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A systems approach for the development of a sustainable community—the application of the sensitivity model (SM)

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Abstract

Corresponding to the concept of 'Think globally, act locally and plan regionally' of sustainable development, this paper discusses the approach of planning a sustainable community in terms of systems thinking. We apply a systems tool, the sensitivity model (SM), to build a model of the development of the community of Ping-Ding, located adjacent to the Yang-Ming-Shan National Park, Taiwan. The major issue in the development of Ping-Ding is the conflict between environmental conservation and the development of a local tourism industry. With the involvement of local residents, planners, and interest groups, a system model of 26 variables was defined to identify characteristics of Ping-Ding through pattern recognition. Two scenarios concerning the sustainable development of Ping-Ding are simulated with interlinked feedbacks from variables. The results of the analysis indicate that the development of Ping-Ding would be better served by the planning of agriculture and the tourism industry. The advantages and shortfalls of applying SM in the current planning environment of Taiwan are also discussed to conclude this paper.

Keywords: Bio-cybernetics; Systems thinking; Sensitivity model; Semi-quantitative simulation; Sustainable community

1. Introduction

The concept of sustainability and sustainable development has been discussed for years since the oft-quoted World Commission on Environment and Development (WCED, 1987) in 1987. It has been touted as a new planning agenda, though the viewpoints regarding the meaning of sustainability are still diverse (Beatley and Manning, 1997). Two questions concerning the sustainability movement have frequently been addressed. The first is the appropriate geographical scale for action. Since 'local action' (a bottom-up perspective) is the consensus approach to practical action, and since a community can serve as the fundamental element of a hierarchical structure of an urban area, it would be appropriate to address sustainability at the scale of community development. In addition to this geographical scale question, there is concern for finding an effective method to plan and manage local development in a sustainable manner. Much effort has been made to develop sustainability indicators for local development (see Huang et al., 1998). However, sustainability indicators by themselves only partially improve our understanding of community development. Systems thinking and an integrated approach would be more appropriate for dealing with the sustainability of local development, and this has become a key focus of a number of studies (Huang and Chen, 1999; Rothman, Robinson and Biggs, 2002; Rotmans and Asselt, 2002).

In this paper, we apply a sensitivity model (SM),[1] a systems approach developed by Vester and Hesler (1982), as a planning tool for dealing with development issues in the small village of Ping-Ding. With its foundations in systems thinking and bio-cybernetic rules, SM provides us with a convenient tool to assess the sustainability of a local community by identifying the pertinent characteristics of a community, and by simulating its development in scenarios using semi-quantitative data.

Following this introduction, Section 2 will elaborate the fundamental concepts of sustainable communities and

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[1] Internet: http://www.sensitivity-model.com.

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systems thinking. The bio-cybernetic based systematic planning tool, SM, will be described in the third section. The SM is then applied to the case of the Ping-Ding community in Taipei city to identify important system characteristics in Section 4. A simulation of Ping-Ding with some partial scenarios and discussion of results are presented in Section 5. The last section discusses the advantages and shortfalls of SM to conclude the paper.

2. Systems thinking and sustainable community

Sustainable development has become an influential and widely used term, even though it has diverse meanings. The 1987 report, *Our Common Future*, by the United Nations World Commission on Environment and Development (WCED), sets forth the most widely used definition of the concept, 'Sustainable development is the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs' (WCED, 1987). At the Earth Summit in Rio, considerable attention was devoted to sustainability, and the concept was embodied in the resulting UN Framework Convention on Sustainable Development. In addition, the OECD, the LYNCTAD, and the US Presidential Council on Sustainable Development, and many international policy-oriented institutions, are devoting time and energy to the analysis of sustainable policies.

Though the concept of sustainability has been adopted in principle, there are still some issues that seem unclear from the practical viewpoint. The first is the issue of appropriate geographical scale. It is argued that sustainability planning would be less efficient in a large region (Kildow, 1992). Under the concept of 'Think globally, act locally and plan regionally (Forman, 1995),' the scale of a community, which contains some important elements for local development, is suggested to be a proper one. The second issue in the implementation of sustainable development is the need for an effective tool to assist in achieving the goal. Since a community is a complex system of humans and natural environment, it is necessary to deal with it from a comprehensive and systematic viewpoint.

The sustainable development of a location should avoid system overshoot by imposing negative feedback to system growth when approaching carrying capacity. That is, from the viewpoint of sustainability, a sound growth pattern of a community should be a logistic S-curve type (see Fig. 1) to avoid the collapse of over-development, rather than an exponential curve that most human societies have shown after the industrial revolution (Vester, 1988).

The definition of sustainable community varies according to the interest, needs, and culture of different communities, but most focus on economic, environmental, and social issues. The analogy of a three-legged stool has been used to stress the importance of addressing and balancing the three categories of issues, in which the legs of the stool represent economic, social, and environmental components (Lachman, 1997). To stand well the stool requires balance among these three legs that are usually in conflict and competition. In the way toward balancing the three components, many emphasize the involvement of open processes in which all members of a community are encouraged to participate. The focus is on consensus building through communication and cooperation among

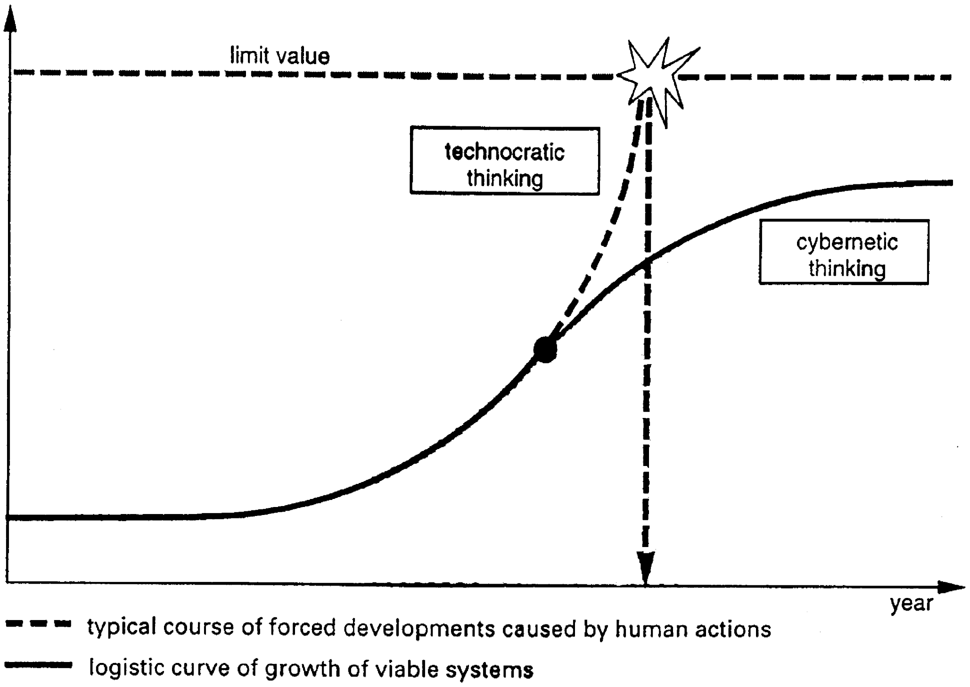

Fig. 1. Logistic S-curve of sustainable development.

many different interest groups from both the community and those outside the geographic neighborhood. Such sustainability activities enhance the individuals' and organizations' feelings of attachment, value, and connection to the community. By means of public involvement, it is possible to foster a sense of community, which is a critical element of a sustainable community, in addition to a sound physical environment.

Achieving a healthy, sustainable community requires a long-term, integrated, and systems approach to addressing economic, environmental, and social issues. There are two strategies for analyzing a community system, namely the micro and macro viewpoints. The former focuses on the individual features of a community such as population growth, industry or transportation issues. It argues that progress towards sustainable development should be based on indicators of standardized measurement (Hodge and Hardi, 1997). Many efforts have been devoted to developing the principles and indicators for a sustainable community (Maureen, 1999; Huang et al., 1998; Zachary, 1995). The macro view regards the community as a holistic system. Since the elements of a community are dynamically interlinked, it is likely that a community will be misinterpreted by overemphasizing an individual sector without taking the interaction into account, like the old Chinese idiom 'seeing a tree without seeing the forest,' or the disconnected community as shown in Fig. 2.

