A Digital Twin Model for Comprehensive Development in Backward Areas

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Abstract: Based on the digital twin technology, this study proposes an integrated modelling framework aimed at assisting sustainable development planning and policy formulation in remote and impoverished areas. Taking Zhaojue County in Sichuan Province as an example, a digital twin model including three core modules of geography, economy and policy intervention is constructed. The geographic model uses GIS and remote sensing data to dynamically simulate changes in regional geographic features and infrastructure; the economic model evaluates the dynamic changes in economic indicators such as GDP and employment rate through time-series analysis and multi-intelligent body system; and the policy intervention model combines the multi-intelligent body system and system dynamics to simulate the integrated impacts of the policy implementation on the regional economy, society, and environment. The study evaluates the economic benefits, environmental impacts and social well-being of different policy options through policy scenario simulation, and provides suggestions for optimal policy combinations through optimisation algorithms. Ultimately, the study provides policy makers in remote areas with a scientific, data-driven tool to support more accurate pro-poor policy formulation and implementation, and help the region's sustainable economic and social development. By modelling the long-term impacts of economic policies, this study can contribute to the development of sustainable development strategies that balance economic growth with social and environmental considerations, and the proposed digital twin model can be continually updated with new data and insights to continually improve recommended policies and intervention strategies.

1. Introduction

China had made remarkable progress in poverty reduction over the past few decades, with hundreds of millions of people having been lifted out of poverty and the rate of extreme poverty having fallen sharply. However, challenges remain to the complete eradication of poverty, especially in remote and underdeveloped areas, where the problem of poverty is more complex. Zhaojue County in the Liangshan Yi Autonomous Prefecture in Sichuan Province is a typical example. The county is remote, has poor infrastructure and is mostly inhabited by ethnic minorities, and its development is subject to multiple constraints arising from natural conditions, the geographical environment and cultural differences. Therefore, how to effectively help these areas to get rid of poverty is an urgent problem.

Digital twin technology offers new possibilities to solve these problems. Initially used in the industrial sector, digital twin technology is able to optimise management and decision-making by creating virtual representations of physical objects, enabling the combination of reality and fiction. In recent years, the technology has gradually expanded to urban planning, environmental protection and other fields. The core of digital twin lies in constructing virtual models synchronised with reality through real-time data, providing decision makers with a comprehensive, real-time perspective to help them better understand the current state of regional development and formulate more effective intervention strategies.

This study proposes to construct a set of digital twin models for backward regions, such as Zhaojue County, to establish an integrated virtual representation of the region's geography, economy and policy interventions through virtualisation and digitisation techniques. First, a geographic digital twin model is constructed to represent physical attributes such as topography, infrastructure, and natural resources using GIS data, and to simulate environmental factors such as

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climate and natural disasters. Second, an economic digital twin model is constructed to analyse economic data such as the region's GDP, employment rate, and income level, and to dynamically simulate changes in key economic sectors. Finally, a policy and intervention simulation model is constructed to simulate the dynamic impact of policy implementation on the economy, society and environment based on successful experiences such as the Yiwu model.

Through the simulation of different policy scenarios, this study can assess the comprehensive impacts of various types of policies on economic efficiency, environmental protection and social well-being, and provide a scientific basis for policy choices. At the same time, such analyses can reveal potential risks in policy implementation and help policy makers to better cope with these challenges. This study not only provides a new approach to poverty alleviation in remote areas, but also hopes to achieve dynamic optimisation of policies through the digital twin technology, promote economic and social progress in backward areas, and ultimately contribute to the achievement of the goals of comprehensive poverty alleviation and inclusive growth.

2. Related Work

2.1. Poverty alleviation and digital transformation

Over the past decades, poverty reduction has made remarkable progress globally, but still faces enormous challenges. Especially in remote, rural and ethnic minority-populated areas, the poverty problem is complex and diverse, involving economic, social, cultural and other factors [1]. In recent years, with the rapid development of digital technology, digital transformation has provided new ideas and tools for poverty alleviation [2]. Studies have shown that the application of information and communication technologies (ICT), especially the popularity of the Internet and mobile technologies, can significantly increase the productivity and income level in poor areas. For example, the spread of digital financial services has enabled more people to access financial resources, and the rise of e-commerce platforms has broken down market barriers in impoverished areas and enhanced the economic vitality of these areas [3]. In addition, the application of distance education and online healthcare has, to a certain extent, improved the level of education and healthcare services in remote areas and reduced the urban-rural gap.

