The Analysis and Simulation of the Materials Inflow and Outflow of Macao

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Abstract: *The metabolism of a city can be seen as the process of transforming all the materials and commodities for sustaining the city's economic activity. The Macao Special Administrative Region (SAR) is a highly developed metropolitan region where prosperous tourism has made it possible to support a population of 0.54 million people on an area about 29.2 km^2. This paper highlights the economic and environmental transformation of Macao by emphasizing the following aspects: the population trends, tourists changing trends, GDP, foreign investment trends, material resource consumption and waste generation, so as to forecast the trend of the Macao development and provide valuable reference to government policy makers.*

Keywords: material flow analysis; Stella; system dynamics; simulation; Macao

1. Introduction

Increasing urbanization continues to rely on different resource intakes and with disposal of wastes. Modern cities are characterized by the routine use of energy for power production, transportation of goods, construction of building and infrastructure as well as domestic comfort. For instance, they stop relying on resources from local regions to keep their fossil fuel powered vehicles running. They have to rely on the ecosystems beyond the city limit. As they draw more and more resources from far off areas, they also accumulate large amounts of materials within their area (Huang and Hsu, 2003).

Compared with other ecosystems, the urban systems are relatively immature due to rapid growth and inefficient use of resources. Odum (1996) observed that cities were one of the heterotrophic ecosystems in the biosphere and as good parasites not destroying their host, rather, remaining in symbiotic relationship with each other. From this point of view of system ecology, cities are self-regulating systems and may be seen as super-organisms, created for the benefit of human beings and for sustaining their livelihood. Cities can not be self-regulating without maintaining stable links with the hinterland from which they draw energy, food, materials and into which they release their wastes.

The classical Second Law of Thermodynamics states that for a closed, isolated, physical system, entropy will always tend to increase to maximum. Furthermore, it cannot be decreased without opening up the system and supplying some free energy from the outside. When useful free energy is used up it is degraded into heat energy and entropy increases. To sustain the globe biosphere, negative entropy flows would input to the system, this negative entropy is either the usable mineral stocks in the earth's crust or the products synthesized by autotrophic organisms in the biosphere.

The materials, energy, and food supplies brought into cities, transformed within them and the products and wastes sent out from the cities are often referred to as the urban metabolism. The metabolic cycle is not completed until the residues of daily consumption have been removed and disposed of adequately with minimum nuisance and hazard to life (Newman, 1999).

At the beginning of the 20th Century, different scientists working in diverse fields formulated the main characteristics of systems thinking. The most important thinking of system was the shift from the parts to the whole, considering that living systems as integrated wholes with properties that could not be reduced to those of smaller parts (Odum, 1994). A system lost its properties as a system when its elements were taken apart and isolated. Modeling has been used for years to help scientists and policy makers find solutions to complex problems. It was one of the most valuable and useful applications of mathematics. Modeling and simulation were intellectually creative and quantitatively rigorous and as mainstream ways of connecting ideas with reality (Odum and Odum, 2000).

In 1970, John Collins and Jay Forrester published a book titled Urban Dynamics (1970); the model in their books was very controversial, because it illustrated why many well-known urban policies were either ineffective or making urban problems worse. Other applications in urban ecology have used a mathematical ecology approach. Mathematical models of the urban dynamic constructed by Allen and Deneubourg (1978) and Wilson (1981) were believed to be among the first attempts to adapt a nonlinear ecological approach (Allen and Deneubourg, 1978; Wilson, 1981). Systems Dynamics thinking software like STELLA offered an opportunity to learn how systems and their components grew and changed (Lei and Wang, 2008). In this paper, using the dynamic principle, we created a dynamic model to simulate the material flow tends by employing the STELLA software.

2 Methodologies

With the population of 538,100, Macao lies between the longitude of 111^{o}31’33”E and 111^{o} 35’43”E, and the latitude of 22^{o} 06’39” N and 22^{o} 13’06”N.It is located at the west side of the Pearl River estuary. Its annual temperature is 22.3^{0}C (DSEC, 2008) and it is situated near the southern edge of the north tropic. Its area was 29.2 sq km in 2007, consisting of Macao Peninsula, Taipa, Coloane and Cotai reclaimed area (Fig. 1).

System dynamics is a methodology for studying and managing complex feedback systems to study the world around us. The central concept to system dynamics is to understand how all the objects in a system interacting with one another. The objects and people in a system interact through "feedback" loops, where a change in one variable affects other variables over time, which in turn affects the original variable, and so on. What system dynamics attempts to do is to understand the basic structure of a system, and thus underling the behavior it can produce. Many of these systems and problems which are analyzed can be built as models in a computer. The data used in this paper are cited from the Year books and relevant website of Macao’s statistics from 2001 to 2007， when Macao’s economy was booming, and tourists increased quickly.

In this study, a system dynamics approach allowed us to synthesize information about different components of the urbanization process and to analyze their dynamics over time. The sub-model of the Macao’s ecological and economical model included 3 main sub-models (Fig. 2).

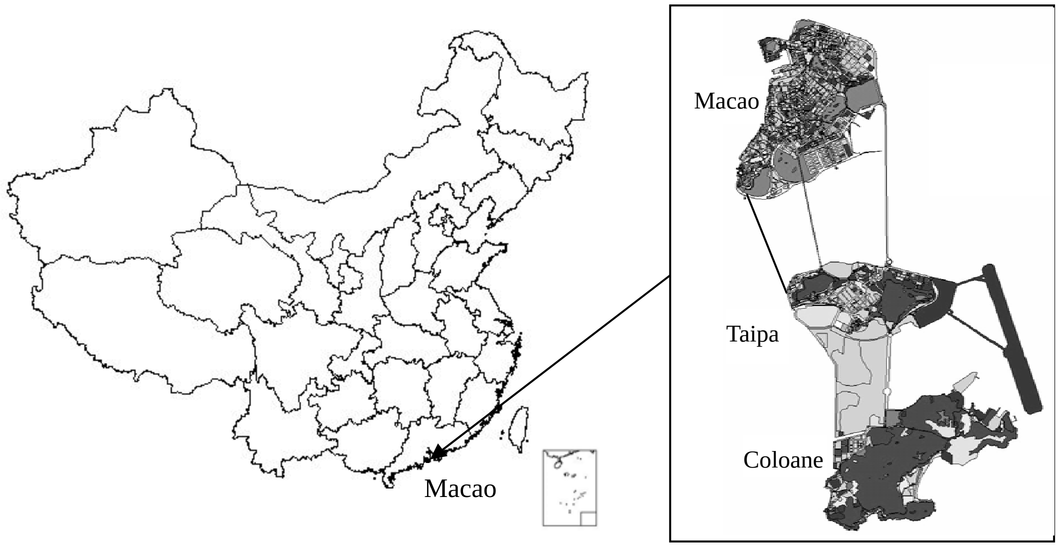

Fig. 1. Location of Macao.

Correlation analysis was performed among various parameters in the relevant ecological system in Macao, such as population, *GDP*, tourists, area, population density, wastes and time. As for those correlation coefficients bigger than 0.9, it was assumed that the level of correlation was high and therefore reliable. All the statistic data were from DSEC. The following equation shows the primary relations in the generation of flows of input to or outflow from Macao:

Flows=f(Population, GDP, Tourist, time,…)

We made the flows to be dependant variable and setting up the corresponding regression equation by using statistics software. A system dynamics simulation tool – STELLA was used to perform the simulation, and correlation analysis of the parameters and selection of suitable equations were carried out by statistic analysis software – SPSS (SPSS Inc., Chicago, Ill.). Most of the information about Macao flows, especially parameter values, was obtained from The Statistics and Census Service (2008).

