Sustainable Operation Responsibility Mechanism for Inter-jurisdictional Rail Transit Project in the Shenzhen Metropolitan Area

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***Abstract*—As the core city of the Shenzhen Metropolitan Area, Shenzhen takes the lead in promoting the planning and construction of the metropolitan area. The development experience of world-class metropolitan areas has demonstrated that rail transit plays a fundamental supporting role. Currently, the full-process work of planning, construction, and operation of rail transit in the Shenzhen Metropolitan Area is being vigorously advanced. The sustainable operation responsibility mechanism for inter-jurisdictional rail transit project in the Shenzhen Metropolitan Area is crucial to ensuring the long-term operation after completion. It is necessary to clarify the scope of sustainable operation responsibilities, accounting principles, sharing methods, and funding/resource pathways. The mechanism aims to foster a sound situation for the sustainable development of rail transit in the Shenzhen Metropolitan Area and support the coordinated development of the region.**

***Keywords*—Shenzhen metropolitan area, rail transit, inter-jurisdictional project, sustainable operation responsibility mechanism**

I. Introduction

Building modern metropolitan areas is a key direction for China to construct a new urban development pattern, promote regional coordinated development, and advance new-type urbanization, which requires the support and guidance of multi-level rail transit. The Guiding Opinions of the National Development and Reform Commission on Cultivating and Developing Modern Metropolitan Areas [1] requires "comprehensively considering the layout of the metropolitan area's rail transit network to build a commuter circle with rail transit as the backbone; compiling rail transit plans for metropolitan areas where conditions permit, promoting the integration of trunk railways, intercity railways, suburban railways, and urban rail transit into a 'four-network integration'; exploring a 'unified network' for the operation and management of metropolitan area rail transit, and creating an 'on-track metropolitan area'" [2,3]. The Plan for the Construction of Intercity Railways in the Guangdong-Hong Kong-Macao Greater Bay Area[4] points out that "to improve the quality of intercity transportation supply in the Guangdong-Hong Kong-Macao Greater Bay Area and serve the construction of the Greater Bay Area, it is agreed to sequentially implement a number of intercity railway projects in the region, actively explore and innovate institutional mechanisms, and strive to develop a diversified and orderly competitive operation model; in accordance with the principles of resource sharing and mutual benefit, support railway enterprises to participate in intercity railway operation through entrusted operation, service procurement, etc., and build an 'on-track Greater Bay Area'".

Guangdong Province has implemented national strategies, accelerated the construction of intercity railways and metropolitan areas in the Greater Bay Area, and clearly designated Shenzhen to take the lead in advancing the planning, construction, and operation of rail transit in the Shenzhen Metropolitan Area. In November 2020, Guangdong Province presided over a special meeting to study the institutional mechanisms for intercity railway construction in the Greater Bay Area. He pointed out that "Guangdong Province will vigorously promote the construction of intercity railways and hub projects in the Greater Bay Area during the '14th Five-Year Plan' period. Faced with the arduous and urgent task of intercity railway construction in the Greater Bay Area, the current construction system dominated by the Guangdong Provincial Railway Investment Group is unsustainable. There is an urgent need to form a new system for advancing intercity railway construction classified by functional positioning and matching project funding principles, fully mobilize the enthusiasm of Guangzhou and Shenzhen, clarify that inter-jurisdictional rail transit project in the Shenzhen Metropolitan Area will be led by Shenzhen, delegate the provincial approval and operation authority for intercity railway projects within Shenzhen to the Shenzhen Municipal Government, and allow state-owned enterprises in Shenzhen to take the lead in raising project capital in conjunction with cities along the routes [4, 5]."

