

Zhang, Linyun; Li, Wei; Štreimikienė, Dalia

Article

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MEASUREMENT OF POPULATION CARRYING CAPACITY BASED ON A P-S MODEL: A CASE STUDY OF ZHEJIANG PROVINCE

Linyun Zhang¹, Wei Li^{2*} and Dalia Streimikiene³

¹*Zhejiang University of Finance and Economics, Hangzhou, China*

²*Zhejiang University of Finance and Economics Dongfang College, Haining, China*

³*Lithuanian Institute of Agrarian Economics, Vilnius, Lithuania*

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Abstract

The implementation of the “second child policy” and the influx of large numbers of people have led to an increase in the population of Zhejiang Province in China, placing pressure on the environment, health care, and education. In this context, this study intends to use the possibility-satisfaction (P-S) model to predict the population carrying capacity of Zhejiang Province from 2020 to 2025. This prediction system comprises economic, social, resource, and environmental systems. The following conclusions are drawn: the maximum population carrying capacity of Zhejiang in 2025 is 62 million. According to the current population development trend, the population of Zhejiang Province in 2025 will still be within the carrying capacity range. The population carrying capacity of the social system is the weakest.

Keywords: population carrying capacity; index system; possibility-satisfaction model

JEL Classification: C44, J11, J18, O15

* Corresponding author, **Wei Li** – liwei0220@zufe.edu.cn

Introduction

Zhejiang Province has the second largest floating population in China, with its net people inflow ranking second in the country. Since the implementation of the “two-child policy” in 2015, the birth rate has reached its highest level in 20 years. In recent years, increases in the net population inflow and birth rate have led to a sustained population growth. Population is the driving force of economic development, but overpopulation creates pressure on the economy, society, the environment, and resources, leading to social problems such as difficulties in school enrolment, shortage of hospital beds, traffic congestion, high house prices, environmental deterioration, and so on. In this context, this paper intends to estimate the population carrying capacity of Zhejiang Province.

There are currently numerous definitions of population carrying capacity in international organizations and academia. Although most definitions have different expressions, they have some basic commonalities. According to the International Society of Ecology, population carrying capacity refers to the number of people who can obtain long-term and stable support from various resources without destroying the biosphere or consuming unreasonable non-renewable resources. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) suggests that population carrying capacity refers to the number of people that the country or region can maintain in a predictable time, using local energy, resources, information, technology, and other conditions to ensure that material living conditions are met. Based on the above definition, this paper defines the carrying capacity of population as the population scale that the ecological environment, resources of a region can support under certain living conditions.

According to the above definition, this paper views Zhejiang Province as the research object and then do the next steps. First, it constructs four sub-systems (including 30 indicators) of economy, resources, environment, and society. Second, the P-S approach is used to estimate the population carrying capacity of economic, resource, environmental, and social sub-systems in Zhejiang Province from 2020 to 2025 under different satisfaction levels. Next, it calculates the overall population carrying capacity of Zhejiang Province. Finally, based empirical conclusions, it summarizes the research findings.

1. Literature review

There has been extensive research on regional population carrying capacity according to different ecological and resource categories. Brown and Kane (1995) examined the impact of food fluctuations on population carrying capacity. Daily and Ehrlich (1992) investigated the impact of agriculture, water, renewable, ecological, soil, forest, and other resources on population carrying capacity. Cohen (1995) estimated the impact of the economy, environment, and culture on population. Seidl and Tisdell (1999) mainly focused on estimating the capacity of culture to limit population. A series of studies have been conducted on the relationship between land, water, urban power supply, urban greening, housing prices, economic level, marine fishery resources, and population carrying capacity (Ali, 2018; Dorini, Ceconello and Dorini, 2016; Peters et al., 2016; Diachenko and Zubrow, 2015; Ma et al., 2017). Based on a review of the aforementioned literature, we find that the restrictive conditions of population carrying capacity mainly include economy, natural resources, ecological environment, and social resources. Therefore, in the empirical

analysis, this research will calculate the population carrying capacity of Zhejiang Province based on these aspects.

