AN APPLICATION OF SYSTEM DYNAMICS TO BEIJING URBAN ECOSYSTEM RESEARCH

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ABSTRACT

The study on urban ecology has its world-wide significance due to the phenomenon of growing "urbanization" nowadays. With System Dynamics, the author has studied the simulation model of ecosystem in Beijing. While determining the variable set and doing the sensitivity analysis, the author has posed a new method. A retrospective verification is done with historical data and then several strategies are analyzed by using this model. The research shows that the simulation model is an important method in urban ecosystem study and of great value to practical use.

1. INTRODUCTION

System Dynamics has been widely applied since it began in 1960's. It can be successfully applied to solve a big and complicated systertic problem which is difficult to be treated by other ways. It can provide policy-makers with information and policy basis for future development. Thus, the System Dynamics is greatly concerned and applied.

Because of its short history and constant development, the System Dynomics gives a much inquisition in many aspects, for instance, how to build up a simulation model which can not only accord with the behavious of a practical system but also give a simple description in a complicated system? How to combine the simulation model with policymaking so as to provide policy-makers with a powerful tool? That is the orientation of future researches.

The urban ecosystem is a complex one which not only consists of biological and non-biological factors, but also includes social, technical and economical ones. All of the factors depend on each other and affect each other by multi-feedback processes.

It is unable to get full view of it and have better understanding on its developing trend neither by the intuition nor by a traditional mathematical method or any other means. Hence, it is reasonable to select a proper way to study such a big and complex system. The simulation model set up according to the System Dynamics is capable to answer the macro problems rather than micro particulars. It emphasizes the urban eco-system as a whole, seizes the development of its own, compares distinct strategy plans, and chooses the better one to avoide plan failure.

System Dynamics studies feedback large system. It holds that each system embodies itself in a regular and recognizable structure, which determines system behaviour. System Dynamics is a method by which a structure is to be found and expressed. Its main characteristics are dynamic, feedback and wholeness. So, System Dynamics has been widely applied since it began in 1960's.

For those reasons, System Dynamics is a powerful tool to study urban ecosystem, and in turn,urban ecosystem research open up the wide domain of its application.

The purpose of this research is:
(1) Understanding better Beijing urban ecosystematic structure and its trend of dynamic change.
(2) Supplying information for policy-making bodies on the basis of policy analysis of the models concerned.
(3) Accumulating necessary experience and means in the study of urban ecosystem.

2. THE SIMULATION MODEL OF BEIJING URBAN ECOSYSTEM

To the simulation model made by System Dynamics, different openions focus on :
(1) Which major elements and important feedback loops would be included in the model, the point of the issue is how a simulation model representing reality will be refined;
(2) to what extent the model can be applied. This is the effectiveness of the model. Some people think even the widely-used world model and urban model are short of their applied effectiveness.

