Simulation and Analysis of Taichung Urban Ecosystem

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ABSTRACT

In Taichung there is considerable concern about urban problems, such as the deterioration of living conditions, overcrowding and empty dwellings, the congestion of traffic, the shortage of open space and many other aspects of the urban social, economic and environmental situations. Most of the existing planning methods in this context addressed only one or two of the three aspects. The purpose of this study is therefore to develop an integrated framework for establishing an urban ecological system to maintain a balanced relationship between human needs and urban ecology. A dynamic simulation model, combining urban ecological theory with the techniques of system dynamic, is suggested so that the multiple objectives of urban development can be pursued sustainably to achieve a better quality of life for every citizen, now and for generation to come.

Keywords: Urban ecosystem, System dynamics, Dynamic model.

Introduction

The development of Taichung has, like other cities in Taiwan, been subject to the effects of urbanization, resulting in unlimited urban sprawl. The high population density, inadequate public infrastructure and poor urban planning have led to the degradation of the city's transportation and environment. In order to solve the problems caused by urbanization, the causes of the problems must be identified within the city system itself. A complete understanding must thus be acquired of the unique features and complications associated with the city system to find solutions from an ecological perspective. Only then can the balance between the city's socio-economic development and environmental quality be maintained to create a great urban living environment. In 1990 the OECD proposed two basic principles for city development: "City functionality and self-regulated growth" and "Minimization of waste generation". This means that city development planning must achieve a balance between ecology, environment and society. By seeking the overall advancement of society, assigning equal importance to the environment and development, all while maintaining a balanced society at all levels, a symbiotic relationship between socio-economic benefits and environment energy can be established. This will enhance the overall quality of life in the city and create an urban development model where "Ecology, Life and Production" are all given equal weight, ensuring the sustainable use and development of environmental resources.

Human society forms the basis of a city with all kinds of spaces and facilities forming a multi-variable, non-linear city ecological system. A very complicated and inter-linking relationship exists between these different components. Any study of urban development should therefore begin with a systematic examination on the chronology and space of urban system development. This requires not only quantitative analysis but also qualitative judgment. In this study, the balance between human activity and urban environments within Taichung City was analyzed from an urban ecological system balance perspective. Using system dynamics techniques a model for Taichung City was constructed. This was used for simulations that examined how the system changed over time. Recommendations were then formulated from an ecological perspective to suggest the management strategies that should be adopted to achieve the desired urban development goals, improving the city's environmental quality and standard of living for residents.

Over the years a plenty of research has been accumulated both locally and overseas on research into ecological development. (Huang, 1996; Hugo, 1999; Ibrahim and Rosen, 1999; Li et al., 2000; Nisar, 2000; Robin, 2000; Roseland, 2000; Rao, 2000; Ye, 2000; Roy, 2001; Ho et al, 2005, 2006). The problems in modern city development however are a result of how urban development has changed the urban ecological structure to inflict immense damage on urban ecology. The population's consumption-oriented urban lifestyle and production methods in particular lack a resource regeneration/recycling mechanism and do not conform to the principle of resource recycling in ecological systems. How to propose a practical city management strategy is therefore an issue in urban development that should be studied in great detail.

Research Method

1. System analysis

System analysis takes into consideration all variable factors of a real or planned system, searches and evaluates all feasible means of an achieving the pre-set goal, thus helping the policy-makers to evaluate and choose the strategies to be adopted. Hence, systems analysis employs both quantitative and qualitative analytical tools to search and confirm the target through assessing all feasible alternatives. It emphasis comprehensiveness and allows intuition a role to play when making judgment (Ossenbruggen, 1984). This research uses the principles and approaches of the systems theory, which focuses on complexity and interdependence of relationships, to analyze the indicators of the different subsystems and how they relate to and affect each other. With the knowledge concerning the nature of the whole system and the rules governing it, we can establish a comprehensive system model that takes into account all the variables of the different subsystems.

2. Fuzzy Delphi

The Fuzzy Delphi Method is where Fuzzy Theory is used in conjunction with the traditional Delphi Method to deal with problems encountered during the use of the traditional Delphi Method. In Fuzzy Delphi, a series of surveys is carried out with all of the experts and researchers involved in the study. The survey is completely anonymous with no direct contact between those involved. The first survey deals with the more general questions and the respondents' answers are used to modify the survey content. The second survey thus created goes into further detail and is sent to the same people as before. The process continues until all of the participants have achieved a consensus or the amount of shared information meets the needs of the primary objective. Apart from helping to deal with the more fuzzy parts of human understanding, Fuzzy Delphi can also identify the uncertainties that the subjective respondent may have been certain about. In this manner it helps to develop a consensus among experts and derive a unanimous opinion from the experts involved on specific issues (Wang, 2004).

In this paper the fuzzy expert survey was used with experts from the fields of ecology, urban design, system analysis, sociology, economics and environmental protection. By using the feedback from the experts, the sub-systems within Taichung City's urban ecological system and their relationship to each other could be established. The variables within the model as well as their structural diagram could then be set up.

3. System Dynamics

Due to the complexity and effect of random factors in the eco-economic system dynamic model, if traditional mathematical methods were used to construct a simulation for the city's sustainable development dynamics, this may result in over a hundred partial differential equations involving time-delays and having to measure hundreds of parameters. It is also impossible to try to solve such combinations of equations. System dynamics is a discipline dedicated to the analysis and study of multi-variable, non-linear, complex systems with inherent time-delays through the use of special methods to develop a simulation of the system model (Sterman, 2000). Its defining feature is its ability to handle dynamic systems that change over time. For studying urban development with its complicated planning processes, multi-variable, multi-objective and multi-level future behaviors and short-term/long-term policy issues, system dynamics provide a way to identify the solutions for urban development.

Model Formulation

1.Formulation of System Indicators and Feedback Loop Diagram

We formulate Taichung City population、land、industry、service industry, socio-economics and environment pollution five subsystems. The establishing of eco-economic system indicators must be conducted in an objective, scientific, verifiable and comparable manner. Fuzzy Delphi Method was employed for screening the indicators. From the government, the industrial and the academia, 30 experts and scholars were selected to choice the indicators for Taichung City (Table 1). The causal feedback loops of different subsystems in the eco-economics system of Taichung City was formulated and shown in Figure 1. The Structural Diagram clearly defines the interaction between each of the sub-systems and uses these to construct the feedback loop between the system variables. This resulted in 20 positive causal loops and 25 negative causal loops. Of these the Population variables determined the behavioral characteristics of population activities and affected the associated system indicators for population planning; the Land variables determined the reasonable level of land development and utilization; the Industry variables determined the city's economic production capacity and type; the Service Industry variables determined the nature of the city's economic commercial development; the Socio-Economics variables determined the amount of space planning authority available during the city planning process; finally, the Environmental Pollution variables determined how good or bad the urban environmental quality is.

Table 1. eco-economic indicators and their assessment value

Subsystem	Indicator		Subsystem	Indicator	
population	population	0.121		industry labor population procreation rate	0.116
	population density	0.125			
	population growth	0.118	Service industry	service industry density	0.114
	environment quality index	0.121		service industry amount	0.114
	average district provide water resource	0.117		service industry labor population	0.116
	average district provide electricity	0.117		service industry output value	0.117
				service industry labor population rate	0.117
	average of water source	0.116			
land	open space	0.121		average of national product	0.116
	average of open space	0.121	Socio-economics	environment protection expense	0.120
	development land	0.117			
	development land dext	0.118		education culture expense	0.117
	development land rate	0.117		communication and transportation expense	0.116
	open space quantity	0.117			
	culture development land quantity	0.117		public sanitation expense	0.116
				police and social security expense	0.116
	development land rate	0.118			
industry	industry pollution product	0.123	Environmental pollution	air pollution	0.123
	industry land	0.116		refuse disposal of men	0.122
	industry used electricity amount	0.118		waste water processing amount	0.123
	industry used water amount	0.118			
	industry output value	0.116		refuse disposal of industrial	0.121

