WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945
DOI: 10.24425/ace.2024.151907
ARCHIVES OF CIVIL ENGINEERING
Vol. LXX ISSUE 4 2024
pp. 521 –534

Research paper

How to achieve sustainable operation of transport infrastructure development: a case study of 30 transport infrastructure projects in China

Jie Chen[1], Chongsen Ma[2]

Abstract: Transport infrastructure projects are distinguished by their high levels of investment, lengthy construction periods, and reliance on government subsidies during operation. These factors have far-reaching impacts, not only on the sustainable operation and success of the projects themselves, but also on the orderly functioning of society and the sustainable development of the economy. As such, it is of paramount importance to thoroughly investigate the sustainable operation of transport infrastructure. This paper examines the impact of sustainable operation on transport infrastructure by analysing 30 projects in China's transport infrastructure sector. The study employs the qualitative comparative analysis method. To achieve the aim of this paper, we identified five dimensions for assessing a project's sustainability. These include the economic environment of the construction site, operational market demand, government support capacity, and enterprise management level. This analysis offers valuable guidance for future engineering projects. Finally, the study identified seven strategies for achieving sustainable operation of the project. The findings revealed that the economic development status, population size, and government subsidies of the construction site do not effectively promote sustainable operation of the project. Rather, they can hinder enterprises' market competitiveness. The study's results can assist decision-makers in determining the feasibility of implementing sustainable management practices in the new project. Examine the factors that influence the achievement of sustainable business while enhancing the operational efficiency of ongoing initiatives. This research aims to produce a valuable addition to risk assessments in sustainable operation research and the advancement of transportation infrastructure reduction.

Keywords: transportation infrastructure, sustainable operation, QCA method, sustainable development pathway, case study, sustainable economic development

[1]PhD., Hunan Modern Environment Technology CO.,LTD, Furong South Road 128, Changsha, China, e-mail: chenjiehunan2022@126.com, ORCID: 0009-0009-5820-7008

[2]PhD. candidate, Changsha University of Science & Technology, South Wanjiali Road 960, Changsha, China, e-mail: machongsen@stu.csust.edu.cn, ORCID: 0000-0001-9990-2300

1. Introduction

The concept of sustainable infrastructure development was first introduced in the Brundtland Report in 1987. Almost all infrastructure services are provided by complex socio-technical networks with economies of scale: as they increase in size, they generate progressively greater benefits. However, they also have this disadvantage of high start-up costs and high risks [1, 2]. The analysis of whether a transport infrastructure project achieves sustainable operation varies depending on the project, for example, the type of project, the mode of operation, the economic development of the construction site, the boost to the surrounding economy and the overall benefits to society. The analysis of whether a transport infrastructure project achieves sustainable operation varies depending on the project, for example, the type of project, the mode of operation, the economic development of the construction site, the boost to the surrounding economy and the overall benefits to society. If the level of corporate management is taken into account in the above factors, then certain specific operational elements may also contribute to the project achieving sustainability. Huang and Yeh believe the importance of sustainable infrastructure development is reflected in its environmental, economic and social impact [3]. Meanwhile, Lothebelieves that infrastructure development is always unsustainable because of the length of time and investment involved in the project [4]. Therefore it is of great importance to study the sustainable development and operation of transport infrastructure.Some of the researcherthink the forecast of traffic demand is considered to be one of the key factors in transport projects [5,6].

Currently, global infrastructure investment is around US$2.3 trillion per year, and the results of one study suggest that by 2040 the reduction in infrastructure will reach US$94 trillion [7]. Although the scale of investment is currently expanding, the construction and promotion of transport infrastructure has been affected by the fact that infrastructure investment requires the mobilisation of large amounts of capital, but the construction of infrastructure itself is less profitable and the projects are less sustainable.

In China, for example, the number of transport infrastructure projects is growing. The development methods are also more diverse. According to publicly available data, there are currently more than 13,000 transport infrastructure projects in the pipeline in China, with operating methods including PPP (Public-Private Partnership), BOO (Build-own-operate), TOT (Transfer-Operate-Transfer), etc.. Over 80% of the projects are operated using government payments or feasibility gap subsidies, while only 12% can be operated entirely on a user-pay basis (Fig. 1). The data in Fig. 1 is from CHINA PUBLIC PRIVATE PARTNERSHIPS CENTER(https://www.cpppc.org/). Current transport infrastructure projects have an impact on the construction of new projects due to their inability to achieve their own sustainability and operation. At the same time, for developing countries like China, transport infrastructure projects are heavily invested in, and although the construction of transport infrastructure projects will indirectly contribute to the development of the local economy, if they are built blindly or are unable to achieve their own sustainable operation after construction, they must rely on government subsidies to maintain their operation, which will have a certain impact on local finances.