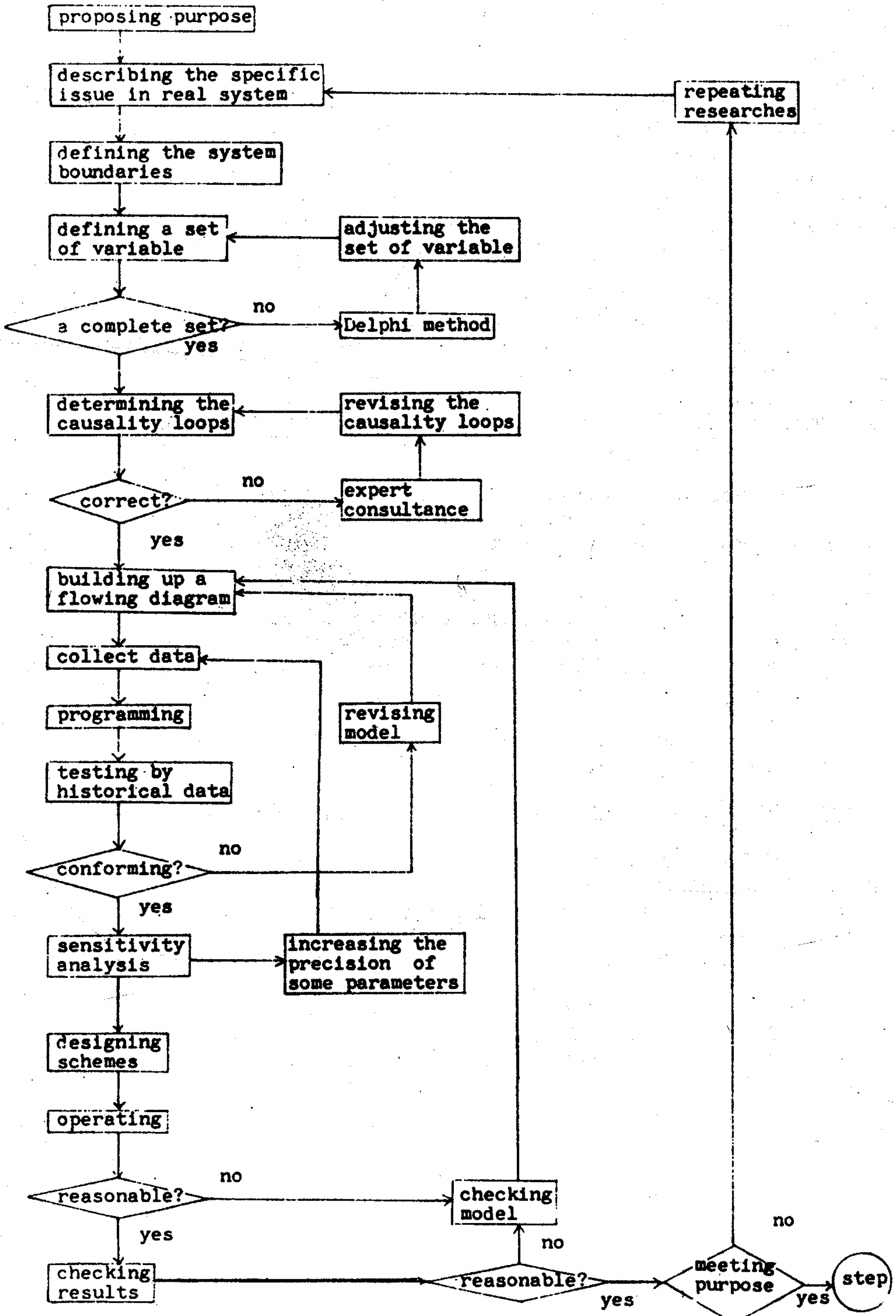

Fig.1. Working procedure

Considering the situation mentioned above, we propose a new chart of working procedure. The main purpose of this chart is clear: it is required to give solution of problems presented in the system. To have many information feedback is one of the characters of the chart. The model can be constantly adjusted to conform with the actural situation and to make the most of its effectiveness.

The behaviour of model is determined by factors in the boundary, and the boundary of model is determined by two parts:

Boundary of area: planning urban region of Beijing-- 750 square kilometers.

Boundary of issue: that the effects of city dwellers activities on urban ecological quality is the content of this research.

This research set its focus on the relationship among population, economy, resources, environment in Beijing planning region with pollution tackled in particular. Meanwhile, the fact that Beijing is the political and cultural centre is to be taken into account.

The first important problem while establishing a model is how to make the model emform to the reality.

Hence the choice of variables is a key step. So a model maker is not only required to have a deep understanding of the object to be studied, to have considerable professional knowledge, but also to cooperated with specialists in the same field. While defining the set of variables and selecting the indexes, 49 specialists were invited to join the work with the help of Delphi method.After two rounds of investigations, the set of variables was defined. The set of variable is divided into six sub-system: the urban population, the urban land utilization, industry, the urban service trade, the politics and culture, and the environmental pollution.

(1) Pollution is a main indication reflecting the quality of urban ecology.
(2) Urban population, induestry, urban land are "level" variables which reflect scale of the city.
(3) The number of people working in government organs, scientific and educational institutions, and urban service trade are the "level" variables demonstrating the nature of the city.
(4) Land, water and energy are main material basis for urban existance and growth, having a direct bearing on the six "level" variable groups mentioned above.