Quantification of a region's population carrying capacity has always been the focus of academic attention. The calculation methods include the Logistic model, resource supply balancing model, index system, and system model approaches. The Logistic model (Korobenko and Braverman, 2012; Dushoff, 2000; Scarano, 2012) is simple and easy to implement but does not consider the restrictive factors of population as it only sets a Logistic regression model based on sample data. As a result, it is commonly used to forecast population, but not a region's population carrying capacity. The resource supply balancing approach includes land resource carrying capacity (Ye, Xie and Tan, 2017), ecological footprint (Wackernagel et al., 1999; Gossling et al., 2002; Ester, 1999; Wackernagel et al., 2004), and the energy value analysis methods (Songsore and Buzzelli, 2017; Sliogeriene et al., 2009). These approaches are more inclined to consider the regional population capacity based on the ecological carrying capacity, do not involve the social and economic carrying capacity, and cannot comprehensively measure the population carrying capacity; they therefore have certain limitations. Since the 1970s, the index system approach (Gong and Jin, 2009; Zubrow, 1971; Ma et al., 2017) has been used with greater frequency. However, the complexity of the index system leads to incomplete data and high correlation between the indicators, affecting the accuracy of the study. It is therefore necessary to maintain independence between the indicators when constructing the index system. The system model approach considers research areas as a system and deduces the population carrying capacity through system optimization. This type of approach includes multi-objective decisions, scenario analysis, and system dynamics. The multi-objective decision approach (Carrion et al., 2008) first designs the development goals of the research area and calculates the population carrying capacity from the perspective of such development goals. Scenario analysis (Stewart and Scott, 1995; Brook et al., 1997; Peters et al., 2016) can essentially be viewed as a multi-objective decision approach because these two methods utilize the same processes to estimate the carrying capacity. That is, this approach builds an objective utility function (or effect function) and analyzes it using multi-level analysis. Systemic dynamics (Holt and McPeck, 1996; McCann and Yodzis, 1994; Klee and Allen, 2016; Robra and Heikkurinen, 2019) were first used by the Club of Rome to evaluate the relationship between resources (including land, water, food, minerals, etc.) and people. Domestic and foreign scholars applied the systemic dynamics approach to the study of population carrying capacity. This approach uses a differential equation system with time delay, which can conveniently deal with non-linear and time-varying phenomena, and can be used for long-term, dynamic, and strategic simulation analysis.

The aforementioned methods lay the foundation for the current study. However, most of the traditional methods of population carrying capacity analysis are based on single factors such as land resources, grain production, environmental resources, and so on. In fact, the factors affecting urban population carrying capacity are more complex. Natural resources, urban infrastructure construction, social public service system, urban ecological environment, and other factors will all become constraints of urban population development. Therefore, the population carrying capacity determined by single factor analysis has some limitations. In contrast the possibility-satisfaction (P-S) approach can incorporate many factors related to population carrying capacity through the index system design and can comprehensively consider the population carrying capacity of the region from the perspectives of possibility and satisfaction.

2. Research methodology

Two primary concepts of possibility–satisfaction model are possibility degree and satisfaction degree. In general, the possibility degree of one thing is maximum being 1 if it is doomed to happen ($P=1$); and $P=0$ if it never happens. Real numbers in the range of $[0, 1]$ indicate different levels of possibility degrees. Similarly, the satisfaction degree of one thing is 1 if it in line with people's expectations totally ($S=1$); and $S=0$ if it is totally not accepted by people. Different real numbers in the range of $[0, 1]$ indicate different levels of satisfaction degrees.

Assuming that an event has a probability curve $P(r)$ for one attribute R and a satisfaction curve $Q(s)$ for another attributes S . R , S and another attribute A satisfy a certain relationship, that is, $f(r, s, a) = 0$. Then $P(r)$ and $Q(s)$ can be merged into a possible–satisfaction curve of attribute A through certain rules, which quantitatively describes the degree of both possibility and satisfaction, and is recorded as $w \in [0, 1]$. When $w=1$, the thing is completely possible and satisfactory; when $w=0$, it is either entirely impossible or entirely unsatisfactory.

