Modeling and Simulation for the Coordinated Development of Sports - Economy Complex System Based on Complex System Theory

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Abstract

The regional development of the sports industry and its role in the economy could be potentially facilitated by more research into the sports – economy complex system (SECS). However, the existing studies on SECS overlook the differences between the subsystems, failing to systematically analyze the features of each individual subsystem or the complex system in different phases. Thus, the basic purpose of this research is to solve the major and urgent problems regarding the regional complex system in order to advance the research on SECS. Based on the theory of complex systems, this paper mainly studies the coordinated regional development between sports and economy and constructs a model for simulation and verification. Specifically, the authors examine the relationship between sports development and regional economic growth, modeling the coordination of SECS in the course of development, and setting up an evaluation index system (EIS) for the coordinated development of SECS. For this purpose, the experimental research design is used in this study as the research methodology. On this basis, the accelerated genetic algorithm (AGA) is introduced to evaluate the coordinated development of that system. The proposed model is proved valid through experiments.

Keywords: sports-economy complex system (SPCS); accelerated genetic algorithm (AGA); coordinated development evaluation; evaluation index system (EIS)

Introduction

To promote national fitness, China is encouraging all citizens to participate in sports. Against this backdrop, it is important to stimulate national consumption in the sports industry, and promote the technical upgrading and profit-making of sports enterprises, making regional and national economic growth more inclusive (bin Abdullah et al., 2021; Cheng & Song, 2021)

The national fitness campaign is a potential driver of sports consumption, which could inject new vitality into the economy. The economic growth that ensues could achieve coordinated development of the sports industry (Guinot, 2020; Mendoza Torralba, 2020).

For this reason, several different researchers have shifted their focus onto the sports economic complex system which is also termed as SECS. These researchers also offer countermeasures for the developing economy and industry at the regional level. The sports industry of China has become a critical force in the development of the economy. On the other hand, many challenges, as well as setbacks, are also being faced by the sports industry of China. The requirement of development at a rapid pace is not met by the sports industry of China presently. The legacy concept of sports has also raised the issue of finding ways through research to promote the intervention of policies of sports to achieve the organizational goal. Most past researchers have not addressed this issue in past studies before (Ma & Kurscheidt, 2021).

It is key to mention that the theory of complex systems does not pertain to the research of complexity. It is mainly concerned with studying and understanding the behavior system. Most of the time, this system is complex as well which is evolved, learnt and adapted. For the organizational manufacturing, the complex system of theory can play the role of alternative perspective to model and conceptualize internal dynamics (Condorelli, 2016).

The harmony between the sports industry and the economy is the ultimate goal of SECS development (Xu & Yang, 2019). Drawing on the theories of composite systems and coordinated development, Fang (2019), constructs a scientific EIS for the harmony of regional SECS, creates an SPSS-based linear regression model for SECS harmony, and numerically simulated the harmony with the concept of membership in fuzzy mathematics. This study focuses on foreign as well as local theories regarding development of sports industry and economic growth. Moreover, empirical literature studied in past is also focused in this study regarding the development of SECS.

To date, few scholars have discussed the coordinated development between the regional sports industry and the regional economy. The relevant studies overlook the differences between the subsystems, failing to

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systematically analyze the features of each subsystem or the complex system in different phases. Based on the theory of complex systems, this paper probes into the coordinated regional development between sports and the economy and constructs a model for simulation and verification.

The current study initially analyzes the relationship between sports development and regional economic growth and models the coordination of SECS in the course of development. Subsequently, it sets up an EIS for the coordinated development of SECS. The next part builds an evaluation model for SECS coordination based on the accelerated genetic algorithm (AGA). The proposed model is proved valid through experiments.

Therefore, the main objective of the present study is to advance the research on SECS by solving the urgent and major issue-areas to develop the subsystem of a complex system at every region on the basis of several predecessors. This study also promotes the development of the economy and sports in every region.

Literature Review

Sports Development

Researchers point that most sports graduates are of the view that they were not able to fully polish their financial skills, entrepreneurship skills, networking, commercial awareness and several different business skills. In the last few decades, the sports industry of China has integrated firmly with the tourism industry as sports play an important role in boosting the level of tourism in the country. Therefore, a number of researchers are paying a lot of attention to this concept. There are four important characteristics to develop the sports industry within any country. These steps include the realization of industrial clustering, focusing on the management of brands, emphasizing innovation within the country, and the cultivation of a mature market (Wang, 2018).

To support and encourage issues related to the environment, sustainable development of sports, as well as games within a country, plays a very important role (Giulianotti, Darnell, Collison, & Howe, 2018) With the growth of health awareness, urban residents are increasingly concerned with and in need of healthy life and physical exercise (Bi, Niu, Liang, & Li, 2020). Jing and Wang (2020) analyze disposable income and cultural factors and summarize the consumption features and psychological laws of urban residents in sports services and products. C. Yang, Lan, and Wang (2019) evaluate the quality of sports consumption of residents from three aspects, namely, sports products, sports environment, and sports services, comparing the sports consumption qualities of residents from regions with different levels of economic development, and exploring how regional economic development influences sports consumption level.

The existing studies on regional sports and economy primarily concentrate on the management strategies, operating mechanisms, and development trends for regional sports industry, utilization of regional sports resources, regional sports consumption in the market, and regional sports service activities (Yongming, Wang, & Haohao, 2019). Kumar, Selvaraj, Desingu, Chelliah, and Upadhyayula (2020) carry out microscopic measurement and empirical analysis of the layout and structure for the sports industry in Shanghai, Zhejiang, and Jiangsu, and compared the features of regional sports – economy structure in the orders of regions and industries. In a similar vein, Voyer, Farmery, Kajlich, Vachette, and Quirk (2020) model the clustering effect and growth poles of the sports industry in the Yangtze River Delta and quantify predictive variables like market share, and profit of the dominant industry, as well as hypothetical variables like market concentration, and produce scale effect. Voyer et al. (2020) construct the models for the layout and structure of sports product manufacturing clusters, compare the economic indices (e.g., relative density of technical factors, and elastic coefficient of sports product income) for the cluster development of the sports industry shortly, and predict the trend of the cluster development.

Regional Economic Growth

Economic development of the region reflects the capacity of the economic system at the local level to constantly create and find a specific and proper role for the labors at the international level through creative and efficient utilization of available resources. There are four stages of the maturity of the economic system at the local level including wealth and affluence, innovation, investment and production. As the economic development of any region is getting promoted, the local factors become less dependent upon it and their reliance is increased on innovation (Wang, 2018).

Sports Development and Regional Economic Growth

It is not possible to measure the sports economy independently as a single unit. It can be assessed as part of different economic as well as industrial sectors. In terms of economy, there are several economic effects of the sports industry on different areas of society (Värja, 2016).

A simple applied microeconomic analysis is required for the basic approach of sports economics so the resources can be allocated at the optimum level. It is important because the competition in every industry is becoming more intense. Researchers have defined the sports economy as the industry which is formed by a number of different firms that are known as the teams. In this industry, the product is provided in entertainment form which is produced through the team of the sports industry by the games. In the sports industry, entertainment is provided through several different resources. These resources include the stadium and players (Stan & Anton-Prisacariu, 2016).

