Advances in Natural Science *ISSN 1715-7862*
Canadian Research & Development Center of Sciences and Cultures

Application and Prospect of Geographical Information System in Strategic Environmental Assessment[1]

BAI Hongtao[2] XU He[3]

Abstract: Strategic environmental assessment (SEA) is a new and promising tool to evaluate the possible environmental impacts and other sustainability aspects of government policies, plans and programs as well as their alternatives, aiming at the effectively integration of environmental concerns into their decision-making processes. It is recognized that spatial issues are always evolved in the SEA process for the reason that the strategic decision-maker pays much attention to the geographical distribution of various impacts. The essential features of strategic decisions, such as the macro-scale on time and geography, complexity of spatial information and social-economic-environmental multiplex system, are leading to the insufficiency of traditional EIA-based methods in assisting strategic decision-making. SEA practitioners have to seek for more effective approaches to handle the spatial uncertainties. Geographical information system (GIS), integrating computer design and database technology, is able to gather, simulate, analyze and display spatial information effectively, and provides a technological support to the synthesized evaluation and quantitative analysis. Based on the statement of SEA conception and characteristics, the author employs a detailed discussion on the advantages of GIS in SEA process and finds that GIS can not only help SEA operators to grasp the macro-scale of time and geography of strategic decisions much better, but also provide visible and intuitionistic displays on the spatial information to make

[1] **Financial supports from National Social Sciences Fund (NSSF) in China: Research on Circular Economy Based on Win-win of Economic Development and Ecological Environmental Protection (06&ZD029) are highly appreciated.**

[2] Ph.D candidate, Research Center for Strategic Environmental Assessment, Nankai University, China.
Address: 94 Weijin Road, Tianjin, 300071, China.
E-mail:Baiht@nankai.edu.cn
[3] Vice Director, Professer, Research Center for Strategic Environmental Assessment, Nankai University, China.
* Received 2 May 2008; accepted 5 September 2008

decision-makers and publics understanding and accepting final conclusions much easier. Meanwhile, the author indicates that GIS with various tools, simulation models and powerful spatial analysis functions, can contribute to a more scientific, synthetic forecast and cumulative effects evaluation; provide much more quantitative analysis and improve the reliability of SEA results. Finally, the challenges and prospects of GIS in SEA process are presented in this paper.
Key words: Strategic environmental assessment; Geographical information system; Information display; Spatial analysis

1. INTRODUCTION

Since "Our Common Future" was issued in 1987, most countries have accepted the concept of sustainable development as the basis of their national development strategies. It is commonly acknowledged that the essential key to sustainable development is the fulfillment of sustainable strategies and policies, that is to say, considerations on the extensive effects of ecological, environmental and social issues should be integrated into the decision-making processes of all the policies, plans and programs (PPPs) as well as the constructions of projects. Accordingly, the National Environmental Policy Act (NEPA) first requested that federal departments and agencies were in duty bound to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and reasonable alternatives. To meet this requirement, federal departments and agencies have carried out “programmatic impact statements” as part of NEPA implementation and prepared a detailed statement known as an Environmental Impact Statement (EIS), which is the beginning of strategy environmental assessment (SEA). Generally speaking, SEA can be defined as the formalized, systematic and comprehensive process of evaluating the environmental impacts of a policy, plan or program and its alternatives, including the preparation of written report on the findings of that evaluation, and using the findings in publicly accountable decision-making (Therivel et al., 1992). Furthermore, current SEA is expected to be used as an effective supporting tool for sustainable development and provide effective assistance for officials and managers in the PPPs’ decision-making process.(Partidario, 2000)

2. CHARACTERISTICS OF SEA

As definition indicated, the PPPs and their alternatives are the objects that SEA concerns. So we can argue that a scientific and successful SEA practice must pay more attention on the backgrounds and characteristics of the PPPs. Since current PPPs often refer to long time and large areas, the macro-scale on time and geography brings great challenges to the SEA practice. In the mostly situations, What SEA deals with is the long-term plans or programs which would cause cumulative and potential effects on the environment. Unluckily, these effects always have a significant feature of lag. Therefore, SEA operators have to scientifically and reasonably forecast and analyze the future influences of the PPPs. In addition, the areas SEA refer to are often more than 100 square kilometers, especially in China, which is much greater than project-level environmental impact assessment (EIA). In order to suit with the characteristics of the overall situation of environmental impacts of PPPs, SEA operators are requested to have stronger abilities of large-scale spatial expression and analysis.