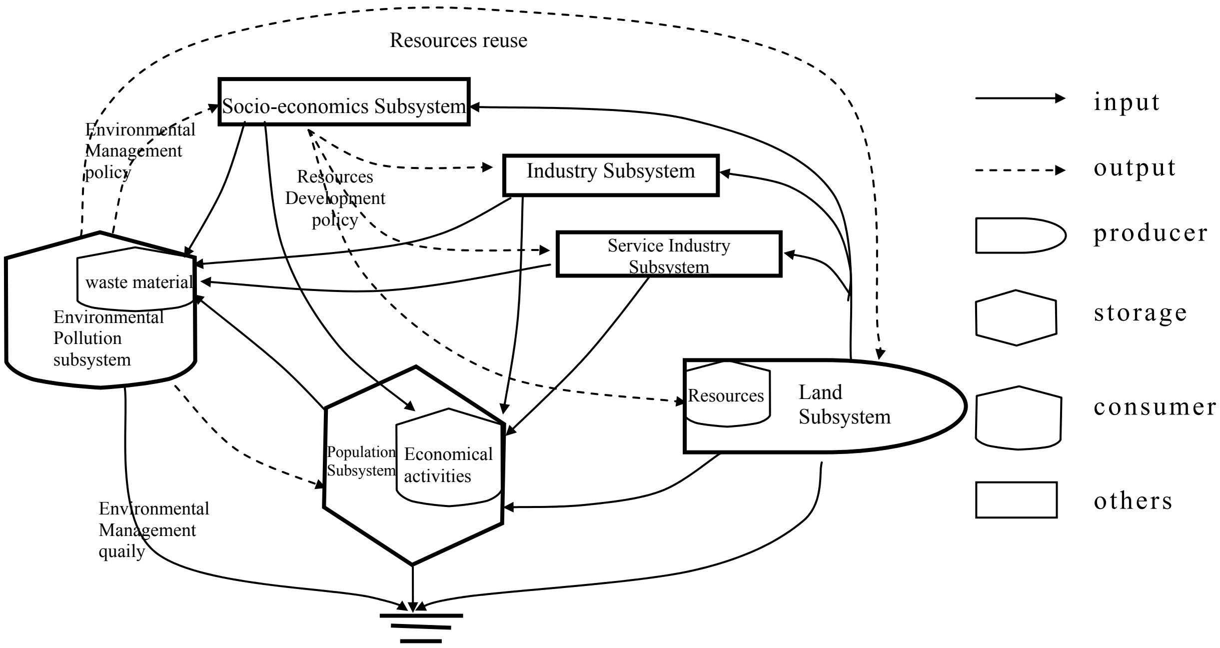

Fig 1. Structural diagram of Urban Ecosystem of Taichung City

2. Model Formulation

In this study, variables such as Population, Pollution, Energy and Land Resources were used to link the various sub-systems together to form Taichung City's Eco-economic System Dynamic Model. The model has 63 variables and 179 equations of which 8 are level equations, 8 initial value equations, 17 rate equations, 142 ancillary equations and 4 constant equations. An explanation is provided below for each of the sub-system's dynamic models:

(1) Population Sub-System:

The main stock variable in this system is the size of the population. The main stock equation is: POPULATION.K=POPULATION.J+DT* (BIRTH POPULATION.JK+ MIGRATION POPULATION GROWTH.JK-DEATH POPULATION.JK) (Fig. 2). The main factors that influence the total size of the population are the rates of birth, death and migration. The rate equation is: BIRTH POPULATION.KL= BIRTH RATE.K* POPULATION.K；DEATH POPULATION.KL= DEATH RATE.K* POPULATION.K；MIGRATION POPULATION.KL =FLOATING POPULATION.K* ENVIRONMENT QUANTITY INDEX.K. The birth and death rates in the system change with fluctuations in the total population while the overall rating of regional environmental quality index is the main factor behind population movements. In this study a simulation of the urban attraction effect was used with three regional values (ratio of water supply, ratio of electricity supply and average income) and greater environmental values compared to derive a regional indicator value for environmental quality. This was then matched to time conversion coefficients to determine the size of population movements caused by changes in urban environmental quality.

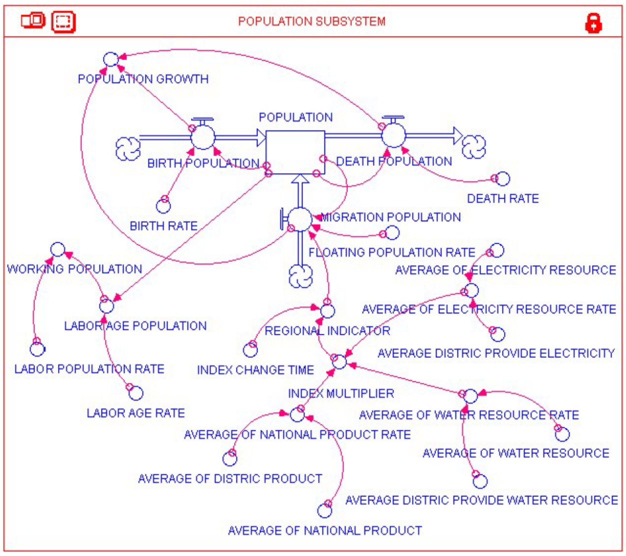

Fig 2. System diagram of population subsystem

The simulation's results showed that the population of Taichung City had grown rapidly. Between 1981 and 2001 the population grew from 607,000 to 1,000,000, an increase of 170%. The model predicted that by 2016 the population of Taichung City would increase four-fold to 2,353,000. This rate of growth was attributed mainly to the number of births because Taichung City is growing steadily at around 20,000 people a year. At the same time, advances in medicine and improvements in environmental quality are now attenuating the effect of negative factors such as death and migration. Overall, the system currently tends towards positive growth. The development of the working population showed that employment in the Service industry was growing more rapidly than those in the Industry sector. Though the ratio of Industrial to Service industry sector workers will be maintained at 1:2, the total number of workers however will increase from 118,000 versus 235,000 in 1996 to 341,000 versus 677,000 in 2016.

(2) Land Sub-System:

The main stock variable in this system is the area of land. The main stock equation is: LAND.K=LAND.J+DT* (LAND UTILIZATION.JK-LAND REVERSION.JK) (Fig. 3). The main factors that affect the land area are the rates of land utilization and land reversion. The rate equations are LAND UTILIZATION.KL=DEVELOPMENT LAND DEXT.K* DEVELOPMENT LAND.K/LAND ADJUST TIME; LAND REVERSION.KL= REGRESSES LAND RATE.K*LAND.K. In this study the urban land was categorized into three types according to usage; Residential, Commercial and Public Facility Open Space. Changes in urban land use and urban development history were then studied to construct a system cause-and-effect loop and adjust the urban land usage. In the relationship loop the expansion of the city leads to an increase in land utilization area but this results in a decrease in ratio of developed urban land. The balance between supply and demand is affected along with willingness in land development, creating an internal regulation loop. As land is developed, public facilities expand and increase, resulting in a positive internal loop. Additionally in Taichung's urban planning very little land is reverted to non-urban planning land. This meant that the land reversion rate is virtually nil.

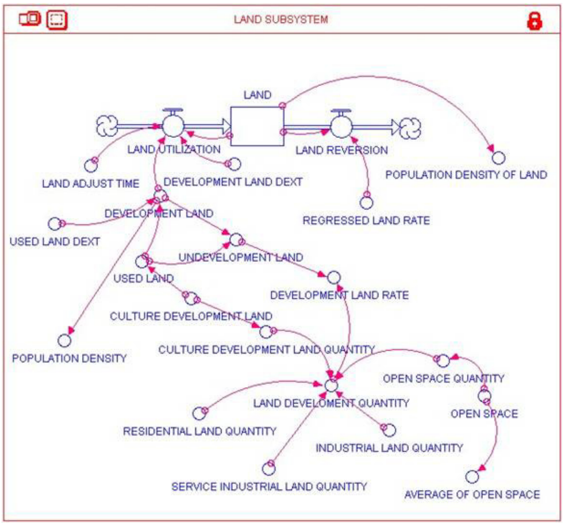

Fig 3. System diagram of land subsystem

The simulation results indicated that the amount of developed land in Taichung City increased over time. A more unusual variation in the system trend was the large-scale development of residential land in 1981. This led to a short period of negative growth in the ratio of population versus residential land. Limited land availability and continued growth of the overall population however meant that population density has continued to increase steadily. Looking at the system variables, the planned density in 2006 was based on 201 people per hectare. The simulated value for that year reached 263 people – 131% of the planned value. The amount of open space also grew from 145.54 hectares in 1996 to 1178 hectares in 2016. This showed that in earlier periods the development of Taichung City was limited by its hinterland. Over the years the City Government has made various rezoning decisions in order to meet the various demands for land use. Many of the rezoned areas have so far been left undeveloped, leading to the pressure curve for land demand being relatively flat. Taichung City's high density development however will lead to a big increase in demand for green open spaces, water supplies, sewer systems and garbage disposal facilities.