In practical application, according to the definition of possibility and satisfaction, we can express possibility and satisfaction by using the mathematical form of curves such as three-fold curve and S curve. For example, for the description of possibility degree P , we use three-fold curve follows:

$$p(r) = \begin{cases} 1, & r \leq r_A \\ \frac{r - r_B}{r - r_A}, & r_A < r < r_B \\ 0, & r \geq r_B \end{cases} \quad (1)$$

In addition to the three-fold curve, there are also S curves. This is a curve often be used. This paper mainly uses this kind of curve in the study of population capacity. Equation is described as follows:

$$p(r) = \frac{1}{1 + \exp(2 - 4 * \frac{r - r_B}{r - r_A})} \quad (2)$$

The mathematical form of the satisfaction curve $Q(s)$ is similar to that of the above probability curve. With functional expressions of , and , possibility degree and satisfaction degree can be combined to possibility–satisfaction curve:

1. When the restriction conditions are: $r = as$, $\forall r, s \in R$, the three-fold curves of and can be solved as follows:

$$w(\alpha) = \begin{cases} \frac{-r_B + \alpha s_B}{(r_A - r_B) - \alpha(s_A - s_B)}, & 0 < w < 1 \\ 1, & w \geq 1 \\ 0, & w \leq 0 \end{cases} \quad (3)$$

The S curves is:

$$w(\alpha) = \frac{1}{1 + \exp \left\{ 2 - 4 * \frac{-r_B + \alpha s_B}{(r_A - r_B) - \alpha(s_A - s_B)} \right\}} \quad (4)$$

2. When the restriction conditions are: $a = rs$, $\forall r, s \in R$, the three-fold curves of and can be solved as follows:

$$w(\alpha) = \begin{cases} \frac{1}{2} \left\{ -\left(\frac{r_B}{r_A - r_B} + \frac{s_B}{s_A - s_B} \right) + \sqrt{\left(\frac{r_B}{r_A - r_B} + \frac{s_B}{s_A - s_B} \right)^2 + \left(\frac{4\alpha}{(r_A - r_B)(s_A - s_B)} \right)} \right\}, & 0 < w < 1 \\ 1, & w \geq 1 \\ 0, & w \leq 0 \end{cases} \quad (5)$$

3. When the restriction conditions are: $a = r + s$, $\forall r, s \in R$, the three-fold curves of and can be solved as follows:

$$w(\alpha) = \begin{cases} \frac{\alpha - s_B - r_B}{(r_A - r_B) + (s_A - s_B)}, & 0 < w < 1 \\ 1, & w \geq 1 \\ 0, & w \leq 0 \end{cases} \quad (6)$$

After figuring out several possibility-satisfaction curves, some of them should be combined when making decisions. There are many combination algorithms. Here we mainly consider three types.

Assume that there are two possibility-satisfaction curves w_1, w_2 , several combination algorithms can be used for them:

1. Weak combination.

$$w_1(m)w_2 = \min \{w_1, w_2\} \quad (7)$$

2. Strong combination.

$$w_1(M.)w_2 = \max \{w_1, w_2\} \quad (8)$$

3. Weighted summation.

$$w_1(M+)w_2 = \alpha * w_1 + \beta w_2, \quad \alpha + \beta = 1 \quad (9)$$

3. Empirical analysis and results

There are four steps in calculating population carrying capacity using the P-S model: construction of an index system, estimation of extreme values corresponding to possibility and satisfaction, calculation of population carrying capacity of sub-systems, and calculation of total population carrying capacity.

3.1. Construction of the index system

This paper selects four sub-systems to construct the index system: economy, society, resources, and environment.

In the economic sub-system (figure no.1), we use GDP, local financial revenue, and total retail sales of consumer goods to measure the scale of regional economic development from three aspects: the degree of regional economic development, the vitality of regional economic development, and the degree of regional economic prosperity. The output value of tertiary industry can well reflect the regional economic structure, and the number of employees can reflect the scale of employment, which is also a symbol of regional economic development. The corresponding per capita indexes reflect the relationship between population and economic systems.