However, although digital transformation has demonstrated great potential in poverty alleviation, there are still many obstacles in the process of practical application. For example, the lagging infrastructure development, the difficulty of technology implementation, and the prominent digital divide problem have all limited the effect of digital transformation to a certain extent. Many studies have pointed out that relying solely on technology cannot solve the problem of poverty, and that it is necessary to formulate a targeted and comprehensive strategy that takes into account the specific geographical characteristics and characteristics of the population. Particularly in areas with a high concentration of ethnic minorities, where cultural differences and language barriers often make it difficult to implement policies successfully, more localised and personalised programmes are needed.

2.2. Application of digital twin technology

As an emerging digital tool, Digital Twin technology is gradually changing the mode of operation of various industries. Originating from the Industry 4.0 revolution, Digital Twin technology has been widely used in the manufacturing industry to create virtual models of physical equipment to help enterprises monitor the operating status of equipment in real time, optimise production processes and reduce operating costs. In recent years, the application scope of digital twin technology has been expanding, gradually covering areas such as urban management, traffic scheduling, smart energy and environmental monitoring, as shown in Figure 1. For example, in urban planning, digital twin models can simulate various scenarios of city construction, predict the potential impacts of different planning scenarios, and provide decision support for city managers [4]. In traffic management, digital twin technology can monitor traffic flow in real time, optimise traffic signal control, and improve urban traffic efficiency.

In environmental protection and disaster management, the application of digital twin technology has also begun to show its unique value. By constructing a digital twin model of the ecosystem, the impact of environmental changes on the ecosystem can be simulated, and possible environmental problems in the future can be predicted, providing a scientific basis for the formulation of environmental protection policies [5]. In terms of disaster management, digital twin technology can simulate the process of natural disasters, help relevant departments make emergency preparations in advance, and reduce the impact of disasters on human society.

However, although digital twin technology has demonstrated strong application potential in several fields, its application in poverty alleviation and rural revitalisation is still in the initial exploration stage. Most of the existing research focuses on the urban and industrial sectors, and there is relatively little research on how to apply digital twin technology to the economic and social development of remote and impoverished areas. Exploring the application of digital twin technology in the field of poverty alleviation can not only fill the research gaps in this field, but also provide new ideas and methods for solving the poverty problem.

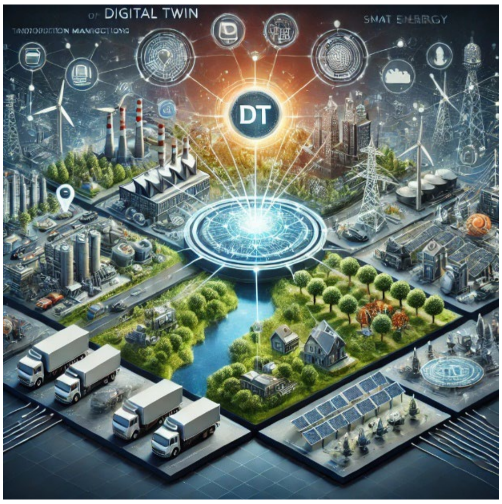

Figure 1 Digital twin technology.

Combining digital twin technology with poverty alleviation policies is an important direction of current research. The digital twin model can provide a virtual experimental platform for policy makers to predict the potential impact and effect of different policies by simulating their implementation process in poor areas. For example, by constructing a digital twin model of a poor county, it can simulate the economic and social changes after the introduction of strategies such as market infrastructure improvement, trade facilitation policies, and small business support programmes, providing a scientific basis for policy formulation and optimization.

2.3. The Yiwu model and its implications for impoverished areas

As one of the successful economic development models since China's reform and opening up, the Yiwu model has provided valuable experience for many developing regions. With its unique small commodity market and flexible business model, Yiwu has successfully achieved the transformation from a poor county to the world's largest small commodity distribution centre [6]. The core of the Yiwu model lies in promoting rapid growth of the local economy by improving market infrastructure, promoting trade facilitation, encouraging the development of small enterprises and optimising resource allocation. The Yiwu experience shows that a favourable market environment, flexible economic policies and active government support are key factors in promoting economic development.