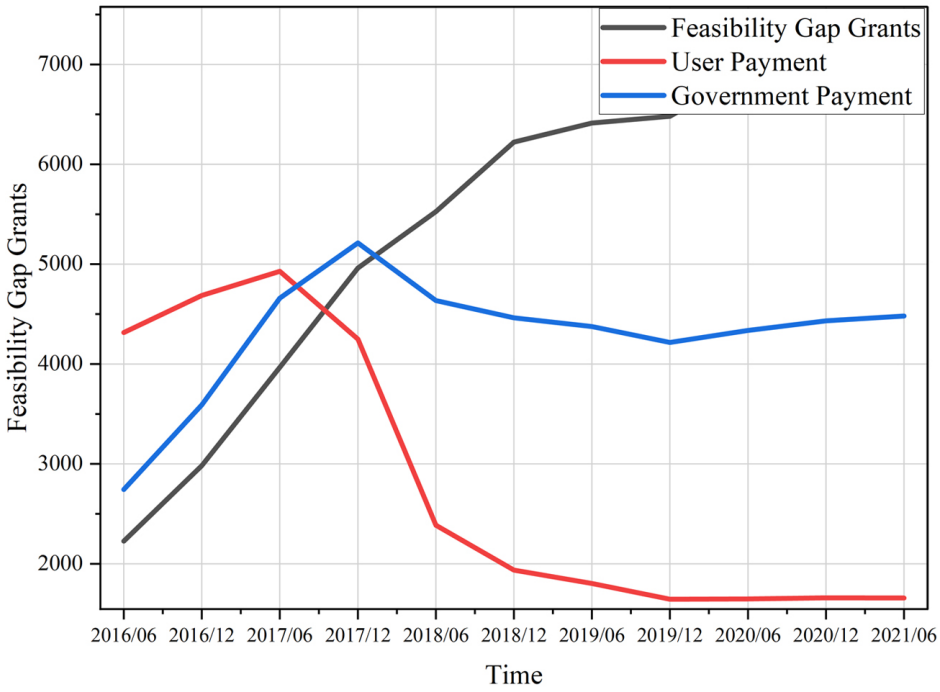

Fig. 1. Sources of revenue for transportation infrastructure projects

Figure 1 shows that the vast majority of projects in China are currently operating on a viability gap subsidy and government payment model. Only a very small number of projects use user fees. This is a reflection of the poor sustainability of transport infrastructure projects. Therefore, the sustainability of a project has a significant impact on society.

However, it is difficult to identify an effective way to make a valid judgement on whether a project can achieve sustainable operation before construction, due to the complexity of the factors influencing the development of transport infrastructure and the wide variation between projects.

Many researchers have attempted to analyse whether infrastructure achieves sustainable operation and project performance. Some scholars have achieved an assessment of infrastructure projects by analysing the critical success factors of the projects. Some scholars determine whether a project achieves sustainability by evaluating the financial effectiveness of the project. However, Zhouargues that effective evaluation of the sustainability and performance of infrastructure operations is rare, and there is not enough research to evaluate whether the whole process of infrastructure development achieves sustainability [8].

Drawing on previous studies, the contribution of this study is two-fold. Firstly, through this study it is found that there are a variety of different pathways leading to the achievement of sustainable operation of transport infrastructure. The thesis provides a comprehensive analysis of the determinants of success of 30 Chinese transport infrastructure projects (project clusters)

by using a relatively new comparative qualitative analysis method. The second is that, as developed through the study, the traditional typical evaluation approach of assessing the impact of only a few variables on transport infrastructure alone does not yield satisfactory results. Only by combining different combinations of conditions can the results of a project achieving sustainable operation be adequately explained.

The development of the concept of sustainability has gone through several stages; Hans first proposed the concept of sustainable use in 1713; however, it was not until 1952 that the concept was applied to the economic field to refer to a future-oriented, long-term development orientation with development potential and became an important concept in the formulation of long-term strategies. With the development of research, the three-pillar model of sustainable development: economic development, social progress, and environmental protection has been further proposed, which provides a possible solution and direction for the future sustainability of human beings. In this study, the sustainability of urban metro is examined mainly from an economic perspective.