A systematic approach emphasizes identifying and describing the interactions between system components. As shown in Fig. 2, planners frequently ignore the interactions between land use, resource, culture, tourism and communal life of a local community. A systematic approach has to connect the broken linkages among the sectors of the community, as well as define the sectors of the community. A feedback system then is built with all the system components and linkages. Through the linkages, changes in one component will induce changes in another component, which may in turn induce a change in the third component. Many such interactions can be linked together in chains of cause and effect relationships and chains of cause and effect relationships can intersect themselves. This means that a component can start a sequence of causes and effects that eventually loops back, so that each of the components in the loop indirectly influences itself. A system can contain more than one feedback loop. The behavior of a given component, in such a set of relationships, is the outcome of multiple competing factors (Clayton and Radcliffe, 1996).

The discussion above gives us a fundamental idea of what is essential for managing the sustainable development of a community. It is not surprising that there have been a number of recent studies emphasizing public participation and systems thinking. For example, the integrated assessment (IA), in which communication between different participants is at the very heart, has become a rapidly evolving field in the past decade (Rotman and van Asselt, 2002). In addition, with the same philosophy of linking indicators and providing visions that make sense to the participants, an approach similar to SM can be found in the QUEST project at the University of British Columbia (Rothman, Robinson and Biggs, 2002). Vester (1988, 1999) provides the rules of bio-cybernetics as a guideline for

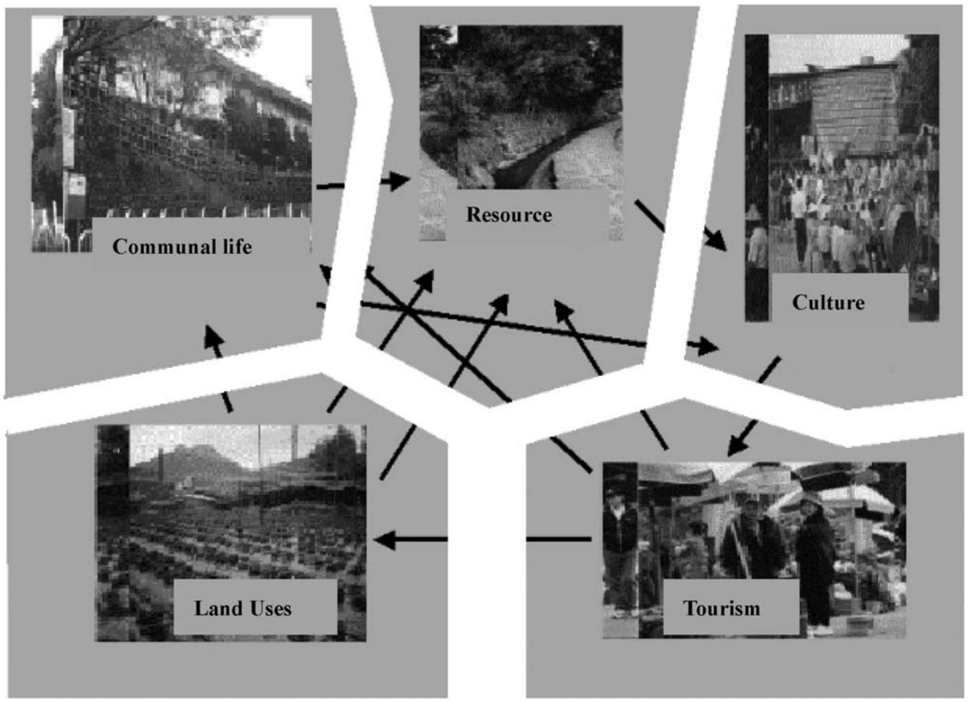

Fig. 2. Torn network of local development.

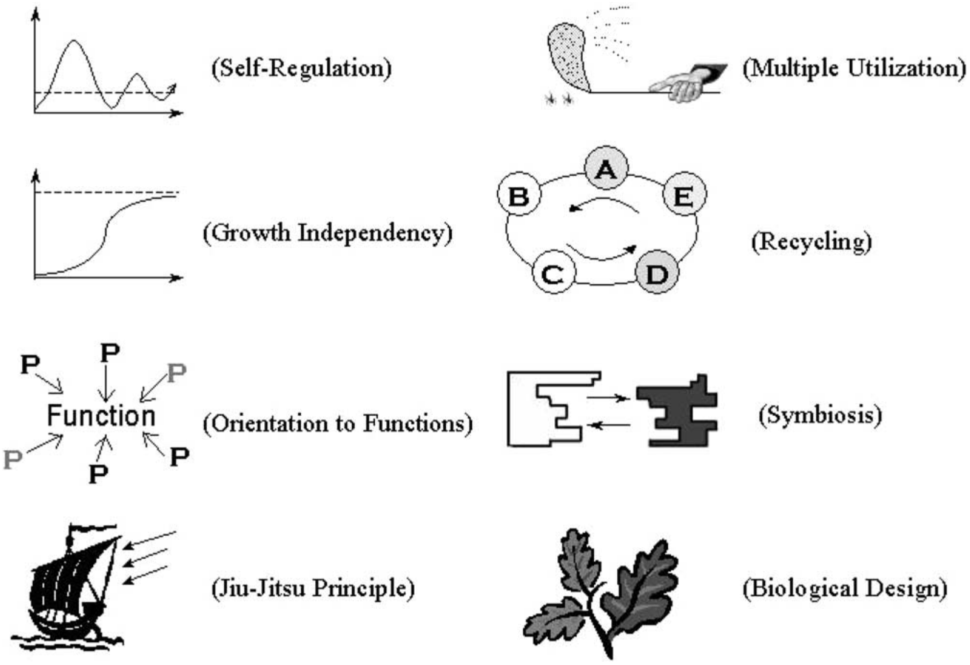

Fig. 3. Bio-cybernetic criteria of SM.

further application. These principles basically incorporate the concept of feedback loops to check and balance the performance of systems for symbiotic relationships between humans and environment. Eight rules to evaluate the sustainability of a community system are shown in Fig. 3. They include: (1) negative feedbacks must dominate positive feedbacks; (2) the vitality of a system must be independent from quantitative growth; (3) the system must be function-oriented and not product-oriented; (4) use of existing forces (principle of *jiu-jitsu*) instead of fighting (boxing-method); (5) multiple usage of products, functions and organizational structures; (6) recycling processes for the utilization of waste and sewage; (7) symbiotic reciprocal usage of difference by employing coupling and exchange; and (8) biological design of products, procedures and forms of organizations by feedback planning. These rules have been further applied to develop a systems tool for planning, which will be introduced later in this paper.

In Section 3, the tool for implementing the systems approach, sensitivity model, will be introduced and applied to the Ping-Ding community. The experience gained from the application of this SM tool can provide better planning for sustainable development in the local context.

3. A systems approach—sensitivity model

The systems tool—sensitivity model—was developed by Vester and Hesler in 1975 (Vester and Hesler, 1982), during work on a UNESCO-program, Man and the Biosphere (MAB II), to solve increasingly complex problems in the world. It is a systems tool for planning based on Bio-cybernetics that was intended to ameliorate dissatisfaction with conventional planning aids. Since the development of SM, it has been applied to many different fields of research including corporate strategic planning, technology assessment, developmental aid projects, examination of economic sectors, city, regional and environmental planning, traffic planning, insurance and risk management, and financial services.

The philosophy behind SM includes many principles that are emphasized in the literature of General System Theory. The fundamental ideas of SM, which make it different from other planning approaches, include systems thinking, fuzziness, and simulation of semi-quantitative data. It emphasizes pattern recognition and the theory of feedback mechanisms rather than mono-causal form of recognition, and it makes the analysis of complex systems possible by using the approach of fuzzy logic. The application of semi-quantitative simulation has been discussed in ecological modeling in recent years (Jorgensen, 1997; Ecological Modeling 1996, Vol. 85). The planners are able to capture the examined system and its socio-economic-ecological environment as a bio-cybernetic entity without getting lost in a countless number of factors and variables (Vester, 1988). Most traditional quantitative simulation models require precise parameters that might be unavailable because of the complexity of system relationships. The data required in the SM are prepared with the fuzzy logic approach. Fuzzy logic provides a new systematic way of thinking by which complex systems can be understood without detailed precision but nevertheless accurately with only a few ordinal parameters.