For poor areas, the Yiwu model provides important insights. Firstly, by improving infrastructure, such as roads, electricity and Internet access, barriers to transport and information can be broken down, creating better conditions for local economic development. Secondly, through the development of special industries, such as agricultural product processing and handicraft manufacturing, the self-development capacity of the local economy can be strengthened, and industrial upgrading and optimisation of economic structure can be promoted [7]. In addition, encouraging the development of small enterprises, especially supporting local enterprises to participate in market competition, can effectively increase the employment rate, increase residents' income and reduce poverty.

However, the direct replication of the Yiwu model in remote areas is not easy. Firstly, the natural environment and geographical conditions of these areas limit the speed and scale of infrastructure development. Second, cultural differences and language barriers make many policies and measures face greater difficulties in implementation. Therefore, policies and models need to be adjusted and optimised according to the actual situation in these regions. In this regard, digital twin technology can play an important role in finding the most suitable path for local development by simulating the implementation effects of different policies and measures.

3. Relevant Technology

A number of key technologies are involved in building digital twins for remote areas, including geographic information systems (GIS), data modelling and simulation, and machine learning and predictive analytics. Together, these technologies form the core of the digital twin, allowing decision makers to understand the dynamics of the region more comprehensively and to predict the potential impacts of policy and environmental factors, leading to more scientific and efficient development strategies.

3.1. Geographic Information System

Geographic Information System (GIS) is one of the key components in the digital twin model. GIS is a computerised system that captures, stores, analyses and presents geospatial data [8], as shown in Figure 2. It not only provides detailed descriptions of geographic features (e.g., terrain, rivers, roads, and buildings), but also allows for integrated analyses in conjunction with a variety of non-spatial data (e.g., demographics, economic activity, land use, etc.). In this study, GIS was used to construct a geo-digital twin model representing the geographic and infrastructural attributes of Zhaojue County, including topography, roads, power lines, bridges, buildings, natural resources, and land use. The high-precision geospatial data allows researchers to have a more intuitive understanding of the physical environment and existing infrastructure conditions in Zhaojue County.

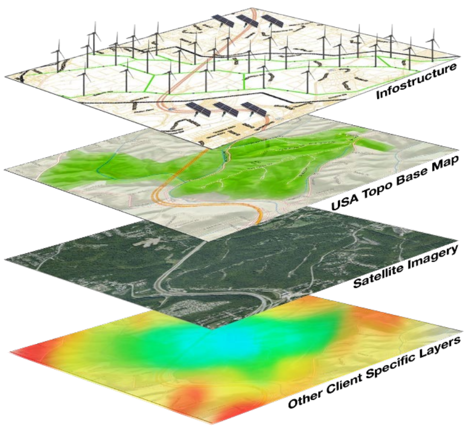

Figure 2 Geographic Information System.

The advantage of GIS technology lies in its powerful spatial analysis and visualisation capabilities. Through GIS, it is possible to analyse the topographic changes, land use patterns and distribution of natural resources in a region, providing a scientific basis for development planning. For example, GIS technology can be used to simulate the impact of different land development programmes on the ecological environment and predict the driving effect of road construction on regional economic development. In addition, GIS can be combined with remote sensing data to monitor environmental changes in the region in real time, such as forest coverage, water resource changes, soil erosion, etc., to provide support for the formulation and implementation of environmental protection policies [9].

GIS technology can also play the role of data integration and sharing in the development planning of remote areas. Through integration with other data sources, the GIS platform can be used as a comprehensive decision support system to help governments at all levels and related organisations to better coordinate and manage resources. For example, by combining economic, social and environmental data with geographic information, researchers can construct a more comprehensive digital twin model to simulate the combined impact of different policies and development strategies on regional development.

3.2. Data modelling and simulation techniques

Data modelling and simulation techniques are another core component of the digital twin model. Modelling and simulation techniques enable researchers to reproduce real-world complex dynamic processes in virtual environments and predict the impact of different variables and policy changes on the system. Multi-intelligent system modelling (MAS) and system dynamics (SD) are important methods used in digital twin technology to simulate complex systems, and they provide researchers with powerful modelling and simulation tools to understand the impact of policy changes on systems through different technical principles.