Theory Of Complex Systems

Rational and new thinking is the basis of the development of the complex system theory. This theory must be studied for the emergent properties of the system. A few researchers sometimes associate complex system theory with self-organizing systems. It is key to note that the base of complex system theory can be located with the help of a number of system thinking (Silva & Guerrini, 2018). These complex systems are also observed in several different sports which are formed of functionally and structurally heterogeneous component that often interacts through the variation of spanning of different scales. These changes are also goal-directed and adaptive as well.

Many different challenges are faced by the modelling techniques by the property increase. It is important to mention that the same rules should be used to understand the coordination of humans (Pol et al., 2020).

Sports - Economic Complex System (SECS)

Researchers have established a systematic and scientific evaluation of index systems at different hierarchical levels with the purpose of developing coordination among regional economies and mass sports at the regional level (Zheng, 2015). Moreover, it is also used to build the evaluation of the regression model for the development of coordination. Based on an evaluation of the results, scholars have put forth several suggestions which include optimizing the sports, increased investment in the sports industry, economic development and improved quality of mass sports (Hulme et al., 2019).

Coordinated Regional Development (Coordinated Development of Sports Between Sports and Economy

Economic globalization is the main goal to be achieved through inclusive growth. Moreover, countries are also looking to achieve economic development across all of the states of the country and to the entire population of the country. For this purpose, coordinated efforts among different segments of the society is required. Sports industry is the collection of departments and organizations which are engaged in the products of sports which also meets the demands of sports shows, physical exercises, and watching sports games. The sports service industry is included in the sports industry which includes sales as well as manufacturing of athletic products. Moreover, the sports service industry also covers the competitive performance industry, the entertainment industry and the sports fitness industry (Ghildiyal, 2015).

The aspect of the regional sports industry is the new perspective regarding development programs of different regions of the sports industry which help the region to gain competitive advantage and push regional stakeholders for the establishment of the industry within the region. Moreover, the resources of the region are utilized at the optimum level and people try to be environment friendly. The evaluation system regarding coordination development in the sports industry is achieved through the theory of complex systems (S. Yang, Xu, & Yang, 2020).

Generally, the development of coordination means the coordination among two or more resources to achieve mutual goals and develop a win-win situation. Additionally, three principles are reflected in the development of coordination. Firstly, the principle of competition and coordination is not to eliminate each other; secondly, there must be fairness in the competition, and thirdly, it must promote each other by the principle of diversity (He, 2020).

Sports Evaluation Index System (EIS)

Scientific construction regarding the system of evaluation of the resources of sports is the base to realize excessive allocation of the resources of sports. Construction regarding evaluation as well as index system of resources of sports should be same in the principles of operable, feasibility, dynamics, and systematic except for the observance of basic statistical discipline. In this way, it can establish an index system, practicable evaluation, and a feasible and scientific system for the resources of sports. To evaluate the problems and effects of the systems of sports and for the promotion of sports sustainability, many stakeholders are trying to establish a system.

There are five aspects of the basic index system of EIS. These aspects include intellectual property, technology, innovation, knowledge creation and innovation-driven (Liu, Fei, Du, & Li, 2017)

Methodology

The current study utilized an experimental research design for the modelling and simulation of the coordinated development of the Sport-Economy complex system. A certain number of regional manufacturers are producing 14 different types of sports products, including indoor fitness, ball game, sportswear, sports venue paving, fishing gear, bow and arrow, and winter sports. For the complex system of SECS, the subsystems refer to all the economies in a region, considering sports-related manufacturers or service providers. In the experimental research design, the researcher manipulates one variable to determine whether the change in one variable causes change in another variable. To test a hypothesis this method relies on the manipulation of variables and random assignment. In this paper, the coefficient of variation (COV) method has been adopted to determine the weights of the indices that affect the final evaluation, and the combination weighting approach was adopted to synthesize the index weights obtained by the COV method and the AHP, overcoming the one-sidedness of the evaluation results by using a single weighting method.

Correlation Analysis

In this paper, the relationship between sports industry development and regional economic growth is investigated by the endogenous economic growth model about economic growth determinants and the complex system coordination model about the coordinated development of SECS.

Let GO_h and TC_h be the total output and total capital of the regional economy related to the sports industry, respectively; C be a constant not related to production technology. Without considering the diminishing returns to capital, the endogenous economic growth model can be expressed as:

$$GO_h = C \cdot TC_h \tag{1}$$

If there are two or more sports-related manufacturers or service providers in the region, then the total capital can be divided into physical capital PC and human capital HC, both of which can be adjusted instantaneously. In this case, HC/PC is a constant. Let $\xi = HC/PC$. Then, the production function can be described by a standard connectionist temporal classification (CTC) model:

$$GO = C^* \cdot TC \tag{2}$$

where, C^* can be obtained by:

$$C^* = C \cdot \xi^{1-e} \tag{3}$$

where, $e \in [0, 1]$. Combining formulas (2) and (3):

$$GO_h = C \cdot TC_h^e \cdot HC^{1-e} \tag{4}$$

The logarithmic form of the above formula can be described as:

$$LnGO = LnC + eLnTC + (1-e)LnHC \tag{5}$$

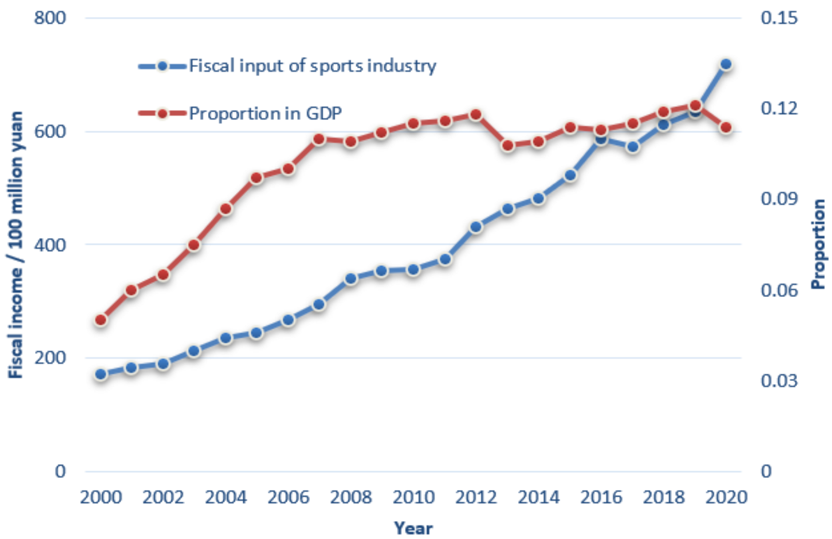

Figure 1. Variations in regional sports industry input and its proportion in GDP

Figure 1 shows the variations in regional sports industry input and its proportion in GDP. It can be inferred that the regional sports industry has been developing step by step. To accurately describe the influence of sports industry development on regional economic growth, this paper gives full consideration to progressive factors like production technology, and service quality, and aims to produce a thorough and deep analysis on the coordinated development between sports industry development and regional economic growth.