Shenzhen has taken the initiative to set up a coordination mechanism for intercity railways in the Shenzhen Metropolitan Area, and the Shenzhen Municipal Development and Reform Commission has organized special research on rail transit planning, institutional mechanisms, and investment and financing plans for the metropolitan area. In April 2021, led by Shenzhen and with the joint participation of Dongguan and Huizhou, the Intercity Railway Construction Headquarters of the Shenzhen Metropolitan Area was established [5], aiming to coordinate the design, construction, operation, and management of intercity railways in the Shenzhen Metropolitan Area. It was clarified that "faced with 10 recent construction projects in the Shenzhen Metropolitan Area, with a total length of 351 km and a total investment of 187.2 billion yuan, the task is arduous and the responsibility is significant". The three cities jointly signed the Memorandum of Cooperation on the Investment, Construction, and Operation of Intercity Railways in the Shenzhen Metropolitan Area, reaching principled consensus on six aspects: project funding

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mechanism, construction management, approval procedures, land acquisition and demolition, comprehensive land development, and bus-style operation. Shenzhen has actively played the leading role of the core city in the metropolitan area [6,7], and in accordance with the work idea of "constructing a batch, starting a batch, reserving a batch, and planning a batch", has launched the planning of intercity railways and suburban railways in the Shenzhen Metropolitan Area, and formulated the development plan and construction arrangements for the next phase of intercity and suburban railways in the metropolitan area at an early stage. To better implement the national requirements for approval depth and guide the implementation of subsequent projects, special research has been conducted on the investment, construction, and operation management system mechanisms and investment and financing plans for metropolitan area rail transit, streamlining the implementation path of planning, approval, investment, construction, and operation of metropolitan area rail transit, and providing institutional and policy guarantees for the sustainable development of rail transit in the Shenzhen Metropolitan Area.

Existing studies on metropolitan area rail transit have focused on network layout optimization [8], transfer efficiency improvement [9], and intelligent operation and maintenance [10], but there is a lack of in-depth exploration of the sustainable operation responsibility mechanism for inter-jurisdictional rail transit project. The cross-city nature of intercity rail transit leads to unclear responsibility boundaries among multiple administrative subjects, which easily causes problems such as unclear funding channels and inadequate loss compensation during the operation period. Addressing these gaps is of great significance for ensuring the long-term stable operation of inter-jurisdictional rail transit project in the Shenzhen Metropolitan Area and promoting the integrated development of the metropolitan area. This study aims to clarify the scope, accounting principles, undertaking methods, and operation modes of sustainable operation responsibilities, and verify the feasibility of the mechanism through practical cases, so as to provide a reference for the construction and operation of similar projects.

The construction and operation of metropolitan area rail transit has always been a research focus in the field of transportation. Foreign scholars have carried out in-depth research on the operation mechanism of intercity rail transit. For example, Vickerman [11] pointed out that the success of intercity rail transit depends on the clear division of responsibilities among government departments, railway enterprises, and other subjects, and the establishment of a sound cost-sharing mechanism. Nash [12] studied the operation modes of intercity rail transit in European metropolitan areas and found that the combination of government subsidies and market-oriented operations can effectively improve the sustainability of projects.

Domestic research on metropolitan area rail transit mainly focuses on policy interpretation, network planning, and investment and financing models. Li *et al.* [13] analyzed the policy requirements for the development of metropolitan area rail transit in China and proposed that it is necessary to strengthen the coordination among cities and improve the intercity cooperation mechanism. Wang *et al.* [14] studied the investment and financing model of intercity rail transit in the Pearl River Delta and put forward suggestions such as diversifying investment subjects and expanding financing channels. However, there are few studies specifically targeting the sustainable operation responsibility mechanism of inter-jurisdictional rail transit project. Most studies only mention the importance of responsibility division in general terms, but lack detailed analysis of the specific scope of responsibilities, accounting methods, and undertaking ways.

In terms of the sustainable operation of rail transit, some scholars have explored loss compensation mechanisms. Zhang *et al.* [15] proposed that the loss of urban rail transit can be compensated through land comprehensive development, but they did not involve the cross-city coordination issues. Chen *et al.* [16] studied the cost-sharing mechanism of intercity rail transit, but their research focused on the construction period and ignored the operation period responsibilities.