Secondly, the decision-makers of PPPs are targets SEA is to face ultimately (Xue et al., 2004). The success of a SEA practice lies on whether its evaluation could be understood and accepted by the decision-makers and whether the SEA results could persuade them finally giving full consideration to environmental factors in their decision-making processes. Then SEA is required to: a) not only provide

reliable, abundant evaluation information (including the current status and prediction of the environmental, economic and social issues that PPPs are addressing), b) but also present the evaluation to decision-makers in a clear, intuitive and easily-understood manner, c) and ,above all, convince decision-makers adopting the SEA results.

SEA is a formalized, systematic and comprehensive process of evaluating the environmental impacts, which concerns not only the traditional issues such as contamination lets, pollution effects and ecological influences but also the other factors including social, economical, cultural issues and even human health and institutional analysis. The objects are so complicated that how to synthetically deal with the direct/indirect influences of PPPs is becoming a technological matter SEA has to solve as soon as possible.

Another characteristic of SEA is the scientifically forecast of the potential environmental impact of PPPs, and relevant measures should be provided to prevent/reduce the adverse environmental impacts. Compared with the project-level EIA, SEA has more uncertainties and complexities which mainly come from the essential features of strategic decisions, such as the macro-scale on time and geography, complexity of spatial information and social-economic-environmental multiplex system. All discussed above require the introduction of appropriate technological means to deal with uncertainties.

Public participation is regarded as one of most important components in SEA processes, aiming to improve the SEA effectiveness as well as avoid mistakes in decision-making processes. It is said that the accessibilities to environmental baselines in SEA process can be improved by establish a corresponding public participation mechanism for the sensitive and personal experiences on environmental quality and changes of the publics. However, public participation in the SEA has its own characteristics: it is difficult to find the general public who strategic decisions will directly affect and, therefore, SEA pays more attention to the participation of relevant department officials and experts.

3. APPLICATIONS OF GIS IN ENVIRONMENTAL PROTECTION

Geographic Information System (GIS), integrating the computer design and database technology, is a multidisciplinary geographic technique. On the ground of the computer hardware and software, GIS has the abilities of gather, storage, management, simulation, analysis and display of spatial information and result, providing spatial and dynamic information to decision-makers for the comprehensive evaluation, management and quantitative analysis. The objects of GIS include not only geospatial information, but also the social science data of real world. Therefore, GIS has infiltrated many fields of modern sciences as an advanced tool to support decision-making. Based on its outstanding spatial analysis functions and powerful graphics and data processing capabilities, GIS has been more and more introduced into environmental protection, particularly into the field of environmental assessment (EA). Some representative cases of GIS applied to the environmental impact assessment in the past 10 years are shown in Table 1 (Zhao et al. , 2004).

Compared with project-level EIA, SEA makes scientific evaluations to change and leap from micro to macro, from tails to sources, from minors to trunks, from the operation to the decision-making (Pan, 2006). It is the expansion of evaluation scale, the ahead of cut-in time as well as the increase of the consideration issues and the change of main objects that lead to the new requirements for the SEA technology. So far, the SEA technological system is still far from perfect and the lack of the necessary methodology is thought as the key factor. What SEA is to analyze and evaluate is the environmental impact of human activities in a large scope region, which inevitably has closely relationship with the spatial distribution of environmental elements. Therefore, GIS technology is bound to become a SEA technology. In the vast majority of SEA cases in the past several decades, none but overlay mapping were widely used, which has simply indicated the advantage of GIS in spatial analysis and data expression.