Sustainability in this paper refers to the sustainable operation of the project, i.e. the sustainable and healthy development of the project itself through rational decision-making and control instruments, with no or less external subsidies and a positive impact on the surrounding environment [9]. The thesis is divided into four parts. The first part provides a review of the relevant research literature. The qualitative comparative approach (QCA) used for the case studies is also presented. The second part discusses the case study methodology used in the study and describes the process of identifying the cases. The third part presents the identification of the indicators used in the research process, and the data processing. The fourth part presents the findings and outlook on the sustainable operation of transport infrastructure.

The research scope of this paper is mainly limited to the sustainable operation of transportation infrastructure in China. Transportation infrastructure in this paper mainly refers to subways and expressways.

The innovation of this paper is mainly reflected in the following three points:

1. Innovation of evaluation method: This paper innovatively uses QCA research method to analyze and study the influencing factors of the sustainable operation of transportation infrastructure.
2. Innovation of the evaluation object: As a rapidly developing country, China has a large scale of transportation infrastructure construction. But transport infrastructure is not working as well as it should. Therefore, the research on China's transportation infrastructure operation is not only helpful to improve China's operation level, but also can provide certain reference value for the construction of other developing countries.
3. Innovation of research results: The results show that the traditional economic conditions of construction sites and the level of government subsidies do not play a good role in promoting the sustainable operation of projects, and in some cases, even hinder the market-oriented operation of projects.

2. Literature review

In order to achieve project sustainability, project sustainability assessment instruments have been implemented in many countries. Internationally sustainability assessment systems for infrastructure are usually national in scope. The partners include governmental or non-governmental institutions [10]. These systems are used in different ways to analyse the factors that affect the sustainability of projects during the development and operation of infrastructure [11]. In the field of transport infrastructure development in China, this is mainly in the form of state approval of project feasibility and monitoring of development data for key projects. The sustainability factors of transport infrastructure are regulated in the USA through the INVEST assessment system. argues that every stage of an infrastructure project must be oriented towards sustainability principles and through further research on Australian road projects 23 key factors affecting the sustainability of projects were identified. These factors include: environmental, economic, social, engineering, institutional, project management and 10 other aspects. Another evaluation system for transport infrastructure projects is GreenLITES, developed by the New York Department of Transportation, which only integrates planning, design, construction and maintenance operations [12–14]. In this system, environmental, social and economic identified as factors to evaluate the sustainability oe project. Through the above studies, it can be found that most scholars agree that the sustainability of projects is related to social, economic, project management and environmental factors. At the same time, all of these evaluation systems agree that to achieve project sustainability, it is important to incorporate this goal into the whole process of the project. Achieving sustainable operation of a project minimises the negative impact on society throughout the project's life cycle.

3. Method and theoretical framework

Qualitative comparative analysis is a method that integrates quantitative and qualitative analysis and allows for organic integration between case studies and variable studies [15].

For case-based studies, it is more difficult to compare various variables among a large number of cases or the cases themselves, and cannot be well applied to studies with large amounts of data; variable-based studies explain changes in the project as a whole by controlling for variables, ignoring the interactions between variables. qca can analyze the similarities and differences among cases while retaining the integrity of the cases. qca deals with the complex relationships between variables and outcomes based on pooled relationships, and in this approach outcomes are considered to be generated by combinations of conditions. Given that it is based on Boolean algebra, rather than linear algebra, it is not limited by degrees of freedom and can be applied to small N comparison case studies with 5 to 50 samples, as in this case.

In studies on transport infrastructure sustainablilty, observe how to achieve the conditions for sustainable development of transportation infrastructure remains a less travelled. Until now, Verweij, Stefan are the only two scientists that use QCA to assess transport infrastructure construction [16].

As a new analytical methodfs, QCA has been criticised by some scholars for being too fuzzy in dealing with benchmarks and intersections [17, 18]. Beersargues that any research method has certain drawbacks and that traditional quantitative analysis methods (including regression or significance tests) are more sensitive to sample size and p-values, and that QCA can be used as a complement to traditional methods to analyse and study the overall effect between influencing factors and to establish relationships between factors [19].