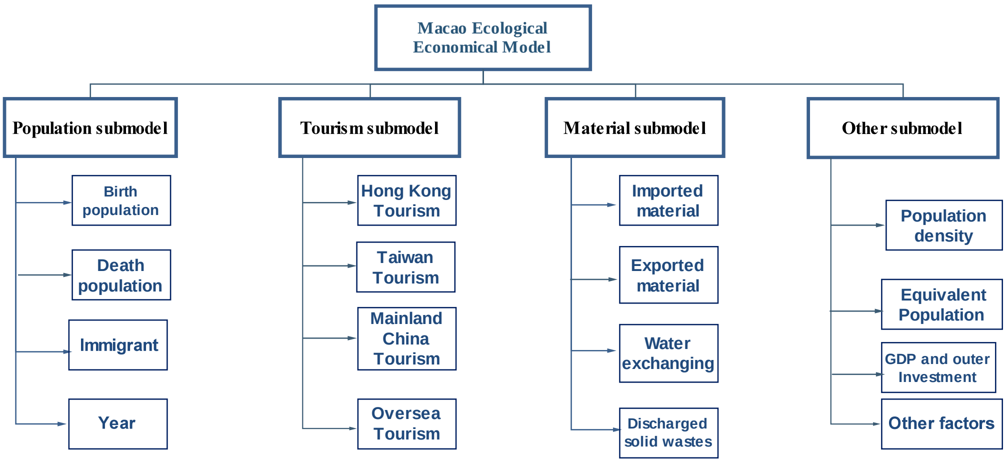

Fig. 2. Conceptual representation of model structure

Based on the results of the correlations among the cited data, we have obtained some parameters which were run by SPSS from the foundational statistical analysis and a set of the potential formula was listed. Then we selected out the most suitable equations through comparison of the real data and the simulated data. Finally, linking up the relative equations, the model for simulating the materials inflow and outflow flows Macao was formed. A graph of the generation of Macao flows from 2007 to 2017 was derived by running the model.

2.1 Population sub-model

The population sub-model simulates total population in Macao and interacts with the three sectors through the birth, death and immigration and the relevant reclamation action with will influence the population density. Macao is one of the most densely populated regions in the world, with a population density of 18,007 persons per square kilometer (DSEC, 2008). According to the 2007 by-census, 47% of the residents were born in mainland China, of whom 74.1% born in Guangdong and 15.2% in Fujian. Meanwhile, 42.5% of the residents were born in Macau, and those born in Hong Kong, the Philippines and Portugal shared 3.7%, 2.0% and 0.3%, respectively (DSEC, 2008).

The growth of population in Macao mainly is due to immigrants from mainland China and the influx of overseas workers since the birth rate of Macao is one of the lowest in the world. According to a recent survey conducted by the U.S. Central Intelligence Agency (CIA), Macao is the top country/region for life expectancy with an average of 84.33 years (CIA, 2007), while its infant mortality rate of Macao ranks among the lowest in the world.

The population sub-model included 2 parts (Fig. 3). The left part refers the local population, and is divided to 5 groups of Youth (0-14), Adult (15-39), Middle Age(40-59) , Elderly (60-74) and Geriatric(≧ 75). In the past 10 years, the real population change data and age distribution were listed in Table 1. The average birth rate and death rate were shown in Table 2.

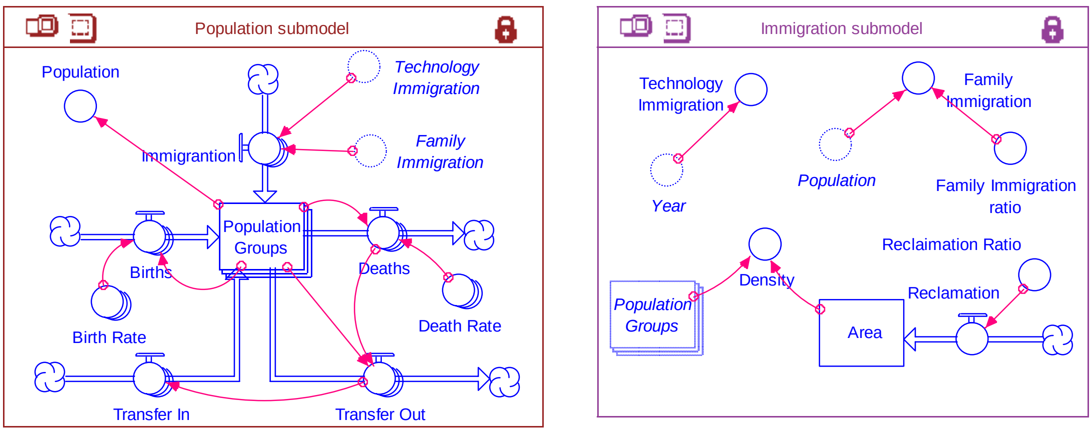

Fig. 3 The population sub-model of Macao

The data were collected from the website provided by Department of Macao, Statistics and Census Service. The actual birth rate and the relevant actual death rate were in the following:

$$\text{Actual birth rate} = \text{birth} / \text{total population} \quad (3)$$

Actual death rate of age group= death in age group / population in that group (4)

Table 1 The mortality and the relevant population in different age groups of Macao from 1998 to 2007

Year	Youth (0-14)	Adult (15-39)	Middle Age(40-59)	Elderly (60-74)	Geriatric(≧ 75)	Total population	Legal Immigrant
1998	104803/44	177536/98	102919/198	28765/368	11167/648	425190/1356	3700
1999	102579/26	177373/126	109670/224	28493/389	11517/609	429632/1374	5957
2000	99026/26	176106/86	115914/211	28623/351	11837/664	431506/1338	4046
2001	92932/22	176737/96	124870/220	28754/345	13007/644	436300/1327	6980
2002	88544/18	176009/97	133097/255	29044/337	13821/708	440515/1415	7202
2003	83993/8	177624/89	141140/258	29372/368	14555/751	446684/1474	5242
2004	80559/16	185797/100	150313/282	30441/381	15527/754	462637/1533	14164
2005	77849/23	198735/79	159169/314	32122/354	16402/845	484277/1615	14730
2006	75372/14	217348/79	169301/344	34273/351	17133/778	513427/1566	11438
2007	72600/22	231000/91	178700/290	37300/339	18500/803	538100/1545	8102

Note: The number in each cell was population over death. The data were cited form DSEC, 2008.

Table 2 The average birth rate and death rate in different age groups of Macao from 1998 to 2007

	Youth (0-14)	Adult (15-39)	Middle Age(40-59)	Elderly (60-74)	Geriatric (≧ 75)
birth rate	0	0.017864	0.000718	0	0
death rate	0.0002574	0.0005242	0.0020254	0.0120693	0.0520038

The immigration policy of investment promoting the immigrant increase since 2003 was ended in 2006. We divided the immigration population into family immigrant and technology immigrant (Lam et al., 2008):

1). Quantity of the family immigrant: The Mainland China immigrant was about 2201 in 2007 for family reunion. We assumed that the number of other family immigrant was half of 2201 to about 1101. Then the total family immigrant should equal to 3302, obtained by multiplying the family immigrant rate (0.006136) and the population of 2007 (538100).

The quantity of family immigrant = population ×family immigrant rate (5)

2). Quantity of the technological immigrant: In 2007 the technological immigrant was about 4800, we assumed there should be a fluctuation in the scope of 1000 person, the cycle of the fluctuation was about 10 years from past statistical data.

Quantity of technological immigrant =4800-1000×SIN ((year-2007)×2×PI/10) (6)

Citing the distribution data from the Mainland immigrant of relevant age group, we used Youth group 20%, Adult Group 62%, Elder Group 18% from the immigrant distributed data of 2007.

2.2 The Tourist sub-model

The gaming, tourism and hospitality industry were estimated to contribute more than 53.3% of Macau's GDP and 75% of Macau government revenue. From 9.1 million visitors in 2000, new arrivals to Macau has risen to 27 million in 2007, with over 55.2% coming from mainland China, 30.3% from Hong Kong, 5.3% from Taiwan and 9.3% from overseas countries (Lei et al., 2008). The number of tourists of Macao coming from Mainland China, Hong Kong, Taiwan and Oversea due to the influence of different economical and political factors etc, were shown in Fig. 4.