(3) Industry Sub-System:

The main stock variable in this system is industry assets. The main stock equation is: INDUSTRIAL ASSETS.K= INDUSTRIAL ASSETS.J+DT*(ASSET INCREASE.JK-ASSET DECREASE. JK) (Fig. 4). The main factors that affect industry assets are the rates of asset increase and asset decrease. The rate equations are ASSET INCREASE.KL=

INDUSTRIAL NET INCOME.K* INDUSTRIAL TRANSFORM RATE.K; ASSET DECREASE.KL= INDUSTRIAL QUIT.K* INDUSTRIAL OUTPUT VALUE.K. In this study the flow of capital is used to construct the Industry sub-system. The negative feedback loops for increase in industry assets are made up of industrial employment rate, worker productivity and investment restrictions on industrial asset income. The decrease in industry assets is a result of industrial pollution treatment cost and industry asset decrease. For the overall system, the industrial employment population within the Industry sub-system is affected by the employment rate of the working population in the Population sub-system as this causes fluctuations in industry asset expenditure; additionally, the number of industrial companies and the land area is used to estimate the industrial density. By linking together the number of industrial companies and the demand for land for industrial use the sub-systems can be linked together.

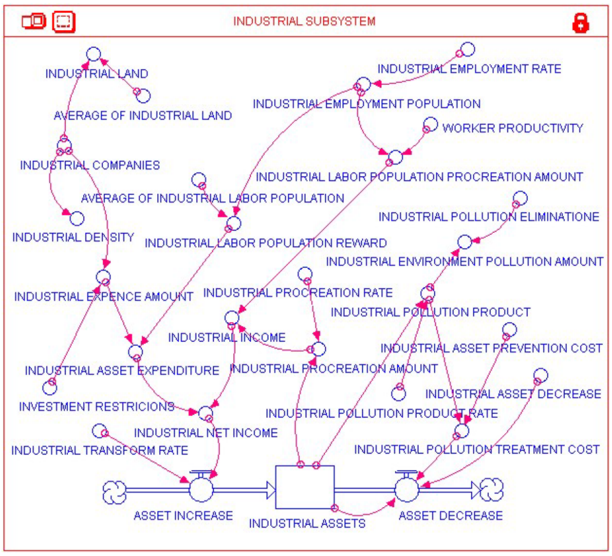

Fig 4. System diagram of industry subsystem

The simulation results indicated that a slow and steady growth would continue for industry assets in Taichung City. The total amount of industry assets grew from $602.3 billion in 1996 to $643.7 billion in 2016, an increase of just 7%. The number of industrial companies grew from 9989 in 1996 to 15,990 in 2016, an increase of 160%; industrial asset income grew from $292 billion in 1996 to $329.8 billion in 2016, an increase of 13%; industrial asset expenditure increased from $278.1 billion in 1996 to $356.7 billion in 2016, an increase of 28%. Generally speaking, though industry assets and the number of industrial companies show a trend for positive growth, the asset expenditure component is showing a tendency to increase as well. By 2016 this will exceed the asset income, indicating that future industrial development will have to contend with the problem of decreasing profitability.

(4) Service industry Sub-System:

The main stock variable in this system is service industry assets. The main stock equation is: SERVICE INDUSTRIAL ASSETS.K= SERVICE INDUSTRIAL ASSETS.J+DT* (SERVICE INDUSTRIAL ASSET INCREASE.JK- SERVICE INDUSTRIAL ASSET DECREASE.JK) (Fig. 5). The main factors that affect service industry assets are the rates of service industry asset increase and service industry asset decrease. The rate equations are SERVICE INDUSTRIAL ASSET INCREASE.KL= SERVICE INDUSTRIAL OPERATION EFFICIENCY.K* SERVICE INDUSTRIAL NET INCOME.K; SERVICE INDUSTRIAL ASSET DECREASE.KL= SERVICE INDUSTRIAL QUIT.K* SERVICE INDUSTRIAL OUTPUT VALUE K. In this study the flow of capital is used to construct the cause-and-effect relationship loop for the Service Sub-System. The service industry's asset increase is affected by factors such as number of people employed in the service industry, the service industry income and service industry asset expenditure. These form the system's internal negative feedback loop. The decrease in industry assets is a result of service industry pollution treatment cost and service industry quit. For the overall system, the service industry employment population within the Service Sub-system is affected by the employment rate of the working population in the Population Sub-system as this causes fluctuations in service industry asset expenditure; additionally, the number of service industry companies and the land area is used to estimate the service industry density. By linking together the number of service companies and the demand for land for use by the service industry the sub-systems can be linked together.

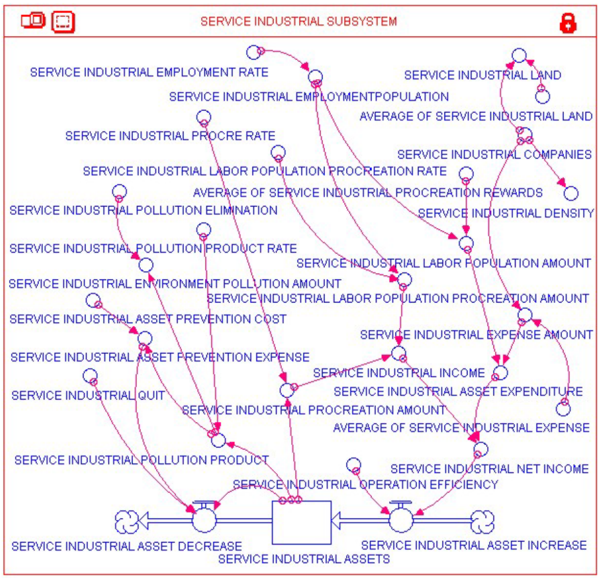

Fig 5. System diagram of service subsystem

The simulation results indicated that Taiwan's service industry assets would maintain a steady rate of growth. The rate of growth in total asset value will slow from the 54% between 1981 ($296.5 billion) and 1994 ($2,526 billion) to 16% between 1995 ($2,632 billion) and 2016 ($3,606 billion). The number of service companies grew from 40,490 in 1996 to 73,620 in 2016, an increase of 180%; service industry asset income grew from

$608.9 billion in 1996 to $1,197 billion in 2016, an increase of 97%; service industry asset expenditure increased from $523.6 billion in 1996 to $1,054 billion in 2016, an increase of 101%. Generally speaking, the service industry assets, the number of service companies, the asset income and expenditure all show growth. While asset expenditure's rate of growth is higher than the rate of growth for asset income, the peripheral asset expenditure in 2016 is still lower than the peripheral asset income. This indicated that there is still room for development in the service industry but attention must be paid towards asset management. Overall, Taichung City's commercial development trends show that the service industry's output is far higher than that of the industrial sector. This means that in the future Taichung's commercial sector will be dominated by the service industry, making it a consumer and service-oriented commercial city.