Based on the good practice criteria needed to improve the quality of QCA application [20], the thesis applies multiple regression analysis and crisp-set qualitative comparative analysis (csQCA) to analyse the factors influencing sustainable development of transport infrastructure. The results of the multiple regression analysis showed that of the individual variables tested, only a positive and significant effect on the sustainable operation of transport infrastructure was found. However, the aim of this approach is only tocapture the correlation between the influencing factors and the sustainable operation of transport infrastructure. It is rather limited in its ability to fully explain why some cities with diversified industrial development and good urban economic conditions perform worse than cities without lower levels of economic development. Therefore, by running csQCA, this investigation aims to complementand seek further structural analysis of the pathways that help to explain thecauses of sustainable transport infrastructure development.

Step1 – Defining evaluation indicators

This paper requires an evaluation of the sustainability of transport infrastructure. In this paper, sustainable measures are 'the ability to operate independently, without external support, to achieve profitability and sustainability'. Sustainability is one of several measurable values that help to understand and quantify an indicator.In other word,sustainable capacity are not 'direct measures of project success or failure; rather, they are flags to alert users to possible opportunities for improvement'. Taking into account the above factors, and in conjunction with 2.1, a set of indicators for evaluating the sustainable operation of the project has been developed. In order to reduce the influence of human factors, the indicators have been chosen primarily as quantitative indicators in order to develop the 'sustainable' approach of this paper. The methodology used to develop the indicators is discussed below.

The thesis identifies five dimensions: the economic development of the construction site, the need for transport infrastructure construction, the importance of the government, the diversified means of operation, and the economic driving effect as the evaluation indicators of whether the project achieves sustainable operation, and whether the transport infrastructure operating enterprises can achieve profitability after deducting government subsidies as the evaluation criteria of whether the project achieves sustainable operation. The thesis identifies five dimensions: the economic development of the construction site, the need for the construction of transport infrastructure, the importance of the government, the degree of diversified operation and the economic driving effect as the evaluation indicators for the sustainable operation of the project, and the profitability of the transport infrastructure operator after deducting government subsidies as the evaluation criteria for the sustainable operation of the project. The economic development of the construction site includes the population of the city, the GDP of the construction site and the general revenue of the government. These three indicators provide a good description of the economic development of the construction site. To determine whether

the construction of transport infrastructure is suitable for construction and the necessity of construction. The necessity of transport infrastructure is reflected by the degree of need of local residents for transport infrastructure, which includes the number of people served by the project per year, the travel time per capita and the commuting distance. These three indicators reflect the saturation level of existing facilities. The degree of governmental importance is reflected by the amount of government subsidies, which are generally greater for key projects than for general projects, and reflects whether the operation of the project receives the attention of the local government. Due to the public interest nature of transport infrastructure, the profitability of the project mostly requires the relevant enterprises to expand the relevant business models. The thesis selects four common business models, namely real estate development, commercial development, cultural products and advertising operation, for analysis to determine whether the above-mentioned enterprises have adopted a diversified operation strategy. The economic driving effect is then extracted through the annual increase of the tertiary industry in the city where the project is being built. As the thesis focuses on two transport infrastructures, namely the motorway and the metro, their construction has a greater impact on the tertiary industry, so this indicator is chosen for evaluation.

Step 2 – Data collection

The study was calculated using fsQCA 3.0 software, calibrated using Boolean algebra for cases and influences. The method focuses on testing for causal effects and making judgements about the importance of the factors in the set through the variability of the data. The calculations entailed first transforming the raw data collected into a score of 0,1. In case selection, the conditions for case selection are first specified. The selected cases were required to meet two or more of the following requirements: (1) the enterprise was truly involved in the operation of the project, rather than a financial investment; (2) the enterprise was established more than three years ago; (3) it was a key or well-known enterprise in the industry; and (4) the main business content of the enterprise revolved around being a rail transit or highway. Through the selection of relevant indicators, the paper finally selected 22 metro operating companies in Beijing, Shanghai and Shenzhen and 8 listed Chinese highway operating companies in China, with a total of 30 cases for analysis.

The source of macroeconomic data for the project is the China Statistical Yearbook and government reports on economic performance; the source of data on the profitability of each case company is annual financial reports, annual reports of some listed companies and other public data; the source of data on the annual number of people served by public transport is the annual report of the Ministry of Transport of the People's Republic of China. (The data node selected for the paper is 2020, Companies in Hubei Provence were selected to study data from 2019 in order to reduce the impact of chance variables on the study due to the heavy impact of the COVID-19 in 2020.). Table 1. Variable interpretation and assignment rules.

