a transportation system exhibits while operating in concert with an urban system. As mentioned above, the transportation system maintains an uninterrupted exchange of materials, energy, and information with the outside world; both the supply side and the loaded demand side of the system are non-static but are always in the course of evolution. The carrying capacity of a transportation system is related to the "carrying" of the system itself, and it also largely depends on the manner in which the external demand is "loaded" on the system.

Firstly, as the "carrying" side, the carrying capacity of a transportation system is not a simple summation of the designed carrying (load) capacities of the various subsystems or functional primitives in the system. On the one hand, the random compensation-transfer of capabilities between subsystems is bound to occur because of the entropy change of the operating system as well as the nonlinear correlation between the subsystems. On the other hand, the overall carrying capacity of the system is not only determined by the quantifiable scale of system facilities but largely determined by multiple factors that are difficult to quantify, such as functional structure, operating model, and operating environment of the system.

Secondly, the large urban functional system (urban human settlement, industrial economy, social organizational structure and governance, public services, etc.), as the "loading" side for the demand of the transportation system, is not an isolated and closed static system. It is always in the process of evolution. Therefore, the generated traffic service demand fluctuates randomly in terms of constituent forms (time-space distribution and model choice), and the total capacity of traveling and logistics demand is changed due to the diverse choices of social behaviors (e-commerce + online shopping, online social interaction, etc.). Even if the total capacity of traveling and logistics demand and the primary demand constituting it remains unchanged, the derived demand directly loaded on various traffic subsystems (traffic load on the road, load of passenger volume on rail transit and bus networks, throughput of people and objects at various stations, etc.) also fluctuates randomly.

In addition, "restricting urban development by traffic carrying capacity" is even more debatable. The bias of this way of thinking is that it ignores the synergistic interaction and two-way regulation between the transportation system itself and the external environment. The interaction and regulation are based on the positive and negative feedback mechanisms. This continuous synergistic interaction will not lead to the collapse of urban operation due to the loss of "carrying capacity" of the transportation system. Instead, it is the normal evolutionary process of "order-disorder-higher-level order." From the viewpoint of system evolution, the so-called ultimate carrying capacity of transportation facilities in absolute terms does not exist.

3.4.2 Connotation and strategic position of urban transportation intelligence

1) Intelligent urban transportation—the dual requirement for the system's hetero-organization and self-organization

It is necessary to break through the barriers of information asymmetry among system participants with the help of informatization technology. In this way, we can minimize to the largest extent the "involution (degeneration)" caused by the blind intervention in the system performed by the blind application spots of the hetero-organization function of the system. Furthermore, the development of informatization will inevitably lead and give birth to intelligent hetero-organization mechanisms.

Intelligent urban transportation is required for comprehensively improving the efficiency of hetero-organization and hetero-organization functions, and it is also an important means for the evolution of self-organization functions. The technological process in the future will make it possible to master the pattern of complex relationships between the various urban transportation subsystems and the external environment. With the aid of modern information communication technologies such as 5G and the Internet of Things (IoT) and artificial intelligence (AI) technology, the exchange of information [14] and energy between the urban transportation system and external environment system as well as between the various subsystems within a system is likely to continuously enhance the system's self-perception, self-diagnosis, self-recovery, and self-adjustment capabilities. In this way, the intelligent evolution of system self-organization can be achieved.

2) Intelligent urban transportation—an inevitable strategic path to system evolution

The construction of intelligent transportation service systems and intelligent operation-and-maintenance management systems is the corresponding task to the development of the intelligent urban transportation system. There is nothing wrong with this consensus; however, in view of the objective patterns of system evolution, it is indeed necessary to rediscover the strategic position of intelligent transportation in the evolution and the sustainable development of transportation systems in the future.

The evolution of the urban transportation system is a process of constantly discarding useless entropy (broken infrastructure and equipment, outdated organizational structures, waste emissions, etc.) while continuously introducing negative entropy flows required by the system from the outside world, such as materials, energy, and information. This will inevitably result in an increase in entropy in the external environment and the irreversible deterioration of the environment. By the principles of high-quality development and sustainable development, the urban transportation system must change its development model and evolve to a higher level of intelligence to adapt to the changing external environment. This means that only a smarter way of development can be chosen. Specifically, intelligence should be taken as the strategic path to achieve self-evolution; the system's capability of perception-cognition-self-adjustment toward the external environment should be timely and continuously improved, and the dependence on external resources and human intervention should be reduced. It is self-evident that intelligence is by no means just a specific construction task but a novel model for the transformation of urban transportation development.