MAS is a modelling approach to simulate the behaviour of individuals and their interactions in complex systems. Each ‘intelligence’ is considered as an autonomous decision maker in the model, which acts independently according to predefined rules and goals [10].The key of MAS is to show the dynamic evolution of the whole system by simulating the behavioural changes of these intelligences in different contexts. For example, in the economic digital twin model of Zhaojue County, MAS can be used to simulate the responses of local residents, enterprises, and the government in the face of different policy interventions. The decisions of the intelligences will not only affect their own economic activities, but also influence the behaviour of other individuals through interactions, creating an overall feedback of the system. For example, simulating how a farmer adjusts his production plan when receiving an agricultural subsidy policy, or how an enterprise expands its investment under an open market policy, etc. The flexibility and dynamics of MAS enable it to effectively capture subtle changes at the individual level while reflecting the impact of inter-individual interactions on the whole system, thus providing a more comprehensive understanding of the effects of policy interventions.

On the other hand, system dynamics (SD) is a modelling method based on differential equations that focuses on describing the relationship between variables in a system over time and is particularly suitable for modelling complex systems with feedback mechanisms [11]. With SD, researchers can establish the dynamic relationships among different variables in the system, especially when policy changes trigger nonlinear feedbacks.SD excels in capturing the long-term and delayed effects of the system. For example, in modelling the impact of infrastructure improvement policies on the local economy, SD is able to capture the time lag between when infrastructure is invested and when it is actually put into use, and reveal how this lag affects the path of economic growth. In addition, SD can simulate the systemic effects of policy changes on multiple economic variables and track how these effects act on the entire system through feedback loops. For example, improvements in market infrastructure not only directly increase productivity, but also indirectly boost GDP growth through feedback mechanisms such as lowering transaction costs and boosting investment. In this way, SD can help researchers anticipate the long - term effects in policy implementation and identify potential system bottlenecks.

The combination of MAS and SD can play complementary roles in modelling complex socio-economic systems; MAS can capture the micro-dynamics of individual behaviours, while SD can simulate the overall feedback and delayed effects of the macro-system. By combining these two techniques, policy makers can experiment with different policy scenarios in a virtual environment, predict the global effects of policies, optimise resource allocation, and minimise uncertainty in policy implementation.

3.3. Machine learning and predictive analytics

Machine learning and predictive analytics is one of the core technologies of modern data science and an important tool for building digital twin models [12]. By analysing and learning from a large amount of historical data, machine learning algorithms can identify complex patterns and trends and then make accurate predictions. In this study, machine learning techniques were used to analyse and predict economic, social and environmental changes in Zhaojue County under different development strategies.

In this study, supervised learning algorithms, such as linear regression, support vector machine (SVM) [13], and random forest, are commonly used to predict economic indicators such as GDP growth, employment rate, and poverty rate. These algorithms are trained with input historical data and learn to recognise the relationship between input and output variables so that they can make predictions on new data. For example, based on Zhaogu County's economic data for the past few years, a model can be trained to predict the GDP growth rate in the coming years under different policy conditions.

Unsupervised learning algorithms, such as cluster analysis and principal component analysis (PCA) [14], on the other hand, can be used to mine hidden patterns and structures in the data to help understand the economic and social characteristics of Zhaojue County. For example, through cluster analysis, different types of households or businesses can be grouped together to identify those groups or industries that are most vulnerable to policy changes.

Deep learning is particularly well suited for dealing with complex non-linear relationships and large-scale data. In the construction of digital twin models, deep learning can be used to analyse time-series data, such as climate change and market price fluctuations, to predict the impact of these factors on regional economic and social development. Deep learning models such as Recurrent Neural Networks (RNN) and Long Short-Term Memory Networks (LSTM) are particularly suitable for processing time series data [15], and they can capture the long and short-term dependencies in the data to provide more accurate predictions for decision makers. In this study, deep learning can be used to construct more complex digital twin models, e.g., by fusing data from multiple sources (e.g., geographic, economic, and social data) to construct a global multidimensional forecasting model that provides more accurate and integrated policy recommendations.

4. Digital Twin Model

In this study, we propose an integrated modelling framework based on digital twin technology to aid development planning and policy formulation in remote and impoverished areas such as Zhaojue County. The framework includes three core models: a geographic digital twin model, an economic digital twin model, and a policy and intervention simulation model. Each model comprehensively portrays the development characteristics of a region and its dynamic changes from the physical, economic and policy dimensions respectively. The construction methodology of each model and its application are described in detail below.