During the process of model construction, pattern recognition, and system simulation, many key inputs are obtained by means of group discussion and consultation.

These open participatory processes focus on communication, cooperation, and compromise among many different participants to build consensus for the local development. These participants include the residents, industries, government, environmental groups, and community groups. Although such a process usually is very time consuming, it is a remarkable impulse of a new culture of group learning. Often, many public community meetings are held and from which, different groups learn to trust, communicate with, and listen to one another. The process helps foster a sense of community that is one of the keys to creating a sustainable community, and a goal of SM as well.

There are nine steps in the operation of SM Tools (see Fig. 4), they can be divided into three phases: system definition, pattern recognition, and system simulation and evaluation. In the first phase, the system components are compiled according to the characteristics and contents of the system, which is called a working variable set. The relationships among the system variables are defined in the second phase to represent variable behaviors and patterns for the purpose of system recognition. Finally, with the variables and their interactions defined, we can perform scenario simulation and evaluation for a system in the third phase. The SM applies a top-down approach to deal with complex system problems. In Fig. 4, the 'effect system' is used to overview the interrelationships among system variables. The causal relationships of variables are shown in a system diagram. After the identification of focus issues in the study area (i.e. traffic, local tourism, etc), 'partial scenarios' are then incorporated to develop simulation models for each issue, respectively. Each partial scenario will select from the effect system the variables that are related to the issue identified, and disaggregate these variables into more detailed ones. Quantitative relationships between variables can be identified to simulate the rates of flow.

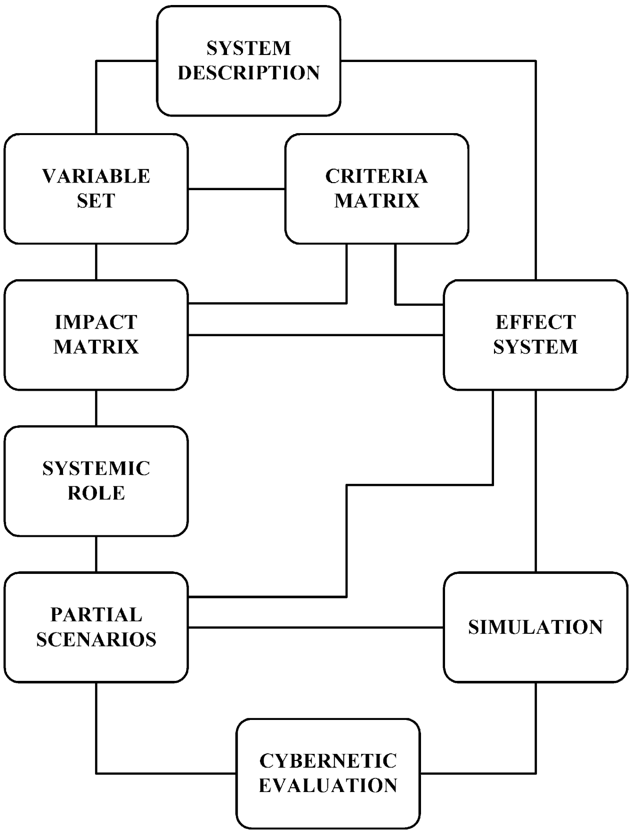

Fig. 4. Procedure of SM.

3.1. Phase 1: system definition

Using the SM tool, a system model is defined by a group of related variables that cover all important system components. The process begins with a general system description of the study area and the identification of influential factors for local development (see the top of Fig. 4). These factors are further refined to a limited number of variables by examining the data available and through public discussion. This serves as the initial working variable set.

The completeness of the variable set from a systems viewpoint is examined with a cybernetic checklist called the Criteria Matrix. The 18 criteria in the matrix compose essential parts of a system, including life sectors (7), physical categories (3), system dynamics (4), and system relations (4). The variable set should be connected with these 18 criteria in a well-balanced pattern, which means the variables construct a complete system. The work of variable identification and criteria matrix examination will proceed recursively until a well structured system is defined.

3.2. Phase 2: pattern recognition

Based on the variable set defined in the first phase, the magnitude of the cause-effect relations between the variables are examined to identify their functional roles in the system. There are two key products in the second phase, the impact matrix and the systemic role of variables. The impact matrix is an array composed of the effects of each pair variable. The effect between two variables is evaluated by the joint discussion of all members of the community for consensus, referencing the data compiled in advance. The values of the effect will be summed-up by rows and columns and we can recognize the different roles of variables with their influences in the system, as well as characterize the system behavior accordingly. Each variable can be categorized into active, passive, critical or buffering according to the value derived from the impact matrix. A similar method can be found in sustainability assessment maps (SAM), which is a graphic tool for displaying positional information and assisting decision making (Clayton and Radcliffe, 1996). The result helps planners to identify the pattern of system behavior and key variables of the system, which are useful for policy design in the later phase.

3.3. Phase 3: system simulation and evaluation

The effect system, composed of a causal network of variables, is organized to serve as a conceptual framework of system relationships. Both positive and negative causal networks can be identified from the impact matrix. The partial scenario of the focus issue can be simulated to observe system dynamics and the interrelationships between system variables. In addition, the policy designed to improve the system can be examined as well. In summary, the SM tool, a bio-cybernetic evaluation based on the eight rules above (see Fig. 4) was chosen for its ability to evaluate the sustainable and long-term viability of the system under consideration.

4. The case example of Ping-Ding

4.1. Description of Ping-Ding

Ping-Ding is a small village in northern Taipei (Fig. 5). It is located adjacent to the Yang-Ming-Shan National Park, a major attraction for residents of Taipei metropolitan during weekends and leisure time. The population of Ping-Ding was about 1600 in the year 2000, a figure that has grown only 2% since 1990.

Due to its specific location and natural resources, Ping-Ding has become one of the most attractive spots in Yang-Ming-Shan National Park area. The natural resources there include several canals that were the major water resource for both agriculture and daily living in the past. Some very old religious sites are also interesting. In addition, the agricultural products such as high mountain vegetables and orchids are also attractive to the tourists.

The rapid development of tourism has resulted in positive and negative consequences for Ping-Ding as well as for Yanh-Mng-Shan National Park. Large numbers of tourists support the growth of the local economy and provide the income for residents. The number of orchid farms and field restaurants has increased to provide service to tourists. At the same time the development of tourism has caused some negatives in pollution and turbulence. The community is facing the conflict between development and environmental conservation, and how to find a solution to these problems is a major concern of the residents of Ping-Ding community currently.

4.2. System definition of Ping-Ding

By reviewing the history and local development of Ping-Ding, and discussing with participants that included local residents, the Chi-Shin Conservation Association and the planning team, we identified some key variables that define the community. These 26 variables and their definitions are listed in Table 1. The *Variable Set* will serve as a basis for the follow-up procedure. These variables will be refined within the criteria matrix below.