(5) Socio-Economics Sub-System:

The main stock variable in this system is local financial assets. The main stock equation is: LOCAL FINANCIAL ASSETS.K= LOCAL FINANCE ASSETS.J+DT* (LOCAL FINANCIAL INCOME.JK-LOCAL FINANCIAL EXPENDITURE.JK) (Fig. 6). Here the main factors that affect local financial assets are the rates of local financial income and local financial expenditure. The rate equations are LOCAL FINANCIAL INCOME.KL= NET INCOME RATE.K*INCOME TAX AMOUNT.K; LOCAL FINANCIAL EXPENDITURE.KL=FINAL EXPENDITURE.K*ADMINISTRATION EFFICIENCE INDEX.K. This study uses the flow of capital to construct a cause-and-effect relationship loop for the Socio-Economic Sub-System. In this study, Taichung City's annual revenue structure is examined. Taxation revenue comes from local government land taxes and housing taxes as well as the Distribution Tax System's business taxes and income taxes. These four variables form the framework of local government finances and were used to simulate the increase in annual budget, establishing the system's internal positive feedback loop. Local government expenditure is governed by variables such as education and culture, law enforcement and public safety, political authority, transportation, administration and civil affairs. Together with budget implementation efficiency these form the system's internal negative feedback loop.

The simulation results indicated that Taichung City's taxation revenue come mainly from income tax. By using the finalized average annual budget expenditure for each person, the balance of the budget was examined. Between 1996 and 2016 education and culture, transportation and law enforcement and public safety were always the three major areas of expenditure but their relative proportions changed over time. Education and culture dropped from 53% to 44%, transportation increased from 18% to 28% while law enforcement and public safety decreased from 16% to 13%. Generally speaking, education and culture formed the majority of expenditure but as the city expands basic infrastructure such as roads and transportation will consume a greater share of the budget, leading to restrictions on budget allocations.

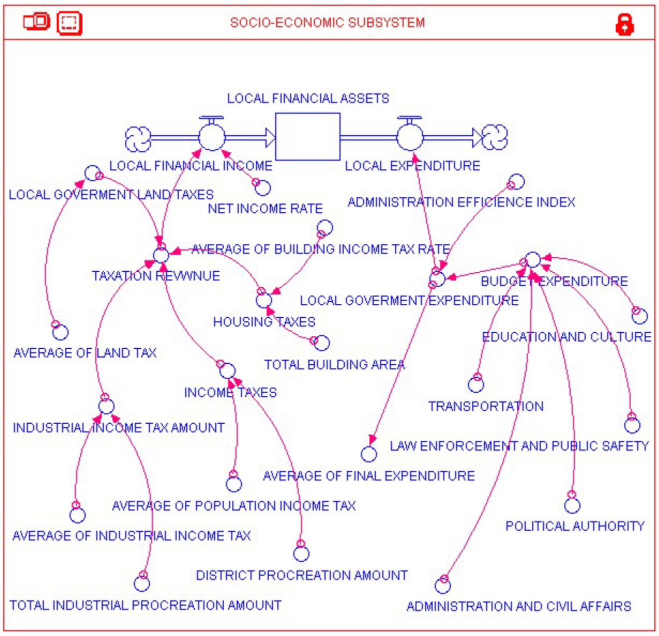

Fig 6. System diagram of socio-economics subsystem

(6) Environmental Pollution Sub-System:

The main stock variables in this system are the levels of water pollution, air pollution and waste pollution. For water pollution, the main stock variable is WATER POLLUTION.K= WATER POLLUTION.J+DT* (WATER POLLUTION GENERATION.JK- WATER POLLUTION REMOVAL.JK). For air pollution, the main stock equation is AIR POLLUTION.K= AIR POLLUTION.J+DT* (AIR POLLUTION GENERATION.JK- AIR POLLUTION REMOVAL.JK). For waste pollution, the main stock equation is WASTE POLLUTION.K= WASTE POLLUTION.J+DT* (WASTE POLLUTION GENERATION.JK- WASTE POLLUTION REMOVAL.JK). (Fig. 7) The main factors that affected the volumes of each pollution type were the pollution generation rate and pollution removal rate. The main rate equations are: WATER POLLUTION GENERATION.KL=HOUSEHOLD SEWAGE VOLUME.K+HUSBANDRY INDUSTRY SEWAGE VOLUME.K+INDUSTRIAL SEWAGE VOLUME.K, WATER POLLUTION REMOVAL.KL= WATER POLLUTION DEAL AMOUNT.K; AIR POLLUTION GENERATION.KL=SUSPENDED PARTICULAT INDEX.K+ DUST FALL INDEX.K+ COEFFICIENT OF HASE INDEX.K; AIR POLLUTION REMOVAL.KL= AIR POLLUTION REDUCE INDEX ; WASTE POLLUTION GENERATION.KL=THE QUANTITY OF PURGES.K; WASTE POLLUTION REMOVAL.KL= WASTE DISPOSAL AMOUNT.K. In this study sub-systems were constructed for each of the three types of pollution (water, air and waste). In each sub-system circulation loops were constructed for pollution generation and removal to observe changes in each kind of pollution. Increases in system pollution volume were mainly dependent on the amount of pollution generated by the

Population, Industry and Service Sub-systems. For example, household sewage volume was determined by the total population within the Population sub-system and the total household water consumption; the husbandry industry sewage volume was determined by the total number of stock animals and the pollution coefficient for each animal; the industrial sewage volume was determined by the land utilization for each type of industrial land use and their pollution ratio; the waste volume was determined by the amount of waste disposal workers and the average amount of waste generated by each person. By linking the sub-systems together a circulating urban ecological loop can be created and the relationship between each of the sub-systems highlighted. Existing technologies show that pollution prevention and treatment has become quite effective. Therefore in the negative adjustment mechanism for pollution reduction, the pollution treatment capacity was composed of factors such as maximum treatment volume of sewage treatment plants as well as waste disposal rate of incinerators and landfills. These results were then used to provide an indication of the overall urban environmental quality.

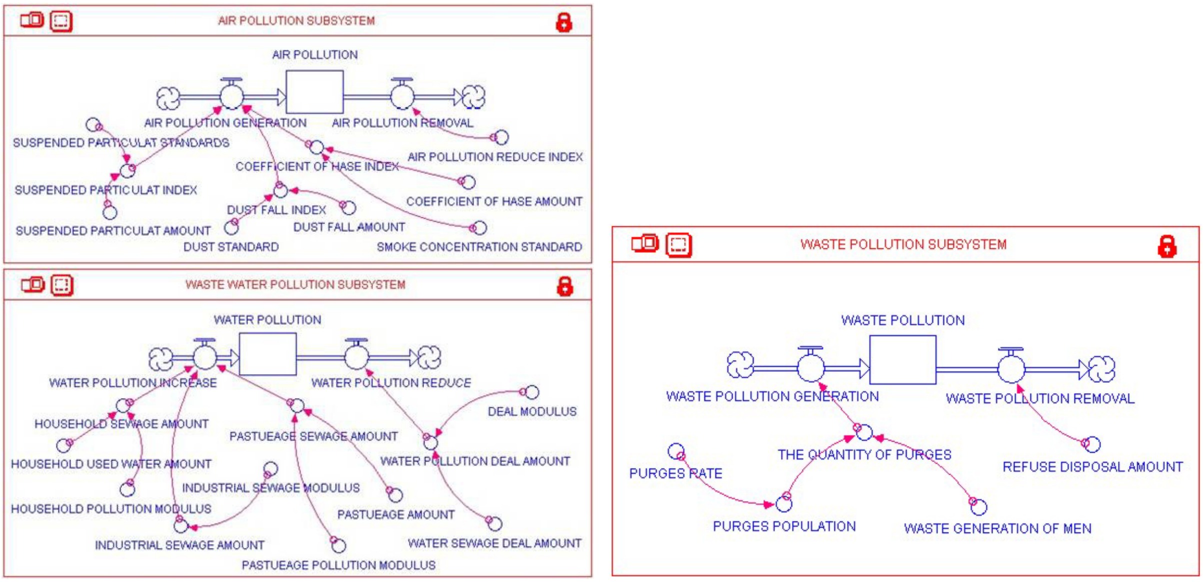

Fig 7. System diagram of environmental pollution subsystem

The simulation was verified against the historical data for Taichung City's total sewage volume between 1986 and 1996. It was found that characteristics such as the fluctuation types, changes over time and lengths of cycles from the simulation results resembled the historical curve quite closely. The average deviation of the simulation data was 4.6% indicating that the model's validity was within the acceptable range. The simulation results indicated that the gradient of the water pollution curve will increase after 2011. With the population and total water pollution volume both growing, in the future Taichung City will have to deal with the issues of a big increase in urban population, a decrease in amount of open space enjoyed by each person, a lack of life-sustaining resources and increasingly severe environmental pollution (Tong, 1996). Looking at the simulated trends in water pollution volume, it was discovered that the household water pollution trend matched that of the water pollution volume. 2011 in particular saw a massive increase in household water pollution volume. If the sewage treatment capability is not increased then this will compound the problem of water pollution volume exceeding the sewage treatment volume.