By the strategic requirements for the evolution of the urban transportation system, the connotation of intelligence is not limited to the construction of intelligent transportation systems in a traditional sense. Instead, it should focus on intelligent coordination containing all factors of system planning, construction, operation, maintenance, and service within the system's full lifecycle. In addition, a multi-agent system (MAS) operating on distributed collaborative decision-making (CDM) should be established, and each subsystem (RNs, bus and rail transit networks, logistics distribution systems, etc.) of the system is an agent with autonomous decision-making ability. Each agent depends on a collaborative feedback mechanism to exchange information and take concerted steps. An integrated MAS not only has a stronger self-organization ability than a conventional comprehensive transportation system but also possesses self-learning, self-diagnosis, as well as reasoning and decision-making abilities. Meanwhile, the modular combination structure and the decentralized distributed information processing can greatly improve the efficiency of handling demand response and complex events.

4 Conclusions

In this paper, the evolutionary trend and mechanisms, as well as the intrinsic properties of the urban transportation system, were analyzed and discussed from the perspective of urban transportation system evolution. The specious understandings in the urban transportation system, such as supply and demand balance, and traffic carrying capacity, were reexamined. Moreover, the strategic orientation, goal orientation, and thinking methods for planning were proposed from the perspective of system evolution, and major problems, such as the carrying capacity and the intelligence of the urban transportation system, were investigated. The opinions are proposed for exploration and still need to be revised and improved in the future in combination with the practice of transportation in the new era.

References

[1]Quan Yongshen, Wang Ting, Yu Liu. Issues on Urban Transportation[J]. Urban Transport of China, 2018, 16(2):1–8 (in Chinese).

[2] Qian Xuesen, Yu Jingyuan, Dai Ruwei. A new discipline of science: the study of open complex giant system and its methodology [J]. Nature, 1990 (1): 3–10 + 64.

[3] Lian Bin, Feng Yongbo. The application of dissipative structure and gray entropy theories in models of transportation system and regional economic development[J]. Highways & Automotive Applications, 2013(4): 231–234 (in Chinese).

[4]Nie Wei, Shao Chunfu, Yang Liya. Study on the Application of Dissipative Structure and Entropy Change Theory in Regional Transportation System[J]. Journal of Highway and Transportation Research and Development, 2006, (10): 95–98 (in Chinese).

[5] Li Tao, Ye long. Study on the entropy change mechanism of rail transit drivers' competency based on the dissipative structure[J]. Journal of Transportation Systems Engineering and Information Technology, 2014, 14(3): 148–153 (in Chinese).

[6] Beijing Transport Institute. Annual report on development of Beijing transportation (2019)[R]. Beijing: Beijing Transport Institute, 2019 (in Chinese).

[7] Beijing Transport Institute. Annual report on development of Beijing transportation (2020)[R]. Beijing: Beijing Transport Institute, 2019 (in Chinese).

[8]Wang Yong, Wang Pusheng. On Emergence and Open Complex Giant Systems[J]. Chinese Journal of Systems Science, 2014, 22(2):16–19 (in Chinese).

[9]Quan Yongshen, Liu Jianfeng. Issues and Thoughts on Regional Rail Transit Planning[J]. Urban Transport of China, 2017, 15(1): 12–19 (in Chinese).

[10] China Urban Railway Transit Association. Annual statistics and analysis report on urban rail traffic in 2018[R]. Beijing: China Urban Railway Transit Association, 2019 (in Chinese).

[11] Guojie Li. The Scientific Value of the Research on Big Data[J]. China Computer Federation, 2012, 8(9): 8–15 (in Chinese).

[12]Guo Yi, Mao Xinjun, Dong Menggao. A Survey of the Research on Complex Self-Organized Systems[J]. Computer Engineering&Science, 2012, 34(2):159–167 (in Chinese).

[13]Bai Tongzhou, Liu Xuejie, Li Xian. Discussions on Transportation Capacity as a Constraint for Urban Development: Taking Beijing as an Example[J]. Urban Transport of China, 2019, 17(5):91–98 (in Chinese).

[14] Reyna V F. A Scientific Theory of Gist Communication and Misinformation Resistance, with Implications for Health, Education, and Policy[J/OL]. Proceedings of the National Academy of Sciences, 118(15): 201912441.