Let $LnGO$ be the natural logarithm of per-capita GDP, which reflects the regional level of economic growth; $LnTC$ and $LnHC$ are the natural logarithms of fixed asset investment and human capital investment, which reflect the degree of influence from the physical and human capitals in sports industry on level of economic growth, respectively; $LnTP$ be the natural logarithm of the progress or improvement of production technology and service quality, respectively; λ be a random error term, which reflects the degree of influence of other factors on the level of economic growth. Then, the measuring model of endogenous economic growth can be expressed as:

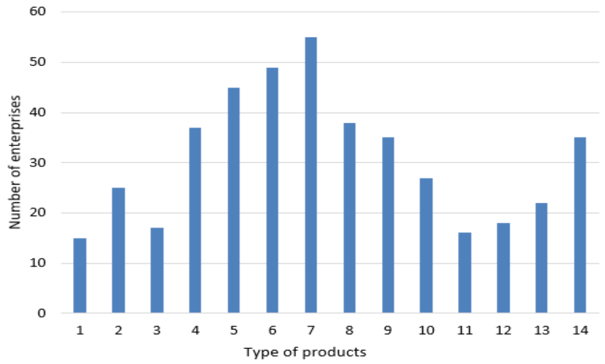

Figure 2. Number of manufacturers producing different types of sports products

Based on the concept of coordination, the complex system coordination model measures the coordination of subsystem development and aims to maximize the correlation between subsystems in positive development. Figure 2 shows the number of regional manufacturers producing 14 different types of sports products, including indoor fitness, ball game, sportswear, sports venue paving, fishing gear, bow and arrow, and winter sports. For the complex system of SECS, the subsystems refer to all the economies in a region, involving sports-related manufacturers or service providers (Figure 3). The calculation steps of the coordination for the coordinated development between the subsystems of the complex system are detailed below.

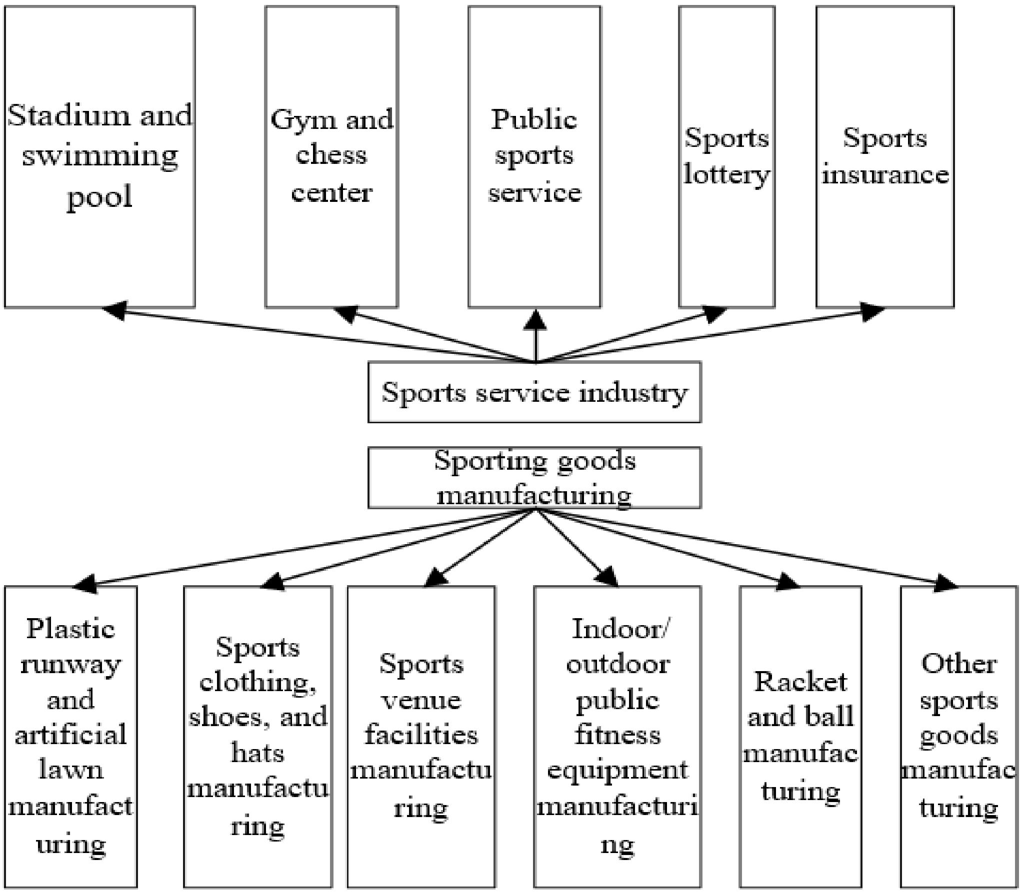

Figure 3. Division of complex system into sports manufacturing system and sports service system

Suppose the complex system contains O subsystems. The i-th subsystem and the ordered variables of subsystem development are denoted as R_i and $r_i=(r_{i1}, r_{i2}, \ldots, r_{im})$, respectively. The system degree of order corresponding to r_i is denoted as $v_i(r_{ij})$, where $i\in(1, O]$, $j\in(1, m]$, $m\geq1$.

To calculate $v_i(r_{ij})$, it is necessary to assume that the values of $r_{i1}, r_{i2}, \ldots, r_{ik}$ are positively correlated with the degree of order for the development of the corresponding subsystems, and that the values of $r_{ik+1}, r_{ik+2}, \ldots, r_{im}$ are negatively correlated with the degree of order for the development of the corresponding subsystems. Then, the degree of order $v_i(r_{ij})$ for the ordered variables r_i of a subsystem can be calculated by:

$$v_i(r_{ik}) = \begin{cases} \frac{r_{ik}-r_{max-ik}}{r_{min-ik}-r_{max-ik}}, i \in [1,k] \\ \frac{r_{min-ik}-r_{ik}}{r_{min-ik}-r_{max-ik}}, i \in [k+1,m] \end{cases} \tag{6}$$

After the $v_i(r_{ij})$ values of each subsystem had been obtained, the degree of order $v_i(r_i)$ of the complex system can be obtained by linear weighting and geometric averaging.

Finally, the coordination of complex system can be modeled in the course of development. Let v_i^0 (r_{ij}) be the degree of order for the ordered variables r_i of a subsystem at the initial time t_0. Then, the degree of order for r_i can be described as $v_i^l(r_{ij})$ in the course of development. Thus, we have:

$$SO = \delta * \sqrt[O]{\left|\prod_{i=1}^{O}[v_i^l(r_i) - v_i^0(r_i)]\right|} \quad (7)$$

Figure 4 shows the variation in coordination for the coordinated development of SECS in the study area.