Looking at the waste pollution situation, by 1995 Taichung City was on average dealing with 1100 tons of waste per day. This already significantly exceeds the maximum processing capability at incinerators of 900 tons/day. If the excess waste volume can only be dealt with through landfills, this will increase the demand of land for landfill as well as worsen the environmental pollution associated with secondary pollution. In particular by 2009 the total volume of rubbish will become positive, meaning that Taichung City is going to have a waste disposal issue.

3. Model Justification

To establish the model's validity the study used the Forrester and Senge (1980) model behavior recreation. Using Taichung City's historical data for total population, land area, industrial asset, service industrial asset, local finance and total water pollution volume between 1986 and 1996, the results of the simulation were compared to the actual system behavior. Validity was then tested by examining traits such as the model's stability, the type of fluctuations, changes over time and the length of cycles. The simulation results (Table 2) indicated that the Industry Asset and Local Finance indicators showed greater discrepancies between the simulation values and the actual historical data. This was due to the longer intervals between the data sets. The simulation's development types as well as the positive/negative changes over time were however quite close to the historical trends. This model was therefore judged as being a suitable simulation of dynamic changes in Taichung City's urban development and could therefore be used to plan a reasonable ecological economic system for Taichung.

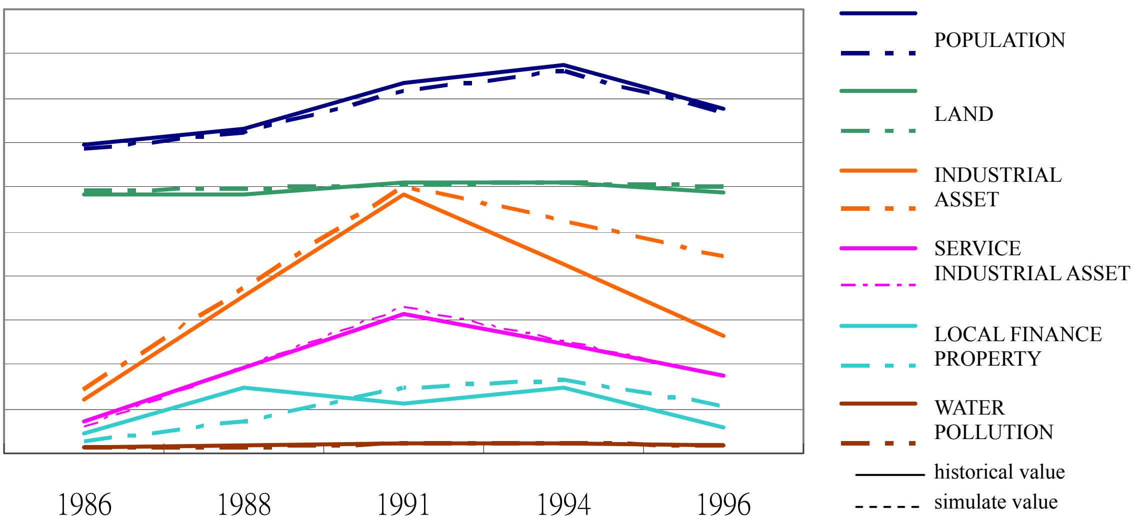

Table 2. The comparison of Taichung City's urban development dynamic simulation volume

4. Sensitivity Analysis

The variables and parameter values used in the model are based on past socio-economic projections or statistics from Taichung City. These parameter values will change in accordance with changes in the city's socio-economic conditions. Knowing what parameter changes to watch out for during the strategy simulation and what effects they have on urban development are therefore very important. In this study the matrix graph method (Kano, 1990) was used to actively concentrate 10% of each variable for change propagation sensitivity analysis. Using the cause-and-effect relationships within the entire system, 14 independent variables and 12 dependent variables were selected. A total of 14 changes were carried out with the independent variables and each time the changes in the independent variables will result in a corresponding change of the 12 concentrated dependent variables. From this a total of 168 curves were derived and each curve could be used to calculate the amplitude of change for that variable. As the amplitude of change could be positive (positive effect) or negative (negative effect), the arithmetic average of each variable's variation and the average deviation was used for normalization. These were then given a score of 0 for no change, 1 for minor effect (below the range of average deviation); 2 points for significant effect (within the range for average deviation); and 3 points for major effect (above the range of average deviation). This allowed the relevance between variables to be determined. Their effect and response values could be calculated as well. The results of the analysis indicated that the active group variables with the greater effect were: Birth Rate, Region Average Water Supply Volume and Employment Rate. The most sensitive dependent variable was Pollution followed by Population (Table 3).

Table 3. Effect-Efficiency Matrix of variables of eco-economics system for Taichung city

Active set \ Passive set		Indicator												Active Solution
		POPULATION	MIGRATION POPULATION	LAND	POPULATION DENSITY	INDUSTRIAL OUTPUT VALUE	INDUSTRIAL DENSITY	SERVICE INDUSTRIAL OUPUT AMOUNT	SERVICE INDUSTRIAL DENSITY	LOCAL FINANCE PROPERTY	AVERAGE OF FINAL EXPENDITURE	WATER POLLUTION	WASTE POLLUTION	
Ancillary variables	BIRTH RATE	3	3	2	2	2	2	2	2	1	3	2	1	25
	LABOR POPULATION RATE	1	2	0	0	1	1	1	1	1	1	1	1	11
	USED LAND	1	1	3	1	0	1	0	1	0	0	0	0	8
	RESIDENTIAL LAN QUANTITY	1	1	2	3	0	1	0	1	0	0	0	0	9
	INDUSTRIAL LABOR POPULATION RATE	0	0	0	0	3	1	0	0	0	0	1	1	6
	INDUSTRIAL COMPONIES	0	0	0	0	2	3	0	0	1	0	1	1	8
	SERVICE INDUSTRIAL LABOR POPULATION RATE	0	0	0	0	0	0	3	1	0	0	1	1	6
	SERVICE INDUSTRIAL COMPONIES	0	0	0	0	0	0	2	3	1	0	1	1	8
	ADMINISTRATION AND CIVIL AFFAIRS	0	0	0	0	0	0	0	0	3	2	1	1	7
	AVERAGE OF POPULATION INCOME TAX	0	0	0	0	0	0	0	0	2	1	1	1	5
	AVERAGE DISTRICT PROVIDE WATER RESOUCE	2	2	2	2	0	0	0	0	1	2	3	2	16
	WATER POLLUTION DEAL AMOUNT	1	1	0	1	0	0	0	0	0	0	3	1	7
	WASTE GENERATION OF MEN	1	1	0	1	0	0	0	0	0	0	1	3	7
	REFUSE DISPOSAL AMOUNT	1	1	0	1	0	0	0	0	0	0	1	3	7
Passive Solution		11	12	9	11	8	9	8	9	10	9	17	17	—

5. Simulation of Development Strategies

Based on the results of the simulation, this study proposes five strategies for future issues that Taichung will have to deal with such as population management, land utilization and environmental pollution. These are: Slow down the rate of population increase to avoid the over-development and exploitation of resources; provide enough green areas to satisfy the need for outdoor activity space; maintain basic water allocation levels to satisfy the needs for habitability; increase sewage treatment capacity and waste incineration capacity to reduce pollution. Simulations were then carried out with the variables sensitive to these policies. The simulation results and their explanations are provided below:

(1) Maintain an appropriate level of urban population growth:

Population density is an important indicator to consider in urban planning and city management. Based on the concept of neighborhoods/ward units, an appropriate population density is between 100~200 people per hectare while residential density is between 160~330 people per hectare. Based on Taichung City's system dynamics model, this study predicted that by 2016 Taichung's residential density will be 386 people/hectare. The study hoped that the density could be reduced to 300 people/hectare and with this as the standard entered the above five strategies into the model for simulation. The simulation results for each strategy were then compared against each other (Fig. 8).