In summary, although existing studies have laid a foundation for the research on metropolitan area rail transit, there is still a gap in the systematic research on the sustainable operation responsibility mechanism of inter-jurisdictional rail transit project. This study fills this gap by clarifying the core content of the sustainable operation responsibility mechanism for inter-jurisdictional rail transit project in the Shenzhen Metropolitan Area, which is of great theoretical and practical significance for promoting the sustainable development of metropolitan area rail transit.

II. Scope of Responsibilities

With reference to the Notice of the General Office of the People's Government of Guangdong Province on Printing and Distributing Several Policies and Measures to Support Railway Construction and Promote Comprehensive Land Development and the current negotiation progress on the sustainable operation responsibility of specific intercity railway projects in the Shenzhen Metropolitan Area, the scope of the sustainable operation responsibility mechanism for rail transit projects in the Shenzhen Metropolitan Area includes the principal and interest repayment of debt funds during the construction period and the daily operation losses during the operation period, as shown in Fig. 1.

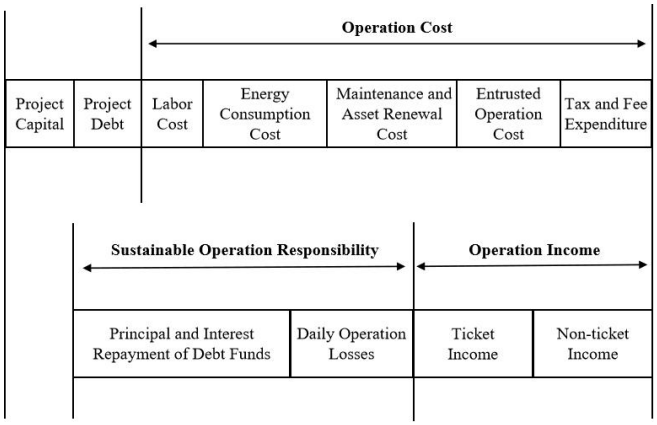

Fig. 1. Scope of sustainable operation responsibilities.

This section briefly describes the calculation logic of project operation income, project operation expenditure, and project principal and interest repayment:

A. Project Operation Income

$$CI = CI_{ticket} + CI_{non\text{-}ticket} \quad (1)$$

$$CI_{ticket} = p \cdot r_{ticket} \quad (2)$$

$$CI_{non\text{-}ticket} = CI_{ticket} \cdot r_1 \quad (3)$$

where, CI refers to project operation income (100 million yuan); CI_{ticket} refers to ticket income (100 million yuan); $CI_{non\text{-}ticket}$ refers to non-ticket income (100 million yuan), including station supporting commercial rental income, advertising income, and communication income; p refers to passenger turnover (100 million passenger-kilometers); r_{ticket} refers to passenger fare rate (yuan per passenger-kilometer); r_1 refers to fixed coefficient.

B. Project Operation Cost

$$CO = CO_{daily} + CO_{update} + CO_{tax} \quad (4)$$

$$CO_{daily} = \sum_{i=1}^{5} CO^{i}_{daily} \quad (5)$$

Where, CO refers to project operation cost (100 million yuan); CO_{daily} refers to daily operation cost (100 million yuan); CO_{update} refers to heavy maintenance and asset renewal cost (100 million yuan); CO_{tax} refers to tax and fee expenditure (100 million passenger-kilometers); CO^{i}_{daily} refers to labor cost, energy consumption cost, maintenance cost, management cost, entrusted operation cost (100 million yuan), i=1,2,3,4,5.

C. Project Principal and Interest Repayment

The principal and interest repayment funds refer to the debt principal raised by the project owner through market-oriented financing for project construction, as well as the debt interest generated by the debt principal in accordance with the repayment plan.

$$CR = CR_{principal} + CR_{interest} \quad (6)$$

where, CR refers to project principal and interest repayment amount (100 million yuan); $CR_{principal}$ refers to project debt principal (100 million yuan); $CR_{interest}$ refers to project debt interest (100 million yuan).

