System Dynamics Model for the Sustainable Development of Science City

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Abstract

Hsinchu Science Park is an example of developing high technology industry in Taiwan. Its rapid growth has resulted in the tremendous economic benefits. However, it also has produced social and environmental impacts, such as traffic jams, environmental pollution and heightened differences in social class. These impacts result in conflict between economic growth and sustainable development of the science city. The purposes of this study therefore are (1) to understand the interactive relationships between subsystems and indicators in the sustainable development system of a science city, (2) to discuss the social, economic and environmental issues occurring in this system, and (3) to device reasonable strategies for the operation and management of a science city. The indicators for sustainable development of a science city were selected by the method of Fuzzy Delphi with respect to the economic, social and environmental aspects in the theory of sustainable development. A system dynamics model was established by STELLA programming language to simulate the different development scenarios of Hsinchu Science City. Our analysis reveals that the development of the science city should comply with the objectives of (1) maximizing the profits from industries in the science park, (2) minimizing the damages incurred by the science park on its mother city, (3) decrease in consumption of natural resources, (4) reduction in environmental pollution, and (5) attention to relevant social problems. In addition, an integrated management strategy with due emphasis on economic, environmental and social aspects to attain the sustainable development with economic prosperity, environmental and ecological conservation as well as social equality

Keywords: system dynamics model, sustainable development, science city, Scenario

Introduction

Ever since its establishment in 1980, Hsinchu Science Park (HSP) has seen tremendous development, bringing in remarkable economic benefits.   Its annual average output between 1998 and 2000 accounted for 8% of Taiwan's GNP, and its production doubled that of other domestic industries.   However, its rapid growth also resulted in adverse social and environmental impacts including rising land price in Hsinchu, chaotic traffic, environmental pollution and social segregation in Hsinchu City (HC).   These problems all violate the 3E (Environment, Economic and social Equality) principles of sustainable urban development. Hence, efficient handling of the problems related to the growth of the HSP will be an important indicator of whether Taiwan would succeed in developing into a green silicon island in the 21st century.

The purpose of this study is to simulate the strategies of sustainable development for HSC. (Fig.1) Urban development are closely related to social and cultural custom, ecological and economic resources.   The achievement of the formulation of sustainable development strategy is require a systematic and flexible methodology; including an indicators system and most importantly, a simulation model to relate the social, ecological and economic aspects of urban planning together as a whole.
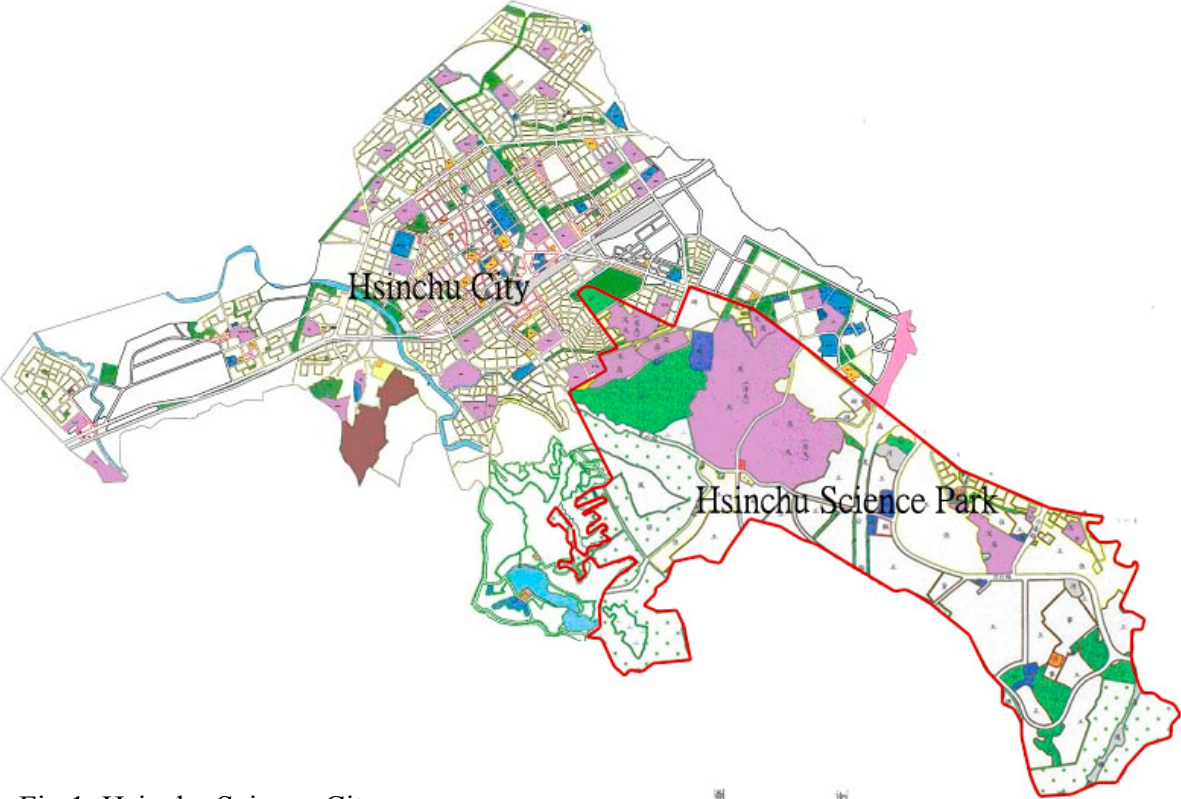

Fig 1. Hsinchu Science City

The application of system dynamics in urban systems has been raised by Forrester since 1974.   In recent years, considerable interest has been generated in the use of system dynamics, as an aid in urban planning to assist planner in understanding the complex interaction among social, ecological、economic and other factors. A number of people,

Nijkamp & Perrels (1994)、Gulen & Berkoz (1996)、Ho et al (2002), have been involved in research in this field, resulting in a rapid growth in the literature on the subject.   So it is possible to search for the strategies of sustainable development in a system dynamics model.

Different urban development scenarios can be simulated with the model to shed light on the effectiveness of sustainable development strategies and their impacts.   The results obtained in this study can serve as useful references for managing the HSC and devising future development strategies with due emphasis on the economic, environment and social aspects.

Research Method

Sustainable development is a dynamic process which recognizes the needs of everyone; effective protection of the environment; prudent use of natural resources; and maintenance of high and stable levels of economic growth and employment.   In this case, the strategies to be formulated will be more complex.   It is obvious that the need has thus arisen for a new and more capable method which will tend to produce improvement of system behavior to the problem.

In HC considerable concern exists about urban problems, such as the deterioration of living conditions, overcrowding and empty dwellings, traffic congestion, the shortage of open space and many other aspects of urban social, economic and environmental situations.   Most of the existing planning methods in this context addressed only one or two of these three aspects.   This study is to develop an integrated framework for establishing a sustainable urban structure to maintain a balanced relationship between human needs and urban environment.

System dynamics can assist in strategy assessment and provides insights into possible changes in the system during policy implementation (Sterman, 2000). A simulation model, combining urban system analysis with system dynamics techniques is suggested. Through model simulation, the proposed strategies are taken as changes in parameters and structure. The objectives of sustainable development can be pursued to achieve a better quality of life for every citizen, now and for generation to come.

Model Formulation

Formulation of Sustainability Indicators and Feedback Loop Diagram

Reviewing the establishment of Hsinchu Science City and its industrial development and aiming to achieve more efficient management, we formulate science park industry、population、housing、environmental pollution and economic five sub-systems (Appendix I) and 52 indicators, as shown in Table 1.   Fuzzy Delphi Method is employed for screening the indicators.   From the industrial sector, the government and the academia, 20 experts and scholars were selected to assess the 52 indicators formulated in order to establish the

sustainability indicators for HSC. Indicators with experts' assessment value above the threshold will be selected while those below will be screened.   In the end, 22 sustainability indicators are obtained as marked with * in Table 1.