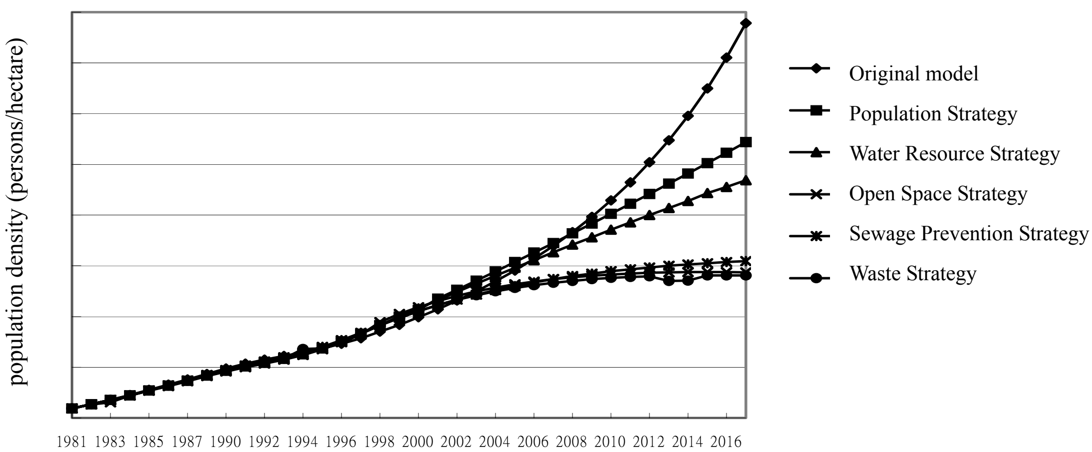

Fig 8. Simulation results of population strategy

The simulation results indicated that the original model reached a population density of 386 people/hectare by 2016 and a total population of 2,353,000; implementing the population strategy reduced the population density to 318 people/hectare with a total population of 1,342,000; implementing the water resources strategy reduced the population density to 287 people/hectare with a total population 1,285,000; implementing the open space strategy reduced the population density to 237 people/hectare with a total population of 1,126,000; implementing the sewage prevention/treatment strategy reduced the population density to 241 people/hectare with a total population of 1,171,000; implementing the waste strategy reduced the population density to 232 people/hectare with a total population of 1,107,000.

Among the different strategies the Population strategy slightly exceeded the desired population density of 300 people/hectare. This strategy however effectively reduced the total population from 2,353,000 to 1,342,000. As for the water resource, open space and pollution prevention strategies, though they achieved a lower population density than the target value the total population was on the low side. Looking at the rate of population growth, Taichung City's population in 1996 was around 880,000. Using the average increase of 20,000 people per year between 1986 and 1996, it was projected that by 2016 the total population will reach around 1,300,000. Therefore the simulation result of the population strategy was a better match for Taichung City's development.

To achieve the goal of effective management and growth for the city's population, construction in Taichung City's re-zoned districts should be accelerated. An outpost-based development strategy should be adopted to create growth centers and promote regional development. Alternatively, new residential areas should be developed in Taichung and urban renewal encouraged in Taichung City's old/rundown areas. Regional and small business centers should be set up in accordance with population distributions and community locations as well. These will reduce the crowding in the central business district and improve everyday amenities for local communities. For fast growing areas, development should be encouraged under existing conditions although care should be taken to avoid an excessive concentration of population and commercial activities.

(2) Increase the amount of urban open space:

A general evaluation was carried out on the amount of green/open space per person in Taichung City. It was found that in 1996 Taichung City had 1.5m^2/person – far lower than the average values from other Taiwanese cities and developed cities in other parts of the world. In order to maintain a high level of urban lifestyle quality, provide open spaces required for homes and workplaces as well as take into account the development of the urban population/industry and shape an urban spatial environment, 3.5 square meters was set as the minimum amount of open space per person. This was intended to achieve the goal of increasing the amount of open space (Lin, 1997).

The simulation results (Fig. 9) indicated that the original model in 2016 achieved an average open space ratio of 3.3m^2/person; by implementing the population strategy, the average open space ratio was 3.2m^2/person; by implementing the water resources strategy, the average open space ratio was maintained at 2.9m^2/person; by implementing the open space strategy, the average open space ratio was increased to 3.5m^2/person; by implementing the sewage prevention/treatment strategy, the average open space ratio dropped to 2.4m^2/person; by implementing the waste strategy, the average open space ratio dropped to 2.3m^2/person.

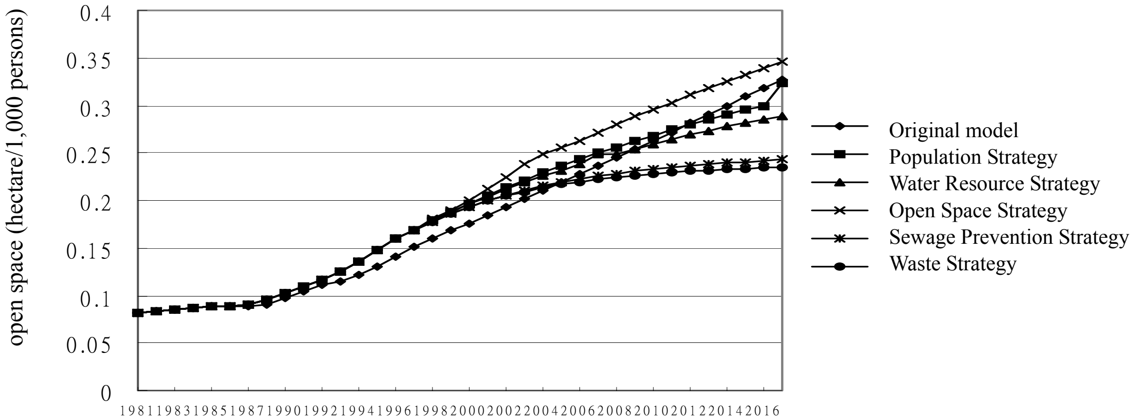

Fig 9. Simulation results of open space strategy

Out of all the strategies only the open space strategy reached the set target value. Therefore to achieve the objective of increasing the amount of open space enjoyed by each person, "Urban Renewal" or "Urban Redevelopment" should be promoted for Taichung City's residential areas and public infrastructure as the quality of life improves and the total population increases. The amount of green areas in the city's central business district should be increased as well; make available farmland located within 30~50 meters of Taichung County/City's major traffic corridors to build scenic gardens and green belts; use ecological forest planting techniques to cultivate strong and high quality urban forests, introduce recreation and leisure activities along transportation links and encourage the private sector to build urban forest parks; move railways underground, clean-up Luchuan Canal and beautify it's shoreline. Carry out railway square and streetscape improvement projects, use the land to add additional open spaces and beautify the streets. By improving the overall appearance of the city this will encourage it's healthy development.

(3) Ensure the sustainable use of water resources:

Cities must be constantly re-supplied in order to stay alive and nowhere is the reliance on nature more obvious than the demand for water. It is therefore important to avoid resource supply constraints that may lead to shortages and improve the resource self-sufficiency of the city. In accordance with the objectives of the "National Comprehensive Development Plan" and the "Popularization of Water Conservation Measures Initiative", this study used the limit of 300 liters per day as the standard for Taichung residents (WRA, 1999) to carry out strategy simulations.

The simulation results (Fig. 10) indicated that in the original model by 2106 the average water supply per person in the region will reach 325.13 liters; by implementing the population strategy the region's average water supply increased to 448.4 liters; by implementing the water resource strategy the region's average water supply increased to 322.61 liters; by implementing the open space strategy the region's average water supply increased to 360.88 liters; by implementing the sewage prevention/treatment strategy the region's average water supply increased to 338.79 liters; by implementing the waste policy, the region's average water supply increased to 381.88 liters.