4.1. Geographic digital twin model

The geographic digital twin model is mainly used to comprehensively simulate the physical and geographic features of Zhaojue County, covering topography, infrastructure (e.g., roads, power lines, bridges, buildings, etc.), natural resources (e.g., water resources, forest cover, etc.), and land use. To achieve this goal, the model relies on Geographic Information System (GIS) technology and remote sensing data to construct a digital platform with real-time updating and dynamic display functions, which provides an accurate geographic information base for the development planning of the area.

In the construction process of the model, the core work is to obtain high-precision geospatial data. These data come from a variety of sources, including remote sensing satellite data, UAV aerial data, as shown in Figure 3, and ground survey data, and the fusion of multi-source data ensures the high resolution and spatio-temporal accuracy of the model. Firstly, GIS technology is used to carry out detailed mapping of Zhaojue County's geographical boundaries, topographic features and infrastructure layout. Through remote sensing image data, land use types (e.g., arable land, forest land, construction land, etc.) , as shown in Figure 4, and spatial distribution of natural resources (e.g., water resources, mineral resources, etc.) can be extracted. These data are further used to generate topographic maps, slope maps, river network maps and other basic geographic information layers through spatial analysis tools, which lay a solid data foundation for subsequent spatial analyses and model calculations.

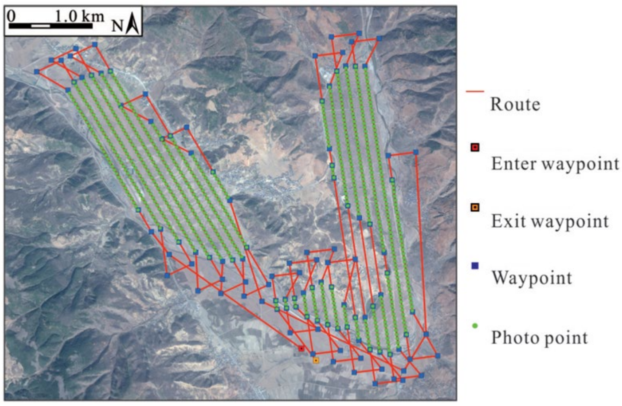

Figure 3 Flight path map with geographic data acquisition.

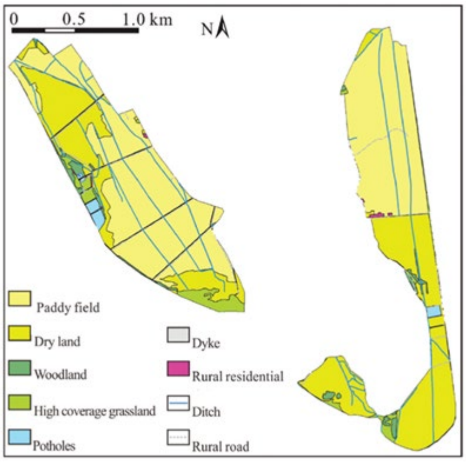

Figure 4 Current status of land use.

In order to enhance the usefulness of the model, the geo-digital twin model must have the ability to dynamically update and simulate environmental factors. The model simulates climate change, weather patterns and the probability of occurrence and scope of impact of natural disasters in Zhaojue County by integrating historical meteorological data and climate prediction models. For example, when analysing the impact of natural disasters such as floods, droughts and landslides on regional development, the model can calculate the spatial distribution of these natural phenomena at different points in time through a formula:

$$\text{Risk value} = f\,(\text{his\_mete}, \text{terr\_feature}, \text{pre\_mete}) \tag{1}$$

This formula describes the complex relationship between meteorological data, topographical data and climate prediction models to assess the potential impact of natural hazards. By dynamically predicting environmental changes, the model can update the state of the environment in Zhaojue County in real time and provide timely risk information to decision makers.

Another important function of the geo-digital twin model is to simulate the dynamic impacts of infrastructure construction. For example, when planning a new road or bridge, the model can predict the impact on regional traffic flow, land use change and ecological environment by simulating the construction process of the project. Such simulations provide data support for the scientific planning of infrastructure, and also help assess the combined impact of different infrastructure projects on regional development in the short and long term.