Table 1 Sustainable indicators and their assessment value

Subsystem	Indicator	Value	Subsystem	Indicator	Value
HSP industry subsystem	Number of companies	0.66	Housing/ Landuse subsystem	Rate of unoccupied houses	0.70＊
	Productivity of SP staff	0.72＊		Average housing price	0.70＊
	Industry value	0.77＊		Rate of land development in SP	0.69＊
	Net revenue of capital	0.69		Land area per SP staff	0.70＊
	Amount of imports	0.64		House rental rate in SP	0.58
	Amount of exports	0.65	Environmental pollution subsystem	Amount of dust fallen	0.69
	R&D expenditure	0.70＊		Total amount of suspended particulates	0.72
Population subsystem	Total population	0.63		Daily sewage disposal per capita	0.83＊
	Population growth rate	0.74＊		Daily refuse production per capita	0.81＊
	Natural increase rate	0.56		Amount of refuse collected per day	0.75
	Social increase rate	0.70＊		No. of motorcycles per 1000 persons	0.64
	Average size of household	0.63		No. of vehicles per 1000 persons	0.70
	Urban-to-total population ratio	0.65		Number of factories registered	0.58
	Population density	0.76＊		Number of environmental pollution lawsuits	0.82＊
	Age structure	0.71＊	Urban economy subsystem	Amount of saving per household	0.68＊
	Education level	0.71＊		Total regular income per family	0.71＊
	Water consumption per capita	0.56		Housing-to-total family expenditure ratio	0.67
	Power consumption per capita	0.57		Rate of self-owned houses	0.61
	Population of SP staff	0.59		No. of automobiles per 1000 persons	0.55
	Age structure of SP staff	0.60		Rate of unemployment	0.70＊
	Education level of SP staff	0.71＊		Low income-to-total population ratio	0.57
Housing/ Landuse subsystem	Area of agricultural land	0.46		No. of industrial units	0.61
	Urban-to-total area ratio	0.58		Industrial population	0.60
	Urban area per capita	0.72＊		Industrial-to-total population ratio	0.65
	Population served by piped water	0.65		Industry value	0.82＊
	Residential floor area per capita	0.70＊		Area of industrial land	0.64

Note:＊Adopted by higher values than the threshold：0.695(HSP industry subsystem), 0.675(Population subsystem), 0.669(Housing/ Landuse subsystem), 0.760(Environmental pollution subsystem), 0.674(Urban economy subsystem)

Taking into consideration the development characteristics of HSC and linking the five subsystems through variables such as industrial production, population and extent of pollution.   The causal feedback loops of the different variables in the sustainable development system of Hsinchu Science City were formulated and shown in Figure 2.   As can be seen, there are 16 causal loops, 11 input and 5 information feedback ones.
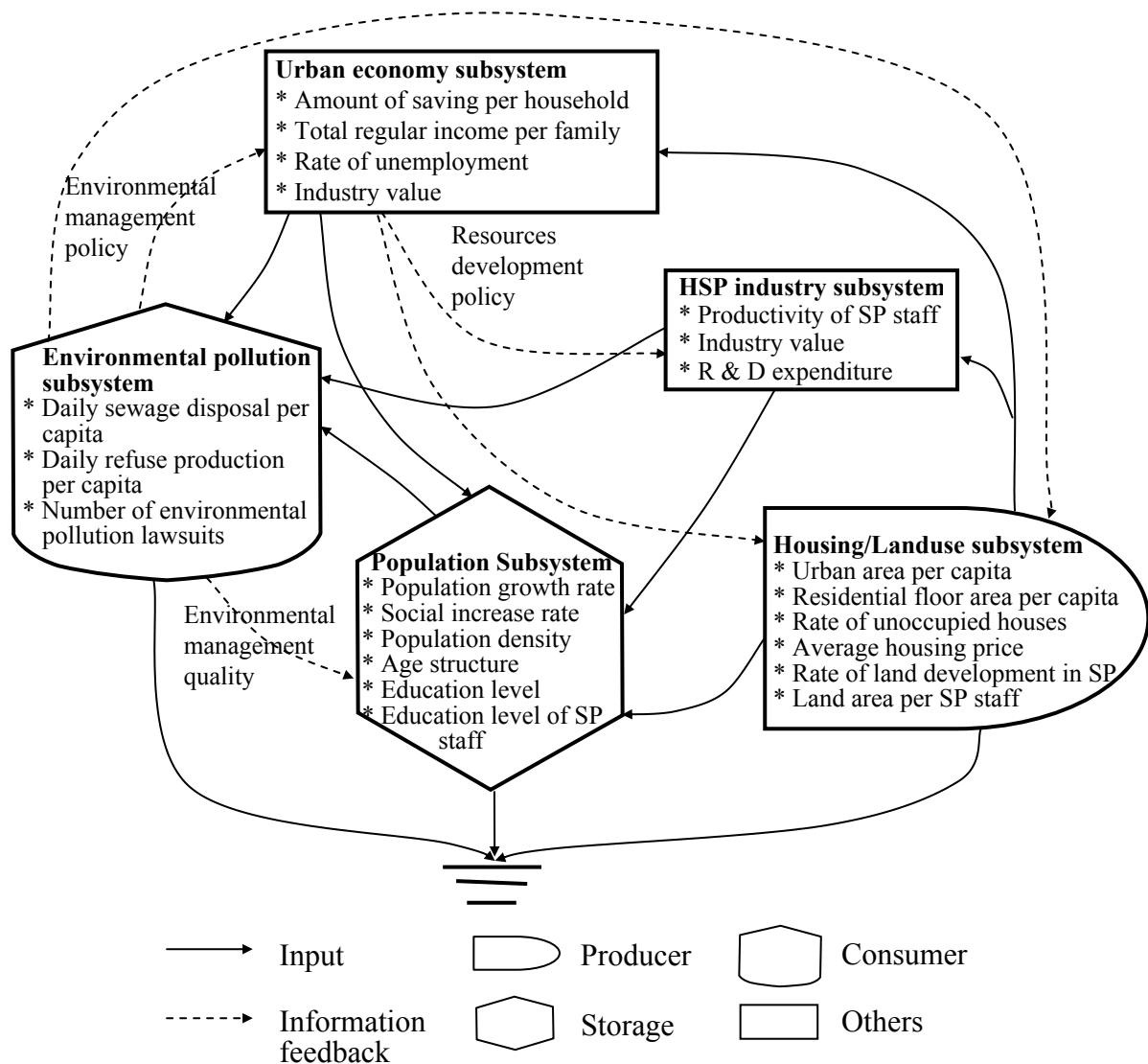
Fig. 2 Integrated system model of the sustainable development of Hsinchu Science City

Model Formulation and Simulation Analysis

In view of the many parameters of an urban sustainable development system and their complex relationships, we assume in this study that the behavior in such system is in a continuous state in order to facilitate model formulation and simulation analysis. Therefore, changes in system behavior are not a matter of probability; rather they are the results of some causal loops of the variables. The formulated urban sustainable development model covers Hsinchu Science Park and its mother city; historical data of the area from 1986 to 2000 are taken as the basis to simulate and forecast the future development of HSC.