Following the step of identifying system variables, a *Criteria Matrix* is applied to check the system completeness in relationship to four categories of criteria, which are the sectors of life, the physical category, the dynamic category, and the system relationship. Each category contains several sub-criteria that in total are 18 items. Each of the system variables was evaluated by the planning team against the 18 criteria, and the matrix was marked with a blank, ○, or ● to show not applicable, partly applicable or fully applicable. Table 2 shows the criteria matrix of Ping-Ding. Take the variable 'Canals' as an example, because it is highly related

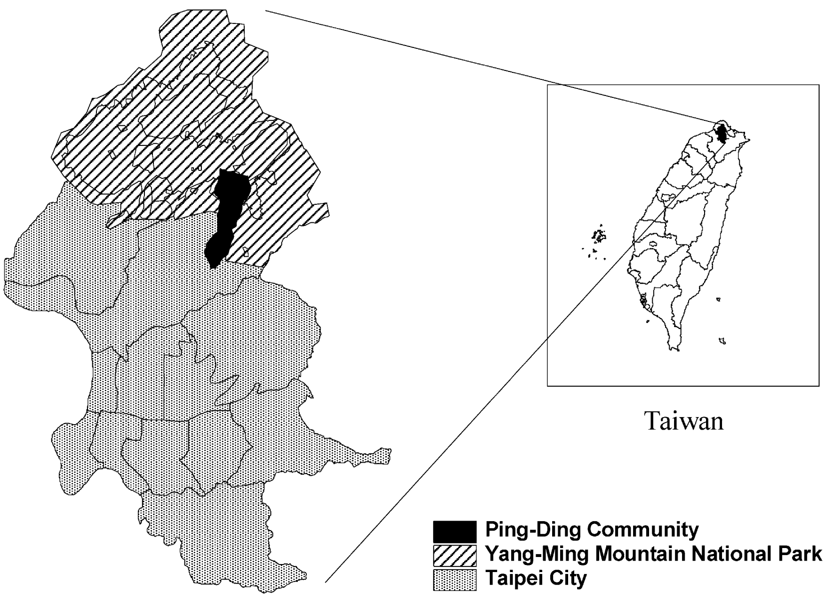

Fig. 5. Location of Ping-Ding.

Table 1
System variables and definitions of Ping-Ding

No	Variables	Definitions
1	Canals	Canal is the most important and unique resource of the Ping-Ding community. It characterizes the community in terms of the function of agriculture irrigation and tourism. In addition, it is the water resource of daily life of Ping-Ding community
2	Cultural activity	The local cultural activity and group activity in front of the temple square has lasted for hundreds of years as a special event of Ping-Ding. It forms the center of life for the residents of Ping-Ding and attracts tourists as well
3	Tourism crops	Orchids and some high mountain crops are the main tourism crops of Ping-Ding because of the geographical conditions here. The high mountain vegetable is one of the attractions that bring people to the community. The restaurant provides tourists with fresh and home raised vegetables
4	Hiking trails	Along with the canal system, there are some hiking trails in the mountain area that provide access for tourists to reach the beauty of the community. To maintain the trails in good condition becomes an important issue for the development of the tourism industry of Ping-Ding
5	Local industry	The local industry of Ping-Ding is composed of agriculture, tourism, farms, and restaurants. They are connected to each other and need more tourists to support them. However, there is a potential concern that pollution caused by large numbers of tourists could affect the development of local industry
6	Marketing promotion	Since the agriculture product and tourism are the main industries of Ping-Ding, it is important to make them known to the public. An effective marketing approach will promote the popularity of Ping-Ding
7	Irrigation resource	To support local agriculture and the tourism industry of Ping-Ding, the irrigation system has to be maintained properly
8	Agriculture	Traditional agriculture is facing challenges from both tourism and geographical conditions. Large numbers of tourists cause pollution. In addition, the farmlands of Ping-Ding community are subdivided too finely, such that they reduce productivity and sustainability
9	Competition	There are more and more places like Ping-Ding that develop local tourism to attract people for recreation activity. It is a major issue for Ping-Ding to keep competitive with other locations in terms of promoting the community image and products
10	Water pollution	Water pollution is becoming an issue of greater concern in the community. Several causes of water pollution are identified including the wastes of tourists, waste water from restaurants, bio-chemical waste of agriculture, etc
11	Waste treatment	There are large amounts of solid wastes and water wastes brought by tourists. To treat waste costs much money, but it is necessary because the development of the community depends heavily on environmental quality
12	Recycling	Much of the waste of Ping-Ding is reusable, such as leftover food from restaurants
13	Employment	To give Ping-Ding an opportunity for self-growth, it is important to keep local employment at a minimal economic level
14	Culture industry	As local culture activity becomes the main attractor of tourists, how to develop the culture industry becomes a main concern of the Ping-Ding community. The local culture industry of Ping-Ding includes activity in the temple square, orchid farms, etc
15	Tourist turbulence	Large numbers of tourists come to Ping-Ding on the weekends to enjoy the beautiful scenery, cultural activity and agriculture products. However, they also bring pollution of many types such as waste, noise, congestion, etc. to the community. It is a concerning issue how to deal with the turbulence for the local residents
16	Traffic congestion	The local network of Ping-Ding is not designed to support the heavy load of tourists in the weekends. Both tourists and residents suffer from traffic congestion that could reduce the attraction of the community
17	Local Transportation	Appropriate transportation planning such as buses and traffic control can help the traffic congestion brought by the tourists
18	Accessibility to water resource	The canal system and Nei-Liao stream compose the water resource of Ping-Ding. It is one of the main tourism resources that attract people to visit. It is important to promote the accessibility to these water resources by providing proper facilities
19	Infrastructure	To accommodate the large amount of tourists and treat wastes, the infrastructure has to be planned and developed properly including waste water treatment, solid waste treatment, local network, etc
20	Community conscience	Ping-Ding is a community with small population, isolated from the metropolitan area. The community conscience is important for local development

(*continued on next page*)

Table 1 (*continued*)

No	Variables	Definitions
21	Environment quality	The environmental quality of Ping-Ding community is worse-off because of tourists' turbulence and waste from tourism activities. It will reduce the attraction of the community and affect the living of the residents if the environmental quality can not be maintained. How to keep a balance between the tourism industry and environmental quality becomes more and more critical for the community
22	Local security	There are several security issues of the community. The first is the large amount of illegal buildings that are disorderly distributed in the area. The second is a shortage of disaster mitigation resources such as medical assistance. And the third is the disturbance of the tourists
23	Local governance	Ping-Ding is composed of a basic political unit, Li. Although the local authority does not have full administrative power and resources, the consensus of all residents will encourage local development
24	Education inputs	Education investment for the education of environmental concerns and protection, in addition to the typical education of elementary school, etc. How to construct environmental consciousness among the residents of Ping-Ding, and facilitate the environmental education of tourists will be an important force in the development of Ping-Ding
25	Dependence on imported resource	Since Ping-Ding location is isolated in the Yang-Ming Mountain National Park area, away from the Taipei Metropolitan area, most matters of daily living are brought from outside areas, except agricultural products. It is one of the input factors from outside of the system
26	Community image	Located around the Yang-Ming Mountain National Park, Ping-Ding has the opportunity to build its own image as a recreation destination. The components of its image include cultural activity, the tourism industry and its landscape

to both the criteria of 'human ecology' and 'natural balance', we mark both cells with ●. It also belongs to conomy because it brings tourists. Therefore, it gets a ○. Finally, the resulting matrix is quantified and summed vertically with a 0 for a blank cell, 0.05 for ○, and 1 for ●, and the final scores are listed in the bottom row of the matrix.

The *Criteria Matrix* serves as a tool to assure that the *Variable Set* sufficiently represents the system from a cybernetics viewpoint. It is an instrument that assists us to modify the set of variables to address all aspects of the system. If a zero appears in the vertical sums, or the numbers show a strange distribution, it means that there might be some important system components missing and we have to check the variables again and change their descriptions. This process could be repeated several times until we have a sound matrix. In Table 2, the higher scores of the 'sector of life' for Ping-Ding are 'economy' (13) and 'human ecology' (13), which means that the system variables are salient along these two criteria and reveals the importance of these two factors for local development. It can be seen in Table 2 that the criterion 'matter' has the highest score (12.5) over 'energy' and 'information' in the physical category, which tells us that material entities such as the tourism industry and agriculture are major components of Ping-Ding system. In addition to these characteristics internal to the system, the high scores within the last three criteria of the category of system relations (11.5, 13.5 and 9) remind us that Ping-Ding is an open system and we should take into account the external factors in the process of policy formulation.

4.3. Pattern recognition of Ping-Ding community

After the system of Ping-Ding community has been defined, the next step is pattern recognition, in which the systematic function of each variable of the community will be identified. This step is based on a pair-wise comparison of each two variables arranged in an impact matrix as shown in Table 3. Each cell in the impact matrix reveals the direct influence of the vertical variable on the horizontal variable, e.g. the cell in the second column and 4th row shows the influence of 'hiking trails' on 'cultural activity'. In the Sensitivity Model, the effect is classified into no significance, low significance, medium significance and high significance, and expressed as 0, 1, 2, and 3 accordingly.