The six "level" variable groups are respective kernal variables of sub-system of Beijing urban ecosystem simulation model. All variables reflect the relationship among population, economy, resources, environment in Beijing urban ecosystem.

Mutual effects among sub-system in Beijing urban eco-system is called causality chart. With the help of specialists' consultation, the causality chart was at last defind by repeated revisions. There are altogether 50 feedback loops, in which 24 positive feedback loops and 26 negative loops are included.

It is more profound, more direct and more effective to build up a simulation model with the aid of Delphi method and specialists' consultation rather than just from visiting and from public opinion polls. The information from different specialists is more reliable and overall.

On the basis of the above work, a flowing diagram of the simulation model of Beijing urban ecosystem was worked out. 184 variables and parameters, 351 equations are defind, in which 13 "level" variables, 29 "rate" variables, 106 "auxiliary" variables, 34 parameters, 2 "delay" function are included.

Can we say the more variables the better? It depends on the practical needs. The objective of a model is to answer the questions in the practice rather than to concentrate on the quantity of variable alone. sometimes there are too many variables to reflect the nature of system. So it should be careful to select decisive variables for ensureing a satisfactory work.

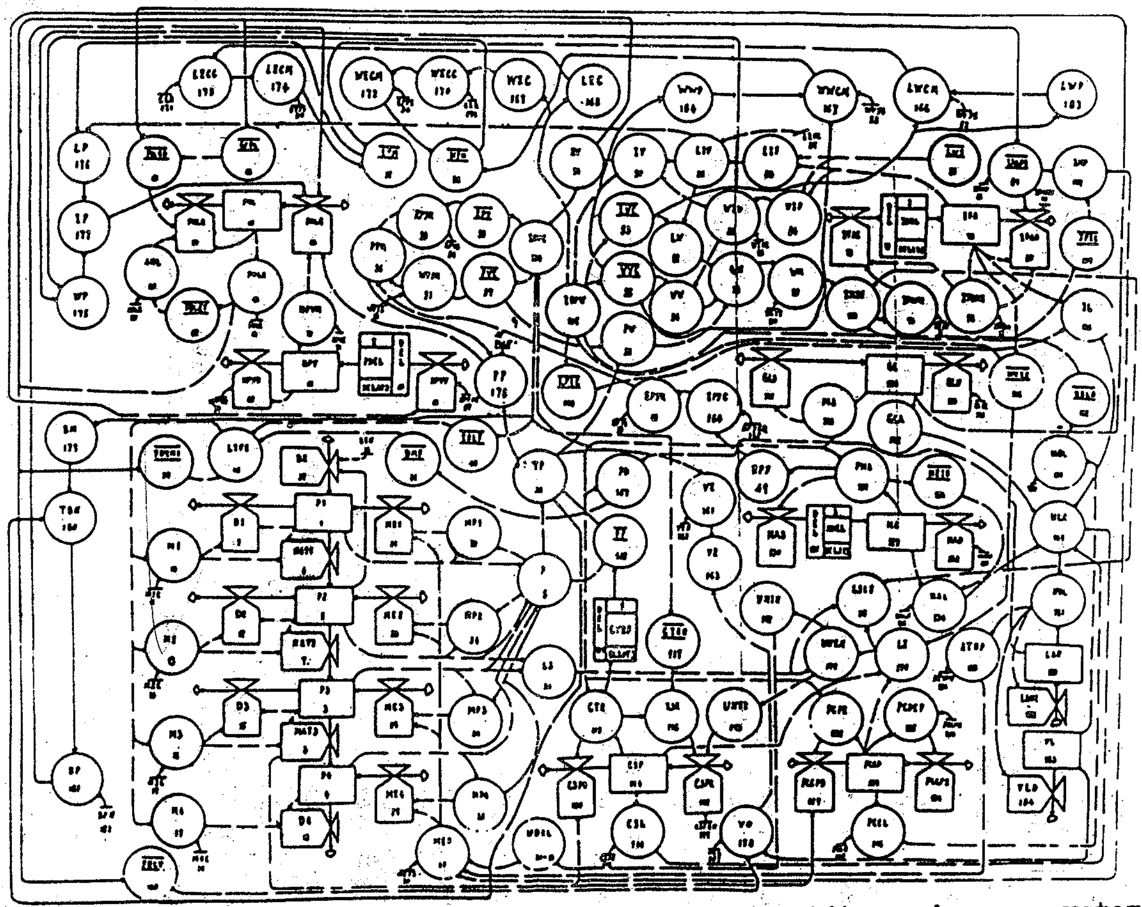

Fig.2. Flowing diagram of simulation model in Beijing urban ecosystem

3.RETROSPECTIVE VARIFICATION WITH HISTORICAL DATA.