Figure 3 shows the dynamic model of the sustainable development system of HSC which is written in the STELLA programming language (HPS, 2000). As can be seen, the model comprises 80 variables and 90 equations. Among these equations, 10 are level equations, 10 are initial value equations, 18 are rate equations, 32 ancillary equations, 15 constant equations and 5 graphic equations. With the system dynamic model formulated, we conducted computer simulation and analysis of the HSC sustainable development strategies.
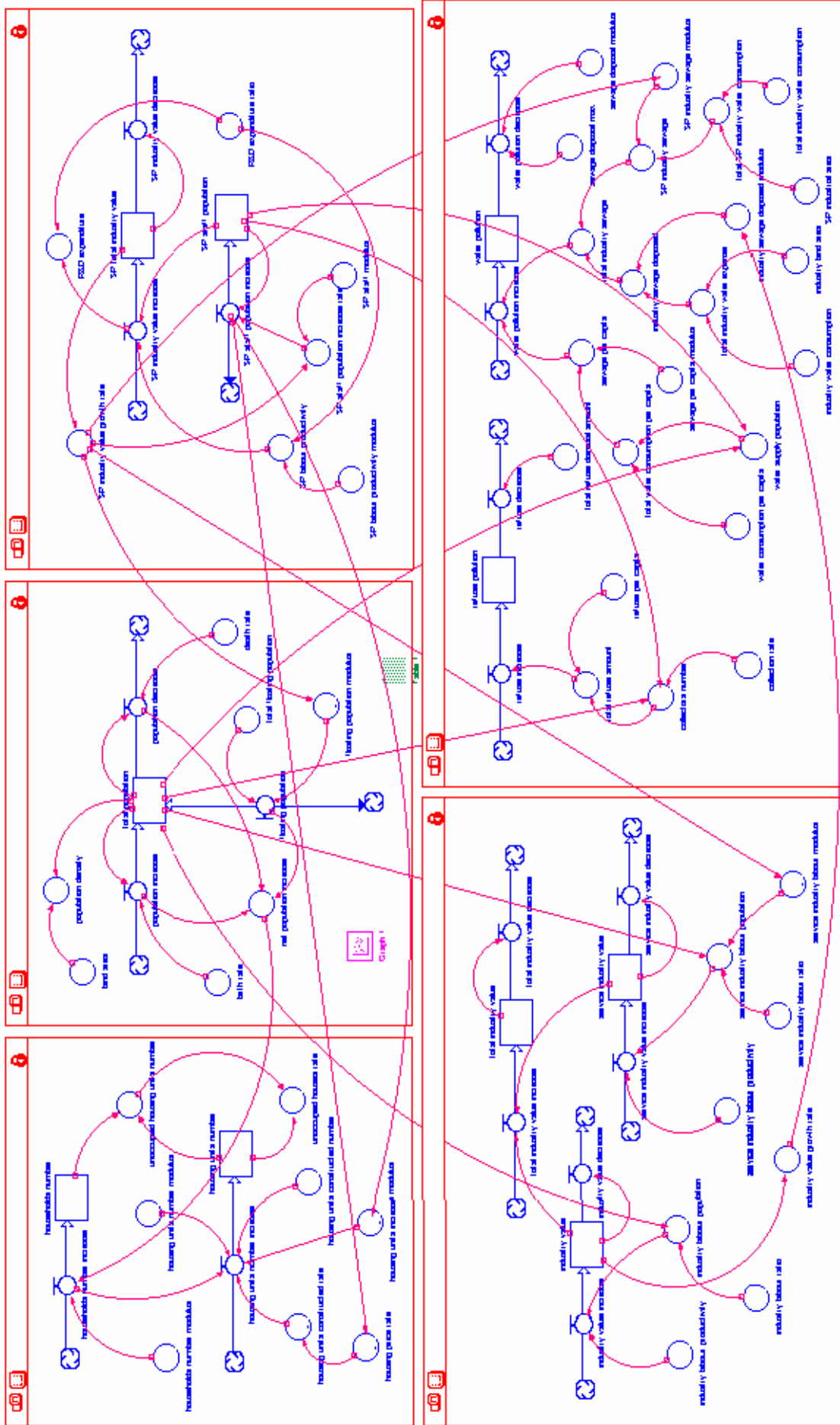
Fig 3. STELLA diagram of the integrated system model of sustainable development for Hsinchu Science City

Justification of the Model

The model was justified with the historical data of Hsinchu City from 1986-2000. The results were very close the real-world behavior. (Fig 4)
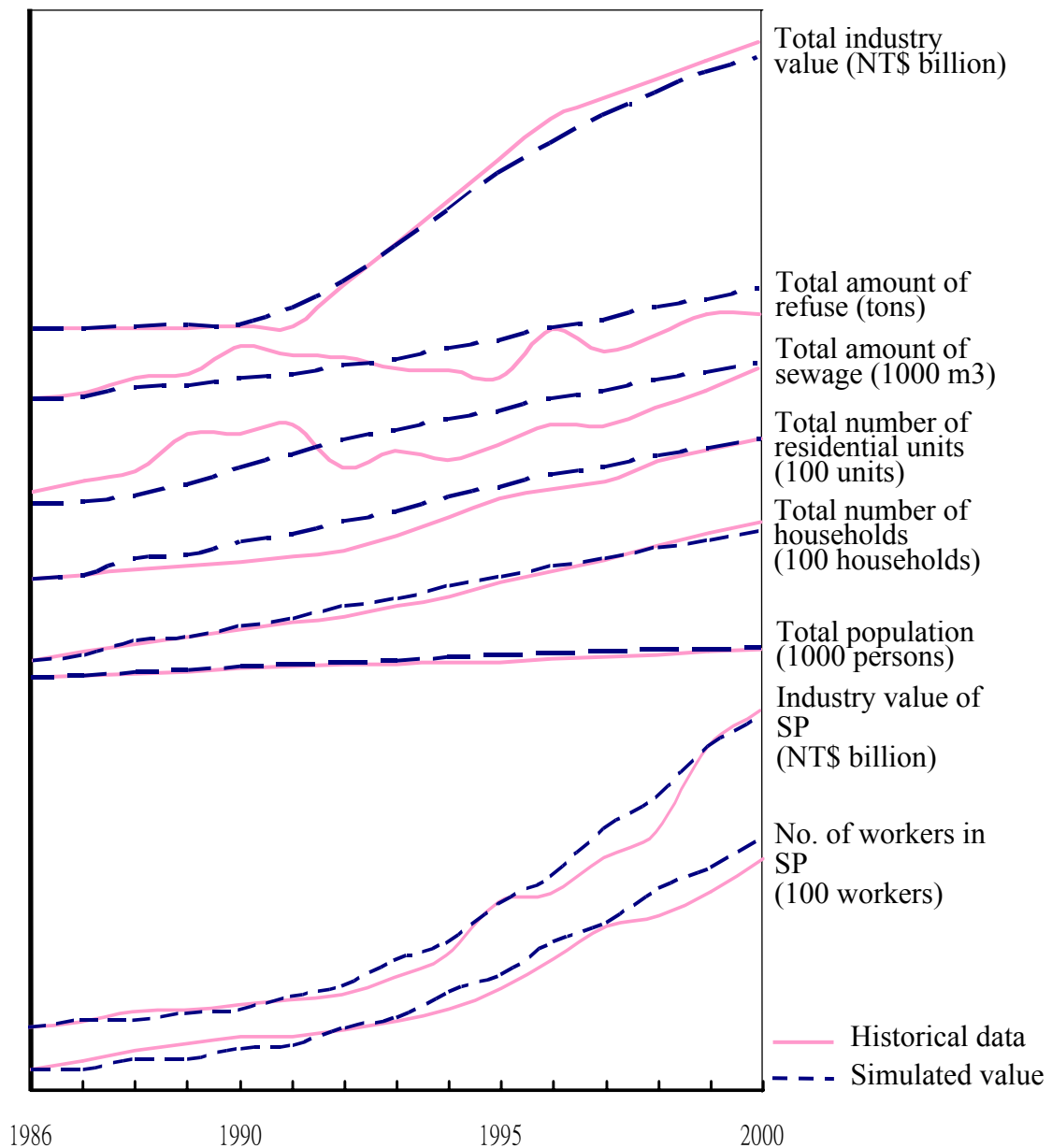

Fig 4. Simulated data with respective to the historical data of Hsinchu City

Sensitivity Analysis

This study used the 'Effect-Efficiency Matrix' to select the sensitive variables in the model (Kano, 2003).   The matrix classified them into an active set consisting of 15 ancillary variables and a passive set comprising 13 variables identified by the experts.   During the test, the value of each active variable was increased by 10% to produce 15 different values. Each increment will result in a corresponding change in the value of the 13 passive variables. In consequence, 196 curves were generated.

Because the changes in value could be positive or active, the values were normalized

by the arithmetic mean and the standard deviation. The relations between the active and passive variables were divided into four classes of different scores as follows: (1) 0 for No effect, (2) 1 for weak effect (lower than standard deviation), (3) 2 for median effect (within standard deviation), and (4) 3 for strong effect (higher than standard deviation). The results are shown in Table 2.

Table 2. 「Effect-Efficiency Matrix」 of variables of sustainable development for Hsinchu Science City

Active set \ Passive set	Indicator variables												
	SPSP	SPTIV	TP	NPI	HN	HUN	UHUN	RI	WPI	IV	SIV	TIV	AS
SPSM	3	3	2	2	2	2	2	2	2	2	2	2	26
SPLPM	3	3	2	2	2	3	3	2	2	2	2	2	28
RDER	3	3	2	2	2	2	2	2	2	2	2	2	26
ILR	0	0	0	0	0	0	0	0	2	2	0	2	6
ILP	0	0	0	0	0	0	0	0	2	3	0	3	8
SILR	0	0	0	0	0	0	0	0	0	0	2	2	4
SILP	0	0	0	0	0	0	0	0	0	0	3	2	5
BR	0	0	2	3	2	2	0	2	2	2	2	2	19
DR	0	0	2	1	2	2	0	2	2	2	2	2	17
HNM	0	0	0	0	1	1	0	0	0	0	0	0	2
HUNM	0	0	0	0	0	2	2	0	0	0	0	0	4
PRC	0	0	0	0	0	0	0	3	0	0	0	0	3
WCPC	0	0	0	0	0	0	0	0	3	0	0	0	3
IWC	0	0	0	0	0	0	0	0	3	0	0	0	3
PS	9	9	10	10	11	14	9	13	20	15	15	19	—

(The "Ancillary variables" label spans the rows SPSM through PS.)