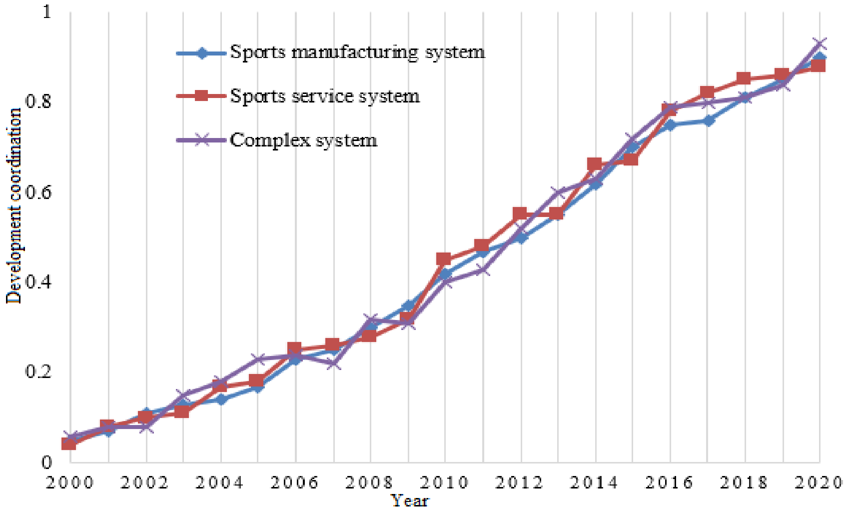

Figure 4. Variation in coordination for the coordinated development of SECS

EIS Construction

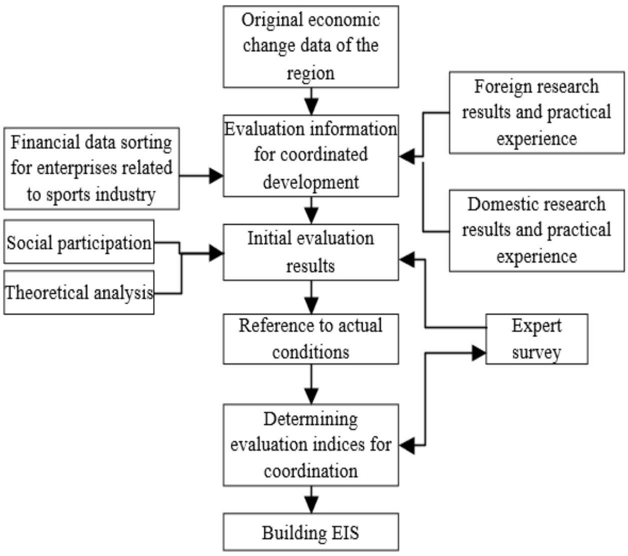

Figure 5. EIS for coordination of complex system development

For accurate analysis on the coordination of complex system development, this paper sets up a progressive EIS for the level of coordinated development of SECS, following the construction flow in Figure 5:

Layer 1 (goal layer):

A={A_1, A_2}={regional sports industry, regional economy};

Layer 2 (primary indices):

A_1={A_{11}, A_{12}, A_{13}}={human input, capital input, construction input};

A_2={A_{21}, A_{22}, A_{23}}={economic aggregate, economic structure, per-capita benefit};

Layer 3 (secondary indices):

A_{11}={A_{111}, A_{112}}={proportion of population receiving sports guidance, proportion of population receiving physical fitness test};

A_{12}={A_{121}, A_{122}}={per-capita input of sports consumption, per-capita input of sports fixed asset};

A_{13} ={A_{131}, A_{132}}={number of public sports service points, number of sports manufacturers};

A_{21}={A_{211}, A_{212}, A_{213}}={regional GDP, regional construction scale of sports industry, regional fiscal input};

A_{22}={A_{221}, A_{222}, A_{223}, A_{224}}={proportion of tertiary industry output in GDP, proportion of tertiary industry in employment, proportion of sports industry output in GDP, proportion of sports industry in employment};

A_{23}={A_{221}, A_{222}, A_{223}, A_{224}}={per-capita consumption expenditure, per-capita net income, per-capita disposable income, per-capita regional GDP}.

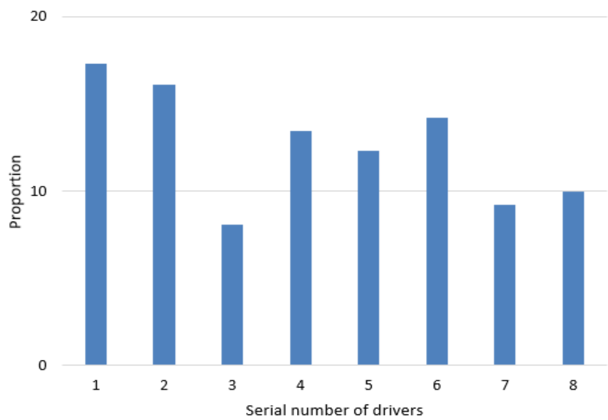

Figure 6. Driving effect of regional economic construction on sports industry development

Figure 6 shows the driving effects of seven aspects of regional economic construction on sports industry development, including infrastructure construction, construction of financial service system, talent support, corporate support policies, tax benefits, etc. Obviously, different aspects contribute differently to the promoting effect of regional economic construction on sports industry development. Thus, it is important to assign a proper weight to each index in the EIS before making an overall evaluation of the coordination of SECS development.

In this paper, the coefficient of variation (COV) method is adopted to determine the weights of the indices that affect the final evaluation. Let A_i be the population of evaluation indices for the coordinated development level between the subsystems of a complex system; U_i and A'_i be the COV and mean of the population, respectively; D_i be the standard deviation (i=1, 2, …, n). Then, U_i can be calculated by:

$$U_i = R_i/A'_i \tag{8}$$

Let ω_i be the weight of A_i. The COV U_i for each index can be normalized into a weight ω'_i:

$$\omega'_i = U_i/\sum_{i=1}^{n} U_i \tag{9}$$

To obtain more realistic evaluation results, analytical hierarchy analysis (AHP) was carried out to finalize the weight of each index for the coordinated development level of SECS. The specific steps are as follows:

Firstly, the judgement matrix for the population was obtained based on expert survey or evaluation criteria:

$$\begin{pmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & \cdots & e_{2n} \\ \dots & \dots & \cdots & \dots \\ e_{n1} & a_{n2} & \cdots & e_{mn} \end{pmatrix} \tag{10}$$

The weight of the i-th index can be calculated by:

$$\omega_i = \frac{1}{n}\left(\frac{e_{i1}}{\sum_{l=1}^{n} e_{l1}} + \frac{e_{i2}}{\sum_{l=1}^{n} e_{l2}} + \ldots + \frac{e_{in}}{\sum_{l=1}^{n} e_{ln}}\right) \tag{11}$$

Next, the consistency test was carried out to judge if there is any logical conflict in the evaluated coordination of SECS development. Let ω_1, ω_2, …, ω_n be the weights of the indices to be tested. Then, the consistency coefficient η of the indices can be calculated by:

$$\eta = \frac{\mu - n}{n - 1} = \frac{\frac{1}{n}\left(\frac{\sum_{j=1}^{n} e_{1j}\times\omega_j}{\omega_1} + \frac{\sum_{j=1}^{n} e_{2j}\times\omega_j}{\omega_2} + \ldots + \frac{\sum_{j=1}^{n} e_{nj}\times\omega_j}{\omega_n}\right) - n}{n-1} \tag{12}$$

According to the number and significance of indices, a list of critical consistency coefficients η_{close} was prepared. On this basis, the following judgements can be made:

(1) If $\eta<\eta_{close}$, the judgements on the level of coordinated development are consistent, the judgement matrix is highly consistent and feasible, and the ω_1, ω_2, …, ω_n are meaningful.