In addition, geo-digital twin models visualise complex geographic data and help decision makers intuitively understand regional characteristics and changes. The developed geographic information visualisation platform enables users to view in real time the topographic changes, infrastructure layout, land use status and environmental risk assessment results of Zhaojue County. This platform not only supports the display of a single data layer, but also enables the display of multi-dimensional data such as population density, economic activities, and infrastructure conditions overlaid on the same map. In this way, decision makers can clearly understand the interactions between different variables and thus make more comprehensive and scientific decisions.

Overall, the geo-digital twin model provides a dynamic, comprehensive and real-time updated geographic information platform for development planning in Zhaojue County. By combining high-precision geospatial data, dynamic environment simulation and multi- dimensional visualisation functions, the model not only improves the science of decision- making, but also provides effective solutions to the geographic challenges faced during regional development.

4.2. Economic digital twin model

The economic digital twin model aims to simulate the economic system of Zhaojue County, providing real-time reflections and forecasts of economic indicators such as GDP, employment rates, income levels, poverty rates, and sectoral growth by dynamically describing and analysing the region's economic activities. At the core of the model is a data-driven approach that uses a large amount of economic data to construct a digital platform that can reflect the current state of Zhaogu County's economy and predict future development, thus providing a scientific basis for formulating and optimising economic policies.

The construction of the model is based on a wide range of economic data, including regional GDP, industry output, employment rate, poverty rate, and income level of residents at the macro level, as well as household income, consumption expenditure, and enterprise income at the micro level. These data are processed through data cleaning and standardisation, and then assembled into a database that can comprehensively reflect the current economic status of Zhaojue County. Through time series analysis, regression analysis, and machine learning algorithms (e.g., Random Forest, Support Vector Machine, etc.), the model is able to identify the relationship between various economic indicators and predict their future trends. For example, time series analysis can reveal the cyclical fluctuations and long-term trends of Zhaogu County's GDP growth, while regression analysis can quantitatively analyse the specific impacts of infrastructure investment, education improvement and market opening on economic growth.

The mathematical basis of the model can be expressed by the regression analysis formula, for example:

$$\mathrm{GDP}_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i X_i(t) + \grave{o}_t \tag{2}$$

Where GDP_t is the GDP at time t, $X_i(t)$ represents a number of indicators related to economic activity (e.g., employment rate, infrastructure investment, etc.), α_i is the regression coefficient for each variable, and $\grave{o}_t$ is the model error term. This regression analysis can help quantify the contribution of different factors to GDP, thus providing a quantitative basis for policy formulation.

One of the core functions of the economic digital twin model is its powerful dynamic simulation and scenario analysis. The model not only reflects the current economic situation in Zhaojue County, but also predicts the impact of different policies and development strategies by simulating their implementation. For example, the model can simulate the ‘Market Infrastructure Improvement’ policy and predict its potential impact on GDP growth, employment and poverty reduction. By adjusting the policy parameters (e.g. investment size, implementation time, resource allocation, etc.), different scenarios can be generated to help policy makers choose the optimal strategy among multiple options.

In addition, the model further enhances the accuracy of the simulation by introducing a multi-intelligent system (MAS). Economic agents (e.g., firms, households, governments) make decisions in the model according to their respective objective functions and behavioural rules, and the interactions of these agents form the macroeconomic dynamics. For example, when simulating a new agricultural subsidy policy, the model can predict how farmers will adjust their production decisions, or how firms will respond in their investment and expansion strategies when a market opening policy is implemented. This multi- intelligence modelling approach captures the complex interactions between economic actors and simulates the specific economic changes that will occur when policies are implemented.

In order to forecast the future development of the economy, the model combines multiple sources of data and policy variables to build a dynamic forecasting system that is able to predict in real time the economic trends in Zhaojue County in the coming years. For example, the model can adjust the prediction of core indicators such as GDP, employment rate and poverty rate in real time according to the newly introduced policies, which are formulaically expressed as:

$$Y_{t+1} = f(Y_t, P_t, Z_t) + \epsilon \quad (3)$$

Where Y_t is the current state of the economic indicator, P_t is the policy variable, Z_t is other external factors affecting the economy, and ϵ is the error term. Through this formula, the model is able to dynamically adjust future economic forecasts to ensure that policymakers are supported by the most up-to-date economic information.