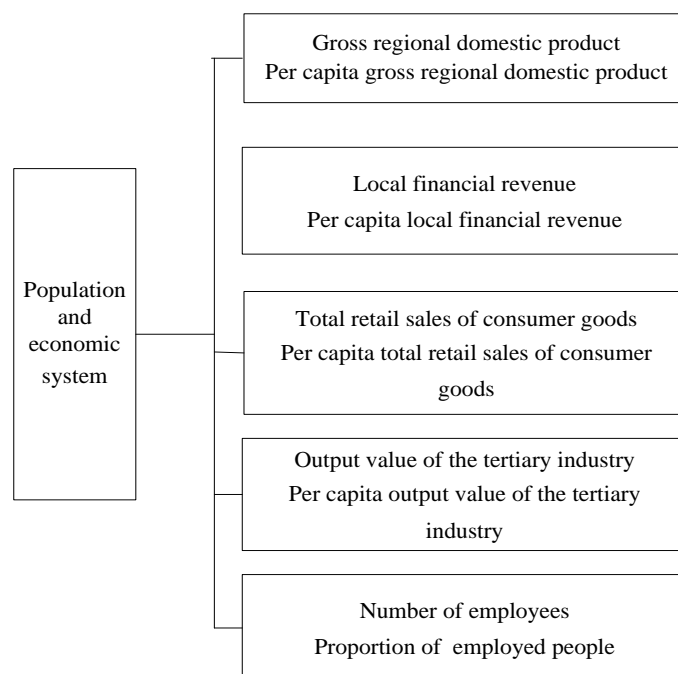


Figure no. 1: Population and economic index sub-system

In the social sub-system (figure no. 2), miles of highway reflects the level of infrastructure construction, the number of beds and staff in health institutions reflect the level of development of social medical and health services, and the number of students enrolled and faculties reflects the scale and level of development of educational resources in the region. Correspondingly, the per capita indexes are used to reflect the correlation between population and social resources.

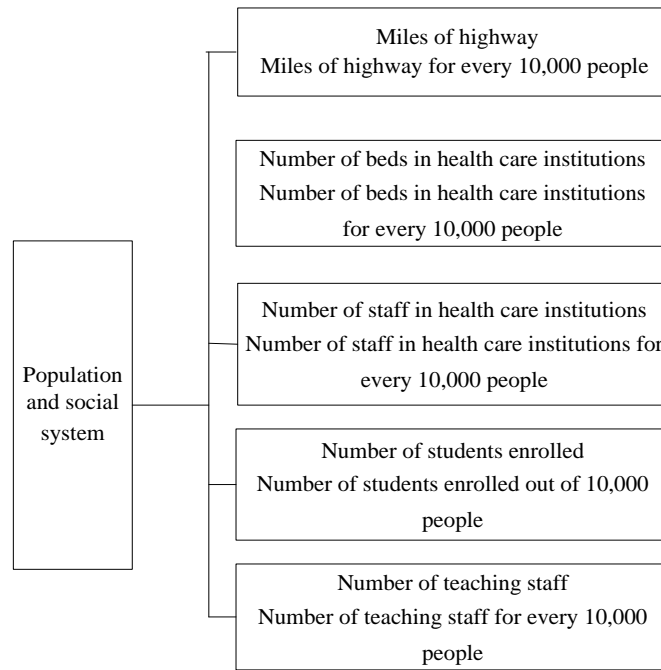


Figure no. 2: Population and social index sub-system

In the resource sub-system, tap water consumption, total electricity consumption, and living area are used to reveal the relationship between population and resources. Corresponding per capita indexes show the relationship between population and basic resources. (Figure no. 3)

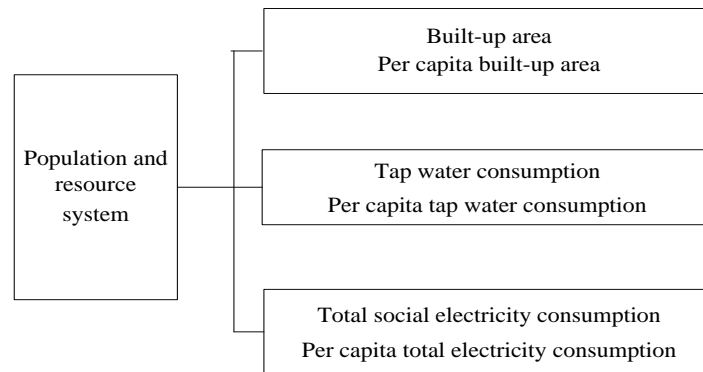


Figure no. 3: Population and resource index sub-system

In the environmental sub-system (figure no. 4), green areas and disposal capacity of domestic waste are selected as the indicators to measure the environmental level. The corresponding per capita indexes are used to reflect the relationship between population and environment.