The process of creating the impact matrix involves group discussion. Three different groups, consisting of residents, experts, and planning faculty, are requested to discuss and fill out the matrix separately. After all three groups have filled out their matrix, the three groups then work together to create the 'consensual matrix'. At the same time, the description of the variables is partly revised and redefined in such a way that each group can agree on the assessment.

The values in the last two columns and rows of the *Impact Matrix* (Table 3) provide us with the information to identify the role of each variable in the system. When we sum up the numbers of one row to the right, we get the active sum (AS) of the corresponding variable. It shows how strongly any variable effects on the other variables of the system. If a variable has a relatively high AS, like 'culture industry (14)' with 45, any change in that variable will affect the system significantly, even a small change. In contrast, if the AS of

Table 2
Criteria Matrix of Ping-Ding

Criteria / Variables	SECTOR OF LIFE							PHYS. CATEG.			DYNAM. CATEG.				SYSTEM RELATIONS			
	Economy	Population	Land Utilization	Human Ecology	Natural Balance	Infrastructure	Communal life	Matter	Energy	Information	Flow quantity	Structural quantity	Temporal dynamics	Spatial dynamics	Opens system to input	Opens system to output	Influenced internally	Influenced externally
1.Canals	○			●	●			○	●		○		○				●	
2.Cultural activity	○			●			●		○	●		○	○		○	○	●	○
3.Tourism crops	●		●	○	○			●								●	○	●
4.Hiking trails					●	○		○			○			●				
5.Local industry	●		○	○	○			●		○		●				●		
6.Marketing promotion				○	○					●		●	○			●		●
7.Irrigation resource	○		●	●	○			○			○			○		○		
8.Agriculture	●		●		●			●			○					●		
9.Competition	●		●	○				●			○			○		●	○	●
10.Water pollution		○			●	○	○				○			○		○	●	
11.Waste treatment				○	●			○			○						●	
12.Recycling	○		○	●	●			○	○		○				○	○	●	
13.Employment	●						○		○	○		○					○	○
14.Culture industry	○	○		●				○		○	○		○			●		○
15.Tourist turbulence	●	○			○		●			●		●	○		●	○	○	○
16.Traffic congestion	●	●	●			●	○	●			●				●			●
17.Local transportation		●	●			●	●	●				●		○		○		○
18.Accessibility to water resource		○	○	●	●	○	○	○			○			○			○	○
19.Infrastructure	○	●	●			●	●	●				●		●			●	
20.Community conscience	●			○			●		○	●		●		○			●	
21.Environment quality		○	●			●	●	●			●			●	○		○	
22.Local security		○		●		●	●			●		○		○			●	
23.Local governance	○			●			○		○	○		●				●	●	○
24.Education inputs	○		○	●		●	●		○	●		●	○		●	○	●	
25.Dependence on imported resource	●	●				○	○	●			●				●			●
26.Community image				●	●		○		○	●		○		●	●	●	○	○
Total	13	7	10	13	10.5	8	11.5	12.5	4.5	9	8	10	3	7.5	6.5	11.5	13.5	9

Note: Null: not applicable (0); ○: partly applicable (0.5); ●: fully applicable (1)

a variable is a small number, this variable has to change dramatically before it produces a significant effect on the other variables of the system. When we add the numbers in a column, we can get the passive sum (PS) of a variable, showing the extent to which the variable is affected by other variables in the system. A high PS value such as 'community image (26)' means that as soon as something happens within the system, this variable will be affected significantly. On the other hand, a small PS means that within the system, a lot can happen without changing this variable, e.g. 'irrigation resource (7)'.

Since AS and PS represent a one directional effect, two other indices are useful for describing the role of a variable in a system. They are P, which represents the product of AS and PS, and Q, which is the quotient of AS over PS. A variable with a high quotient value and a high product value, such as 'community conscience (20),' means that it is a dominant variable in the system. A variable with high quotient value while small product value, such as 'accessibility to water resource (18),' means that it will influence the system with a clear though weak voice. With the aid of P and Q, we can interpret the role of the variable of the system more synthetically. In Fig. 6, each of the variables is located along the four indices AS, PS, P, and Q, which creates a field of tension between *active*, *critical*, *reactive*, and *buffering*. This provides us with the first strategic indications by expressing the four indices in a conceptual way. By their location within this grid, the fields depict the roles of the variables—an answer produced by the particular system, but specific for each variable.

According to the above rules, all the variables of the system are plotted in Fig. 6. We can see that the variables 'cultural activity (2)', 'local industry (5)', 'marketing

Table 3
Consensual impact matrix of Ping-Ding

Effect of ↓ on →		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	AS[1]	P[2]
1	Canals		3	1	3	2	2	3	3	1	2	0	1	0	3	0	0	0	0	2	2	0	0	2	1	1	3	35	1330
2	Cultural activity	3		2	1	2	2	1	1	2	1	0	1	1	3	2	1	1	1	2	2	2	1	2	1	1	3	39	1911
3	Tourism crops	0	1		1	3	2	1	3	3	1	0	0	3	2	2	2	2	1	1	1	1	1	0	2	1	3	37	1554
4	Hiking trails	3	3	1		2	1	1	2	0	2	1	1	1	2	3	2	1	3	2	1	2	1	1	2	1	2	41	1107
5	Local industry	2	2	3	0		2	0	1	3	1	0	0	3	2	3	2	0	1	1	2	1	1	2	1	2	1	36	1728
6	Marketing promotion	2	2	3	0	2		0	1	3	1	1	1	2	3	1	2	2	2	1	2	1	1	1	2	2	3	41	1763
7	Irrigation resource	1	0	2	1	1	0		3	1	2	1	2	0	0	0	0	0	1	1	1	1	2	2	1	2	1	26	572
8	Agriculture	3	1	2	1	2	2	3		2	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	2	2	42	1302
9	Competition	1	2	1	0	2	2	2	3		0	0	1	2	2	1	1	1	1	1	1	1	1	1	1	2	3	33	1221
10	Water pollution	3	2	2	0	2	2	3	2	2		2	2	1	1	0	0	0	3	1	1	1	2	2	1	1	3	39	1131
11	Waste treatment	3	1	0	1	1	1	2	2	2	3		3	1	1	0	0	0	3	1	1	2	2	1	2	1	2	36	828
12	Recycling	2	1	1	1	1	1	2	2	2	3	2		0	0	0	0	0	1	1	1	2	1	1	2	1	1	29	783
13	Employment	1	2	3	0	2	1	0	2	3	0	0	0		2	1	0	1	0	1	2	2	0	1	2	1	2	29	783
14	Culture industry	2	3	2	1	3	2	1	2	2	1	1	1	2		2	2	2	2	1	3	2	1	1	2	1	3	45	2025
15	Tourist turbulence	1	3	3	2	2	3	0	0	1	0	2	1	1	2		3	3	2	1	2	1	1	1	1	1	2	39	1248
16	Traffic congestion	0	3	0	1	2	0	0	0	0	0	0	0	0	2	3		3	0	1	3	0	3	1	0	0	3	25	575
17	Local Transportation	1	2	1	2	2	2	0	0	0	0	0	0	1	2	3	3		1	1	1	1	2	0	0	2	2	29	667
18	Accessibility to water resource	0	1	0	0	0	2	0	0	0	2	0	0	0	1	2	1	2		3	2	3	2	0	1	2	3	27	999
19	Infrastructure	3	2	2	3	2	1	0	0	1	1	1	0	0	1	1	0	1	2		2	2	1	0	1	2	3	32	1152
20	Community conscience	1	3	2	2	3	3	0	0	2	0	2	2	2	3	1	0	0	2	2		2	2	2	2	3	3	44	2024
21	Environment quality	1	2	1	1	0	2	0	1	2	2	2	2	0	2	1	0	0	3	2	3		2	1	1	2	3	36	1368
22	Local security	0	1	1	0	2	1	0	0	1	1	0	1	1	2	1	1	1	1	1	3	2		1	2	1	2	27	918
23	Local governance	0	2	2	0	3	2	0	0	1	0	1	2	1	2	0	0	0	1	2	3	3	2		2	1	2	32	896
24	Education inputs	2	3	3	1	3	3	2	2	1	2	3	3	1	2	0	0	0	1	1	2	1	2	3		2	3	46	1656
25	Dependence on imported resource	3	1	2	2	1	2	1	1	2	1	2	1	1	1	2	2	2	1	2	1	2	2	1	3		2	41	1558
26	Community image	0	3	2	3	3	2	0	0	0	0	0	0	1	2	1	0	0	3	3	3	2	0	0	2	3		33	1980
	PS[3]	38	49	42	27	48	43	22	31	37	29	23	27	27	45	32	23	23	37	36	46	38	34	28	36	38	60		
	Q[4]	92	80	88	152	75	95	118	135	89	134	157	107	107	100	122	109	126	73	89	96	95	79	114	128	108	55		