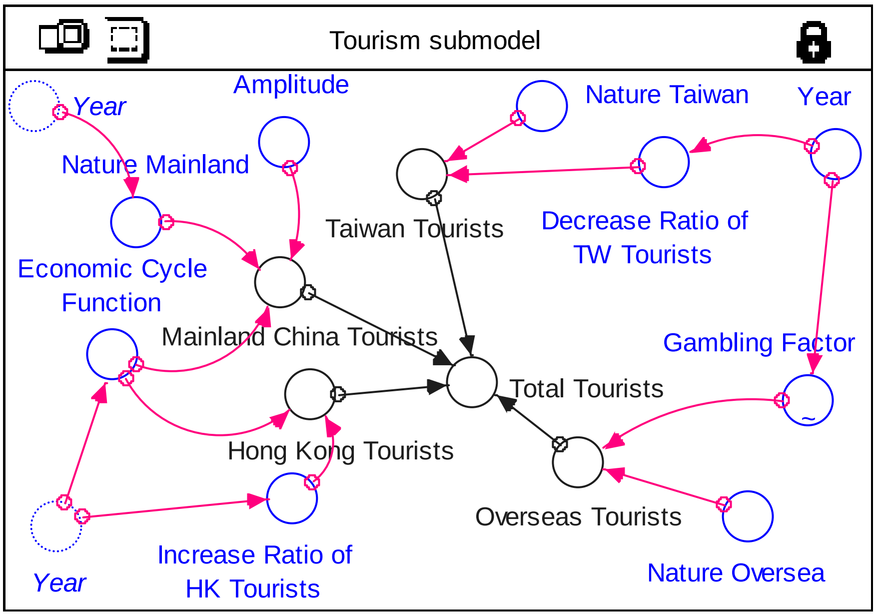

Fig. 4 The sub-model diagram of the categories for tourists of Macao

Table 3 showed the tourists changes in the past 9 years for tourists coming from four places, namely Mainland China, Hong Kong, Taiwan and Overseas.

Table 3 Tourist data of Macao from 1999 to 2007

Year	Tourist	Mainland China	Hong Kong	Taiwan	Overseas
1999	7.44E+06	1.65E+06	4.23E+06	9.85E+05	5.84E+05
2000	9.16E+06	2.27E+06	4.95E+06	1.31E+06	6.22E+05
2001	1.03E+07	3.01E+06	5.20E+06	1.45E+06	6.25E+05
2002	1.15E+07	4.24E+06	5.10E+06	1.53E+06	6.56E+05
2003	1.19E+07	5.74E+06	4.62E+06	1.02E+06	5.00E+05
2004	1.67E+07	9.53E+06	5.05E+06	1.29E+06	8.05E+05
2005	1.87E+07	1.05E+07	5.61E+06	1.48E+06	1.15E+06
2006	2.20E+07	1.20E+07	6.94E+06	1.44E+06	1.63E+06
2007	2.70E+07	1.49E+07	8.17E+06	1.44E+06	2.51E+06

1).Natural tourists

Natural tourists were the potential quantity of tourist that was not influenced by the foreign condition except distance, economy, and culture and language background. We defined the four kinds of Natural tourists as Natural_Mainland, Natural_Taiwan, and Natural_Overseas.

2). Factors of the model

We assume four factors that would affect the quantity of tourist of Macao, and they were Gambling Factor, Economic Cycle condition, Decrease Ratio of Taiwan Tourists and Increase Ratio of HK Tourists.

3). The equation for different regions of the tourist

Mainland Tourists=Natural_Mainland+Amplitude×Economic_Recycle__Function
=-1008670000+(5.10E+05) ×Year+ Amplitude×Economic_Recycle__Function (7)

Hong Kong Tourists=(6000000+500000×(Economic_Recycle_Function+3))
×Increase_Ratio_of__HK_Tourists (8)

Taiwan Tourists =Natural_Taiwan×Decrease_Ratio_of__TW_Tourists
=1454796×Decrease_Ratio_of__TW_Tourists (9)
Natural_Overseas = 2508458
Others country Tourists = Gambling_Factor×Natural_Overseas (10)
= Gambling_Factor×2508458 (11)

2.3 Equivalent Population, GDP and the Foreign Investment

The tourists were the main part of the moving population， we could convert them to tourists equivalent population based on the consumption factor and the stay days of the average tourist with the equation as：

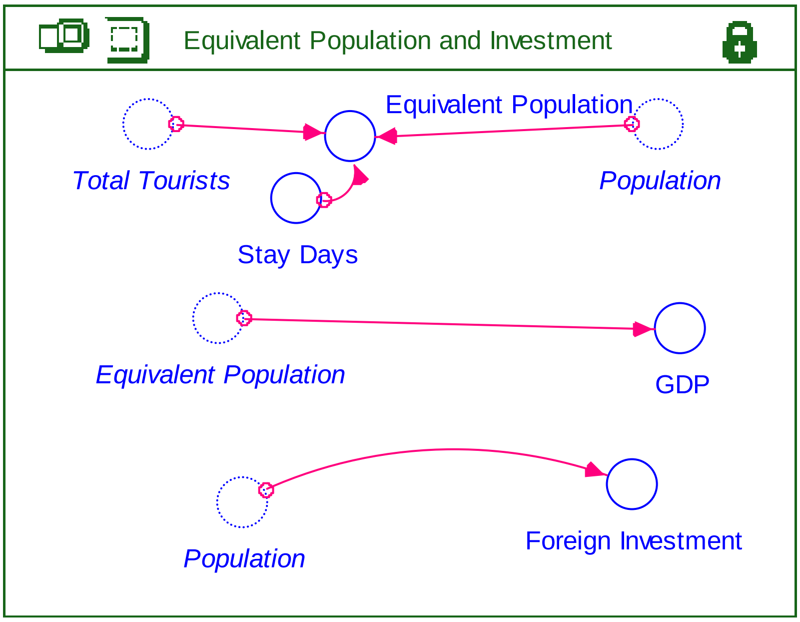

Fig.5 The Equivalent Population, GDP and the Foreign Investment

Tourists equivalent population =Tourist × Stay_Days × consumption factor/365=Total_Tourists×Stay_Days×1.9/365 (12)
Equivalent Population=Macao population+ tourist equivalent population (13)

Table 4 Local GDP and Foreign Investment of Macao from 2001to 2007

	2001	2002	2003	2004	2005	2006	2007
GDP	4.97E+10	5.48E+10	6.36E+10	8.30E+10	9.30E+10	1.15E+11	1.54E+11
Foreign Investment	2.38E+13	2.61E+13	2.85E+13	3.12E+13	4.02E+13	5.21E+13	6.30E+13

We assumed that foreign investment would influence the material inflows of Macao, and we included those two factors into our model. The regression equations and R^2 for GDP and the foreign investment was obtained by running the SPSS software, assuming the finance crisis did not occurred.

Table 5 Regression equations and R^2 for GDP and Foreign Investment

	Regression Equation	R^2
GDP	EXP(28.435+(-1867585.864/Equivalent_Population))	0.989
Foreign investment	EXP(38.198+(-2216361.678/Total_Population))	0.997

2.4 The sub-model of the Material inflow

Macau's economy was based largely on tourism and much geared toward gambling. Other chief economic activities in Macau were export-geared textile and garment manufacturing, banking and other financial services (DSEC, 2008).We divided the imported material of Macao into five categories as food, water, fuel, mineral, raw materials and goods (Fig. 6). The out flow material included raw and production, solid wastes and sewage. The statistical data from 2001 to 2007 were shown in Table 6.