Note：SPSP：SP_staff_population
    SPTIV：SP_total_industry_value
    TP：total_population
    NPI：net population_increase
    HN：households_number
    HUN：housing_units_number
    UHUN：unoccupied_housing_units_number
    RI：refuse_increase
    WPI：water_pollution_increase
    IV：industry_value
    SIV：service_industry_value
    TIV：total_industry_value
    AS：Active Solution
    SPSM：SP_staff_modulus

SPLPM：SP_labour_productivity_modulus
RDER：R & D_expenditure_ratio
ILR：industry_labour_ratio
ILP：industry_labour_productivity
SILR：service_industry_labour_ratio
SILP：service_industry_labour_productivity
BR：birth_rate
DR：death_rate
HNM：households_number_modulus
HUNM：housing_units_number_modulus
PRC：refuse_per_capita
WCPC：water_consumption_per_capita
IWC：industry_water_consumption
PS：Passive Solution

The results indicate the most sensitive ancillary variables in the active set are SP personnel modulus (SPSM), SP labour productivity modulus (SPLPM) and R & D expenditures ratio (RDER) and the second sensitive variables are birth rate (BR) and dearth rate (DR). In addition, the more is the degree of sensitivity, the higher does the degree of the impact complexity it shows. .For instance, the most sensitive variable in the passive set is water pollution increase (WPI). It then includes total industry value (TIV)、service industry value (SIV) and industry value (IV).

Simulation of Development Strategies for Hsinchu Science City

Our simulation analysis shows that HSC has been and will be experiencing continuous development from 1986 to 2021 in terms of SP industry value, total population, rate of

unoccupied houses, amount of sewage disposed, amount of refuse collected and total industry value.   Detailed simulated results of the policies are discussed in the following:

Scenario 1: economic growth strategy

Being the source of prosperity of HSC, the HSP should be given due priority in strategy formulation.   In other words, it is important to maintain a flourishing SP for the economic benefit of its mother city.   Without innovation and ongoing development, there is no guarantee for lasting success of today's hi-technology industries, which may then fall into the fate of unsustainable traditional industries and become idle or oblivious.   Retarded growth of the SP will be a severe blow to the development of HSC.   Our first scenario simulation focuses on maintaining prosperity and sustainable growth of the SP.   Possible strategies for attaining such goal will include enhancing staff productivity and increasing R&D expenditure ratio to foster growth in industry value.

According to historical data, the productivity of SP staff peaked in 2000 at NT$ 9.04 million per worker; while the average productivity per worker in the past 16 years is NT$ 4.91 million, showing an average growth of 10.97%.   Owing to the worldwide economic downturn in 2001, it suffered a decrease in that year and thereafter has maintained a steady growth of 5% per year.   With reference to the highest productivity attained in 2001, the upper limit of annual staff productivity is set to be NT$ 100 million.

Regarding R&D expenditure ratio, there has been a constant, though slow, growth, from 4% of the total sales revenue to around 6%.   The highest percentage of 7% was found in 1998 and the average value was 5%.   We assume that the R&D expenditure ratio will maintain a steady increase and reaches 9% of total sales revenue in 2016.

Simulations under this scenario with and without strategy implementation were performed and the results are displayed in Figs. 5 to 10.   As can be seen, marked increase in industry value is observed starting from 2006, five years after the policies have been launched; the value is forecasted to rise more than two folds by 2021.   On the other hand, total population and total industry value also reveal growth though to a smaller extent.   All these indicate that rising industry value does foster the prosperity of the region, yet not without costs.   The rate of unoccupied houses is predicted to soar to 20%, 2% more than the rate estimated without strategy implementation.   This implies that the strategies will indirectly lead to excess supply of houses.   At the same time, both sewage disposal and amount of refuse collected have shown increase, indicating that overdevelopment in industry will aggravate the problem of environmental pollution.

Efforts made on hi-technology development will certainly bring about economic benefits, though at the expense of further deterioration of the environment and disequilibrium in housing supply.   In other words, over-emphasis on economic development will upset the social and environmental balance.   Hence, to achieve sustainable development of HSC, the industrial development of the SP should not be without constraints and due attention should also be paid to the environmental and social issues in the area concerned.

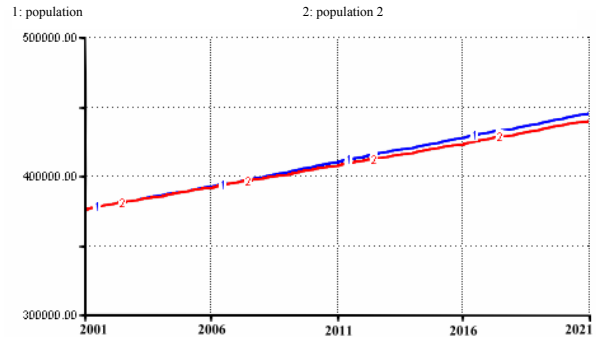Fig 5. Industrial value of SP
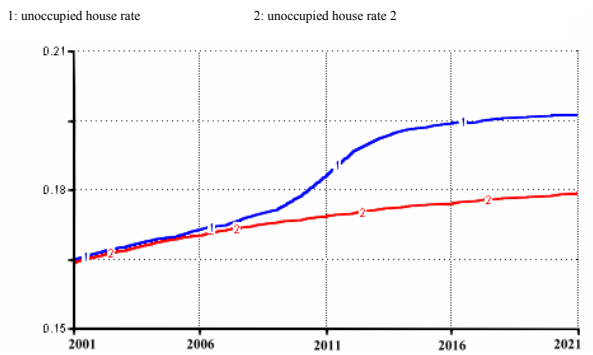

Fig 6. Total population

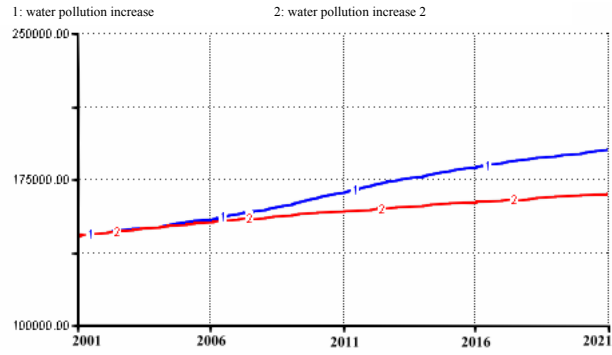Fig 7. Rate of unoccupied houses
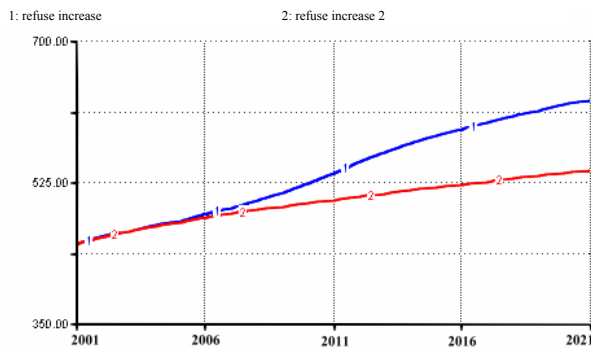

Fig 8. Total amount of sewage disposed

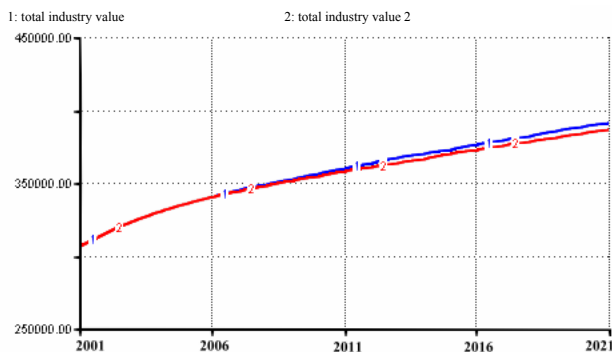Fig 9. Total amount of refuse collected

Fig 10. Total industrial value of HC

Scenario 2: environmental protection strategy

The theory of sustainable development has always given ecological conservation the top priority. With focus on protecting the environment, appropriate industrial and economic development should be fostered without incurring negative impact on the ecology and at minimum depletion of natural resources. To achieve such goal in the HSC, possible strategies would involve restricting industrial and economic development through monitoring the productivity and population of SP staff.

As mentioned in Scenario 1, global recession in 2001 has caused a reduction in productivity. In our model, we assume that such declining trend will continue in future and there will be a gradual decrease in productivity of SP staff from its peak in 2000 to an annual

productivity of NT$ 6 million per person in 2011 and thereafter it will remain unchanged. At the same time, the model also sets the ratio of R&D expenditure constant, with neither increase nor decrease.