Model must be tested and varified just to see to what extent build-up model is in keeping with reality. So, retrospective is necessary.

By applying the model, the Beijing condition from 1950-1980 was tested and verified just to see if the build-up model could be in keeping with the reality, besides, to compare the long-recorded and relatively complete data of population, urban land using and industrial output values. On the whole, the calculated results shows the consistency with the recorded data, which indicates that the way of building up a model is an effective measure and can better reflect the reality of Beijing urban ecosystem. Such a model is reliable. Further more, this model can be used to simulate the dynamic changes and foresee the future of Beijing urban ecosystem.

The conclusions of some models caused heat controversies probably it is because the work in this field was not done enough. To combine closely the model with professional knowledge is one way to avoil the dificiency.

The computer programme was written by DYNAMO, and was operated on IBM-PC computer.

4. SENSITIVITY ANALYSIS

Sensitivity analysis is an important step in the work, the general way of sensitivity analysis is to add a possible parameter change to the model and simply to compare its results with those of a standard operation.

Even if the structure is defined by way of System Dynamics, there still remain 2 problems to be dealt with: one is whether the choice of variables of model tally with reality, the other is which variables deserve our particular attention. So, in this research, a new method of sensitivity analysis, the two-stage method, is proposed.

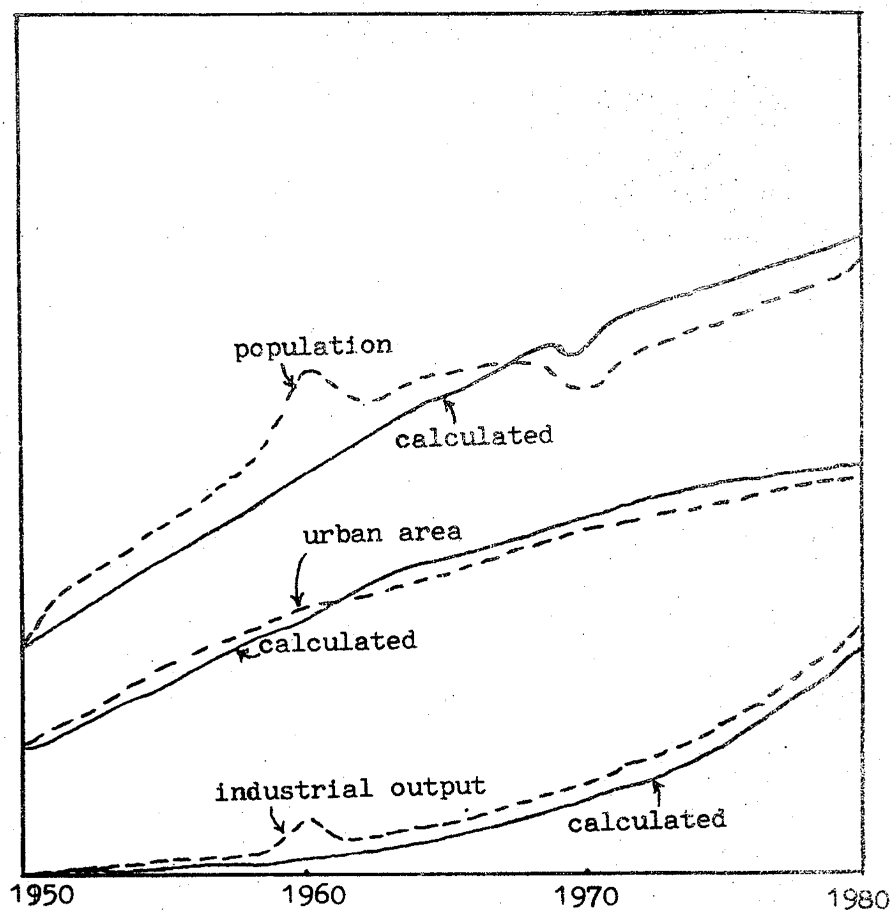

Fig.3. Testing with historical data.