(2) If $\eta>\eta_{close}$, the judgements on the level of coordinated development are inconsistent, the judgement matrix is poorly consistent, and the ω_1, ω_2, …, ω_n are not usable.

Finally, the calculated weight coefficients ω''_i were normalized by:

$$\omega''_i = \frac{\omega_1}{\omega_1+\omega_2+\ldots+\omega_n} \tag{13}$$

After that, the combination weighting approach was adopted to synthetize the index weights obtained by the COV method and the AHP, overcoming the one-sidedness of the evaluation results by using a single weighting method. In this way, the final weights of the indices become more scientific and reasonable. Let ω_i^*, ω'_i, and ω''_i be the composite weights, COV weights, and AHP weights, respectively. Then, the composite weights can be obtained by:

$$\omega_i^* = \frac{\omega'_i+\omega''_i}{2} \tag{14}$$

Thence, ω_i^* can be normalized by:

$$\widehat{\omega}_i = \frac{\omega_1}{\omega_1+\omega_2+\ldots+\omega_n} \tag{15}$$

Evaluation Model Construction

Algorithm description

For the subsystems of a complex system, the evaluation of coordinated development is greatly affected by the composite weights, subjective factors, and the combination rules. Besides, there are many indices that belong specifically to each subsystem. Giving overall consideration to regional economic development, this paper chooses the AGA-based projection tracking model to evaluate the harmony of SECS coordinated development. The block diagram of the coordination evaluation model is presented in Figure 7.

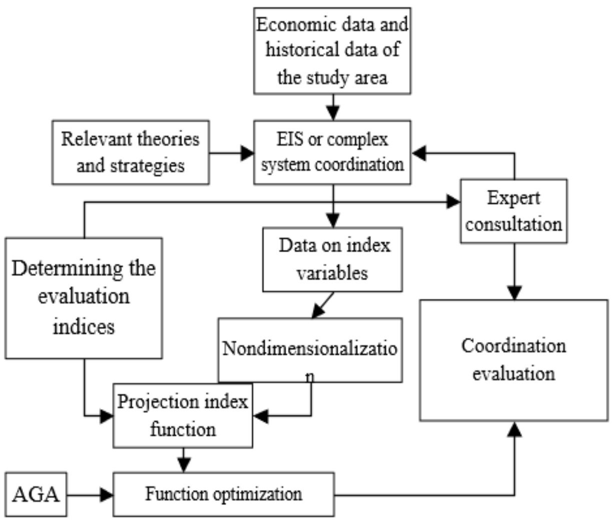

Figure 7. Coordination evaluation model for complex system development

Suppose the variable s_i of the i-th index initially changes in [s_{min-i}, s_{max-i}]. Let g be the optimization criterion function,

$g \geqq 0$. Then, the general optimization of index variables can be described by:

$$\begin{cases} min\ g(s_1, s_2, \ldots, s_t) \\ s_{min-i} \leq s_i \leq s_{max-i} \end{cases} \quad i = 1,2,\ldots,I \qquad (16)$$

The frequent coding and decoding operations of binary codes bring a huge computing load. To avoid this problem, real number codes were adopted:

$$a(i) = s_{min-i} + b(i)(s_{max-i} - s_{min-i}) \qquad (17)$$

The i-th variable $a(i)$ in $[s_{min-i}, s_{max-i}]$ was mapped into a real number $b(i)$ in [0, 1]. Then, $b(i)$ becomes a gene in the GA. The codes $b(1)$, $b(2)$,…,$b(t)$ of the solution to the optimization of all index variables (17) form a chromosome of the corresponding genes connected in sequence. The real number codes help to unify the value ranges of all index variables.

Let M_{GS} be the population size of the GA. The initial parent population could be established by selecting $(2^d)^t \times M_{GS}$ points from the $(2^d)^t$ grids, which had been determined through real number coding. The $(2^d)^t \times M_{GS}$ points belong to M_{GS} groups, each of which has t uniformly distributed numbers $\{v(i, j)|i=1\sim t, j=1\sim d\}$. Let ARR () be the rounding operation. Then, the number of random search steps corresponding to $v(i, j)$ can be obtained by:

$$RSS_i(j) = ARR\left(2^d \times v(i,j)\right) \qquad (18)$$

The number of random search steps $RSS_i(j)$ corresponds to binary coded string $\{B(i, l, j)\}$ of the parent chromosomes and s_i. Substituting $\{B\ (i, l, j)\}$ to formulas (19) and (17), respectively, the value of variable $s_i(j)$, and that of optimization criterion function $g(j)$ were obtained. The latter represents the fitness of the chromosome. After defining and sorting $\{B\ (i, l, j)\}$, $s_i(j)$, and $g(j)$, the fitness of the j-th parent chromosome can be calculated by:

$$G(j) = \frac{1}{g^2(j) + \frac{1}{1000}} \qquad (19)$$

Based on the proportional selection method, the probability for the j-th chromosome to be selected can be calculated by:

$$CP(j) = G(j) / \sum_{i=1}^{M_{GS}} G(j) = \sum_{l=1}^{i} CP(l) \qquad (20)$$

Sequence $\{CP_i|i=1\sim M_{GS}\}$ divides the interval [0, 1] into M_{GS} sub-intervals [0, CP_1], [CP_1,CP_2]..., [CP_{MGS-1},CP_{MGS}], which correspond to the M_{GS} parent chromosomes. Then, M_{GS} random numbers were generated $\{v(l)|\ l=1\sim M_{GS}\}$. If $v(l) \in (CP_{j-1}, CP_j\}$, then the j-th chromosome should be selected, and the corresponding parent chromosome could be described as a binary coded string $\{B'\ (i, l, j)|j=1\sim CP, l=1\sim d\}$. Any other parent chromosome could be described as a binary coded string $\{B''\ (i, l, j)|j=1\sim CP, l=1\sim d, i=1\sim M_{GS}\}$.

The crossover probability HP, which controls the frequency of calling the crossover operator, is positively correlated with the update speed of the coded strings of chromosomes. Suppose there exist two random numbers λ_1 and λ_2, which correspond to decimal integers $DI_1=ARR(\lambda_1 \cdot d)$ and $DI_2=ARR(\lambda_2 \cdot d)$. Then, the two sets of parent chromosomes were randomly paired by two-point crossover. That is, the coded strings $B'(i, l, j)$ and $B''(i, l, j)$ of parent chromosomes were subject to two-point crossover: swapping each digit in the field from the DI_1-th digit to the DI_2-th digit between the two coded strings one by one. The child chromosomes thus obtained can be expressed as:

$$NB'(i,l,j) = \begin{cases} B''(i,l,j) & \text{if } l \in [DI_1, DI_2] \\ B''(i,l,j) & \text{if } l \notin [DI_1, DI_2] \end{cases} \qquad (21)$$

$$NB''(i,l,j) = \begin{cases} NB''(i,l,j) & \text{if } l \in [DI_1, DI_2] \\ NB'''(i,l,j) & \text{if } l \notin [DI_1, DI_2] \end{cases} \qquad (22)$$