Note: 1. Summation of rows, 2. Product of row sum(AS) and column sum(PS), 3.Summation of columns, 4. Quotient of row sum(AS) and column sum(PS) × 100.

promotion (6)', 'culture industry (14)', 'community conscience (20)', 'education inputs (24)', 'dependence on imported resource (25)', and 'community image (26)' are the critical variables in Ping-Ding, which means these variables are the major driving force of local development. Some of the variables are worth further investigation. 'Community image (26)' is important for Ping-Ding community because it helps attract tourists. However, its low Q score 55 indicates that the image of Ping-Ding community would be affected significantly by many other variables. This implies that the community and development policy should pay more attention to preventing negative impact on the community image. Moreover, the variables with high values of Q including 'hiking trails (4)', 'waste treatment (11)', 'agriculture (8)', 'water pollution (10)', and 'tourist turbulence (15)' would be instrumental as the control variables of policy design. This information on the roles of variables within the system can help us formulate policy to correct or guide the development of Ping-Ding as will be discussed in Section 4.4 on system simulation.

4.4. System simulation and evaluation

At the beginning of the third phase of SM, a conceptual but comprehensive causal network of system variables, called Effect System, is built to illustrate the system framework of Ping-Ding. The effect system is composed of positive and negative directional links of variables (see Fig. 7). These interactions are based on the actual interrelation between each pair of variables. It can be compared with the values of the impact matrix to see whether there is a significant difference between the actual network and consensus influence, i.e. a 2 or 3 in the impact matrix that does not connect in the effect system. This could be caused by either a missing link or an inconsistency between actual and consensus. We have modified the effect system in this way repeatedly. Note that since it is too complicated to present all links of variables, it is more effective to focus on the main links in the effect system. As a feedback system, there are over hundreds of feedback loops in which 299 are positive and 321 are negative. We can examine this more closely by

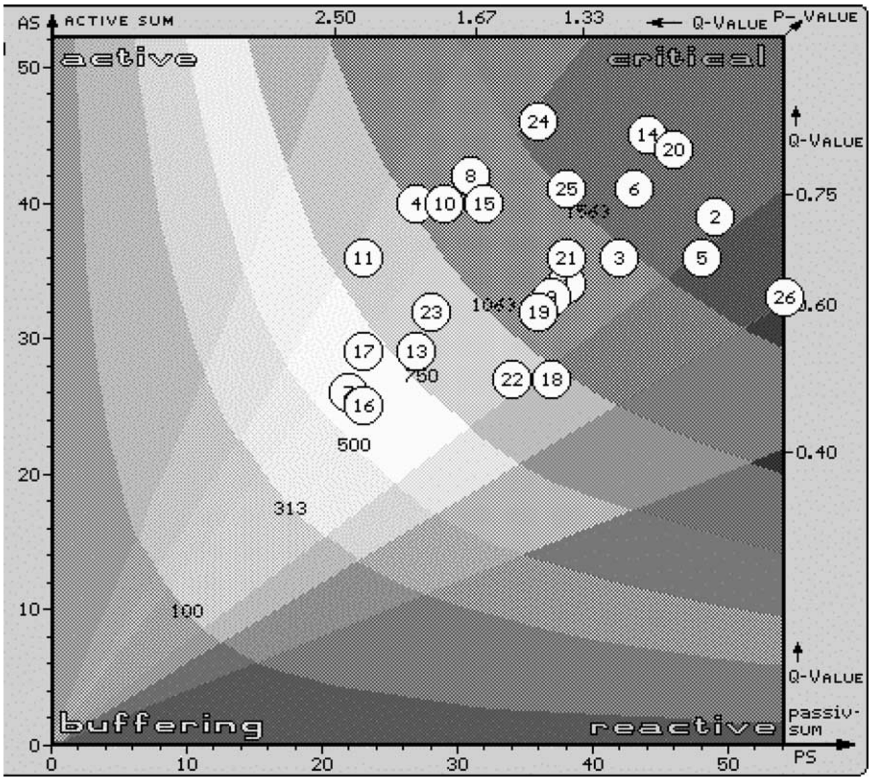

Fig. 6. System roles of the variables of Ping-Ding.

browsing the list of all feedback loops and any concerning combination of variables.

4.5. Partial scenario simulation

The effect system gives us a complete but abstract picture of the internal connections of Ping-Ding. It would be too complicated to conduct a simulation for the entire system. Instead, to perform the system simulation in SM, we have to zoom into a specific part of the system. It is called a *partial scenario (PS)*. The purpose of a partial scenario is to open the system and examine the cybernetics of the interesting parts of the system for the purpose of problem diagnosis, process tracing and policy testing (Wang, 1994). Since each of the partial scenarios originates from the main effect system and is based on the main set of variables, a connection to the total system will always exist (see Fig. 7). The process of building partial scenarios is begun with a discussion, either in the form of a one-to-one interviews or a workshop. In this study, all partial scenarios were sketched through discussion with local participants, including planners, local residents and Chi-Sing Conservation Association.

On the basis of system relationships and discussion with planners, interest groups and local resident representatives, we identified several issues that were of greatest concern to the community, including canal reservation, development of the tourism industry, land utilization, cultural activity and community environment. Each issue is the focus of a partial scenario, along with the interlinked variables that were defined in the previous stages. Though these concerned issues are presented in partial scenarios individually, they are connected by means of the connecting variables that exist in more than one partial scenario. This allows us to perform an integrated simulation for all the concerned issues and have a comprehensive understanding of the development of Ping-Ding.

In addition to the inter-linkage of a scenario, the current value of each variable and the function of each interlink are required for simulation. The current value, which represents the status of each variable and ranges from 1 to 30, is decided by means of the comprehensive index and consultations. Take the variable canal as an example; it is in moderate condition that is not polluted, therefore we mark it with 18. These values serve as the initial points in the simulation. In Ping-Ding community, the variables marketing promotion (6), competition (9), recycling (12), employment (13), and culture industry (14) are set lower than 10 which means that these variables are currently in poor condition. Most variables are in a moderate situation. Note that the traffic of Ping-Ding community is very congested, especially during the weekends. The value is set to 21 with an optimal status set to the lower end.

The function of each interlink in SM is defined such that the vertical axis is the status value of the source variable and the horizontal axis is the percentage change of the effected variable. In Fig. 8, the effect that local security has on community image is illustrated in the lower left. When the status value of local security is lower than 3, then the value of community would diminish by 2%. The value of community would not be affected when the value of local