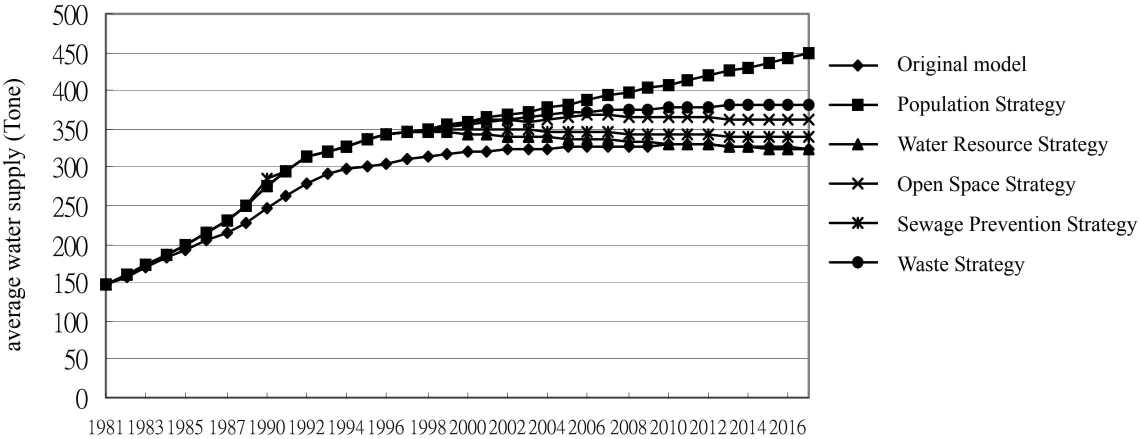

Fig 10. Simulation resalts of Water resource strategy

The simulation showed that while the strategies helped to improve the quality of the urban living environment and improved the quality of living, they also increased the burden on the city's water supplies. While none of the strategy results achieved the desired standard, the implementation of the water resources strategy effectively decreased the needed water supply volume and moderated the demand for water resources. Out of all of the strategies the water resource strategy was therefore the one best suited to a management strategy aimed at improving the sustainable use of water resources by the city.

In other words, to achieve the objectives of conserving water resources and ensuring their sustainable use, beyond adding dam storage capacity and protecting water catchments, past patterns of water use should be changed. A more ecological green city approach must be adopted through green building concepts (Lin, 1996) that utilize water-saving equipment and conserve the everyday use of water. Rainwater storage systems should be used to store rainwater using natural or artificial methods. This after basic purification can be used for many everyday activities. A gray water system should also be established to collect urban rainwater run-off and everyday sewage for treatment. Once treated to the required standard the result can be used as non-drinking water or where it does not contact the human body. These measures are aimed at maintaining the quantity and quality of the city's resources so that they can meet the needs of the urban population while helping residents learn from and be a part of nature. Through this process of familiarization eco-friendly lifestyles can be developed that co-exist in harmony with nature, ensuring the sustainable use of resources by the city.

(4) Reduce urban environmental pollution:

Whether the urban environmental quality is good or bad can be measured by its pollution indicators. When the total amount of pollution exceeds a city's maximum processing capability, the excess pollution is expelled untreated into the urban environment where it degrades the urban environmental quality. This study therefore looked at water pollution and waste pollution. By taking into account the ecology and the city's state of development, strategy simulations were carried out on how the waste generated per person can be reduced and the city's pollution treatment capacity increased.

The simulation results (Fig.11, 12) showed that in the original model, by 2016 the amount of sewage per person was 236.69 liters and the average amount of garbage generated was 2.87 tons; by implementing the population strategy, the amount of sewage per person was 358.72 liters and the average amount of garbage generated was 2.46 tons; by implementing the water resources strategy, the amount of sewage per person was 239.79 liters and the average amount of garbage generated was 2.23 tons; by implementing the open space strategy, the amount of sewage per person was 288.13 liters and the average amount of garbage generated was 1.68 tons; by implementing the sewage prevention/treatment strategy, the amount of sewage per person was 263.45 liters and the average amount of garbage generated was 1.75 tons; by implementing the waste strategy, the amount of sewage per person was 305.51 liters and the average amount of garbage generated was 1.1 tons.

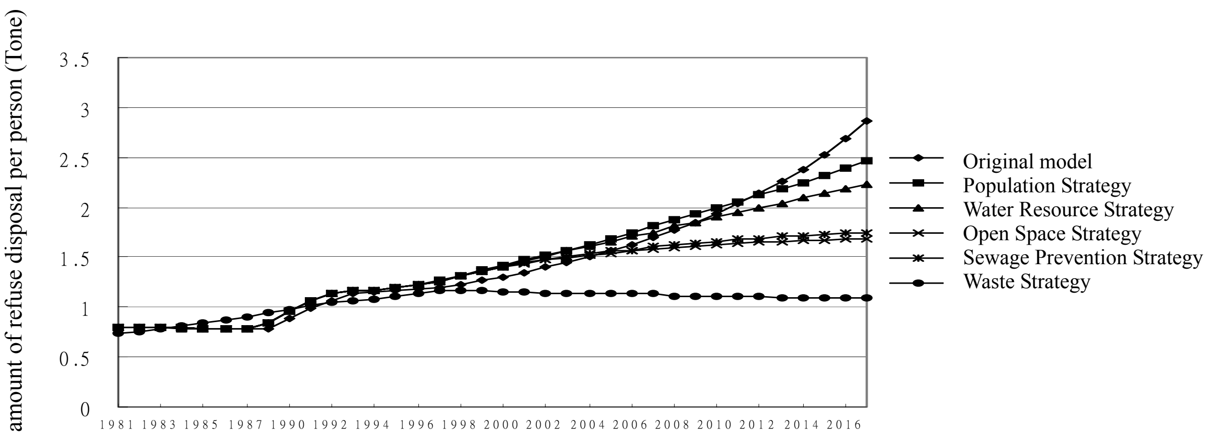

Fig 11. Simulation results of gabage pollution strategy

As the implementation of each strategy improved the quality of the urban living environment, the increase in standard of living also increased the attractiveness of Taichung City leading to an increase in the amount of pollution generated. The simulation results for all strategies were therefore all higher than the original model for the water pollution category. Population strategy in particular had no significant effect on control of pollution. Only through the management strategy for water resources was there an effective reduction in water pollution but this in turn had no real effect on waste; the waste strategy's effect was a complete reversal to that of water resource strategy – both only had an effect on one category; a cross-analysis was therefore carried out of the strategies with the result that the sewage prevention/treatment and open space strategies provided a more uniform and steady development. Of the two the sewage prevention/treatment strategy offered better control of the sewage problem and is more effective on the garbage problem as well. This means that out of all the strategies the sewage prevention/treatment and open space strategies were better suited to a management strategy of pollution control and promotion of the city's sustainability.

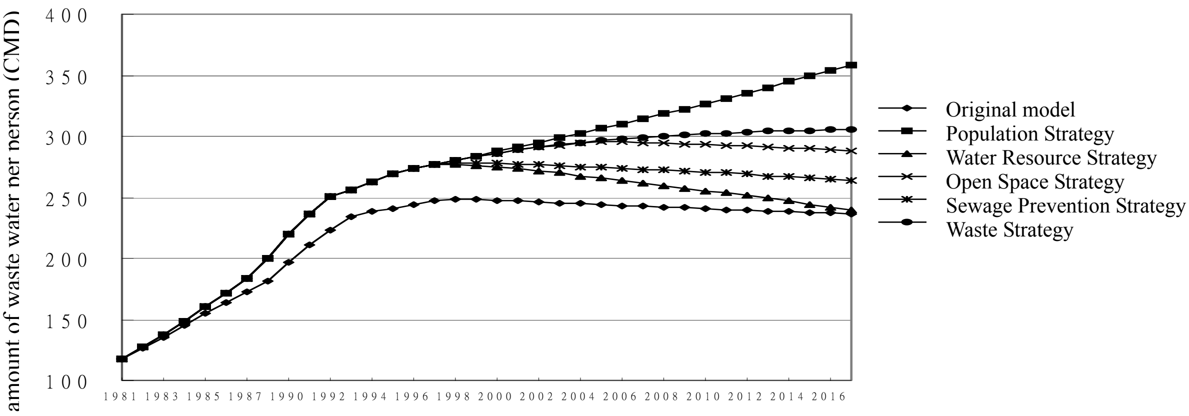

Fig 12. Simulation results of water population strategy

To achieve the objective of reducing pollution problems, Taichung City should make it the city's goal to become a bastion of advanced green technology in central Taiwan. Development should focus on high technology and low pollution industries with appropriate locations selected for treating polluting waste to reduce the amount of environmental pollution from industrial development. This should be the principle that governs the commercial development of Taichung City in order to offer employment opportunities and indirectly encourage the development of nearby real estate. Garbage handling facilities should be reviewed and the requirements established for public infrastructure such as rain/waste water systems. Accelerate the construction of rain/wastewater systems, develop water sources and construct additional waste incinerator plants. At the same time, improve the habitability of the urban environment, reduce the mixing of residential/industrial buildings and control environmental pollution.