To diversify the population, two-point mutation was performed on the child chromosomes, generating four random numbers λ_1, λ_2, λ_3, and λ_4. Among them, λ_1 value determines the calculation formula for the coded strings of child chromosomes. Let $\{NB(i, l, j)\}$ denote the binary coded strings of the M_{GS} child chromosomes. λ_2 and λ_3 were converted into decimal integers smaller than d: $DI'_1=ARR(\lambda_2 \cdot d)$ and $DI'_2=ARR(\lambda_3 \cdot d)$. Then, the two-point mutation can be described by:

$$ia(j,k,i) = \begin{cases} 0 & \text{if } i_a = 1 \text{ and } \mu_4 \leq p_m k \in \{IU_1, IU_2\} \\ 1 & \text{if } i_a = 0 \text{ and } \mu_4 \leq p_m k \in \{IU_1, IU_2\} \\ i_a & \text{Otherwise} \end{cases} \qquad (23)$$

$$NB(i,l,j) = \begin{cases} 0 & NB = 1 \text{ and } \lambda_4 \leq MR, l \in \{DI_1, DI_2\} \\ 1 & NB = 0 \text{ and } \lambda_4 \leq MR, l \in \{DI_1, DI_2\} \\ NB & \text{Otherwise} \end{cases} \qquad (24)$$

Then, the M_{GS} child chromosomes were taken as the new parent chromosomes, and subject to the next round of crossover and mutation. To accelerate the cyclic evolution, the initial interval of index variables could be changed to the interval of the index variables corresponding to the groups of elite chromosomes generated by the first and second rounds of evolutions. In the following iterative optimization, that interval was further adjusted and narrowed until the AGA met the termination condition: the objective function value falls below the preset threshold, or the number of iterations is smaller than the predefined number of accelerated cycles.

Evaluation Procedure

The last step is to describe the similar and different structures between the evaluation indices. Here, the composite index for the coordinate development between subsystems is defined as the projection value; the similarity and difference are evaluated by the projection index function, as well as the relevant distribution and structural features. After nondimensionalization of the index variables, the high-dimensional data $\{b(i, j)|i=1\sim N\}$ of the index variables were synthetized into a one-dimensional (1D) projection $p(j)$ in the direction of $\theta=[\theta(1),$

$\theta(2)\ldots\theta(N)]$, where $\theta(j)$ is the objective weight of the j-th index:

$$\begin{cases} p(j) = \sum_{i=1}^{N} \theta(i) b(i,j) \\ \theta(i) > 0 \\ \sum_{i=1}^{N} \theta(i) = 1 \end{cases} \tag{25}$$

To minimize the distance between local projection points and maximize the distance between projection point clusters, the projection index function can be expressed as:

$$PIF(\theta) = SD_P LD_P \tag{26}$$

where, SD_P and LD_P are the standard deviation and local density of projection $p(j)$, respectively. Once the evaluation indices are determined for the subsystems of a single complex system, $PIF(\theta)$ could only change with θ. Different θ values reflect the structural features of the data on different index variables. The optimal projection direction is the most likely to accurately reflect the cluster features of the said data. The optimal projection direction can be obtained by maximizing the projection index function:

$$max\ PIF(\theta) = SD_P LD_{P_c}$$
$$s.t.\ \ \theta(i) > 0, \sum_{i=1}^{N} \theta(i) = 1 \tag{27}$$

Based on the optimal projection direction θ^*, the projection value $p^*(j)$ could be calculated to demonstrate the composite features of every index for the subsystems of the complex system.

Experiments and Results Analysis

Table 1

Profits and costs of enterprises related to regional sports industry

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Main business profit	2.1	3.5	4.7	5.3	5.2	5.5	8.2	9.5	9.7	10.2
Main business cost	15.2	21.5	42.7	45.9	52.1	42.3	60.8	66.2	62.1	75.9
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Main business profit	10.6	11.3	12.5	16.8	17.4	19.2	23.4	24.5	26.2	27.1
Main business cost	78.1	85.3	90.2	95.3	98.1	103.7	109.2	124.8	135.2	162.7

Table 1 shows the variations in the profits and costs of enterprises related to regional sports industry. From 2001 to 2020, the main business profit and cost of the sports industry enterprises in the study area continued to grow. In terms of change rate, the growth rates were slow in 2003-2006, picked up speed after the global financial crisis in 2008, and reached the highest levels in 2019-2020.

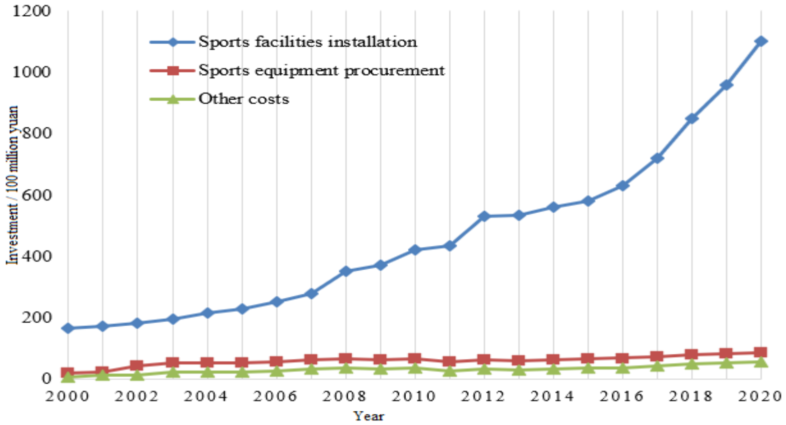

Figure 8. Different types of fixed asset investments in regional sports industry

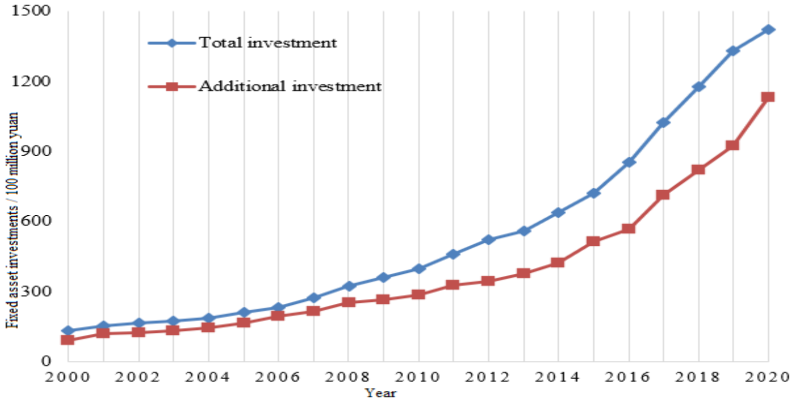

Figure 9. Trend of fixed asset investments in regional sports industry

As shown in Figure 8, among the fixed asset investments in regional sports industry, the investments in sports facilities installation, sports equipment procurement, and other costs increased steadily. Compared with the sports equipment procurement and other costs, sports facilities installation accounts for the largest portion in the total investment and increases at a relatively fast speed. Its increment is the largest between 2015 and 2020. In 2012, the total investment in sports facilities installation reaches 53.21 billion yuan, up by 19.2% from the investment of the previous year. Figure 9 sums up the trend of fixed asset investments in regional sports industry. In 2000-2020, the total fixed asset investment in regional sports industry basically rose steadily, following the same trend as the additional investment.