The first stage: the factors with great effect on the system should be selected. The factors of system are divide into a initiative set and passive set, and advance an "effect-response matrix" is proposed. It is expected to select the "initiative" factors, which have over whelming effect on the system, and the "passive" factors, which are most sensitive to the system, an effect-response matrix demonstrates itself in form as follows:

passive set factor / initiative set factor	1,2, ...	effect value
1, 2, . . .	amlitude value	
response value		

When a initiative set factor varies, all of the passive set factors will be changed correspondingly. An effective screening can be done by the matrix. 38 factors were chosen from initiative set, and 19 factors were chosen from passive set, the change range of each factor of the initiative set is about ± 10% of its quantity. By using the effect-response matrix, 75 operations were carried out, and 1425 curves were get through computer.

In Beijing urban ecosystem, the "initiative" factors which produce great impact on the system are brith rate migration of population, migration of industry, investment of industry, investment in pollution control, proportion of service trade land using, proportion of coal in energy, proportion between light industry and heavy industry, time taken to absorb pollution, harm done to green vegetation by pollution, effect of pollution upon death. The "passive" factor with most sensitivity is pollution.

The second stage: these factors were further analyzed and studied by orthogonal layout and square deriation analysis. Finally the sensitive factors could be found. In this research, orthogonal table $L_{32}(2^{31})$ is used and enables us to find out note- worthy sensitivity variables:

Birth rate, migration of population, investment in pollution control, mutual effect between birth rate and migration of population, birth rate and migration of industry, migration of population and industry, migration of population and investmentinin pollution control, investment in pollution control and Proportion of coal in energy, investment and migration of industry, birth rate and service trade land using, and between migration of industry and proportion of coal in energy.

The programme of sensitivity analysis was writen by BASIC, and was operated on VICTOR-9000 computer.

5. THE APPLICATION OF THE MODEL

One of the most important parts in the whole work is the efficiency of the model application, to which the public will pay their great attention and on which the criticism will focus. A successful research depends on the model application. In our opinion, the main applications are in the strategy plan design and its result analysis.

The strategy design should be combined with the practice. Therefore, it is better for a policy-maker to join the work. Unfortunately, it is not always the case. So, we must obtain the information by different ways: visiting planners and policy-makers, being sure to have a prety clear idea of the alternative strategy and possible change happened in the future. Thus the researchers will not lose contact with the practice too much while they design a strategy plan.

In fact, from the very beginning of building up a model the possible application should be considered. The information feedbacks to the policy-makers should be often carried out, in order to help them understand the model and to reflect their ideas in the model. In this way the strategy analysis will always contact with the practice and become a powerful tools for the policy-makers.

By the simulation model of Beijing urban ecosystem, we study the dynamic developmentaand change of Beijing urban ecosystem acted by eight sensitive factors such as birth rate, migration of population, migration of industry, proportion of investment to control pollution, proportion of coal in energy consumption, industry investment, water/per 10000 yan output values and proportion of house land. Besides , we have designed four schemes according to "A general plan of Beijing urban construction" and "The sexenth Five-year plan" , some results are discussed as follows.