Step 3 – Calibration of crisp-set

For the analysis, we chose the csQCA method for the analysis and binary partitioning of the data results. csQCA, because it is itself based on traditional Boolean sets and dichotomies, reduces processing difficulties during data processing and increases the confidence of the data.

Table 1. Variable interpretation and assignment rules

Variable name	Explanation of variables	Measurements	Assignment rules
PSPY	The number of clients a company serves annually is an indicator of the effectiveness of its operations	500 million visits per year	Reach is 1, otherwise 0
CP	City population, Number of people in the city	10 million and megalopolis	
GDP	Gross National Product	exceeds RMB 1,000 billion	
MIO	Mileage in operation	operational mileage 300 km	
DOPD	Degree of project diversification	more than 2 profitable elements of non-main business	
AVET	Average commuting time	More than 40 minutes	
AVED	Average commuting distance	More than 10 km	
FR	Financial revenue	More than RMB 100 billion	
SED	Surrounding economic drivers	More than 2.1%	
Result	Sustainability of the project	Larger than 0	

4. Results and discussion

4.1. Testing for necessary conditions

Schneider and Wagemann argue that QCA analysis needs to begin witha test of the necessary conditions to explain the desired outcome. A necessary condition is a reason for the occurrence of an outcome that must be present most of the time. The absence of a necessary condition means that the probability of the outcome occurring is significantly reduced. The table below shows the outcome necessity analysis for the conditions affecting the sustainable operation of transport infrastructure. All consistency scores except ~GS and ~AVET are less than 0.9. This suggests that excessive government subsidies and low average urban commuting times are conducive to achieving sustainable operation of transport infrastructure projects, regardless of the condition. This result is consistent with complexity theory, where different paths may lead to the same outcome and the same conditions may have different impacts.

4.2. Conditional portfolio analysis

Following the analysis of conditional necessity, the effect of the combination of consistency factors on the outcome variable is further discussed. The analysis was conducted using fsQCA 3.0 software, setting 0.9, 1 as the consistency and case thresholds. The standard analysis was also selected to output the 3 outcomes of complex solution, parsimonious solution, intermediate solu-

Table 2. Analysis of necessary conditions

Conditions	Consistency	Coverage
PSPY	0.344828	1.000000
CP	0.655172	0.950000
GDP	0.758621	0.956522
MIO	0.517241	1.000000
DOPD	0.448276	0.928571
AVET	0.137931	1.000000
AVED	0.862069	0.961538
FR	0.758621	0.956522
SED	0.793103	0.958333
~PSPY	0.655172	0.950000
~CP	0.344828	1.000000
~GDP	0.241379	1.000000
~MIO	0.482759	0.933333
~DOPD	0.551724	1.000000
~AVET	0.862069	0.961538
~AVED	0.137931	1.000000
~FR	0.241379	1.000000
~SED	0.206897	1.000000

"~" represents the absence of conditions

tion for the influencing conditions. To better explore the causal process, the concepts of core and non-core elements were cited in combination with the parsimonious solution, intermediate solution, and the conditions that occur together in the parsimonious solution, intermediate solution became core conditions, and only those in the compact solution become auxiliary or marginal conditions. Non-core conditions are also referred to as non-core contributory conditions.

The overall consistency of the results was 0.93, which is greater than the recommended threshold, with an overall coverage of 1, i.e. this study explains all the cases. Seven paths were also obtained, which can lead to sustainable operation of transport infrastructure. Of these, paths P1, P2 and P6 are the most important, as they have a higher unique coverage than the rest. More cases can be explained.

Path 1 (~PSPY*~CP*~GDP*~MIO*~DOPD*~AVET*AVED*~FR), Path 2 (~PSPY*~CP* ~GDP*~MIO*DOPD*~AVET*~FR*SED) and Path 8 (~PSPY*~CP*~GDP*~MIO*DOPD* ~AVET*AVED*FR*~SED) shows that in the absence of strong external condi-tions. Sustainable operation of transport infrastructure is still possible.