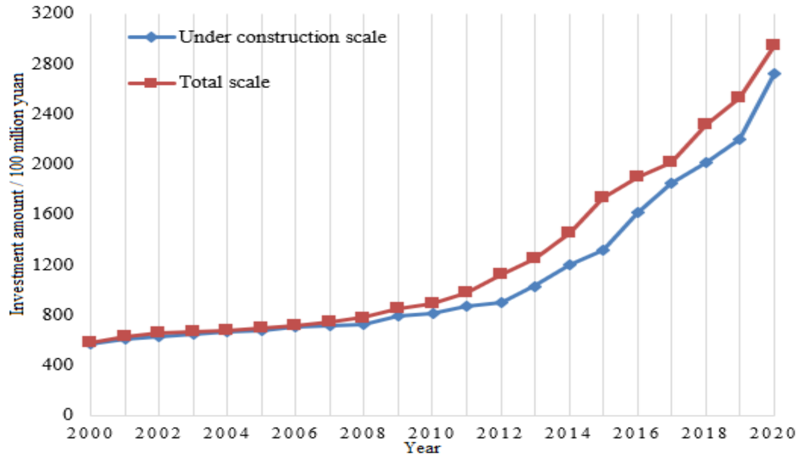

Figure 10. Construction scale of regional sports industry

As shown in Figure 10, the total construction scale of the sports industry in the study area exhibits a steady upward trend, which is the same as the under construction scale. The growth rates are relatively small in 2000-2008, relatively stable in 2008-2014, and rocketed up after 2014, especially after 2016. In 2018, the total scale and under construction scale reaches 18.242 billion yuan and 11.859 billion yuan, respectively. Without considering product price and service quality, the two scales in 2018 are found to be 19.4% and 12.3% greater than those in 2017, and 66.2% and 59.4% higher than those a decade ago, respectively.

Table 2

Coordinated development of SECS in different regions

Region	Composite score	Coordination	Coordination coefficient	Region	Composite score	Coordination	Coordination coefficient
*A*1	0.1347	0.2631	0.6657	*A*11	0.0329	0.1235	0.3739
*A*2	0.1295	0.1457	0.9321	*A*12	0.1239	0.1621	0.9268
*A*3	0.2516	0.3329	0.3549	*A*13	0.0588	0.1856	0.9655
*A*4	0.1135	0.1672	0.6233	*A*14	0.0861	0.1273	0.7532
*A*5	0.1319	0.1867	0.4805	*A*15	0.0895	0.1594	0.6843
*A*6	0.1166	0.1935	0.5072	*A*16	0.1998	0.1082	0.7231
*A*7	0.2857	0.4521	0.0015	*A*17	0.1532	0.1351	0.6882
*A*8	0.2531	0.1238	0.1164	*A*18	0.0524	0.0675	0.9831
*A*9	0.1365	0.1291	0.9352	*A*19	0.2546	0.1176	0.0276
*A*10	0.2043	0.1582	0.9041	*A*20	0.1721	0.1293	0.8361

Table 2 shows the coordination of SECS development in different regions predicted by our model. It can be seen that, the sports industry development was weakly or slightly coordinated with regional economic growth in regions like Beijing, Shanghai, Inner Mongolia, Ningxia, and Jiangsu. In these regions, the composite score of sports industry development is slightly greater than the coordination of the complex system development, suggesting that the economic growth in these regions lags the sports industry development. Therefore, these regions should make some adjustments to the policies on the sports industry.

In contrast, Anhui, Hebei, Shandong, Guizhou, Hunan, and Hubei achieve strong coordination between sports industry development and regional economic growth. In these regions, the composite score of sports industry development is found to be slightly smaller than the coordination of the complex system development, indicating that the economic growth in these regions leads the sports industry development. Therefore, these regions should further promote the development of the sports industry.

Figure 11 shows the dynamic changes of regional economic growth rate and sports consumption growth rate in the course of the coordinated development. The trends of economy and sports consumption predicted by our model are highly consistent and correlated.

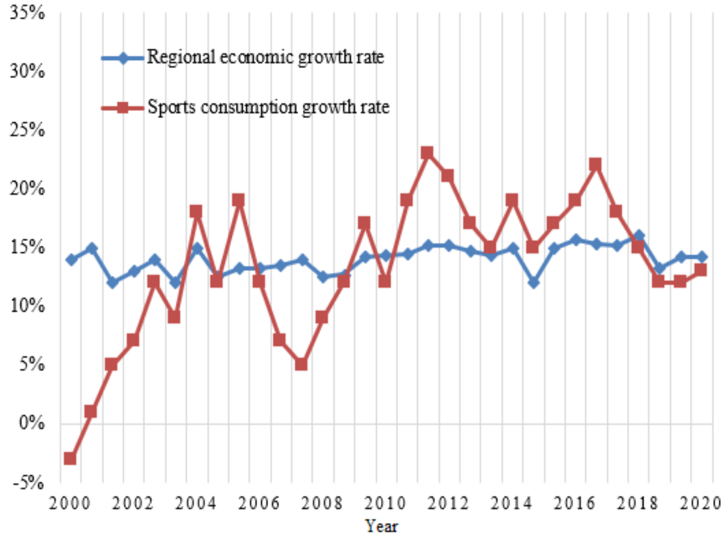

Figure 11. Dynamic changes of regional economic growth rate and sports consumption growth rate

Table 3

Cyclic dependence between regional economy growth and sports industry development

Variable	Correlation coefficient	Cyclic dependence	Variable	Correlation coefficient	Cyclic dependence
Expansion	0.29	0.23	Buildings	0.53	0.15
New construction	-0.42	-0.45	Equipment	-0.29	-0.25
Technical update	0.35	0.43	Others	-0.23	-0.28
Total investment	-0.31	-0.28	Investment above provincial level	0.03	0.59
Additional investment	-0.37	-0.31	Regional investment	-0.11	-0.31

Table 3 presents the results of cyclic dependence between the coordinated development of regional economy and sports industry. It can be learned that expansion, building, technical update, and investment above provincial level are positively correlated with regional economic growth; the first three items have relatively strong correlations with regional economic growth, while the fourth item has a relatively weak correlation with regional economic growth. This result verifies that regional economic growth is closely associated with the fixed asset investments in sports industry. Moreover, the variations in additional investment, which is dominated by industry-level factors, and regional investment are loosely coupled with the overall economic situation in the region. In particular, the additional investment did not change prominently in the early phase of the coordinated development of the complex system. The change law of additional investment is more in line with the development features of the regional sports industry and weakly related to economic growth in the region.

Conclusions

Drawing on the complex system theory, this paper explores the coordinated development between economic growth and sports industry development in a region and designs a model for simulation and verification. Specifically, a coordination model for the complex system in the course of development, plus an EIS for SECS coordination, is proposed after analyzing the relationship between sports industry development and regional economic growth. Then, the AGA is called to evaluate the coordination of SECS development. After that, multiple experiments are carried out to observe the fixed asset investments in the sports industry of different regions, the trend of fixed asset investment in the regional sports industry, and the construction scale of the regional sports industry. The observations show that all indices increase steadily over time, and exhibit a consistent trend. Further, our model was applied to predict the SECS coordination values of different regions. The predicted trends of regional economic growth rate and sports consumption growth rate are found to be highly consistent and correlated. Finally, the authors analyze the cyclic dependence between regional economy and sports industry in the course of coordinated development and identify the variables positively correlated with regional economic growth.