D. Project Lifecycle Funding Gap

$$LC = \sum_{t=1}^{n} (CI - CO - CR)_t \quad (7)$$

where, LC refers to project lifecycle funding gap (100 million yuan); $(CI\text{-}CO\text{-}CR)_t$ refers to net cash flow of the project in year t (100 million yuan); n refers to the number of years in the project lifecycle (years).

III. Accounting Principles and Undertaking Methods

A. Accounting Principles

Combined with the actual operation and accounting methods of intercity railway projects mainly invested by local governments in China and the Pearl River Delta intercity railway projects, it is recommended that the rail transit projects in the Shenzhen Metropolitan Area adopt the principle of independent accounting for single lines, implementing the "one line, one accounting" method for calculating sustainable operation responsibilities. The main subjects involved include the project company and the governments of cities along the project route.

The sustainable operation responsibilities for the entire line of the project shall be shared among the cities along the route. The specific amount to be borne by each city shall be determined based on the proportion of the capital contribution of each city to the total project investment. The governments of cities along the project route are the main subjects responsible for the sustainable operation of the project.

B. Undertaking Methods

Drawing on the operation experience of the sustainable operation responsibility mechanism for the Pearl River Delta intercity railway projects and the research on the sustainable operation responsibility mechanism for cross-city intercity railway projects in the Guangzhou Metropolitan Area, the specific undertaking methods for the sustainable operation responsibilities of projects in the Shenzhen Metropolitan Area can include fund-based methods and land resource-based methods.

IV. Operation Modes

On the premise of clarifying the accounting principles and undertaking methods for sustainable operation, and combining the current development status of domestic metropolitan area projects, the following three categories (four types) of main operation modes are proposed.

A. One Company per Line (Overall Operation)

In accordance with the principle of "unified operation and overall accounting", the sustainable operation responsibilities of the project shall be shared among the cities in proportion to their shareholding ratios in the project company, and compensated to the project company through fund-based or land resource-based methods, as shown in Fig. 2.

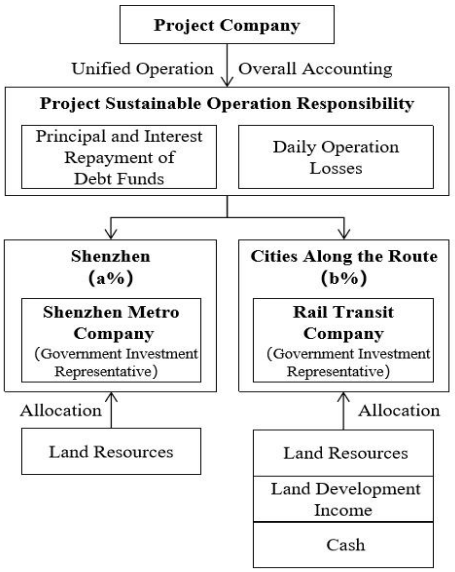

Fig. 2. Schematic diagram of overall project operation.

B. Multiple Companies per Line (Sectional Operation)

In accordance with the principle of "unified operation and sectional accounting", each city shall independently bear the sustainable operation responsibilities corresponding to its capital contribution, and compensate the rail transit company or project company of each city through fund-based or land resource-based methods, as shown in Fig. 3.

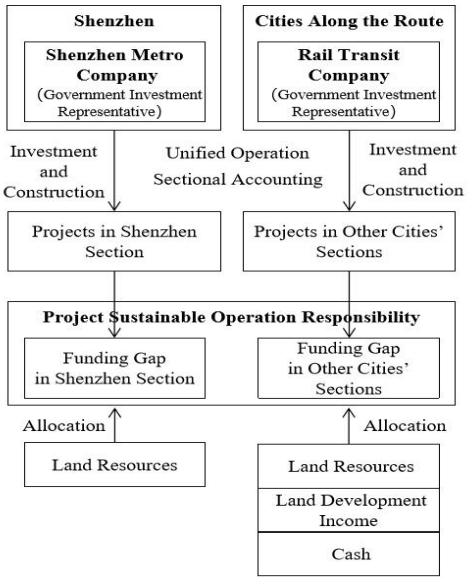

Fig. 3. Schematic diagram of sectional project operation.