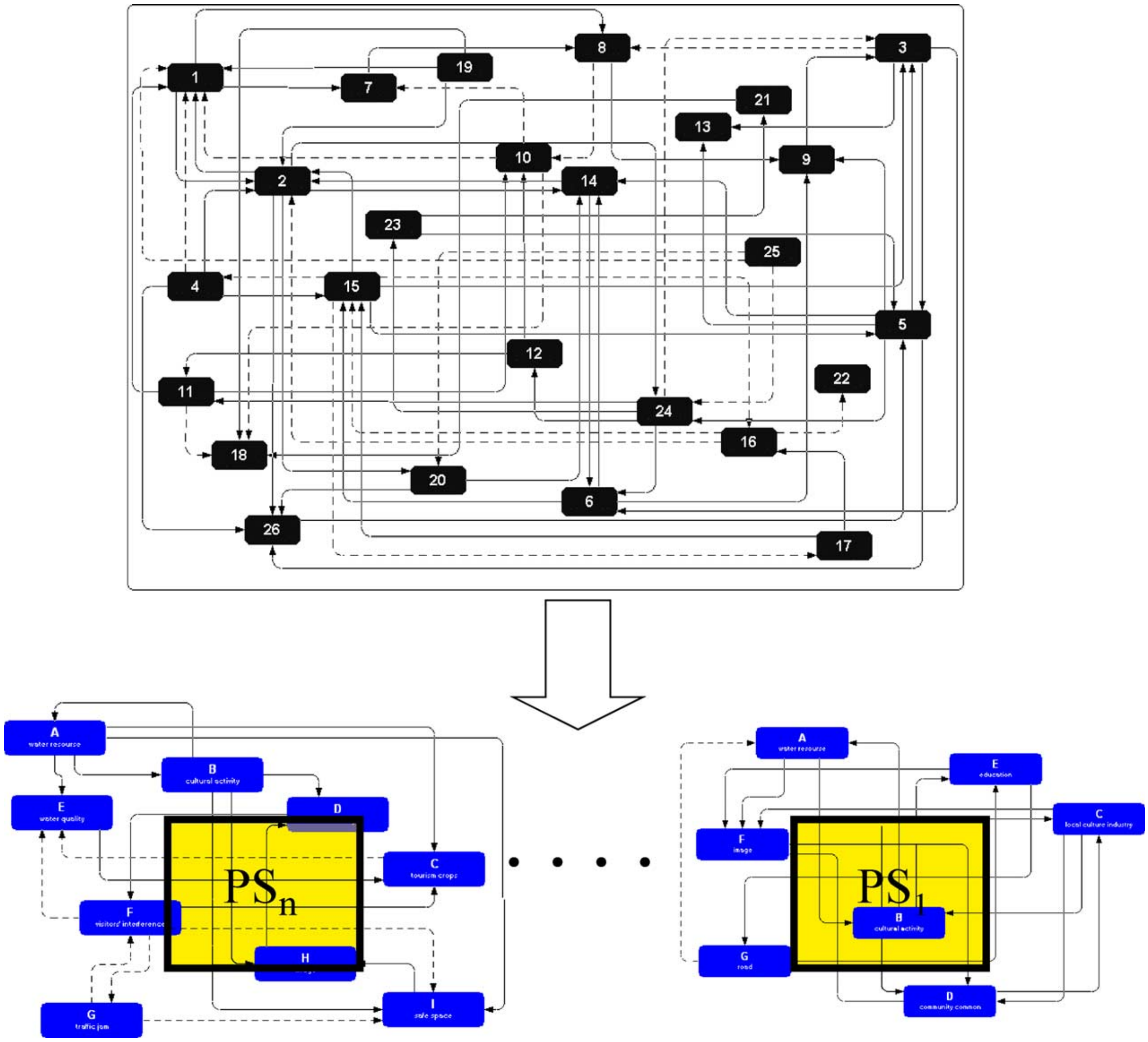

Fig. 7. Relationship of effect system and partial scenarios.

security is between 5 and 20. If the value of local security becomes higher than 20, the value of community image will increase by a corresponding percentage. The right side of Fig. 8 shows the negative impact that tourist turbulence brings to local security. These variable relationships are defined by means of data mining and group discussion.

To obtain a baseline, a 15-year simulation of Ping-Ding without policy intervention was conducted. The results of this baseline simulation of some partial scenarios are shown in Fig. 9. Fig. 9(a) is the simulation of the partial scenario concerned with the canal resource. It shows that agriculture and the physical environment facilities of Ping-Ding rise

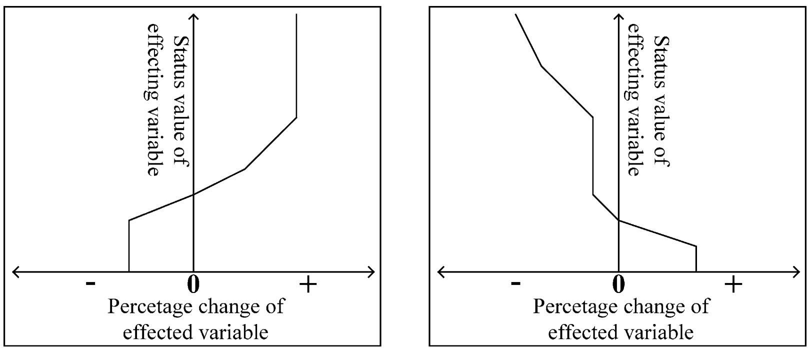

Fig. 8. Functions of positive and negative interlinks.

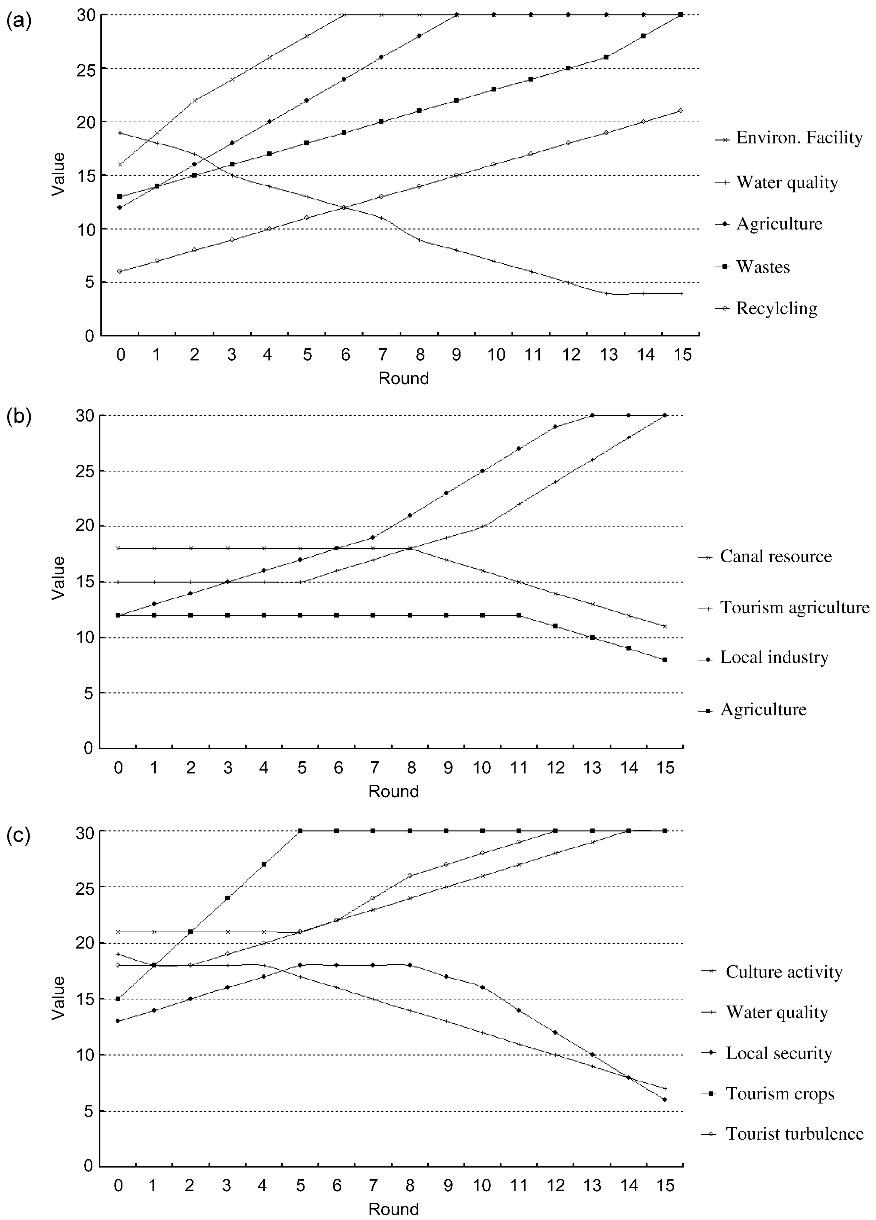

Fig. 9. Baseline simulation of Ping-Ding.

steeply and reach the top after periods 7 and 9 years. In that same time, the quality of water declines. The baseline result of the partial scenario of local industry is shown in Fig. 9(b). It shows that the agriculture of Ping-Ding will decline with the development of tourism crops, and the canal resource will be affected by the increase of tourism corps and local industry. Concerning the community living environment, Fig. 9(c) depicts that over development of the tourism industry and local industry have significant impacts on local security and water quality. These baseline simulations demonstrate possible future problems for Ping-Ding if there is no effective policy to correct the problems.