(1). The effect of sensitive factors on urban ecosystem.

a). energy structure and environmental pollutiom.
To decrease the proportiom of coal in energy consumption is an important way to improve urban environment.If the proportion of coal in energy consumption reachs 50 percent by year 2000,without any change of pollution control investment in Beijing urban area would be controlled rapidly. The top value of pollution will appear in 1987, and by year 2000,it is only 79% as compared with 1980.

b). Pollution control investment and environmental pollution.
To enhance capability of people to control pollution is a necessary way to improve urban environment. Now,the pollution control investment makes up about 0.5% of industry output values in Beijing urban area. One of the figures shows the change while pollution control investment increases to 1% or 1.5% of industry output value.

c). Birth rate and industry investment are factors to stimulate urban expansiom. The expansiom will cause urban population growth, urban extension, industry scale increase and worse pollution, moreover it will decrease the quality of urban ecology. Migration of population and industry are factors which restrict urban expansion and can decrease urban land and population, readjust urban arrangement and reduce pollution. Although the migration of industry has some effects on output value, the quality of urban ecolggy can be improved so , it can be considered as a vigorous measures.

(2). Schemes analysis

The trend of change and development of four schemes which are designed according present policy,"Beijing urban construction general plan", "The seventh Five-year plan", and ideal policy (designed by research) of Beijing urban ecosystem are as figures respectively.

From the results mentionedabove, the general trend of Beijing urban ecosystem is increasing as usual.

a). Population,industry output value , resources used, environmental pollution have an increasing trend within 10 to 20 years. All policy can only change the speed and time of the increase.Althrough the policies of family plan and restricted industry investment in urban area have been carried out, the environmental pollutiom still remain a question until the year 2020.

b). In order to control environmental pollution in Beijimg urban area and to improve quality of urban ecology, the inner structure and resources use of urban ecosystem, e.g. decreasing water use per 10000 yan output values, changing energy structure and increasing capability to control pollution , etc. should be considered besides restriction of industry investment and population control.

c). The industry output values in Beijing urban area is limited by land,water resource and environmental pollution. Its developing speed will decrease step by step . But it is still a center of industry in whole Beijing, and its output values is above 50% of whole industry in Beijing.

d). Now, the policy of population in Beijing is strict, so it is difficult to increase rate of family plan and decrease number of population migration. The only way is to readjust the arrangement of population. There is a need to build suburb of Beijing better as to attract city people migrating to the suburb.