The model also provides an optimisation analysis of economic indicators to help policy makers identify the optimal policy mix and resource allocation options. The optimisation algorithm allows the model to find the best balance between different policy objectives (e.g. economic growth, employment growth and poverty reduction), which are often constrained by each other, under multi-objective conditions. For policy makers, this optimisation function ensures that policies can achieve economic growth while also taking into account social welfare and environmental protection, maximising economic efficiency.

Wide-ranging applications of the economic digital twin model include regional economic development planning, policy formulation, infrastructure project evaluation and optimisation of social security policies. By simulating and analysing economic changes under different policy scenarios, policy makers can assess the effectiveness, risks and potential benefits of policies, and ultimately improve the scientific and practical effectiveness of policy making. In case of unexpected economic events (e.g. natural disasters or market fluctuations), the model can also provide policymakers with early warning and contingency plans, further enhancing the resilience and adaptability of the regional economy.

Overall, the economic digital twin model provides an integrated and dynamic decision support tool for the economic development of poor regions such as Zhaojue County. Through multi-dimensional data analysis, dynamic simulation and scenario prediction, the model not only optimises policy design and implementation, but also provides a scientific basis for promoting the sustainable development of the regional economy.

4.3. Policy and intervention model

The Policy and Intervention Simulation Model (PISM) aims to simulate the dynamic changes in the regional economy, society and environment in Zhaojue County after the introduction of policies inspired by a certain development strategy model (e.g., the Yiwu model). By combining the Multi-intelligent System (MAS) and System Dynamics (SD) approaches, the model is able to simulate and evaluate the effects of policy implementation in an all-round way, and provide policy makers with suggestions for policy optimisation based on multi-dimensional data. The key to the construction of the model lies in the comprehensive modelling of the economic, social and environmental systems in Zhaojue County to ensure that the pathways of each policy intervention are accurately reflected.

(1) Multi-intelligence system

The first step of the model is to build a multi-level, multi-dimensional intervention model for

Zhaojue County, using MAS to simulate the behaviour and interactions of different subjects. In this model, each 'intelligence' represents an economic agent (e.g., government, enterprise, or household) or a policy instrument (e.g., market infrastructure improvement, trade facilitation, small business support programmes, etc.). Each intelligence has a specific objective function and behavioural rules. For example, the objective of a government intelligence may be to maximise regional economic growth, minimise poverty, or optimise resource allocation, while its rules of behaviour include policy formulation, allocation of public resources, and supervision of market operations. Correspondingly, the goals of corporate intelligences may include profit maximisation or cost minimisation, and their behaviours are reflected in investment decisions, production adjustments, and so on.

Each economic subject (e.g., government, enterprise, household) in a multi-intelligence system makes decisions according to its objective function and behavioural rules. Let's take the economic agent 'enterprise' as an example to illustrate its decision-making process under policy intervention.

The firm's objective is to maximise profits through its production decisions, and this process can be expressed as an optimisation problem. Assume that the firm's profit is determined by the difference between revenue R(t) and cost C(t), i.e.:

$$\Pi (t) = R (t) - C (t) \tag{4}$$

Revenue R(t) depends on the price of the product p(t) and the output q(t) and can therefore be expressed as:

$$R(t) = p(t) . q(t) \tag{5}$$

Costs C(t) include production costs, labour costs, etc. and are assumed to be a function of output q(t):

$$C(t) = c(q(t)) + w(t) . L(t) \tag{6}$$

Where c(q(t)) is the production cost function, w(t) is the wage rate, and L(t) is the amount of labour used. The firm's objective is to maximise profit, eq:

$$\max_{q(t),L(t)} \Pi(t) = \max_{q(t),L(t)} [p(t) . q(t) - c(q(t)) - w(t) . L(t)] q(t), L(t) \tag{7}$$

In the policy intervention scenario, it is assumed that the production cost of the firm can be reduced by introducing some kind of small business support programme, i.e.:

$$C_{new}(t) = (1-\alpha) . c(q(t)) + w(t) . L(t) \tag{8}$$

Where α is the percentage reduction in production costs due to the policy. With this model, firms will make production decisions based on the new cost structure, thus simulating changes in firm behaviour in response to policy intervention.