As seen in the historical data, the total number of SP staff has increased from 8,275 in 1986 to 96,293 in 2001, showing an average annual rise of 18%. However, 2001 saw for the first time negative growth, with a decrease of 349 employees compared with the total staff population of 2000. In view of the declining trend in the SP staff population, the model does not introduce any change in the parameter setting.

Figures 11 to 16 show the simulated results with and without policies implemented to maintain environmental tolerance. Significant decrease in industry value is observed starting from 2006. The declining trend becomes steadier after 2016. The forecasted industry value of 2021 with strategy implementation is around 30% less than that without, while there is little difference observed with respect to total population and total industry value. That is to say, policies related to environmental conservation have little impact on these two aspects. However, the rate of unoccupied houses has become better controlled, showing a value of 16%, 2% less than the rate estimated without strategy implementation. As for the amount of sewage disposed and amount of refuse collected, a slight decline can be seen from 2006. Although the magnitude of decrease is not great, the quality of the environment is on the whole improving.
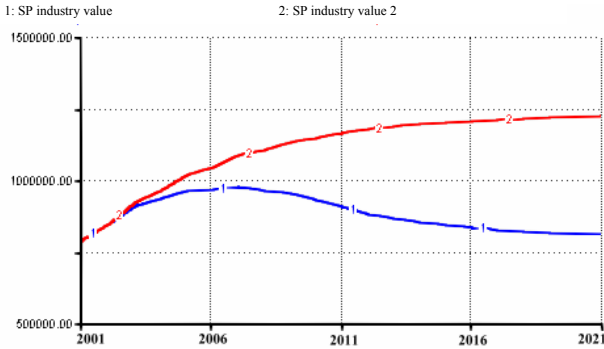

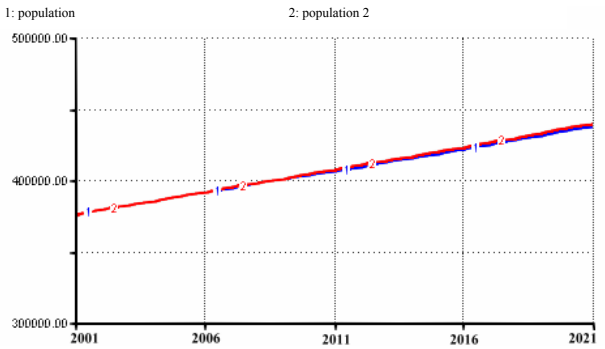Fig 11. Industrial value of SP

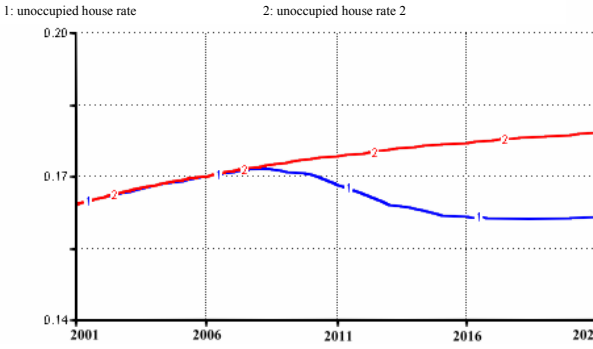Fig 12. Total population

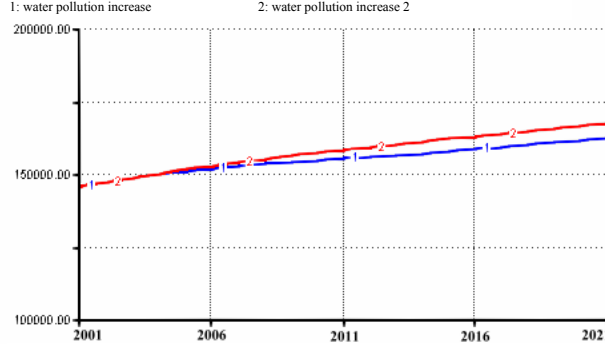Fig 13. Rate of unoccupied houses
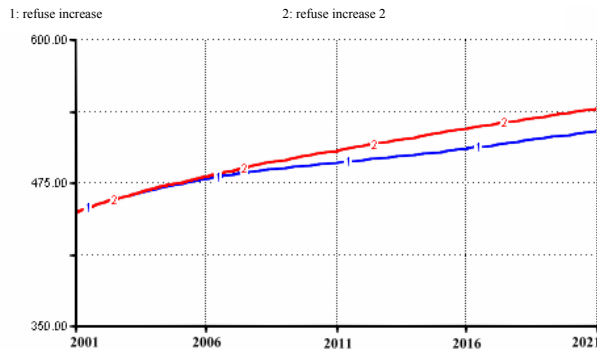

Fig 14. Total amount of sewage disposed

Fig 15. Total amount of refuse collected

Fig 16. Total industrial value of HC

Aiming to conserve the environment and maintain social equality, the policies of constraining industrial development in the SP do achieve reduction in rate of unoccupied houses, amount of sewage disposed and amount of refused collected while showing little impact on the total industry value in the mother city. Nevertheless, the forecasted hi-tech industry value of 2021 will decline by around 30%, a significant economic impact worthy of concern. Hence, too much stress on the environment and social equality but at the expense of economic loss will still be a blow to urban sustainability; particularly so for a science city whose main wealth draws from the industrial prosperity of the science park. Constraints should be posed but steady development has to be preserved while industrial decline should be avoided. In short, strategy-makers have to strike a balance between the 3E concerns so as to realize sustainable development. That is to say, the policies implemented should target at fostering industrial development, reducing environmental pollution and maintaining social equality at the same time.

Scenario 3: Integrated management strategy

As seen in Scenarios 1 and 2, emphasis on any single aspect, be it economic growth or environmental protection, cannot ensure equal progress in environment, economy and social equality. Too much stress on increasing industry value will result in deterioration of the environment and rise in rate of unoccupied houses. Although restricting the increase in industry value may solve such problems, it is at the expense of maintaining steady growth in the SP, which itself is also the goal of sustainable development of the HSC. Hence, a more integrated approach should be considered. Possible strategies would involve both the SP industries and the mother city. With respect to the former, the total population of SP staff should be controlled and the R&D expenditure ratio should be increased; while in the latter, measures should be taken to encourage home purchase so as to reduce rate of unoccupied houses, promote recycling and reuse to cut down refuse production, and to foster economy of water consumption.

As mentioned in Scenario 2, there has been an average annual increase of 18% in SP staff beginning from 1986, which peaked at around 97 million in 2000. Owing to the

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limitation of space in the SP, the total staff population will not rise indefinitely.   Hence, the study model sets the highest population of SP staff at 140 million.   When the simulated SP staff population reaches this limit, the model will stop further increase.

The parameter setting for R&D expenditure ratio in Scenario 1 is adopted for simulation of Scenario 3.   That is, there is constant steady growth in R&D expenditure ratio with no upper limit.   By 2001, the R&D expenditure ratio is forecast to reach 10% of the total sales revenue of the SP.

Statistics shows that the average size of a household in HSC is 4.46 persons and is on the decline at 2% each year.   By 2000, the average size has dropped to 3.28 persons.   With the policy of encouraging home purchase, the rate of unoccupied houses has been on a steady decrease at 2% per year and will reach a constant rate at 2011.   Historical data indicate that the daily average water consumption per capita has increased from 310 liter in 1986 to 330 liter in 2000; while the daily average amount of refuse collected per capita has decreased from 1.05 kg in 1986 to 0.99 kg in 2000.   Economy of water usage is encouraged in the hope to reach the target daily average of 250 liter per capita, as stipulated in the National Conference on Soil and Water Resources.   Moreover, the falling trend of daily average amount of refuse collected is to be maintained to reach the target daily average of 0.96 kg per capita in 2016, which will remain unchanged thereafter.