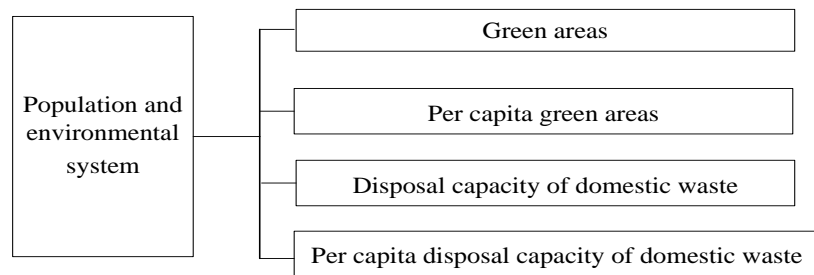


Figure no. 4: Population and environmental index sub-system

3.2. Estimation of extreme values corresponding to possibility and satisfaction

First, we construct corresponding linear or non-linear models based on historical data of each index and also ensure that the model regression parameter passes the examination with significance of . Second, we use the model to estimate the value of this index from 2020 to 2025. We then calculate the variance and standard error of sample distribution and obtain the prediction interval of each index with confidence coefficients of 95%. Finally, we consider the critical value of the prediction interval as the peak value of the index and estimate the corresponding P-S. Due to space limitations, table no. 1 only presents the calculation data for 2025.

In the economic sub-system, Zhejiang's GDP in 2025 is most likely to reach 7.238 trillion yuan. The satisfaction degree is highest when per capita gross regional product reaches 135,100 yuan, but is the lowest when per capita gross regional product is 91,500 yuan. Similarly, the possibility and satisfaction degrees of other indexes can be calculated with coefficients of 95%. The results are presented in table no. 1.

Table no.1: P-S extreme values of each sub-system in 2025

sub-system	index	Minimum possibility degree(0)	Maximum possibility degree(1)	Lowest satisfaction degree(0)	Highest satisfaction degree(1)
Economic	Gross regional domestic product (trillion yuan)	7.7267	7.2380		
	Per capita gross regional product (10,000 yuan per person)			9.15	13.51
	Local financial revenue (trillion yuan)	1.2111	1.0378		
	Per capita local financial revenue (10,000 yuan per person)			1.33	2.14

sub-system	index	Minimum possibility degree(0)	Maximum possibility degree(1)	Lowest satisfaction degree(0)	Highest satisfaction degree(1)
Economic	Total retail sales of consumer goods (trillion yuan)	3.7827	3.3208		
	Per capita retail sales of consumer goods (10,000 yuan per person)			4.30	6.66
	Output value of the tertiary industry (trillion yuan)	4.1543	3.6638		
	Per capita output value of the tertiary industry (10,000 yuan per person)			4.88	7.30
	Total number of employees (10,000 persons)	4614.65	4131.93		
	Total proportion of employees to total population (%)			33.55	67.09
Socials	Miles of highway (10,000 km)	14.50	13.44		
	Per capita highway mileage (km/10,000 persons)			21	35
	Number of beds in health care institutions (10,000 beds)	43.01	37.33		
	Number of beds in health care institutions for every 10,000 people (beds/10,000 persons)			55.42	74.53
	Number of staff in health care institutions (10,000 persons)	77.17	72.31		
	Number of staff in health care institutions for every 10,000 persons			98.23	133.68
	Number of students (10,000 persons)	962.18	922.15		
	Number of students in every 10,000 persons			800	1500
	Number of teaching staff (10,000 persons)	90.95	90.20		
	Number of teaching staff for every 10,000 persons			100	200

sub-system	index	Minimum possibility degree(0)	Maximum possibility degree(1)	Lowest satisfaction degree(0)	Highest satisfaction degree(1)
Resource	Built-up area (square kilometers)	3600.05	3503.54		
	Per capita built-up area (square meters per person)			50.01	61.48
	Tap water consumption (billion tons)	216.62	179.50		
	Per capita tap water consumption (ton per person)			300	400
	Total Electricity Consumption (billion kwh)	6014.84	5567.26		
	per capita Electricity Consumption (10,000 kwh per person)			0.74	1.04
Environment	Green areas (billion square meters)	24.94	21.60		
	Per capita green area (square meter per person)			28.14	43.72
	Domestic Waste Disposal Capacity (ton per day)	84530	71246.85		
	Per capita disposal capacity of domestic waste (ton per day per person)			0.0011	0.0015

3.3. Calculation of population carrying capacity of sub-systems

According to equation (4), the following curve (figure no. 5) is obtained by substituting the interval values of GDP and per capita GDP.