In this process, the MAS method plays a key role in simulating the behaviour of micro - individuals. Each economic agent responds according to its objective function in the face of new policy conditions, such as how a firm adjusts its investment decision under a trade facilitation policy, or how a household chooses its consumption options under a new consumption subsidy policy.The strength of MAS lies in its ability to capture the diversity of individual decisions and how these decisions are propagated through the market mechanism and the social network, which in turn affects the dynamics of the system as a whole.

(2) System dynamics

In order to capture the complex system feedback at the macro level, the model further incorporates the SD approach. System dynamics helps the model understand the multi- dimensional propagation path of policy interventions in the regional economy by simulating the causal relationships and feedback mechanisms between different variables. For example, improvements in market infrastructure not only directly affect transaction costs, but may also have an indirect impact on GDP growth through feedback paths such as increased investment and improved market efficiency.

Assuming that GDP growth in a region is affected by policy interventions, its growth rate depends not only on capital investment but is also driven by policies (e.g., market infrastructure improvements). Therefore, GDP growth can be described by the following differential equation:

$$\frac{dY(t)}{dt} = g\left(K(t), L(t), P(t)\right) + \dot{o} \tag{9}$$

Where Y(t) is GDP, which varies with time t; K(t) is capital inputs; L(t) is labour; P(t) is the intensity of policy interventions (e.g., inputs for infrastructure improvements); g(.) is a function of the growth rate of GDP, which expresses the effect of different inputs on economic growth; and ϵ is a stochastic error term, which is used to model the uncertainty in the system.

The effects of policy interventions (e.g., market infrastructure improvements) are captured in P(t), which may affect GDP through the following path:

$$P(t) = f_{\text{policy}}(t) \tag{10}$$

Where the policy function $f_{\text{policy}}(t)$ describes the strength of the policy intervention at different points in time, e.g. investment in market infrastructure development over time. Assuming that policy is a gradual input, then:

$$P(t) = P_0 \, . e^{-\lambda t} \tag{11}$$

Where P0 is the initial policy input intensity and λ is the policy decay coefficient, which indicates that the impact of the policy diminishes over time.

(3) Risk and sensitivity analyses

By varying policy parameters (e.g. implementation time, policy intensity, resource allocation) and analysing their impact on the final outcome, the model can reveal potential risks and key sensitivities in policy implementation. For example, too much policy intensity may lead to resource depletion, while too little may fail to achieve the desired results. Through this sensitivity analysis, the model can identify key risk points in policy implementation, helping decision makers to make adjustments and optimisations to ensure that the policy is implemented smoothly and the desired goals are achieved. In order to assess the risk and uncertainty of policy implementation, sensitivity analysis is added to the model. Assuming that there is uncertainty in the policy variable P(t), we can express it as:

$$P(t) = P_0 \, . e^{-\lambda t} + \sigma . \zeta(t) \tag{12}$$

Where ζ (t) is a white noise term and σ is the magnitude of policy uncertainty. By introducing the random variable ζ(t), the model can simulate the uncertainty in policy implementation and perform sensitivity analysis. The sensitivity analysis is performed by calculating the extent to which changes in policy parameters affect the model results. For example, the sensitivity of changes in policy intensity to GDP growth can be expressed as the following partial derivative:

$$S_P = \frac{\partial Y(t)}{\partial P(t)} \tag{13}$$

When the S_P is large, it indicates that the model is sensitive to policy changes and that more careful policy intensity design and implementation is needed.

(4) Optimal policy mix

Through optimisation analysis, the model can help policy makers find the optimal policy mix. Assuming that the policy mix objective is to maximise economic growth Y(t) and minimise poverty rate Z(t) simultaneously, we can express it through a weighted multi - objective optimisation equation:

$$max_{P1(t),P2(t)} \; [①_1 . Y(t) - ①_2 \; . Z(t)] \tag{14}$$

Where: P_1 and P_2 are the intensities of the two types of policies (e.g., infrastructure improvement and business support), respectively; $①_1$ and $①_2$ are weights indicating the relative importance of economic growth and poverty reduction. By optimising the model, the optimal policy mix under different weights can be found, ensuring a balance between economic and social benefits.

In summary, the policy and intervention simulation model combines the advantages of MAS and SD to provide an all-round and multi-dimensional platform for policy evaluation and optimisation. By simulating and evaluating different policy scenarios, the model can help decision makers identify optimal policy combinations in complex and changing environments, thus promoting the sustainable development of regional economy, society and environment.

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