Figures 17 to 22 displays the simulated results with and without policies of integrated management implemented.   As can be seen, these policies bring about a slight increment in industry value.   It is interesting to note that the population of SP staff does not rise along with the increasing industry value; rather it is dropping a little.   This indicates that the policies of restricting total SP staff population and raising R&D expenditure have fulfilled the purpose of adding value to the industry.   There is hardly any change in the total population and total industry value.   Measures encouraging home purchase serve to bring the rate of unoccupied houses down to 17%, 1% less than the rate estimated without strategy implementation.   Obvious reduction can be seen with respect to amount of sewage disposed.   This together with the decease in amount of refuse collected evidences the success of the policies in enhancing the environmental quality of the HSC.
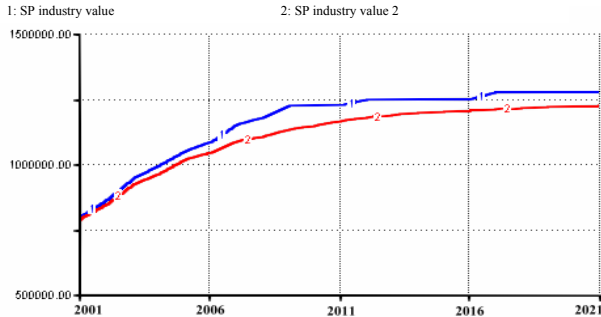

Fig 17. Industrial value of SP

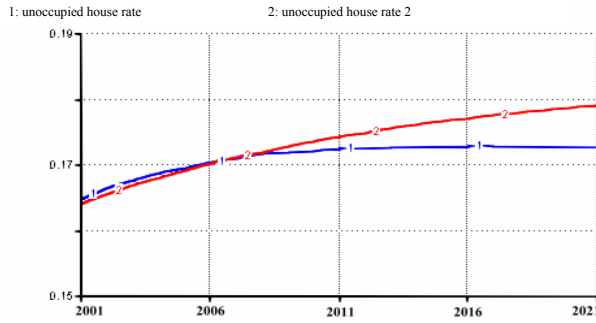Fig 18. Total population

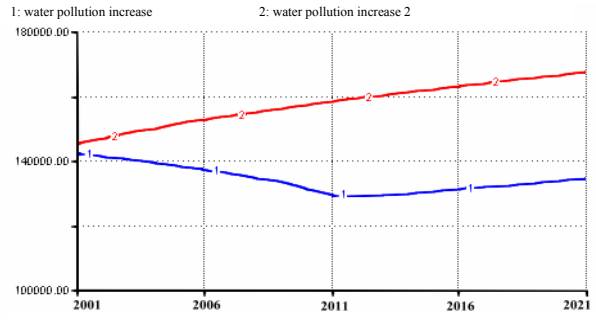Fig 19. Rate of unoccupied houses

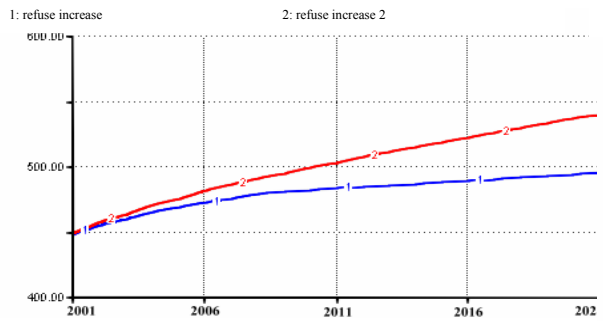
Fig 20. Total amount of sewage disposed
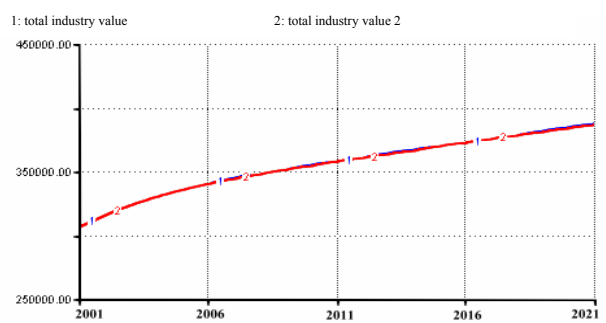

Fig 21. Total amount of refuse collected

Fig 22. Total industrial value of HC

In short, integrated management policies implemented in the SP have achieved increase in industry value, decrease in rate of unoccupied houses and reduction in pollution to the mother city.   All 3E concerns have been addressed with balanced emphasis paid on each, thus serving the purpose of maintaining sustainable urban development.   From this, we can see that the sustainability of the HSC can be achieved not only by preserving continuous industrial development in SP, but also with good integrated management of the mother city from a macro perspective.   Past experience has shown that economic development and environmental conservation are often in conflict with each other.   It seems inevitable that fostering one will make the other suffer.   However, our analysis above seems to indicate a way out.   As seen in our simulated development scenarios, while promoting economic prosperity by adding value to the industry, the impact on the environment can be minimized by appropriate control over industrial landuse and staff population.   At the same time, polices related to environmental conservation can help reduce resource consumption and depletion as well as strengthen pollution control.   Hence, integrated approach to management with equal emphasis on the 3E aspects is the key to the success in achieving sustainable urban development.

Conclusions & Suggestions

Conclusions

According to the simulation analysis, the following polices are possible means of

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realizing sustainability in HSC:

1. Economic strategies

    To promote industry development in the HSP, the emphasis should be on quality rather than quantity.   Increase in production quantity will imply larger labour population, which may incur extra burden on the environment and cause social problems.   Hence, more effort and resources should be devoted to research and development, targeting for more value-added outputs.   In this way, economic prosperity can be realized through increase in industry value with minimum negative impact on the mother city.

2. Environmental strategies

    Measures aiming to reduce resource consumption and depletion should be implemented to put pollution under control.   Education and promotion on proper use of water and 3R (recycle, reuse and reduce) should be launched.   Facilities for refuse disposal and sewage treatment should be added to enhance the efficiency in reducing sources of pollution and curtailing further deterioration of the environment.

3. Social strategies

    Science park employees are usually of higher education and higher pay, thus causing social segregation.   Real estate prices will tend to go up, which is unfair to other residents of the mother city.   Higher profits will attract developers to construct more houses, leading to higher rate of unoccupied houses.   In view of these problems, sustainable development policies should aim at controlling the total staff population of the HSP to avoid excessive increase.   To reduce the rate of unoccupied houses, home purchase promotion schemes should be launched providing greater benefits and low-interest government loans to attract buyers.

Suggestions

Suggestions for future research are as follows:

1. HSC is a steady system with ongoing changes.   Among the subsystems, there exist feedback loops for control and adjustments to be made with respect to further system growth.   Hence, to realize the goal of attaining sustainable development, the assessment and valuation of the sustainability indicators would yield reasonable standard value so that proper limits can be set and appropriate amendments can be made.   In this way, the model formulated would bear closer resemblance to the reality, making the simulated results more reflective of the future scenarios and possible changes.

2. Future studies can explore more in-depth micro-observation of a single subsystem. Take for example the HSP industry subsystem; a more detailed and complete model of the subsystem can be formulated by taking into consideration the impact of the four most important industries, namely opto-electronics, semi-conductor, IC design, as well as

telecommunications and biotechnology, on the development of the HSP.   It is also of interest to investigate further into the interrelationships between two subsystems, such as the HSP industry subsystem and the environmental pollution subsystem, to understand better their causal links so as to establish more complete feedback loops between them.

3. Our simulated results reveal that environmental pollution can be effectively decreased at the cost of reducing 30% of the industry value (NT$ 4000 billion).   It is worth to explore the cost of implementing other pollution control measures.   Comparison between the costs involved can shed light on which is a more economic approach to enhancing environmental quality.

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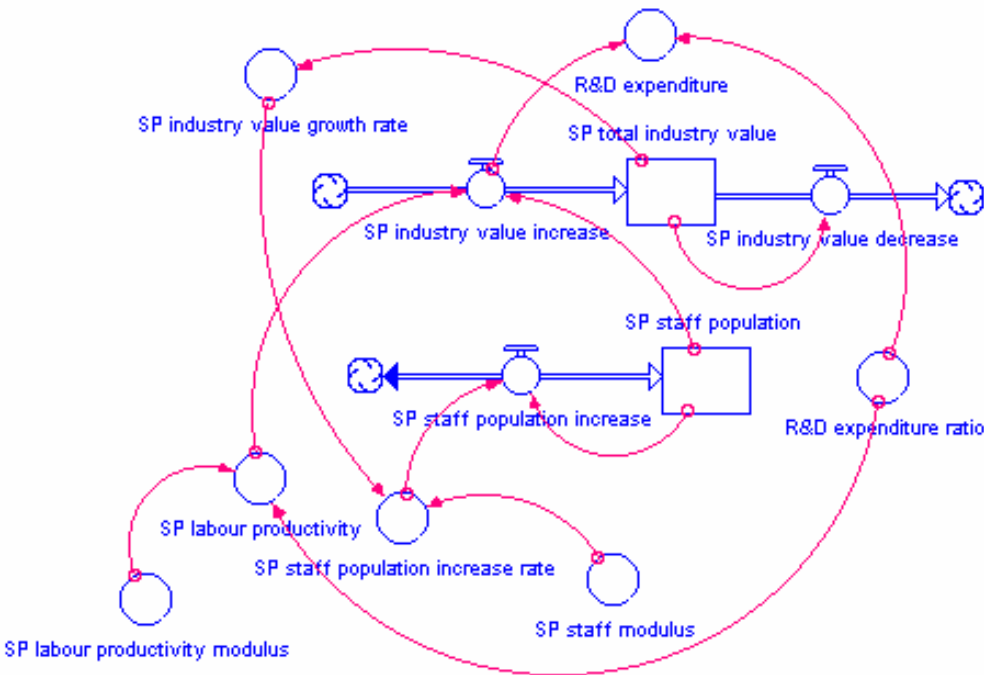# Appendix I. STELLA diagrams of the subsystem of Hsinchu science city