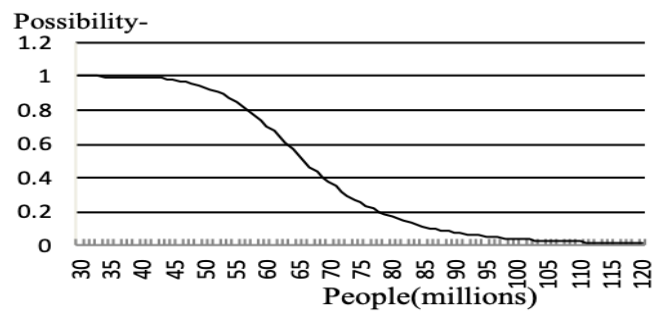


Figure no. 5: P-S curve of gross regional domestic product

The P-S curves of local financial revenue, total retail sales of consumer goods, output value of tertiary industry, the number of employees can be obtained using similar methods. Therefore, the P-S degree curve of population and economic system (figure no. 6) is obtained according to equation (9).

According to figure no. 6, when the population is less than 64 million, the P-S degree starts to decline rapidly. Thus, given the relationship between population and economy, the population of Zhejiang Province should be kept below 64 million.

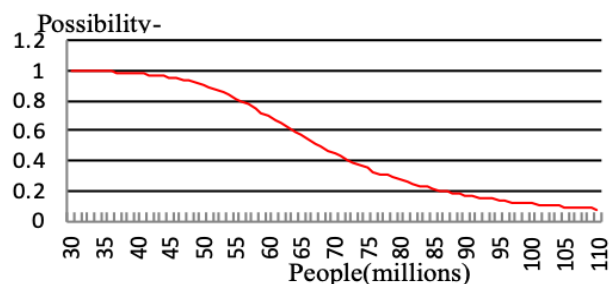


Figure no. 6: P-S curve of economic system

Using the same method, we obtain the P-S curves of society, resources, and environment. For ease of comparison, four sub-system curves are shown in figure no. 7.

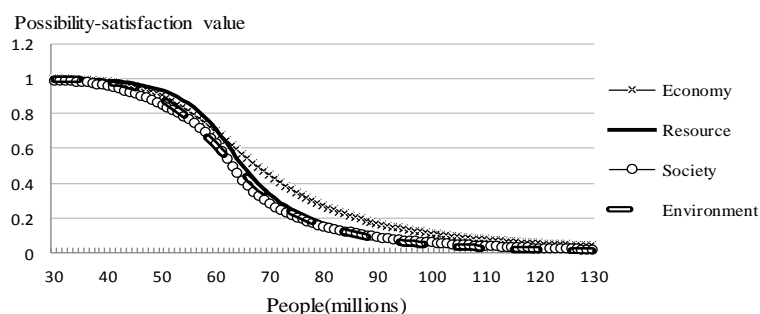


Figure no. 7: P-S curves of four sub-systems

Table no. 2 shows the population carrying capacity of four sub-systems under different P-S values.

Table no. 2: Population carrying capacity of Zhejiang Province in 2025 under single system constraints (unit: millions of people)

P-S values	Economy	Society	Resources	Environment
>0.9	0-50	0-46	0-52	0-49
0.90	51	47	53	50
0.80	55	54	57	54
0.70	60	58	60	57
0.60	64	60	63	60
0.50	68	63	65	64
0.40	72	65	68	67
0.30	78	69	72	71

P-S values	Economy	Society	Resources	Environment
0.20	87	75	77	77
0.10	103	89	90	87
<0.1	>103	>89	>90	>87

According to figure no. 7 and table no. 2, we find that the carrying capacity of different sub-systems is different. Generally speaking, the carrying capacity of economy and resources is greater while the capacity of society and environment is weaker. When the P-S value is high ($P-S > 0.8$), the main factors restricting population growth are social and environmental factors. As the P-S values gradually decrease ($0.6 < P-S < 0.8$), the main factors restricting population growth are environmental factors.