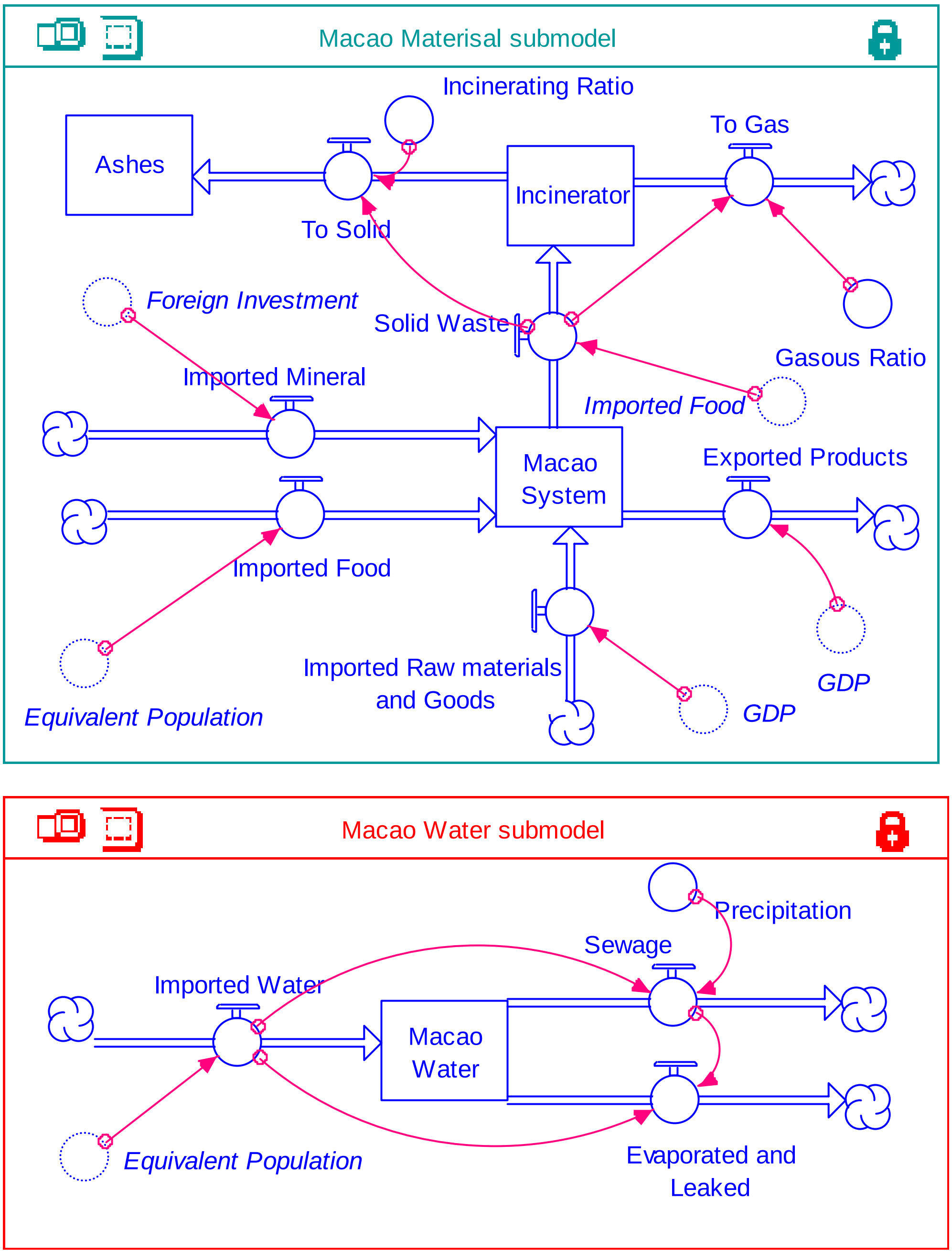

Fig. 6 The Material Inflows (Middle) and Discharged Sewage (Lower) of Macao

Table 6 The imported materials statistical data of Macao from 2001to 2007 (Unit: kg)

Year	Food	Tap water	Fuel	Mineral	Raw materials and Goods
2001	2.46E+08	5.45E+10	5.80E+08	7.49E+08	4.56E+08
2002	2.73E+08	5.46E+10	5.99E+08	7.04E+08	5.74E+08
2003	2.98E+08	5.67E+10	6.13E+08	8.73E+08	8.51E+08
2004	3.36E+08	5.88E+10	7.47E+08	9.50E+08	9.43E+08
2005	3.86E+08	6.15E+10	7.73E+08	1.80E+09	1.70E+09
2006	4.17E+08	6.74E+10	7.45E+08	3.22E+09	1.96E+09
2007	4.18E+08	7.46E+10	7.38E+08	3.79E+09	1.87E+09

Table 7 The exported product and the discharged wastes statistical data of Macao from 2001 to 2007

	Exported Product	Precipitation	Solid waste	Sewage
2001	2.57E+08	2.56E+03	2.33E+08	5.3E+10
2002	2.88E+08	2.18E+03	2.43E+08	5.33E+10
2003	3.00E+08	1.49E+03	2.49E+08	4.88E+10
2004	3.62E+08	1.52E+03	2.56E+08	5.53E+10
2005	3.34E+08	1.90E+03	2.79E+08	5.56E+10
2006	3.89E+08	2.00E+03	2.86E+08	5.54E+10
2007	4.35E+08	1.47E+03	2.88E+08	6.12E+10

Table 8 The Person Correlation Analysis of the collected Factors of Macao

Factors	Food	Tap water	Fuel	Mineral	Imported Raw materials & Goods	Exported Raw materials & Product	Solid waste	Sewage
Tourist	0.95	0.98	0.81	0.95	0.92	0.97	0.94	0.86
Local Resident	0.95	0.99	0.75	0.98	0.94	0.94	0.95	0.81
Equivalent population	0.94	0.99	0.77	0.97	0.93	0.95	0.94	0.84
GDP	0.92	0.99	0.75	0.96	0.90	0.96	0.92	0.84
Foreign Investment	0.92	0.99	0.70	0.99	0.92	0.92	0.93	0.81
Year	0.99	0.94	0.86	0.91	0.96	0.96	0.98	0.73
Precipitation	-0.51	-0.47	-0.51	-0.33	-0.41	-0.64	-0.47	-0.22

The Person Correlation Analysis of the Factors was listed in Table 8. It showed that fuel and sewage had a relation coefficient between 0.70 and 0.86, the other factors had a very close relationship with each other (more than 0.91) except precipitation. In order to briefly analyze the material exchange of among Macao and the exterior systems, we chose the data of 2007 listed in Table 9. The total net imported material of Macao was 5.35×10^{5} ton (Table 9, Fig.7) in 2007, imported water being the first with the quantity of 7.46×10^{8} ton, followed by the minerals and goods.

Table 9 Material flow analysis of Macao in 2007

Note	Item	Import (kg)	Export(kg)	Net Import (kg)	Export/import（%）
1	Water	746241150000	0	746241150000	0
2	Electricity	1683GWH	0	1683GWH	NA
3	Foods	418190000	6999000	411191000	1.67
4	Fuels	737740000	100720	737639280	0.01
5	Minerals	3787336000	1135000	3786201000	0.03
6	Raw and processed materials	765218000	230432000	534786000	30.11
7	Goods	1109072000	204430000	904642000	18.83
Total		81441670000	419871000	81021799000	0.52

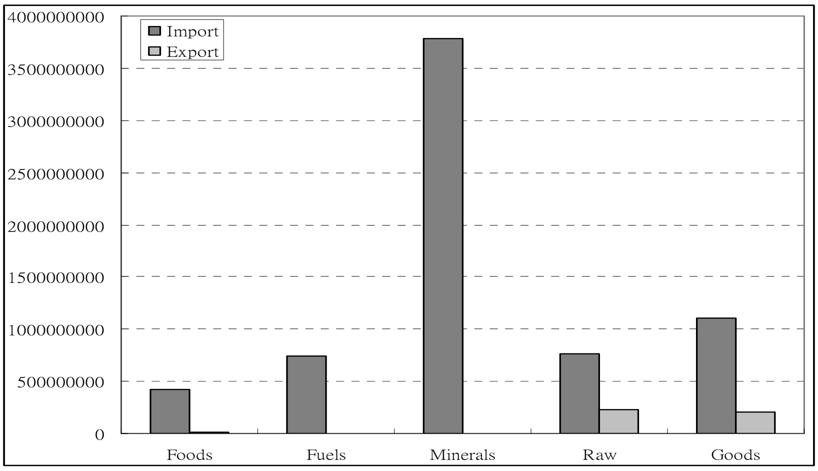

Fig. 7 Materials imported and exported of Macao in 2007

Through the metabolism of the city, 61.47×10^6 tons sewage was discharged and 1.44×10^6 tons goods and processes materials were exported. Table 8 showed the imported fuel had a low correlation with the relevant factors, and it had a small quantity in the total imported material (less than 2%), so we excluded this part in our modeling. After running the SPSS software, we got the regression equation listed in Table 10. We also found that the imported food had a very close relationship with the solid waste (R^2 equaled 0.927).