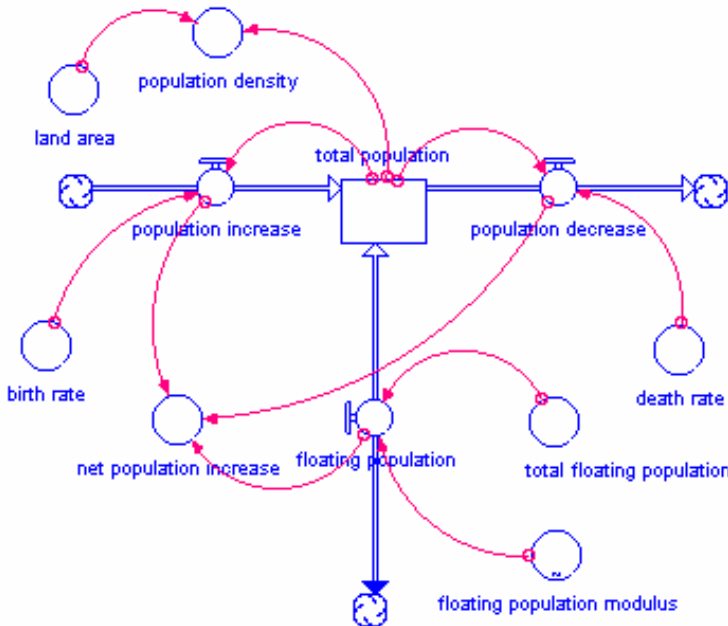Fig23. STELLA diagram of science park industry subsystem
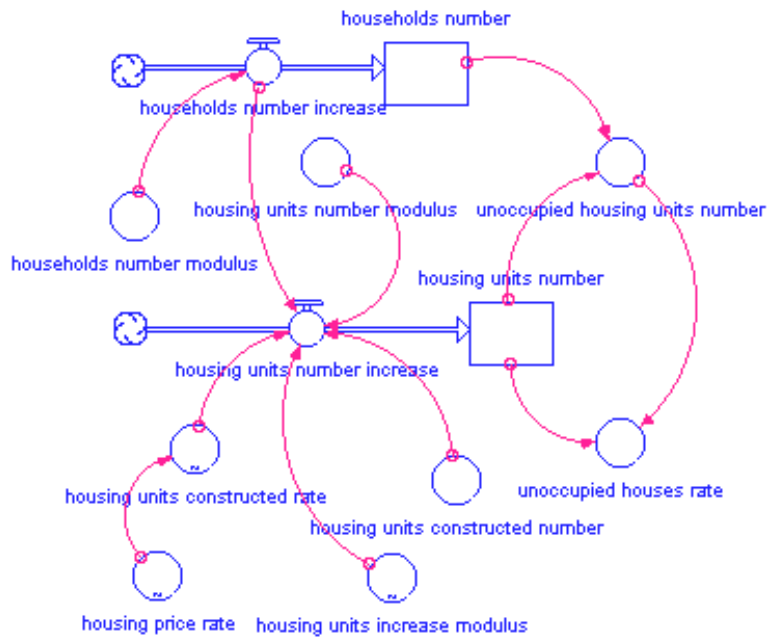

Fig 24. STELLA diagram of population subsystem

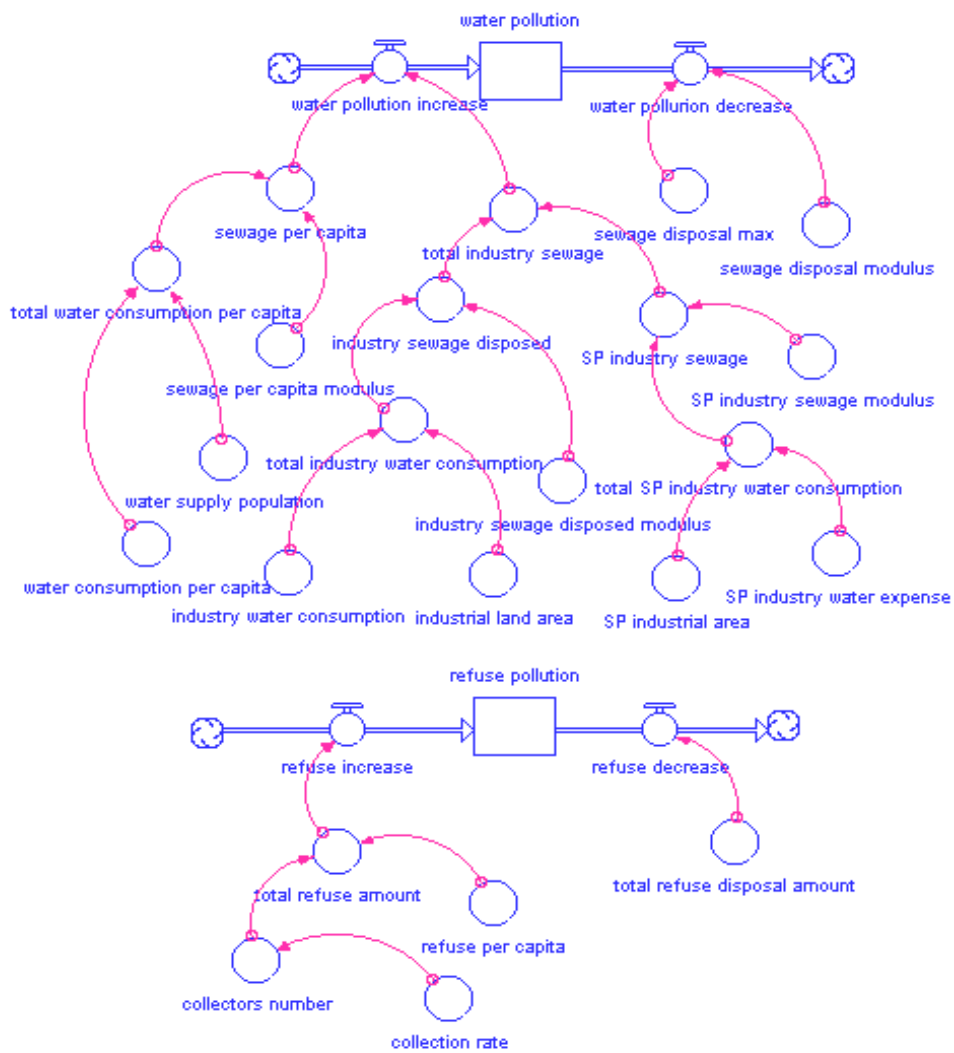Fig 25. STELLA diagram of housing/landuse subsystem