C. Lump-sum Operation

According to the scope of the lump-sum responsibility, it can be divided into overall lump-sum operation and sustainable operation responsibility lump-sum operation.

1) Overall lump-sum operation

The scope includes project capital, project financing principal and interest, and project operation losses. It means that cities along the route fulfill their project funding and sustainable operation responsibilities through land resources of corresponding scale, which are supplied to Shenzhen Metro Group for lump-sum use through conditional bidding, auction, and listing. During the operation period, the cities along the route shall not be liable for the project's profits and losses, as shown in Fig. 4.

Fig. 4. Schematic diagram of overall lump-sum project operation.

2) Sustainable operation responsibility lump-sum operation

The scope includes project financing principal and interest and project operation losses. It means that cities along the route fulfill their sustainable operation responsibilities through land resources of corresponding scale, which are supplied to Shenzhen Metro Group for lump-sum use through conditional bidding, auction, and listing. During the operation period, the cities along the route shall not be liable for the project's profits and losses, as shown in Fig. 5.

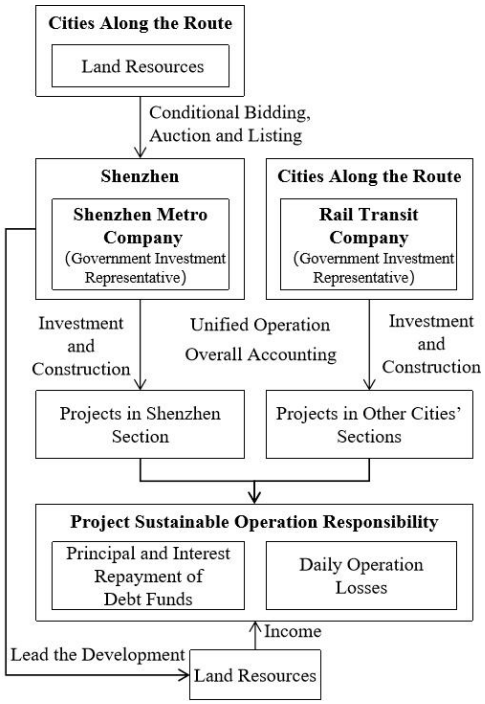

Fig. 5. Schematic diagram of sustainable operation responsibility lump-sum project operation.

V. Case Study

This section selects the Qianhai Free Trade Zone to Pingdi Section of the Shenzhen-Huizhou Intercity Railway as a case study. The newly built Shenzhen-Huizhou Intercity Railway is located in southern Guangdong Province, passing through Shenzhen, Dongguan, and Huizhou. It is a backbone intercity line in the Shenzhen-Dongguan-Huizhou intercity network. The line starts from Qianhai Station in the Qianhai Cooperation Zone of Shenzhen in the west, passes through Nanshan District, Longhua District, and Longgang District of Shenzhen, Fenggang Town and Xiegang Town of Dongguan, Huiyang District, Zhongkai High-Tech Zone, and Huicheng District of Huizhou, and ends in Huidong County of Huizhou. The total length of the line is approximately 142.6 km, with 18 stations. Among them, the Shenzhen section is 52.8 km long with 10 stations; the Dongguan section is 6.0 km long with 1 station; the Huizhou section is 83.5 km long with 7 stations. The design speed of the Qianhai Free Trade Zone to Pingdi section is 160 km/h, and the design speed of the Pingdi to Huibei section is 200 km/h. In accordance with the relevant requirements of the province and city, the Qianhai Free Trade Zone to Pingdi section of the project is launched first, with a length of approximately 58.8 km and 11 stations. The overall route of the Shenzhen-Huizhou Intercity Railway is shown in Fig. 6. The scope of the Shenzhen-Huizhou Intercity Railway