After the incineration, the volume of the solid waste was reduced to about 25 %(Incinerating Ratio), the other materials were changed to the gases and emitted to the atmosphere (Gaseous Ratio was about 75%). For the sewage of Macao, we found it correlated with imported water and precipitation, the precipitation was assumed randomly among from 1466.4mm to 2555.8 mm form 2001to 2007.

Table 10 Regression Equation of the material exchanging between Macao and exterior systems

Item	Regression Equation	Curve	R^2
Imported food	9.232E8+(-3.321E14/Equivalent_Population)	Inverse	0.934
Imported water	Exp(23.876+((1.660E-6)* Equivalent Population))	Growth	0.992
Imported minerals	EXP(23.113- 6.975E10/Investment)	S Curve	0.954
Imported Raw	EXP(22.239+(-1.123E8)/GDP)	S Curve	0.927

material and Goods			
Exported Product	-2.357E9+(1.479E8* LOGN(GDP))	Logarithmic	0.950
Solid wastes	EXP(18.970+ (1.211E-9*imported food))	Growth	0.990
Sewages	2.252E10+imported water*0.465+ Precipitation*1986689.325	Liner	0.715

3. Conclusions and Discussion

Macao is a small city lacking of natural water. Most of Macao's materials come from the other countries or regions, and its production will be exported to international market. At the same time it will discharge sewage and with treatment of its solid wastes. We will deal with the above processes in the following sections.

3.1 Population, Equivalent population, and Tourists of Macao

After running the model, we got the simulated result of population, tourists, and the equivalent population from 2007 to 2017 as showed in Figure 8. It was estimated the result for local resident would rise, while that of the tourists were fluctuating with the impact of neighboring economy and regional political situations. The combined population (equivalent population) varied in different scale.

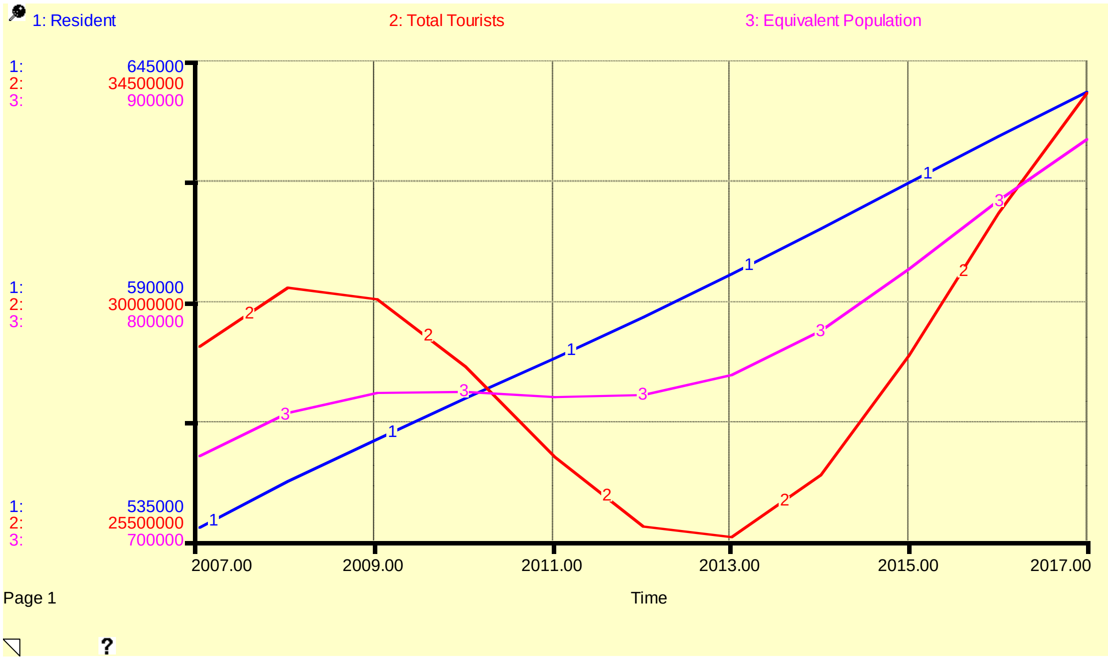

Fig.8. The simulated result of population, tourists, and the equivalent population of Macao from 2007 to 2017

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3.2 Area, Density, GDP and Money Investment of Macao

In the middle of September in 2008, the serious global financial crisis tsunami happened; the financial shortage of the American gambling companies decreased their investment to Macao. Data have shown it has influenced the economical increase tremendously. From the economical trend of the past 6 months, we forecast further down turn of the GDP of Macao. We estimated the influence of the financial crisis would be a recycled function; economical cycle function would be incorporated into the relevant data.

With the development of Macao, its area would increase, and population density would remain the same level, while its GDP might increase to 249.6 billion patacas

(MOP), and foreign investment to 114580.9 billion MOP in the year of 2017 and their simulated figures showed in Figure 9.

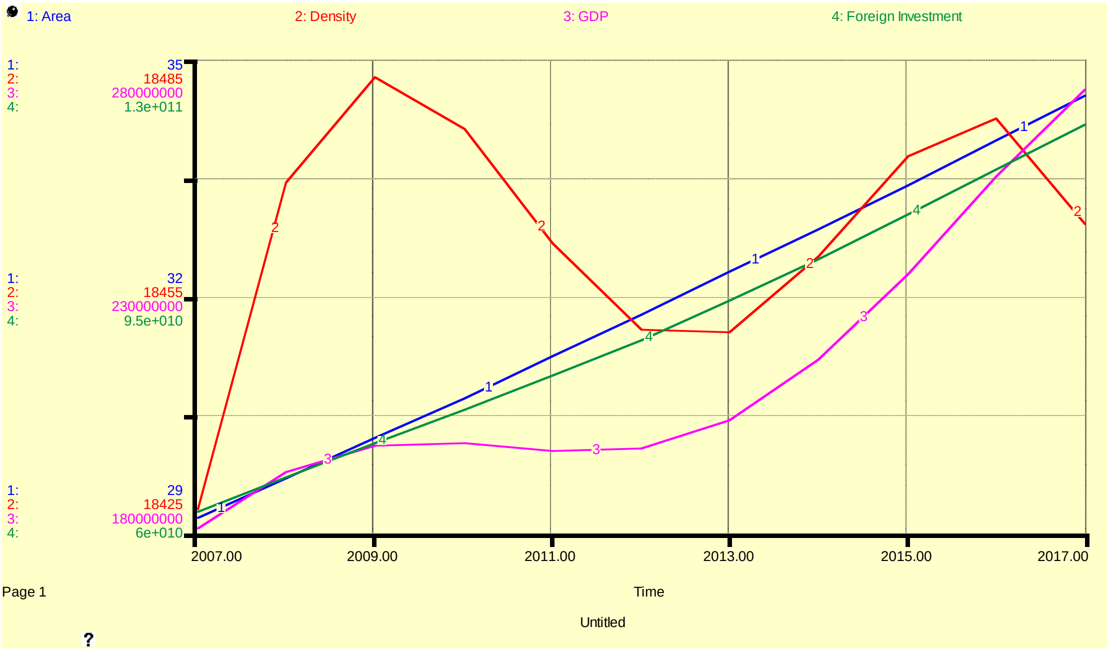

Fig.9 The simulated figure of Area, Population Density, GDP and Money Investment of Macao from 2007 to 2017

We could positively estimate that the economy of Macao would increase again after several years decrease accompanied with the foreign investment of money in Macao in the coming 10 years.