Table 3. Constructing sustainable operating conditions for transport infrastructure

Conditions	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
PSPY	⊗	⊗	⊗	⊗	⊗	●	●	⊗	⊗	⊗
CP	⊗	⊗	⊗	●	●	●	●	⊗	⊗	●
GDP	⊗	⊗	●	●	●	●	●	⊗	●	●
MIO	⊗	⊗	⊗	–	●	●	●	⊗	⊗	–
DOPD	⊗	●	⊗	⊗	⊗	–	●	●	⊗	⊗
AVET	⊗	⊗	⊗	●	⊗	⊗	●	⊗	⊗	⊗
AVED	●	–	●	●	–	●	●	●	●	●
FR	⊗	⊗	●	●	●	●	●	●	–	●
SED	–	●	●	●	●	●	●	⊗	●	●
Raw coverage	0.10	0.10	0.07	0.07	0.13	0.28	0.07	0.03	0.07	0.10
Unique coverage	0.10	0.10	0.03	0.07	0.07	0.28	0.07	0.03	0.03	0.03
Consistency	1	1	1	1	1	1	1	1	1	1
Overall solution coverage	0.931035									
Overall solution consistency	1									

'●' (presence) and '⊗' (absence) represent core condition,
'●' (presence) and '⊗' (absence) represent peripheral conditions,
'–'represent no impact

Path1 covers 3 cases with greater than 0.5 membership in term: 13, 17, 22. In path 1, ~CP, ~DOPD, ~AVET are the core conditions. With Path 1, we can see that the results obtained from the analysis are not the same as our usual perceptions. For transport infrastructure, in the absence of government support and the more average economic development of the city, the project can still achieve sustainable operation, but in the process, a longer average local commuting mileage is required. This also reflects the need to focus on forecasting local demand in the process of achieving sustainable project operations. As a convenience product provided by the government, users of transport infrastructure settings such as metro are mostly paid for their work, and therefore the commuting mileage to work can have a large impact on demand. This indicator should be given more weight in the analysis during the initial project study. Compared with commuting distance, commuting time has little influence on whether people choose to use transportation infrastructure. People tend to choose public transport infrastructure when commuting time is shorter.

Path 2 covers 3 cases with greater than 0.5 membership in term: 14, 19, 20, reflects the fact that it is also feasible to develop and build transport infrastructure in cities with a lower level of economic development and a less supportive external environment. When commuting time distances are long and the surrounding tertiary sector is growing at a high rate, the operation of

transport infrastructure can lead to sustainable development of the project itself. Similar to Path 1's rationale, For cities with poor external conditions such as construction environment, the strategy of diversified operation can effectively promote the sustainable operation of projects. For such cities, due to underdeveloped economy and low disposable income of residents, the demand and usage of transportation infrastructure still lag behind that of large cities. Therefore, for transportation infrastructure projects of this type of city, it is necessary to pay attention to the diversification of operation in the process of operation, and make up for the income of project operation through diversified business forms.

Path 3 (~PSPY*~CP*GDP*~MIO*~AVET*AVED*FR*SED) covers 2 cases with greater than 0.5 membership in term: 7, 18, ~DOPD is the core condition. For cities with a small population but with a developed economy, where the residents are better off, daily commuting times and distances are shorter, there is insufficient demand for the use of transport infrastructure. In this type of city, government support is particularly important. For projects that should be built but cannot be operated sustainably on their own, the government should increase its support for the sustainable operation of the project through the purchase of services by the government.

Path 4 (~PSPY*CP*GDP*~DOPD*AVET*AVED*FR*~SED) covers 2 cases with greater than 0.5 membership in term: 15, 25, ~DOPD is the core condition. In this path, for projects that cannot be diversified and have a low carrying capacity, good external conditions are required to achieve sustainable operation.

Path 5 (~PSPY*CP*GDP*MIO*~DOPD*~AVET*FR*SED) covers 4 cases with greater than 0.5 membership in term: 26, 27, 28, 30, MIO is the core condition. The path reflects that if the project is still unable to achieve sustainable operation despite good external construction and operation conditions, consider expanding the operational mileage to enhance the operation of the project by means of large-scale operation.

Path 6 (PSPY*CP*GDP*MIO*~AVET*AVED*FR*SED) covers 8 cases with greater than 0.5 membership in term: 1, 4, 5, 10, 11, 12, 23, 29. This path illustrates that for projects with good external and internal support conditions, a good level of development can still be achieved even if the main business is not involved in diversified developments with a close focus.

Path 7 (PSPY*CP*GDP*MIO*DOPD*AVET*AVED*FR) covers 2 cases with greater than 0.5 membership in term: 2, 3, MIO is the core conditions. The pathway illustrates that whether a project achieves operational scale is central to whether a project achieves sustainable operation.