For the purpose of solving the possible problems shown in the baseline simulation above, the community proposes some possible policies by gathering information from the previous stages and through discussion with the groups concerned. Some variables that are critical in the system are chosen as the control variables. This can be done by referring to the variables located in the upper-right corner of Fig. 6. The results of policy simulation are shown in Fig. 10. These variables including 'agriculture (3)', 'tourism crops (8)', and 'tourist turbulence (15)' are controlled to a certain level to avoid over-development. Fig. 10 shows the simulation policy result in which the upper part is the simulation result and the lower part is the control of the policy variable. As shown in Fig. 10(a), the variable agriculture is controlled to maintain a certain level after time period 8. This raises the water quality trend above

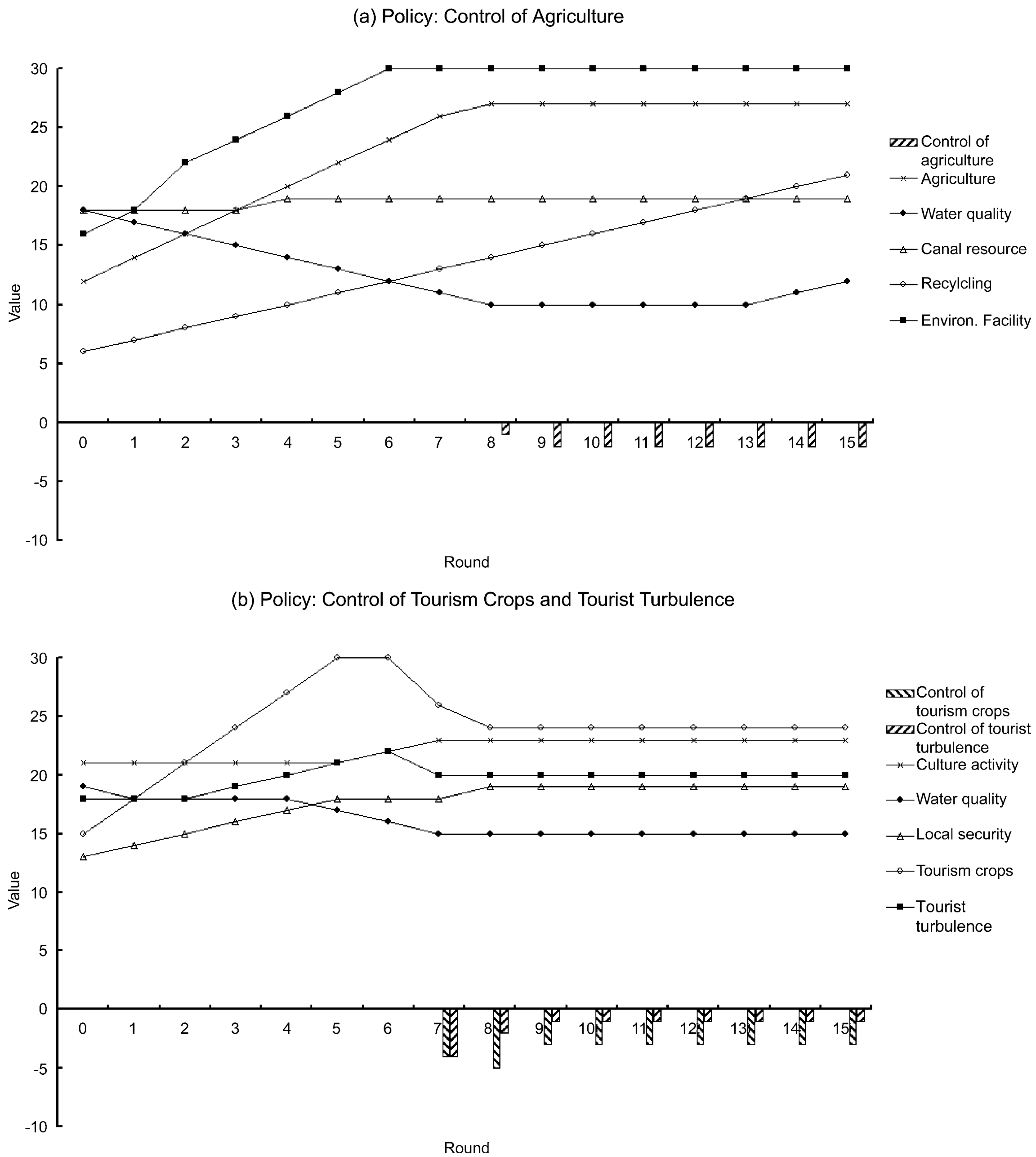

Fig. 10. Simulations of policy intervention of the partial scenarios.

the declining trend in the baseline simulation. Control of agriculture can be achieved with the coordination of the local agricultural association and farmers.

In the second scenario, we considered controlling the variables 'tourism crops (8)' and 'tourist turbulence (15)'. Although the development of tourism is important to the local economy, it could be a potential crisis to community life without appropriate constraints. Policy that controls tourism crops and tourist turbulence was simulated and the result is shown in Fig. 10(b). The upper part of 10(b) is the simulation result and the bottom of 10(b) shows the control of the variables. Both variables are controlled from time period 7 and we reduce control after period 9 to avoid harming the local economy by over control. Fig. 10(b) shows that the policy helps keep the variables local security and water quality from getting worse and remain stable after period 8. Other partial scenarios are simulated in the same way to observe how key variables can be controlled to improve the system.

To evaluate the effect of proposed policy on local sustainable development, a Bio-cybernetic assessment was carried out at the end of session three. The evaluation is based on the eight rules introduced in the second section. Each criterion is marked with a number ranging from 0 to 100 to show the healthy status of the system before and after policy control. Table 4 compares evaluation before and after

Table 4
System evaluation of Ping-Ding

Bio-cybernetic criteria	Evaluation
Negative feedbacks must dominate positive feedbacks	=
Vitality of the system must be independent from quantitative growth	=
System must work function-oriented and not product-oriented	↑
Use of existing forces (principle of jiu-jitsu) instead of fighting (boxing-method)	↓
Multiple usage of products, functions and organizational structures	↑
Recycling processes for the utilization of waste and sewage	↑
Symbiosis reciprocal usage of difference by the employ of coupling and exchange, and	↑
Biological design of products, procedures and forms of organizations by feedback planning	↑

policy intervention. The evaluation results, in which five out of eight criteria get higher scores, show that the overall system is improved with policy intervention. However, the score is evaluated worse under the criterion of the jiu-jitsu principle because the policy intervention uses direct control, not the market mechanism. This result provides information for the next step of policy formulation.

5. Discussion and concluding remarks

Systems thinking about the development of sustainable communities is applied in this paper in the analysis of the Ping-Ding community by means of the SM. The application of SM to community development for sustainability in Taiwan was a very positive experience for us. The tool raises the accessibility of local residents and interest groups to development policy for their community. It brings the people together who are concerned with local development and provides them with a convenient tool to share their view and test the possible policy outcomes. Traditionally, there have been fewer meetings, and they lack concrete and operational methods for the participants to have clear images of a what-if scenario.

SM provides the planner with a convenient and effective tool for the process of public participation and consensus, a key element of the implementation of sustainable development. It provides planners with information about the roles of system variables for the purpose of policy formulation. In the case of Ping-Ding community, the simulation of partial scenarios suggests that the tourism industry of the community should be carefully controlled to avoid the negative impact caused by tourist turbulence and pollution.

This semi-quantitative approach provides a practical solution for dealing with the complicated relations among variables. However, the specification of the interlink function for each pair of variables requires a great deal of consultancy work. Also, the interpretation of the eight Bio-cybernetic rules of system evaluation depends heavily on the experience and subjectivity of the planners. These issues may hinder adoption of the SM model by Taiwan's planning environment and several follow-up studies toward reducing operation costs are in the process to improve the use in planning practice.

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