3.3 Inflows of materials of the Macao system of Macao

Figure 10 reflected the simulated results in total imports, exports and trends in selected material flows for the coming 10 years. From 2007 to 2017, the total imported food would grow from 4.72×10^{8} kg to 5.40×10^{8} kg; the total imported mineral from 3.62×10^{9} kg to 6.11×10^{9} kg, and the total imported raw materials and goods from 2.45×10^{9} kg to 3.02×10^{9} kg and the total imported potable water from 7.93×10^{10} kg to 9.88×10^{10} kg (Fig. 10). At the same time, the total exported raw materials and production would increase from 4.55×10^{8} kg to 5.16×10^{8} kg; total generated solid wastes from 3.07×10^{8} kg to 3.33×10^{8} kg, and total discharged sewage from 6.25×10^{10} kg to 7.25×10^{10} kg (Fig. 11).

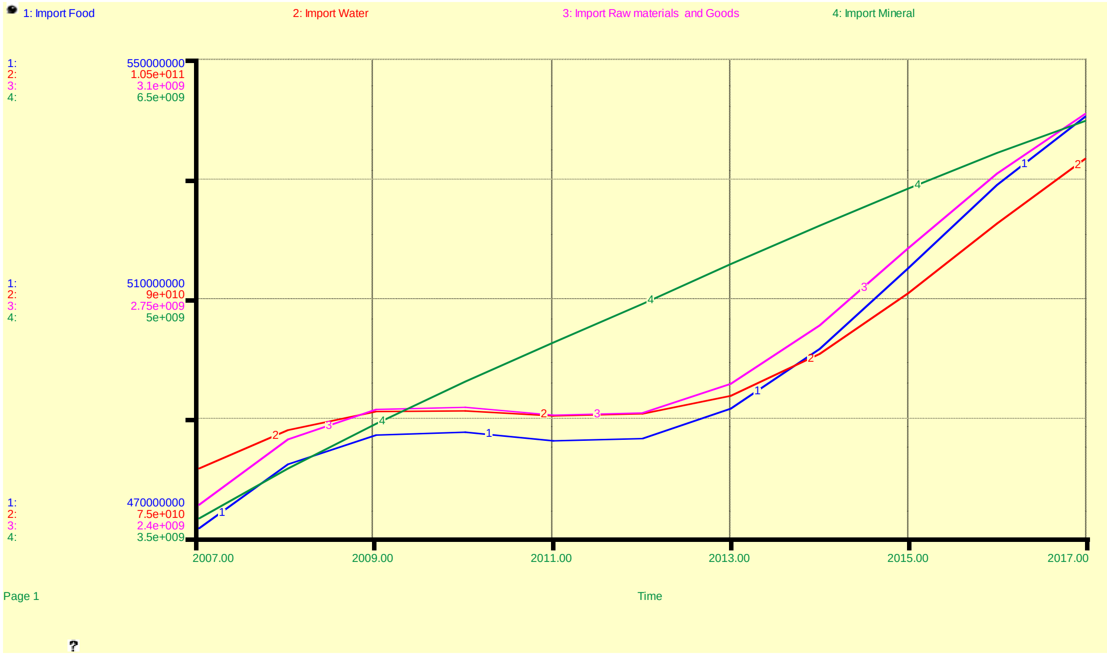

Fig. 10 The simulated result of imported food, water, minerals, Raw materials and goods of Macao from 2007 to 2018.

3.4 Outflows of material of the Macao system

In the further 10 years, accompanying with the increasing economy, the increasing speed of the tourists would slow down first, then it would rise up again in about 2014. The imported materials would fluctuate with the equivalent population. The mineral and the potable water increased, while sewage would be influenced by the uncertain precipitation (Fig. 11).

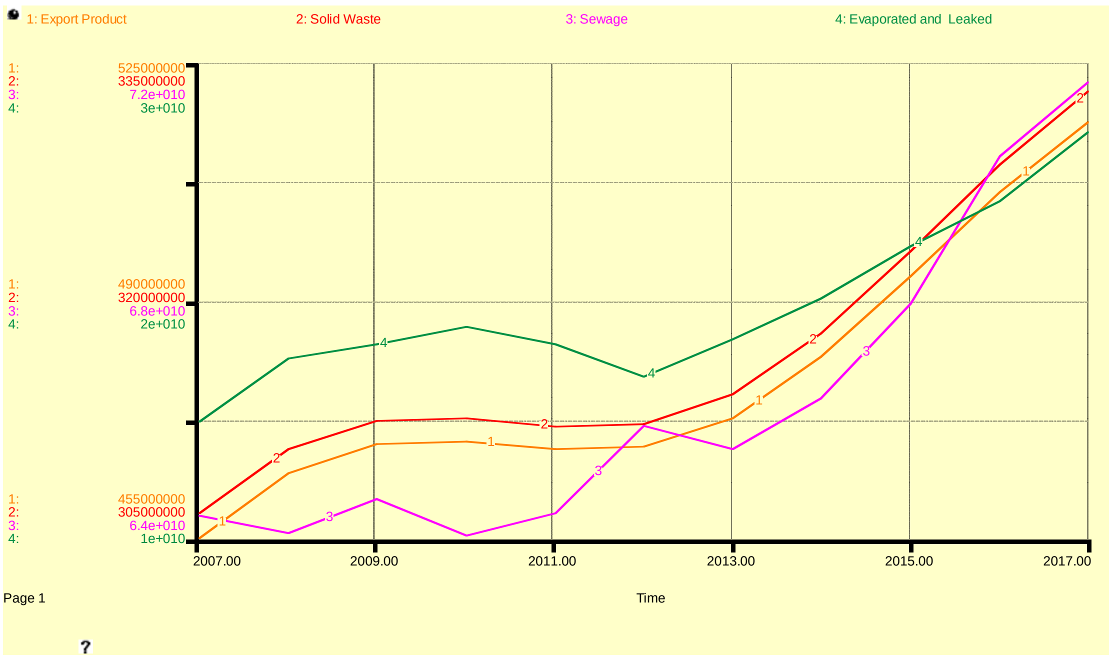

Fig. 11 The simulated result of the exported raw materials and goods, solid wastes and sewage of Macao from 2007 to 2018

4. Sensitivity Analysis

For such analysis, we chose 2 parameters assumed to be important to the results of the simulation to conduct the sensitivity tests. The model would be rerun with different values of the following parameters:

a) Equivalent population responding to family immigration ratio.
b) Equivalent population responding to the stay days of the tourists.