In this study, the management methods for effective management of the city's development were extracted for analysis so a general strategy could be formulated. This was then simulated using the system dynamics model of Taichung City with the result as shown in Fig. 13. A comparison of the simulation results from the original model versus the implementation of the strategy is shown in Table 4. This showed that after the implementation of the strategy, the total population of the city in 2016 is only

57% of that projected for the original model while the population density is only 82%; the average green space per person becomes 4.5 square meters, or 136% of that supplied in the original model; the total amount of sewage will be effectively reduced to just 16% of the original model; the amount of waste processing required in 2016 can be met as well. This means that Taichung City's total population in 2016 could be effectively managed. The amount of green space available to each person is increased while the amount of water pollution and garbage were brought under control as well. This result proves that by defining the appropriate strategy, the urban ecological balance of Taichung City can be maintained to create a high quality urban environment. Within the constraints of land and natural resources, growth of the city's population will even out while the increase in population will enable the use of land to be optimized.

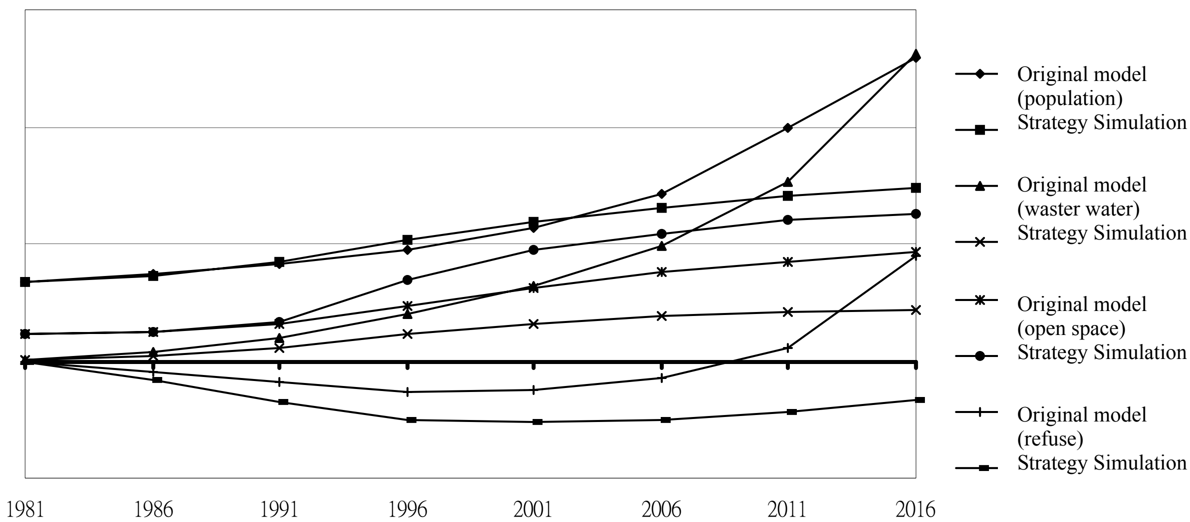

Fig 13. Simulation results of Taichung City's Development strategy

Conclusions and Recommendations

This study adopts a development-based perspective to devise indicators for sustainable development of the city. By using the cause-and-effect relationship of the ecological chain, an understanding of the city's issues can be acquired. Using methods from system dynamics a system dynamics model of Taichung City was constructed. This model was then used to run simulations of feasible development strategies for Taichung in order to formulate a comprehensive vision for the sound development of Taichung. This study arrived at the following conclusions and recommendations:

1. Conclusion

(1) A city is a very complex non-linear system. Between each component of the system are complexities, dependencies and feedback. In this study ecological economy concepts were used to construct an ecological economic system model of Taichung City. This model included 36 indicators and 6 sub-systems: Population, Land, Industry,

Service, Socio-Economics and Environmental Pollution. By analyzing human activity and the balances in the environment within the system, the best approach to management of the city can be derived.

(2) By looking at the cause-and-effect relationships between each of the sub-systems within the ecological economic system for Taichung City, this study used techniques from system dynamics to construct a system dynamics model. The model was then used to analyze the dynamic behavior of changes over time during city development in order to predict the future development trends of the city. At the same time, it is used to offer alternative management strategies to the city planners.

(3) The model's system strategy simulation results indicated appropriate action should be as follows:

a. Maintain an appropriate level of urban population growth:
Control Taichung City's rate of population growth to maintain a population density of 318 people/hectare in 2016, or 57% of natural growth. Also provide effective management of population distribution so there is sound and balanced development in all districts, avoiding the over-development or use of resources.

b. Increase the amount of urban open space:
Actively establish parks and green areas as part of Taichung's city planning; establish scenic forests and green belts along Taichung City's railways, freeways and the Taichung-Changhua expressway; select farmland not in production in the suburbs and encourage farmers to develop urban forests that are both scenic and suitable for recreation. Increase the amount of open public space in the city to provide citizens with a diverse range of outdoor places for recreation and leisure. This will provide 4.5 square meters of open space to each person in Taichung City by 2016, a 136% improvement on 2001.

c. Ensure the sustainable use of water resources:
Modify the water resources consumption behavior of Taichung City. Promote water conservation, construct an urban gray water system and increase the reuse of treated water. Establish controls over the set-up of water-intensive consumer services such as car-washes in order to ensure the sustainable use of water resources. This will enable Taichung City can maintain in 2016 a basic requirement of 322.61 liters per day per person.

d. Reduce urban environmental pollution:
Push for Taichung City's industries to transition over to high technology/ low-pollution sectors such as precision engineering and information technology. By reducing the rate of increase in pollution generation, the amount of produced pollution in 2016 can be reduced to 68% of 2001 levels; at the same time install additional environmental pollution treatment equipment to increase pollution

treatment capacity. This will ensure that sufficient waste disposal capacity is available in 2016 to prevent pollution caused by the dumping of excess garbage.

2. Recommendations

(1) This study used digitization tools to carry out sensitivity analysis on variables that had a greater impact on the simulated system. The most sensitive variables are thus identified with improvements proposed. This achieves the goal of supporting the system through environmental decisions. This direction can be maintained in the future to build an urban development information database management system for Taichung City. This will enable continued development and integration of the system into the city planning process.

(2) In order to study the urban system spatial composition of Taichung City, space analysis systems and remote-sensing technologies can be used to construct an ecological economic system geographic information system database for Taichung City. This can be used to analyze problems in the urban ecological environment, examine the reasonableness of the City's urban ecological system spatial composition as well as study the feasibility of coordinating ecological functions. This will provide a scientific basis for Taichung City's urban development management strategy.

(3) In the future the resources of the four central Taiwan cities and counties can be combined to carry out a system dynamic simulation model study of the Taichung metropolitan region. This will serve as a foundation for the future sustainable development of the Taichung metropolitan region's basic infrastructure. The level of the system itself can also be expanded to explore resource development issues that involve the local and central governments as well as Taiwan and the rest of the world.

(4) In accordance with the issues and goals of the study, the "Expert Survey Method" was used by this study to examine the cause-and-effect relationship between variables. Though this method can establish a cause-and-effect relationship between variables, a problem was encountered where the units of some variables were different and could not be incorporated into the system model for calculation. In the future, to establish the cause-and-effect relationship the "Expert Team Meeting" method should be considered. With the research topic and goal as a guide, experts are gathered together in one place to discuss and decide the variables as well as their cause-and-effect relationship.

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