This is also in line with the reality. Economic development requires the support of the population. Economic system has the strongest demand in terms of population and the strongest carrying capacity. Zhejiang Province is rich in water resources. In addition, as an economically developed province, it has abundant power resources and strong resource carrying capacity. Population has the most significant impact on social system, which represents the carrying capacity of education, medical treatment, and transportation. The population has surged in a short period of time and the corresponding support facilities of education, medical treatment, and transportation have not kept up, which has resulted in the social system having the weakest carrying capacity. The environmental system represents the carrying capacity of garbage disposal and environmental protection. With the development of the economy and the high concentration in cities, the disposal capacity of garbage is improving but the production of domestic garbage is also increasing. As the satisfaction value has continued to fall, the environment has gradually become an important factor restricting population growth.

3.4. Calculation of total population carrying capacity

According to equation (9), the weight of each system was set as 0.25 and is used to calculate all P-S values. The total population P-S curve is presented in figure no. 8. According to Chart 8, when the population is larger than 62 million, it will exceed the population carrying capacity of Zhejiang Province. When the population is between 59 million and 62 million ($0.6 < P-S < 0.7$), which is still acceptable. When the population is between 55 million and 59 million ($0.7 < P-S < 0.8$), the status is better. As the population decreases, the status is getting better. When the population is less than 49 million ($P-S > 0.9$), which is optimal.

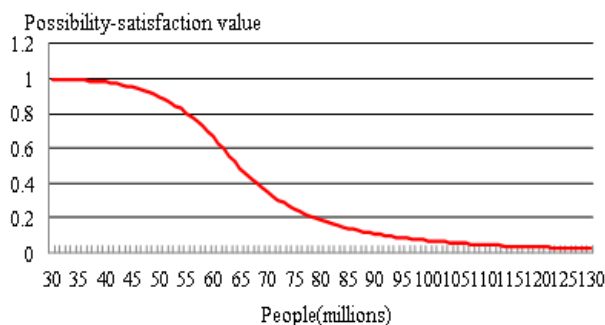


Figure no. 8: Total P-S curve of Zhejiang Province in 2025

Conclusions

In this paper, we applied the P-S model to predict the population carrying capacity of economic, social, resource, environmental system, and then calculated the total population carrying capacity of Zhejiang Province. According to the empirical results, the following conclusions are drawn:

(1) In 2025, the maximum carrying capacity of the population in Zhejiang Province is 62 billion. The total population carrying capacity calculated using the P-S method (Chart no. 8) reveals that when the population is more than 62 million, the P-S ratio is less than 0.6. This population increase will conflict with economic development, supply of resources, social stability, and the protection of the environment, thus reducing the social satisfaction to below the acceptable minimum.

(2) According to the current population development trend, the population of Zhejiang Province is still within acceptable range in 2025. In 2018, the population was 57.37 million with a natural growth rate of 5.44%, and from 2009 to 2018, the average natural growth rate was 5.011%. Based on the 2018 natural growth rate, the population will have reached only 59.59 million by 2025. At this time, population growth is still within the acceptable range but will have reached the critical value for social and environmental systems.

(3) Generally speaking, the population carrying capacity of the social system is the weakest. In the four sub-systems of economy, society, resources, and environment, the carrying capacity of society is relatively weak. When the P-S value is 0.9, the population carrying capacity of the social system is only 47 million. Compared with the current population of 57.37 million people, it can only reach the level of normal acceptance. Moreover, with the increase in population in the future, there will be increased pressure on medical treatment, education, and transportation systems. Therefore, how to improve the population carrying capacity of the social system will be a significant challenge.

(4) Different P-S values correspond to different constraints. When $P-S > 0.8$, population growth is constrained by both social and environmental factors. When $P-S$ is > 0.6 to < 0.8 , population growth is constrained by environmental factors. When $P-S$ is > 0.2 to < 0.6 , population growth is constrained by social factors. When $P-S$ is < 0.2 , population growth is constrained by environmental factors. That is, when society is harmonious and stable, there should not only be adequate medical, educational, and transportation supplies, but also comfortable environmental protection. In the worst case, the environment is the ultimate bottom line. If the population increases to more than 87 million in 2025, the environmental system will collapse first.

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