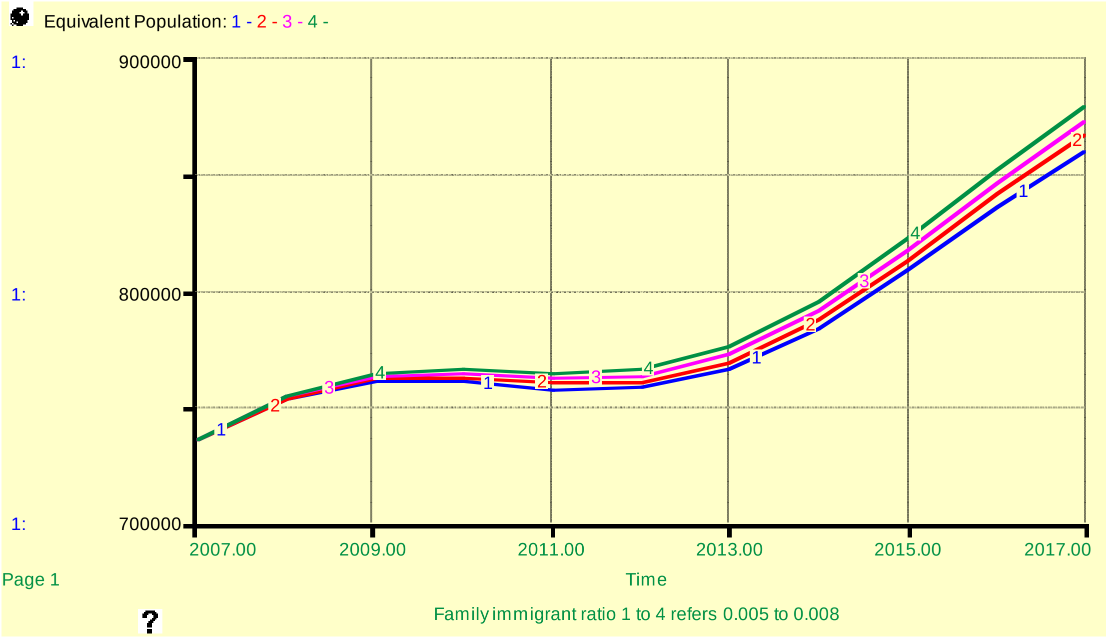

Fig. 12 Equivalent population responding to family immigrant ratio of Macao from 0.005 to 0.008.

The first parameter was family immigration ratio. In the model, we calculated that the family immigration rate was about 0.006136 in 2007. Now we assumed that the value would be 0.005, 0.006, 0.007 and 0.008. Then got the equivalent population shown in Fig.12, with the family immigration ratio changes, the 4 curves showed very differently in quantity. Consequently, this parameter was sensitive.

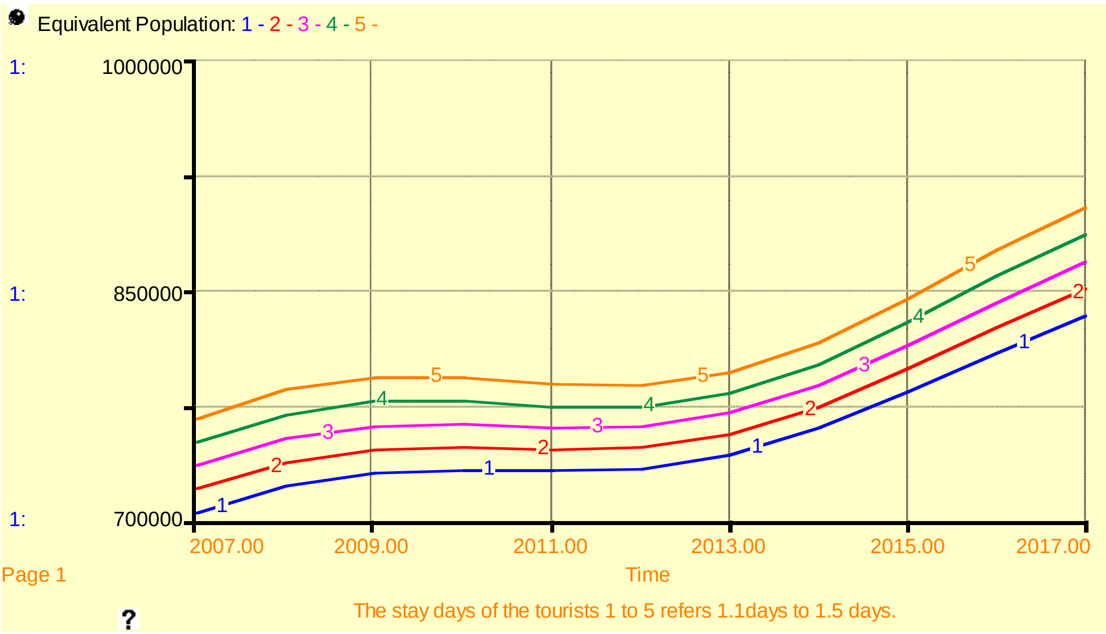

Fig. 13 Equivalent population and the average stay days of the tourists of Macao from 1.1days to 1.5 days

The second parameter was the average stay days of the tourists. In the model, we set the tourist stay days changes from 1.1 to 1.5 days. Then we obtained the graphs of equivalent population in Fig.13. The 4 curves appeared very differently in quantity, so the parameter was estimated to be sensitive. Through the above sensitive tests, the basic patterns of the graphs were all alike despite different parameter used to run the model. We could say the model was a stable model.

5. Limitation and Suggestion

The model has characteristics of:

(1) We adopt the equivalent population concept to include the consumption of the tourists to compare with the local resident according to the consuming factor of the tourists, the stay days, to simplify model.

(2) We assume the development of Macao is a recycle function and the material exchange also varies accordingly.

The limitation of the model:

(1) The fuel part excluded in our model partly because the uncertainty of the policy of Macao's import of electricity, which will decrease the imported of the fossil fuel. Since the fuel imported is less than 2% of Macao's import; its omission will not produce much error.

(2) Due to the unpredictability of the precipitation of Macao, we assume it is in random and in a range of minimum to maximum from 2001 to 2007. But this treatment will bring some error since the reality and the modeling may not be at par.

(3) In 2008, the financial crisis occurred all around the world and damaged the global economy. It decreased the number of tourists and the gambling income, accordingly. In our modeling, this influence can not be reflected accurately.

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References

Allen, P., Deneubourg, J.L., 1978. The Dynamics of Urban Evolution. Final Report to the U.S. Department of Transportation. Washington, DC.

CIA, 2007. The World Fact Book - Macau. Website: https://www.cia.gov/library/publications/the-world-factbook/print/mc.html. Retrieved on 2007-11-15.

DSEC (Statistics and Census Service Department), 2008. Macao Statistic Yearbook 2007. Macao: Statistics and Census Service Department. 1-350.

Forrester, J. W. 1970. Urban Dynamics. M.I.T. Press, Cambridge, Massachussetts.

Huang, S., Hsu, W., 2003. Materials flow analysis and emergy evaluation of Taipei's urban construction. Landscape Urban Plann., Vol. 63 Issue 2:61-74

Lam, C., Lu, L., Lei, K., Chen, F. 2008. The Primary Simulation of the Macao Solid Wastes Basing on Population Model. Environmental Science and Management.33 (10):67-71 (In Chinese).

Lei, K., Wang Z. 2008. Emergy Synthesis and Simulation of Macao. Energy, 33(4): 613-625.

Lei, K., Lu, L., Chen, F., Qin, Y. 2008. The Systems Dynamic Simulation of the Tourist for Macao. Tourism Science. (6):pp.(In Chinese).

Newman, P.W.G., 1999. Sustainability and cities: extending the metabolism model. Landscape Urban Plann. 44, 219–226.

Odum, H.T. 1996. Environmental Accounting—Emergy and Environmental Decision Making.

New York: John Wiley & Sons Inc. 1-234
Odum, H.T., 1994. Ecological and General Systems: An Introduction to Systems Ecology. The University Press of Colorado. pp644.
Odum, H.T., Odum, E.C. 2000. Modeling for all scales. San Diego: Academic Press.
Wilson, A.G., 1981. Catastrophe Theory and Bifurcation: Application to Urban and Regional Systems. Croom Helm, London.