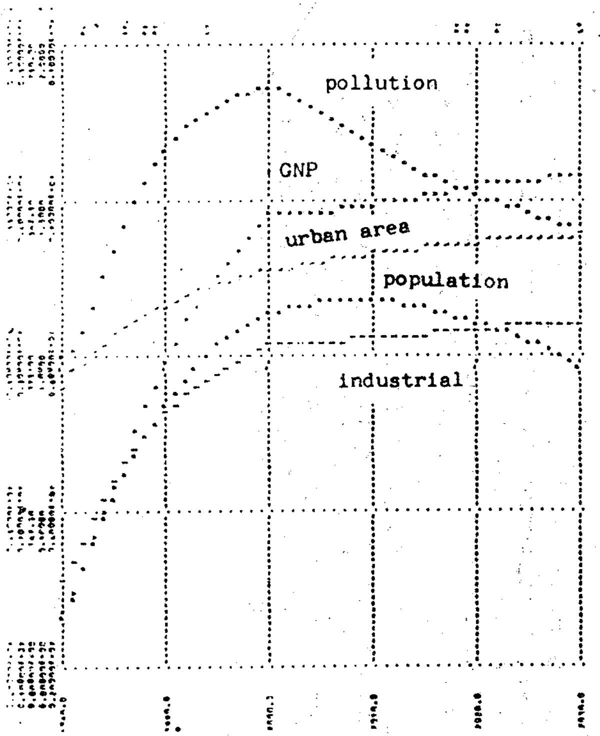

Fig.4.present policy

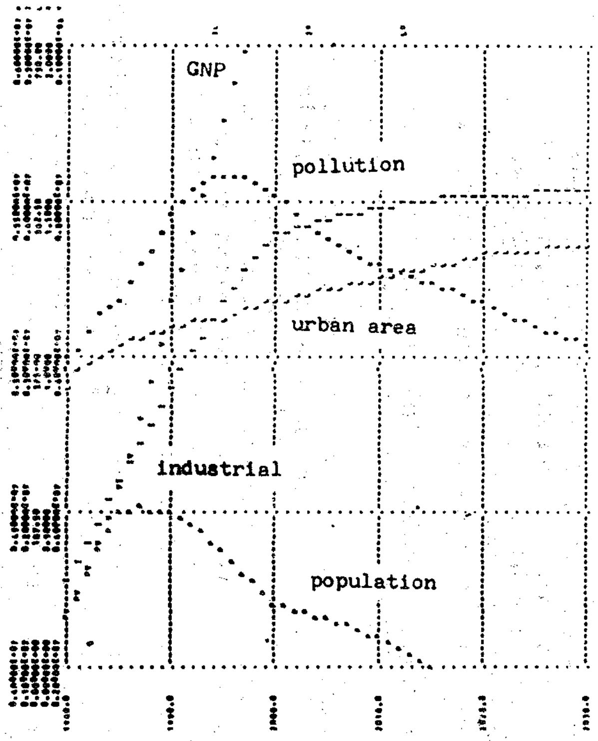

Fig.5.Beijing urban construction general plan

6.CONCLUSION

This paper has made useful discussion on the built up the model, its application and sensitivity analysis, in order to promote the development of System Dynamics.

The results shows clearly that only by bringing urban population under control, restricting investment in pollution-stricken industry, modifying energy structure, raising the economic result of resource utilization, expanding green lands and increasing investment to control environmental pollution, can the present environmental pollution be transformed, quality of Beijing urban ecosystem be changed for better, and to crown all, environmental pollution be checked and improved by the year 2000.

The result shows clearly that in the research work om urban ecosystem, building up a simulation model by the way of System Dynamics is not only acceptable but also rather valuable in its application.

ACKNOWLEDGEMENTS

The authors would like to thank Professor Ching T.Yang and Qifan Wang for helpful this paper.

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VARIABLE NAMES

1.	P1	population ages 0-17
2.	P2	population ages 18-40
3.	P3	population ages 41-60
4.	P4	population ages 60+
5.	P	resident population
6.	MAT1	maturation age 17-18
7.	MAT2	maturation age 40-41
8.	MAT3	maturation age 60-61
9.	D1	death of P1
10.	M1	mortality of P1
11.	M1C	M1. constant
12.	D2	death of P2
13.	M2	mortality of P2
14.	M2C	M2. constant
15.	D3	death of P3
16.	M3	mortality of P3
17.	M3C	M3. constant
18.	D4	death of P4
19.	M4	mortality of P4
20.	M4c	M4. constant
21.	ME1	migration of P1
22.	MP1	rate of P1/P
23.	ME2	migration of P2
24.	MP2	rate of P2/P
25.	ME3	migration of P3
26.	MP3	rate of P3/p
27.	ME4	migration of P4
28.	MP4	rate of P4/P
29.	MEP	migration population
30.	MEP3	population moving out
31.	UDEL	population moving in
32.	MEP1	... ...
33.	MEP2	... ...
34.	LS	labour supply
35.	LSLE	rate of labour supply/need
36.	TP	total population
37.	BR	birth rate
38.	BRN	birth rate normal
39.	PDRM1	effect of pollution to death
40.	IOLF	effect of live level to death
41.	DMF	effect of population density to death
42.	LIFE	life
43.	POLR	pollution rate
44.	POLS	pollution standard
45.	POL	pollution

46.	POLG	pollution generated per year
47.	POLN	pollution normal
48.	EPYM	coal multiplier by live
49.	EPY	energy per year per capita
50.	EPYS	EPY standard
51.	WPYM	water multiplier by live
52.	WPYS	live water standard in 1980
53.	RPYM	rubbish multiplier by live
54.	RPYS	live rubbish standard in 1980
55.	RPY	rubbish per year per capita
56.	PPM	pollution multiplier
57.	LPM	light industry pollution multiplier
58.	WPM	weight industry pollution multiplier
59.	POLA	pollution assimilation rate
60.	AHL	assimilation half life
61.	AHLC	AHL constant
62.	POLAT	AHL alter factor
63.	POLGD	pollution degradation by green land
64.	GPOL	green land harm by pollution
65.	HPV	harness pollution capital
66.	HPVV	harness investment per year
67.	HPVVN	HPVV constant
68.	PDEL	HPVV delay
69.	HPVD	HPV depreciation
70.	HPVDN	HPVD rate
71.	HPVM	pollution harnessed
72.	HPAC	HPVM constant
73.	IFA	industry capital
74.	IFAVM	industry investment multiplier
75.	IFAN	industry investment normal
76.	IFADM	IFA depreciation multiplier
77.	IFADN	IFA depreciation rate
78.	IFAI	industry investment
79.	IDEL	IFAI delay
80.	IFAD	IFA decrease
81.	IFANG	IFA migration
82.	IFAMN	IFANG constant
83.	LIF	light industry capital
84.	WIF	weight industry capital
85.	LWR	rate of light /weight industry
86.	LIV	light industry output values
87.	LIVC	LIV constant
88.	WIV	weight industry output values
89.	WIVC	WIV constant
90.	IV	industry output values
91.	RV	real IV
92.	LW	light industry using water
93.	LWC	LW normal
94.	WW	weight industry using water