involved in this implementation plan is the Qianhai Free Trade Zone to Pingdi section in Shenzhen, passing through Shenzhen and Dongguan, excluding the Huizhou section. According to the submitted feasibility study report of the Qianhai Free Trade Zone to Huizhou section of the Shenzhen-Huizhou Intercity Railway, the total estimated investment of the project is 44.43 billion yuan, including 39.94 billion yuan in static investment, 3.13 billion yuan in interest on construction period loans, 1.34 billion yuan in vehicle purchase cost, and 7 million yuan in initial working capital. The total construction period of the project is 5 years; the project capital accounts for 50% of the total investment, which is 22.21 billion yuan, and the funds beyond the capital are raised through other financing methods such as domestic bank loans.

Fig. 6. Schematic diagram of the overall route of the Shenzhen-Huizhou intercity railway.

Next, the division of sustainable operation responsibilities for the Qianhai Free Trade Zone to Pingdi Section of the Shenzhen-Huizhou Intercity Railway is elaborated, as shown in Fig. 7.

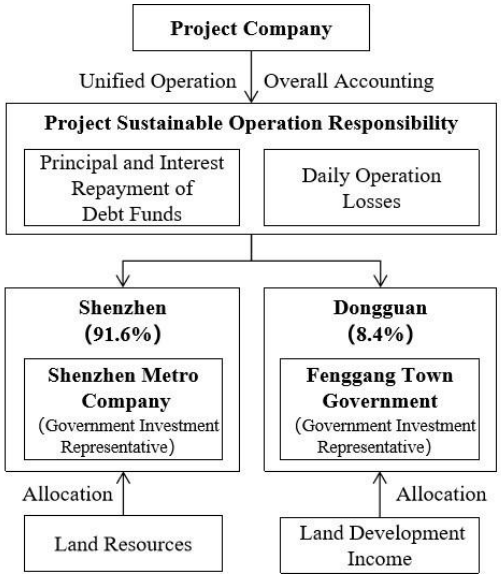

Fig. 7. Schematic diagram of the division of sustainable operation responsibilities.

A. Scope of Responsibilities

It is clarified that the principal and interest repayment of debt funds (excluding project capital) during the construction period and the operation losses during the operation period are included in the scope of the project's sustainable operation responsibilities.

B. Accounting Principles

The responsibilities are shared in accordance with the shareholding ratios of Shenzhen and Dongguan in the project company, among which Shenzhen holds a 91.6% stake and Dongguan holds an 8.4% stake. The shareholding ratios are derived from the capital contributions of Shenzhen and Dongguan specified in the project feasibility study approval.

C. Undertaking Methods

The main subject responsible for the sustainable operation of the Shenzhen section is the Shenzhen Municipal Government, which adopts the land resource-based method. The Shenzhen Municipal Government allocates land resources to Shenzhen Metro Group through conditional bidding, auction, and listing, and the land development income is used to cover the sustainable operation responsibilities of the Shenzhen section. The main subject responsible for the sustainable operation of the Dongguan section is Fenggang Town, Dongguan City, which is required to raise funds through land development income to fulfill the responsibilities. Meanwhile, since the project has not yet been put into operation, any unaddressed matters in the preliminary agreement will be further clarified through special agreements or supplementary agreements in the future to effectively fulfill the project's sustainable operation responsibilities.

VI. Conclusions

The sound situation of "joint planning, co-construction of facilities, shared services, and co-management of operations" for rail transit in the Shenzhen Metropolitan Area has played a good supporting role in the development of the metropolitan area. To achieve this situation, it is first necessary to address issues such as "who will compile, report, and approve", "who will invest, benefit, and compensate for losses", and "how to construct and manage". Based on this, combined with the current development status of domestic metropolitan area rail transit and the key issues in the Shenzhen Metropolitan Area, it is necessary to conduct useful explorations on the institutional mechanisms for the coordinated development of rail transit in the Shenzhen Metropolitan Area.

Conflict of Interest

The author declares no conflict of interest.

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