Area(t) = Area(t - dt) + (Reclamation) * dt
INIT Area = 29.2
INFLOWS:
Reclamation = 0.5+Ashes*Reclaimation_Ratio
Ashes(t) = Ashes(t - dt) + (To_Solid) * dt
INIT Ashes = 0
INFLOWS:
To_Solid = Solid_Waste*Incinerating_Ratio
Incinerator(t) = Incinerator(t - dt) + (Solid_Waste - To_Solid - To_Gas) * dt
INIT Incinerator = 0
INFLOWS:
Solid_Waste = EXP(18.970+ (1.211E-9* Imported_Food))
OUTFLOWS:
To_Solid = Solid_Waste*Incinerating_Ratio
To_Gas = Gasous_Ratio*Solid_Waste
Macao__System(t) = Macao__System(t - dt) + (Imported_Mineral + Imported_Raw_materials__and_Goods + Imported_Food - Exported_Products - Solid_Waste) * dt
INIT Macao__System = 0
INFLOWS:
Imported_Mineral = exp(23.113+-6.975E10/Foreign_Investment)
Imported_Raw_materials__and_Goods = EXP(22.239+(-1.123E8)/GDP)
Imported_Food = 9.232E8+(-3.321E14/Equivalent_Population)
OUTFLOWS:
Exported_Products = -2.357E9+(1.479E8* LOGN(GDP))
Solid_Waste = EXP(18.970+ (1.211E-9* Imported_Food))
Macao__Water(t) = Macao__Water(t - dt) + (Imported_Water - Sewage - Evaporated_and__Leaked) * dt
INIT Macao__Water = 0
INFLOWS:
Imported_Water = Exp(23.876+((1.660E-6)* Equivalent_Population))
OUTFLOWS:
Sewage = 2.252E10

+Imported_Water*0.465
+Precipitation*1986689.325
Evaporated_and__Leaked = Imported_Water-Sewage
Population_Groups[Age0_14](t) = Population_Groups[Age0_14](t - dt) + (Births[Age0_14] + Immigrantion[Age0_14] + Transfer_In[Age0_14] - Deaths[Age0_14] - Transfer_Out[Age0_14]) * dt
INIT Population_Groups[Age0_14] = 72600
Population_Groups[Age15_39](t) = Population_Groups[Age15_39](t - dt) + (Births[Age15_39] + Immigrantion[Age15_39] + Transfer_In[Age15_39] - Deaths[Age15_39] - Transfer_Out[Age15_39]) * dt
INIT Population_Groups[Age15_39] = 231000
Population_Groups[Age40_59](t) = Population_Groups[Age40_59](t - dt) + (Births[Age40_59] + Immigrantion[Age40_59] + Transfer_In[Age40_59] - Deaths[Age40_59] - Transfer_Out[Age40_59]) * dt
INIT Population_Groups[Age40_59] = 178700
Population_Groups[Age60_74](t) = Population_Groups[Age60_74](t - dt) + (Births[Age60_74] + Immigrantion[Age60_74] + Transfer_In[Age60_74] - Deaths[Age60_74] - Transfer_Out[Age60_74]) * dt
INIT Population_Groups[Age60_74] = 37300
Population_Groups[Age75_98](t) = Population_Groups[Age75_98](t - dt) + (Births[Age75_98] + Immigrantion[Age75_98] + Transfer_In[Age75_98] - Deaths[Age75_98] - Transfer_Out[Age75_98]) * dt
INIT Population_Groups[Age75_98] = 18500
INFLOWS:
Births[Age0_14] = Birth_Rate[Age15_39]*Population_Groups[Age15_39]+Population_Groups[Age40_59]*Birth_Rate[Age40_59]
Births[Age15_39] = Birth_Rate[Age75_98]*Population_Groups[Age15_39]*0
Births[Age40_59] = Birth_Rate[Age75_98]*Population_Groups[Age40_59]*0
Births[Age60_74] = Birth_Rate[Age75_98]*Population_Groups[Age60_74]*0
Births[Age75_98] = Birth_Rate[Age75_98]*Population_Groups[Age75_98]*0
Immigrantion[Age0_14] = (Family__Immigration+Technology__Immigration)*0.20
Immigrantion[Age15_39] = (Family__Immigration+Technology__Immigration)*0.62
Immigrantion[Age40_59] = (Family__Immigration+Technology__Immigration)*0.18
Immigrantion[Age60_74] = (Family__Immigration+Technology__Immigration)*0
Immigrantion[Age75_98] = (Family__Immigration+Technology__Immigration)*0
Transfer_In[Age0_14] = 0*Transfer_Out[Age0_14]
Transfer_In[Age15_39] = Transfer_Out[Age0_14]

Transfer_In[Age40_59] = Transfer_Out[Age15_39]
Transfer_In[Age60_74] = Transfer_Out[Age40_59]
Transfer_In[Age75_98] = Transfer_Out[Age60_74]
OUTFLOWS:
Deaths[Age0_14] = Population_Groups[Age0_14]*Death_Rate[Age0_14]
Deaths[Age15_39] = Population_Groups[Age15_39]*Death_Rate[Age15_39]
Deaths[Age40_59] = Population_Groups[Age40_59]*Death_Rate[Age40_59]
Deaths[Age60_74] = Population_Groups[Age60_74]*Death_Rate[Age60_74]
Deaths[Age75_98] = Population_Groups[Age75_98]*Death_Rate[Age75_98]
Transfer_Out[Age0_14] = (Population_Groups[Age0_14]-Deaths[Age0_14])/14
Transfer_Out[Age15_39] = (Population_Groups[Age15_39]-Deaths[Age15_39])/25
Transfer_Out[Age40_59] = (Population_Groups[Age40_59]-Deaths[Age40_59])/20
Transfer_Out[Age60_74] = (Population_Groups[Age60_74]-Deaths[Age60_74])/15
Transfer_Out[Age75_98] = (Population_Groups[Age75_98]-Deaths[Age75_98])*0
Amplitude = 3.00E+06
Birth_Rate[Age0_14] = 0
Birth_Rate[Age15_39] = 0.017864
Birth_Rate[Age40_59] = 0.000718
Birth_Rate[Age60_74] = 0
Birth_Rate[Age75_98] = 0
Death_Rate[Age0_14] = 0.000257383
Death_Rate[Age15_39] = 0.000524212
Death_Rate[Age40_59] = 0.002025402
Death_Rate[Age60_74] = 0.01206927
Death_Rate[Age75_98] = 0.05200383
Decrease_Ratio_of__TW_Tourists = 0.90^(Year-2007)
Density = ARRAYSUM(Population_Groups[*])/Area
Economic_Cycle__Function = cos((Year-2008)*2*PI/10)
Equivalent_Population = Population+Total_Tourists*Stay_Days*1.9/365
Family_Immigration__ratio = 0.006136
Family__Immigration = Population*Family_Immigration__ratio
Foreign_Investment = EXP(28.988+(-2216491.819/Population))
Gasous_Ratio = 0.75
GDP = EXP(21.735+(-2001409.645/Equivalent_Population))
Hong_Kong_Tourists =
(6000000+500000*(Economic_Cycle__Function+3))*Increase_Ratio_of__HK_Touri
sts
Incinerating_Ratio = 0.25

Increase_Ratio_of__HK_Tourists = 1.00561^(Year-2008)
Mainland_China_Tourists =
Nature_Mainland+Amplitude*Economic_Cycle__Function
Nature_Mainland = -1008670000+5.10E+05*Year
Nature_Oversea = 2508458
Nature_Taiwan = 1454796
Overseas_Tourists = Nature_Oversea*Gambling_Factor
Population = ARRAYSUM(Population_Groups[*])
Precipitation = RANDOM(1466.4,2555.8)
Reclaimation_Ratio = 10^(-10)
Stay_Days = 1.3
Taiwan_Tourists = Nature_Taiwan*Decrease_Ratio_of__TW_Tourists
Technology__Immigration = 4800-1000*SIN((Year-2007)*2*PI/10)
Total_Tourists =
Hong_Kong_Tourists+Mainland_China_Tourists+Overseas_Tourists+Taiwan_Tourist
s
Year = TIME
Gambling_Factor = GRAPH(Year)
(2007, 1.00), (2008, 1.01), (2009, 1.02), (2010, 1.04), (2011, 1.05), (2012, 1.05),
(2013, 1.05), (2014, 1.06), (2015, 1.07), (2016, 1.07), (2017, 1.06)