95.	WWC	WW normal
96.	PW	live using water
97.	PWC	PW normal
98.	GW	total water needed
99.	WM	water multiplier
100.	WATT	water supply
101.	UOL	unoccupation land
102.	UOLM	land binding multiplier
103.	IMIN	industry investry binding multiplier
104.	IOPC	industry output per capita
105.	IOPW	production rate
106.	WORK	workers
107.	JPIC	job/per 0.1 bil. capital
108.	LPIC	land/per 0.1 bil. capital
109.	IMP	population follow industry migration
110.	LE	labour need
111.	UNEM	unemploy labour
112.	UMIN	labour lack
113.	UNEX	labour surplus
114.	CSP	city service personnel
115.	CTR	CSP rate
116.	RSR	CSP difference
117.	CTRN	CSP normal
118.	CSPR	CSP increase rate
119.	CSPRN	CSPR constant
120.	CSPD	CSP retire
121.	CTRF	service delay
122.	FP	flowing population
123.	PCCP	personnel of office,culture,science etc.
124.	PCCPR	PCCP increase rate
125.	PCDEF	PCCP difference
126.	PCCPN	PCCP normal
127.	PCCPD	PCCP decrease
128.	PCPR	PCCP rate
129.	HA	house area
130.	HAB	HA build
131.	HDEL	HAB delay
132.	HAD	HA depreciation rate
133.	HADN	HAD constant
134.	HAL	land for HA
135.	HALN	HAL rate
136.	HRIO	total land rate for HAL
137.	PHA	HA per capita
138.	GL	green land
139.	GLN	GL nibbling rate
140.	GLNC	GLN constant
141.	GLB	GL build
142.	GLA	GL area
143.	PGA	GL per capita
144.	CSL	land for city service

145.	CSPN	CSL constant
146.	PCCL	land for PCCP
147.	PCCN	PCCL constant
148.	IL	industry land
149.	ULR	urban land require
150.	LAN	urban land
151.	NDL	new developing urban land
152.	LANG	LAN increase rate
153.	VL	VEGETABLE land
154.	VLD	VL decrease rate
155.	ATUP	population from agri. to urban
156.	ATUPN	ATUP constant
157.	PD	population density
158.	VO	vegetable yield
159.	VOC	VO constant
160.	POLV	effect of pollution to vegetable
161.	VE	vegetable need
162.	VEN	VE normal
163.	VR	vegetable supply rate
164.	EPYC	coal for live
165.	EPYCR	EPYC rate
166.	LWCM	light industry water pollution
167.	WWCM	weight industry water pollution
168.	LEC	light industry energy/per 10000 output
169.	WEC	weight industry energy/ per 10000 output
170.	WECC	weight industry coal/per 10000 output
171.	CER	coal rate
172.	WECM	weight industry coal pollution
173.	LECC	light industry coal/per 10000 output
174.	LECM	light industry coal pollution
175.	WP	weight industry pollution
176.	LP	light industry pollution
177.	IP	industry pollution
178.	PP	live pollution
179.	BM	automobile/per 10000 persons
180.	TBN	total auto.
181.	BP	auto. pollution
182.	BPN	BP constant
183.	LWP	LWCM multiplier
184.	WWP	WWCM multiplier