Path 8 (~PSPY*~CP*~GDP*~MIO*DOPD*~AVET*AVED*FR*~SED) covers 1 cases with greater than 0.5 membership in term: 21, ~CP is the core conditions. The pathway illustrates that better operational results can be achieved on the basis of meeting the strength of government support and longer commuting distances

Path 9 (~PSPY*~CP*GDP*~MIO*~DOPD*~AVET*AVED*SED) covers 2 cases with greater than 0.5 membership in term: 7, 16. Path 9 and path 6 have a high degree of similarity

Path 10 (~PSPY*CP*GDP*~DOPD*~AVET*AVED*FR*SED) covers 3 cases with greater than 0.5 membership in term: 24, 28, 30. This path illustrates that it is easier to achieve better operational results by focusing on the operational project itself, based on having a greater level of government support.

5. Conclusions

In this paper, we reported a structured comparative study examining the variations in operation transport infrastructure development. As China's economy continues to develop and urbanisation progresses, the scale of construction of transport infrastructure is gradually expanding. After the construction is completed, the question of how to achieve sustainable development during the operation of the project is a worthy one. This article analyses the factors that may influence the development and operation of transport infrastructure, and explores how a combination of 10 conditions covering investment decisions, policy support, and level of operation have combined to influence whether 30 projects have achieved sustainability. Through the study we have obtained the following key findings:

1. This study provides valuable theoretical insights into how to achieve sustainable operation of transport infrastructure by examining case studies of China's transport infrastructure. By addressing this issue, we can ensure that our transport infrastructure is not only built to last, but also operates efficiently and sustainably for years to come. While the construction and development of transport infrastructure is critical to supporting economic growth in cities, the projects themselves often lack the capacity to operate sustainably. Cities and transport infrastructure companies have used a variety of strategies to manage operations, many of which have been unsuccessful. There is a need for research into new operational and project evaluation methods that can be better adapted to the Chinese market and benefit governments, companies and users.
2. The analysis identified seven pathways to sustainable project operations. These pathways have varying degrees of coverage, show varying degrees of explanatory relevance, and reflect different paths to success for different types of projects. However, a synthesis of the results shows that the economically sustainable operation of transport infrastructure requires a concerted effort of several instruments. According to a study of 30 major transport infrastructure operators, the traditional approach of focusing solely on the economic development and population of the location where construction is to take place does not lead to profitable projects in most cases. The study shows that sustainable development is achieved by a combination of factors rather than by any single factor, with the exception of excessive government subsidies. It can therefore be concluded that the sustainable operation of a project is influenced by a number of factors.
3. Achieving sustainable operation of transport infrastructure requires maintaining competition for projects. The analysis demonstrates that the conditions typically considered essential for a project to attain sustainable development, such as government subsidies and a high level of local economic development, are not necessary in this specific case. Rather, sustainable operation of the project can be accomplished through enhanced operational means. Furthermore, it was discovered that excessive government subsidies can frequently result in project failure. Government subsidies can weaken the sense of competition and service of operating companies. Railways and highways are substitutable facilities, and a lack of competition among operators makes achieving sustainable operations difficult.

In this study, 30 large transport infrastructure operators were selected, and although the coverage is still not extensive, the findings are still highly relevant as they cover the vast majority of China's metros and highways in economically developed regions. Last but not least, we need to emphasise that the study does not ambitiously provide a comprehensive explanation of the sustainable development of transport infrastructure operations in China. In the thesis, some preliminary explorations were carried out mainly using QCA as a research tool, and the findings obtained could be further investigated to draw more conclusions. This also implies that more series of studies are needed in order to provide a satisfactory explanation of sustainable transport infrastructure operations.

References

[1] V. Polishchuk, M. Kelemen, B. Gavurová, C. Varotsos, R. Andoga, M. Gera, J. Christodoulakis, R. Soušek, J. Kozuba, P. Blišťan, and S. Szabo, "A Fuzzy Model of Risk Assessment for Environmental Start-Up Projects in the Air Transport Sector", *International Journal of Environmental Research and Public Health*, vol. 16, no. 19, art. no. 3573, 2019, doi: 10.3390/ijerph16193573.

[2] S. Thacker, D. Adshead, M. Fay, S. Hallegatte, M. Harvey, H. Meller, N.O. Regan, J. Rozenberg, G. Watkins, and J.W. Hall, "Infrastructure for sustainable development", *Nature Sustainability*, vol. 2, pp. 324–331, 2019, doi: 10.1038/s41893-019-0256-8.