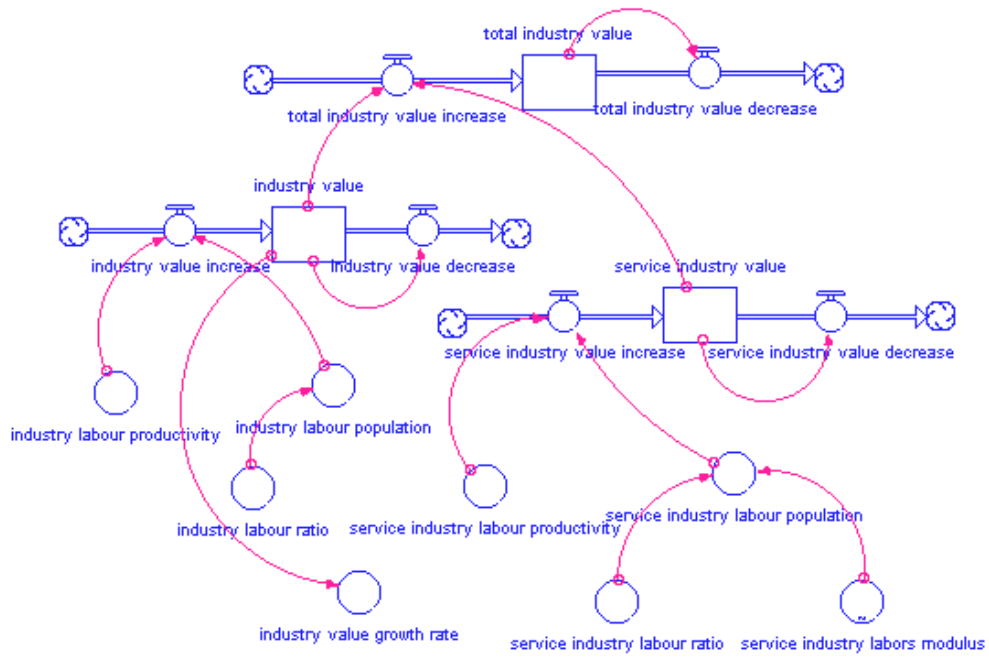Fig 26. STELLA diagram of environmental pollution subsystem

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Fig 27. STELLA diagram of urban economy subsystem

Appendix II. System Dynamics Model of Sustainable Development for Hsinince Science City

1. SP industry subsystem

SP_industry_value(t) = SP_industry_value(t - dt) + (SP_industry_value_increase - SP_industry_value_decrease) * dt

INIT SP_industry_value = 17043

INFLOWS:

SP_industry_value_increase = SP_staff*SP_staff_productivity

OUTFLOWS:

SP_industry_value_decrease = SP_industry_value

SP_staff(t) = SP_staff(t - dt) + (SP_staff_increase) * dt

INIT SP_staff = 8275

INFLOWS:

SP_staff_increase = SP_ staff *SP_ staff _increase_rate

R&D_expenditure = SP_industry_value_increase*R&D_expenditure_ratio

R&D_expenditure_rate = SMTH3(0.065,10,0.04)

SP_industry_value_growth_rate = (DERIVN(SP_industry_value,1))/(DELAY(SP_industry_value,1))

SP_staff_increase_rate = SP_industry_value_growth_rate*SP_staff_modulus

SP_ staff_modulus = 0.64

SP_ staff_productivity = SMTH3(7,6,3.5)*(SP_staff_productivity_modulus*R&D_expenditure_ratio+1)

SP_ staff productivity_modulus = 2.7

2．Population subsystem

population(t) = population(t - dt) + (population_increase + floating_population - population_decrease) * dt

INIT population = 306088

INFLOWS:

population_increase = birth_rate*population

floating_population = floating_population_modulus*total_floating_population

OUTFLOWS:

population_decrease = death_rate*population

birth_rate = SMTH3(0.013,6,0.016)

death_rate = 0.0054

land_area = 104.0964

net_addition_population = population_increase+floating_population-population_decrease

population_density = population/land_area

total_floating_population = 25510

floting_population_modulus = GRAPH(SP_industry_value_growth_rate)

(-1.00, -0.24), (-0.8, -0.21), (-0.6, -0.15), (-0.4, -0.09), (-0.2, -0.03), (-5.55e-017, 0.00), (0.2, 0.03), (0.4, 0.09), (0.6, 0.15), (0.8, 0.21), (1.00, 0.24)

3. Housing/Landuse subsystem

household(t) = household(t - dt) + (household_increase) * dt

INIT household = 68587

INFLOWS:

household_increase = net_addition_population / household_modulus

house_unit(t) = house_unit(t - dt) + (house_unit_increase) * dt

INIT house_unit = 80061

INFLOWS:

housing_units_increase = household_increase*house_unit_modulus+house_construction_unit* housing_units

housing_units_increase_modulus*house_construction_rate

households_modulus = SMTH3(1.4,6,2)

house_construction_unit = 850

house_unit_modulus = 1

unoccupied_house_rate = unoccupied_house_unit/house_unit

unoccupied_house_unit = house_unit-household

house_construction_rate = GRAPH(house_price_rate)

(0.9, 0.7), (1.31, 0.755), (1.72, 0.821), (2.13, 0.914), (2.54, 1.05), (2.95, 1.27), (3.36, 1.55), (3.77, 1.77), (4.18, 1.89), (4.59, 1.96), (5.00, 2.00)

house_price_rate = GRAPH(SP_staff_increase)

(0.00, 0.9), (2000, 1.06), (4000, 1.27), (6000, 1.43), (8000, 1.68), (10000, 1.99), (12000, 2.38), (14000, 2.81), (16000, 3.30), (18000, 3.93), (20000, 5.00)

house_unit_increase_modulus = GRAPH(SP_staff_increase)

(-2000, 0.00), (-1600, 0.2), (-1200, 0.4), (-800, 0.6), (-400, 0.8), (0.00, 1.00), (400, 1.00), (800, 1.00), (1200, 1.00), (1600, 1.00), (2000, 1.00)

4. Environment pollution subsystem

refuse_pollution(t) = refuse_pollution(t - dt) + (refuse_increase - refuse_decrease) * dt

INIT refuse_pollution = 0

INFLOWS:

refuse_increase = refuse_amount

OUTFLOWS:

refuse_decrease = refuse_disposal_amount

water_pollution(t) = water_pollution(t - dt) + (water_pollution_increase - water_pollurion_decrease) * dt

INIT water_pollution = 0

INFLOWS:

water_pollution_increase = person_sewage+total_industry_sewage

OUTFLOWS:

water_pollurion_decrease = disposal_modulus*max_disposal_of_sewage

disposal_modulus = 0.9

industry_land_area = SMTH3(250,5,120)

industry_sewage = total_industry_water_expense*industry_sewage_modulus

industry_sewage_modulus = 0.6+industry_value_growth_rate

indutry_water_expense = 210

max_dispose_of_sewage = 121400

personal_refuse = 0.00105

person_sewage = person_sewage_modulus*total_person_water_expense

person_sewage_modulus = 0.8

person_water_expense = SMTH3(0.33,10,0.29)

purge_population = (population+SP_staff*0.5)*purge_rate

purge_rate = 1

refuse_amount = purge_population*personal_refuse

refuse_disposal_amount = 900

SP_industry_area = 625

SP_industry_sewage = total_SP_industry_water_expense*SP_industry_sewage_modulus

SP_industry_sewage_modulus = SP_industry_value_growth_rate*0.01

SP_industry_water_expense = 180

total_industry_sewage = SP_industry_sewage+industry_sewage

total_industry_water_expense = industry_land_area*indutry_water_expense

total_person_water_expense = water_supply_population*person_water_expense

total_SP_industry_water_expense = SP_industry_area*SP_industry_water_expense

water_supply_population = population+SP_staff*0.5

5. Urban economy subsystem

industry_value(t) = industry_value(t - dt) + (industry_value_increase - industry_decrease) * dt

INIT industry_value = 41768

INFLOWS:

industry_value_increase = industry_labors*industry_labor_productivity

OUTFLOWS:

industry_decrease = industry_value

service_industry_value(t) = service_industry_value(t - dt) + (service_industry_value_increase - service_industry_value_decrease) * dt

INIT service_industry_value = 9372

INFLOWS:

service_industry_value_increase = service_industry_labour_productivity*service_industry_labours

OUTFLOWS:

service_industry_value_decrease = service_industry_value

total_indutry_value(t) = total_indutry_value(t - dt) + (total_industry_value_increase - total_industry_value_decrease) * dt

INIT total_indutry_value = 51141

INFLOWS:

total_industry_value_increase = industry_value+service_industry_value

OUTFLOWS:

total_industry_value_decrease = total_indutry_value

industry_labors = population*industry_labor_rate

industry_labor_productivity = SMTH3(4.1,8,0.65)

industry_labor_rate = SMTH3(0.18,6,0.21)

industry_value_growth_rate = (DERIVN(industry_value,1))/(DELAY(industry_value,1))

service_industry_labors = population*service_industry_labor_rate*service_industry_labors_modulus

service_industry_labor_productivity = SMTH3(1.2,9,0.4)

service_industry_labor_rate = SMTH3(0.13,6,0.08)

service_industry_labors_modulus = GRAPH(SP_industry_value_growth_rate)

(0.00, 1.00), (0.1, 1.01), (0.2, 1.02), (0.3, 1.04), (0.4, 1.06), (0.5, 1.10), (0.6, 1.14), (0.7, 1.16), (0.8, 1.18), (0.9, 1.19), (1, 1.20)