The results of the present study show that local government must highlight the development of sports in the region for the development of sports and economic growth. In this respect, the government can take a number of initiatives like the implementation of fitness campaigns and promotion of sports among youth through advertisements and public service messages. The government must also create and raise awareness regarding the importance of sports for economic development. It is also important that government undertake steps and practical measures to promote sports like construction of sports facilities and proper utilization of venues related to sports. As a result, the cost to coordinate among the region for sports will reduce, which in turn, will enhance economic development.

This research fills several theoretical and practical gaps. The findings of the present research provide a solid base for decision-makers for trend prediction, harmonious development, stability, sustainability, social-economic development and strategic prediction for the future. This research also provides valuable data for the implementation and planning of regional goals of social development and to develop coordination among SECS regions.

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References

Bi, X., Niu, B., Liang, X., & Li, C. (2020). *Research on coordinated development of urban energy system and economic system--Based on coupling coordination model.* Paper presented at the IOP Conference Series: Earth and Environmental Science.

bin Abdullah, M. N., Yeong, C. F., Ming, E. S. L., bin Ramli, M. S., Khor, K. X., & Yang, C. (2021). *Development of ReactRun: Advanced Universal IoT System for Agility Training in Sports and Healthcare.* Paper presented at the 2020 IEEE-EMBS Conference on Biomedical Engineering and Sciences (IECBES).

Cheng, Y., & Song, Y. (2021). Sports Big Data Analysis Based on Cloud Platform and Its Impact on Sports Economy. *Mathematical Problems in Engineering, 2021*, 6610000. doi:https://doi.org/10.1155/2021/6610000

Condorelli, R. (2016). Complex systems theory: some considerations for sociology. *Open Journal of Applied Sciences, 6*(07), 422-448 doi:http://www.scirp.org/journal/PaperInformation.aspx?PaperID=69101&#abstract

Fang, D. (2019). Composite System for the Coupling Degree of Tourism Industry and Regional Ecological Environment: A Case Study of Henan Province, China. *Nature Environment & Pollution Technology, 18*(1), 41-48.

Ghildiyal, R. (2015). Role of Sports in the Development of an Individual and Role of Psychology in Sports. *Mens sana monographs, 13*(1), 165-170. doi:10.4103/0973-1229.153335

Giulianotti, R., Darnell, S., Collison, H., & Howe, P. D. (2018). Sport for development and peace and the environment: The case for policy, practice, and research. *Sustainability, 10*(7), 2241. doi:https://doi.org/10.3390/su10072241

Guinot, J. (2020). Changing the economic paradigm: Towards a sustainable business model. 603-610. doi:https://doi.org/10.18280/ijsdp.150502

He, H. (2020). Research on the coordinated development of sports in Guangdong-Hong Kong-Macao Greater Bay Area: a case study of fencing sports. 1-27.

Hulme, A., McLean, S., Read, G. J., Dallat, C., Bedford, A., & Salmon, P. M. (2019). Sports organizations as complex systems: Using cognitive work analysis to identify the factors influencing performance in an elite netball organization. *Frontiers in sports and active living, 1*, 1-56. doi:https://doi.org/10.3389/fspor.2019.00056

Jing, Z., & Wang, J. (2020). Sustainable development evaluation of the society–economy–environment in a resource-based city of China: A complex network approach. *Journal of Cleaner Production, 263*, 121510. doi:https://doi.org/10.1016/j.jclepro.2020.121510

Kumar, B. A., Selvaraj, R., Desingu, K., Chelliah, T. R., & Upadhyayula, R. S. (2020). A Coordinated Control Strategy for a Diesel-Electric Tugboat System for Improved Fuel Economy. *IEEE Transactions on Industry Applications, 56*(5), 5439-5451. doi:https://doi.org/10.1109/TIA.2020.3010779

Liu, Q., Fei, L., Du, Y., & Li, L. (2017). *A new method of comprehensive evaluation index system on the quality of sports teaching.* Paper presented at the 2017 International Conference on Smart Grid and Electrical Automation (ICSGEA).

Ma, Y., & Kurscheidt, M. (2021). Modifying tradition: Understanding organizational change in Chinese elite sport training at the grassroots level. *Sustainability, 13*(7), 4048. doi:https://doi.org/10.3390/su13074048

Mendoza Torralba, E. (2020). *Sports Ed 3.5: Establishing the value of data-driven sports development programs for universities through machine learning models.* Paper presented at the 2020 The 8th International Conference on Information Technology: IoT and Smart City.

Pol, R., Balagué, N., Ric, A., Torrents, C., Kiely, J., & Hristovski, R. (2020). Training or synergizing? Complex systems principles change the understanding of sport processes. *Sports Medicine-Open, 6*(1), 1-13. doi:https://doi.org/10.1186/s40798-020-00256-9

Silva, A. L., & Guerrini, F. M. (2018). Self-organized innovation networks from the perspective of complex systems: A comprehensive conceptual review. *Journal of Organizational Change Management*, 962-983. doi:https://doi.org/10.1108/JOCM-10-2016-0210

Stan, M., & Anton-Prisacariu, B. (2016). Sports industry–a potential new source of economic growth. *Economie şi Sociologie*(2), 97-100.

Värja, E. (2016). Sports and local growth in Sweden: Is a successful sports team good for local economic growth. 269-287.

Voyer, M., Farmery, A. K., Kajlich, L., Vachette, A., & Quirk, G. (2020). Assessing policy coherence and coordination in the sustainable development of a Blue Economy. A case study from Timor Leste. *Ocean & Coastal Management, 192*, 105187. doi:https://doi.org/10.1016/j.ocecoaman.2020.105187

Wang, Z. (2018). Re-stimulating Chinese entrepreneurship through the mixed ownership reform *Entrepreneurship and Local Economic Development* (pp. 93-112): Routledge.

Xu, J., & Yang, R. (2019). Sports industry agglomeration and green economic growth—Empirical research based on panel data of 30 provinces and cities in China. *Sustainability, 11*(19), 5399. doi:https://doi.org/10.3390/su11195399

Yang, C., Lan, S., & Wang, L. (2019). Research on coordinated development between metropolitan economy and logistics using big data and Haken model. *International Journal of Production Research, 57*(4), 1176-1189. doi:https://doi.org/10.1080/00207543.2018.1503427

Yang, S., Xu, J., & Yang, R. (2020). Research on coordination and driving factors of sports industry and regional sustainable development—Empirical research based on panel data of provinces and cities in eastern China. *Sustainability, 12*(3), 813. doi:https://doi.org/10.3390/su12030813

Yongming, L., Wang, Y., & Haohao, S. (2019). Coordinated development model of E-sports based on three party game. *Cluster Computing, 22*(2), 4805-4812. doi:https://doi.org/10.1007/s10586-018-2390-x

Zheng, D. (2015). *Industrial, Mechanical and Manufacturing Science: Proceedings of the 2014 International Conference on Industrial, Mechanical and Manufacturing Science (ICIMMS 2014), June 12-13, 2014, Tianjin, China* (Vol. 1): CRC Press.