[3] R. Huang and C. Yeh, "Development of an assessment framework for green highway construction", *Journal of the Chinese Institute of Engineers*, vol. 31, no. 4, pp. 573–585, 2008, doi: 10.1080/02533839.2008.9671412.

[4] K. Lothe, "An Analysis of Constructability Strategies in Project Delivery: Making Infrastructure Construction Sustainable in Copán Ruinas, Honduras", M.A. thesis, Michigan Technological University, USA, 2006.

[5] L. Duy Nguyen, S.O. Ogunlana and D. Thi Xuan Lan, "A study on project success factors in large construction projects in Vietnam", *Engineering, Construction and Architectural Management*, vol. 11, no. 6, pp. 404–413, 2004, doi: 10.1108/09699980410570166.

[6] A. Frank Jungbecker and H.W. Alfen, "Analysing traffic demand risk in road concessions", in *TG72-Special Track 18th CIB World Building Congress May 2010.* Salford, United Kingdom, 2010, pp. 133–148.

[7] "Global infrastructure outlook: Infrastructure investment needs–50 countries, 7 sectors to 2040", Global Infrastructure Initiative.

[8] H.B. Zhou, "Transportation infrastructure, industrial agglomeration and regional economic development: correlation and efficiency analysis", PhD thesis, Southeast University, 2017.

[9] J. Du, W. Wang, X. Gao, et al., "Sustainable Operations: A Systematic Operational Performance Evaluation Framework for Public–Private Partnership Transportation Infrastructure Projects", *Sustainability*, vol. 15, no. 10, 2023, doi: 10.3390/su15107951.

[10] A.A. Hezri, "Sustainability indicator system and policy processes in Malaysia: a framework for utilisation and learning", *Journal of Environmental Management*, vol. 73, no. 4, pp. 357–371, 2004, doi: 10.1016/j.jenvman.2004.07.010.

[11] C.D. Martland, *Toward More Sustainable Infrastructure: Project Evaluation for Planners and Engineers*. Hoboken, NJ: Wiley, 2012.

[12] S.K.Y.J. Lim, "Enhancing Sustainability Deliverables for Infrastructure Project Delivery", in *Asian perspective – Proceedings of the World Sustainable Building Conference 2007*. 2007, pp. 467–480.

[13] S.K. Lim, "Framework and Processes for Enhancing Sustainability Deliverables in Australian Road Infrastructure Projects", PhD thesis, Queensland University of Technology, 2009.

[14] G.R. McVoy, et al., "Moving Towards Sustainability: New York State Department of Transportation's GreenLITES Story", in *Green Streets and Highways*, *2010*. ASCE, 2010, doi: 10.1061/41148(389)38.

[15] C.C. Ragin, *Redesigning social inquiry: fuzzy sets and beyond*. Chicago: University of Chicago Press, 2008.

[16] S. Verweij, "Producing satisfactory outcomes in the implementation phase of PPP infrastructure projects: A fuzzy set qualitative comparative analysis of 27 road constructions in theNetherlands", *International Journal of Project Management*, vol. 33, no. 8, pp. 1877–1887, 2015, doi: 10.1016/j.ijproman.2015.08.006.

[17] D. Stockemer, “Fuzzy set or fuzzy logic? Comparing the value of qualitative comparative analy-sis (fsQCA) versusregression analysis for the study of women’s legislative representation", *European Political Science*, vol. 12, pp. 86–101, 2013, doi: 10.1057/eps.2012.25.

[18] D. Stockemer, “Women’s Parliamentary Representation in Africa: The Impact of Democracy and Corruption on the Number of Female Deputies in National Parliaments”, *Political Studies*, vol. 59, no. 3, pp. 693–712, 2011, doi: 10.1111/j.1467-9248.2011.00897.x.

[19] S. Beers, “QCA as competing or complementary method? A qualitative comparative analysis approach to protest event data”, *International Journal of Social Research Methodology*, vol. 19, no. 5, pp. 521–536, 2016, doi: 10.1080/13645579.2015.1051798.

[20] C.Q. Schneider and C. Wagemann, “Standards of Good Practice in Qualitative Comparative Analysis (QCA) and Fuzzy-Sets”, *Comparative Sociology*, vol. 9, no. 3, pp. 397–418, 2010, doi: 10.3390/su15107951.

Received: 2023-12-06, Revised: 2024-02-27