Table 1. Applications of GIS in environmental impact assessment within ten yeas

Year	Item/Project	content/object
1993	Use of geographic information system technology to compare the environmental impacts of human development on Mobile bay, Alabama, and Galveston bay, Texas. (Rosciqno, Pasquale F, McNiff, et al.)	The environmental cumulative impacts on the fish and wildlife on Mobile bay, Alabama, and Galveston bay, Texas were compared and evaluated based on ARC/Info plat.
1994	Environmental impact assessment for regional planning with SAFRaN (Burde, Jackel, Thomas, et al.)	Combination GIS with expert system SAFRaN, the project analyzed the soil and underground water quality influenced by acid rain.
1995	Application of GIS for environmental impact analysis in a traffic relief study. (Wang, Stauffer, Bruce)	GIS was used to develop natural and cultural resource inventory, to identify contamination sources, to assess environmental constraints and to evaluate proposed highway alignment alternatives. GIS provides an ideal atmosphere for professionals to analyze data, to apply models and to make best decisions.
1996	Temporal reasoning using tesseral addressing: towards an intelligent environmental impact assessment system. (Coenen, Beattie, Diaz, et al.)	A temporal reasoning system is described which uses a tesseral addressing referencing system. The tesseral addressing techniques used are directly compatible with raster based Geographic Information Systems (GIS) and by extension vector based GIS
1997	Computerized system for the performance of Environmental Impact Assessments (Rose, Hodqes)	Use the information system, developed by ADB, supported by both traditional knowledge and GIS to assess the environmental impact. This are being used by Russia, World Bank and EU.
1998	Preliminary assessment of human exposure to ozone in Mexico City using a GIS-based methodology. (Cicero-Fernandez, et al.)	Use GIS and other statistics tools to effectively harmonize human's space.
1999	Remote sensing and GIS techniques for the environmental management of areas exposed to industrial pollution events. (Marino,et al.)	Taking Pianura Pontina as example, GIS appraised the risk and environmental impact on the surface water and underground water with the help of TM data.
2000	GIS for environmental assessment of the impacts of urban encroachment on Rosetta region, Egypt. (EI-Raey M,Fouda Y,Gal M.)	Using GIS, this project analyzed the encroachment on Rosetta region.
2001	Air pollution in an industrial area using GIS as an assessment tool. (Puliafito E,Guevara M,Puliafito C.Modelling)	Establish atmospheric pollution model based on GIS and take effectively assessment by inspecting NOx、O_3、CO、TSP
2002	Application of a GIS-based modeling system for effective management of petroleum-contaminated sites. (Chen Z,Huang G H,Chakma A.et al.)	GIS-based modeling system effectively managed the petroleum-contaminated sites.
2003	Closing the loop: A spatial analysis to link observed environmental damage to predicted heavy metal emissions. (Colqan,Anja,Hankard, et al.)	spatial analysis function of GIS and atmospheric emission model are the best tools to observe environmental damage and predict heavy metal emissions

4. ADVANTAGES OF GIS IN THE SEA PROCESS

The greatest advantage of GIS applied in SEA processes rests on its capabilities to analyze the spatial relativities of geographic objects, that is, topological relations. This is also been seen as the main feature and advantage of GIS different from other information systems. In the other hand, a lot of tools are incorporated to handle spatial data requiring no programming knowledge. Therefore, it can be easily achieved that the scientifically and quantitative analysis on the environmental, economic and social data and its spatial distribution, and even the establishment of GIS-based digital SEA information systems. GIS has also proved to translate environmental information from the simple text into visual form and provide better services for decision-makers through its friendly graphical user interface.

4.1 Data management

It is one of basic capabilities of GIS that editing, processing and assessing the data of the macro-scale time and geographic areas, which is just required by PPPs' macro features. Background information, such as designated areas, can be assembled in the GIS, along with detailed background mapping. A database is usually associated with a GIS in order to store information relating to the appraisal of each of the options tested. From this source, information from the appraisal can be displayed geographically, either for options individually or as a means of making comparisons between options. The operators can make use of the spatial database and map display function to grasp the social, economic and environmental status in a broad regional involved in PPPs. Supported by data management function, the interrelation among key elements can be clearly considered and the potential impact sources distribution and their reasons can be well analyzed (Fischer, 2007). Using GIS, figure1 transparently displays the spatial interrelation between the road network plan and the mineral resources distribution in Hubei province. With the help of this map, SEA operators can easily evaluate the impact of highway construction on mineral industries in Hubei.

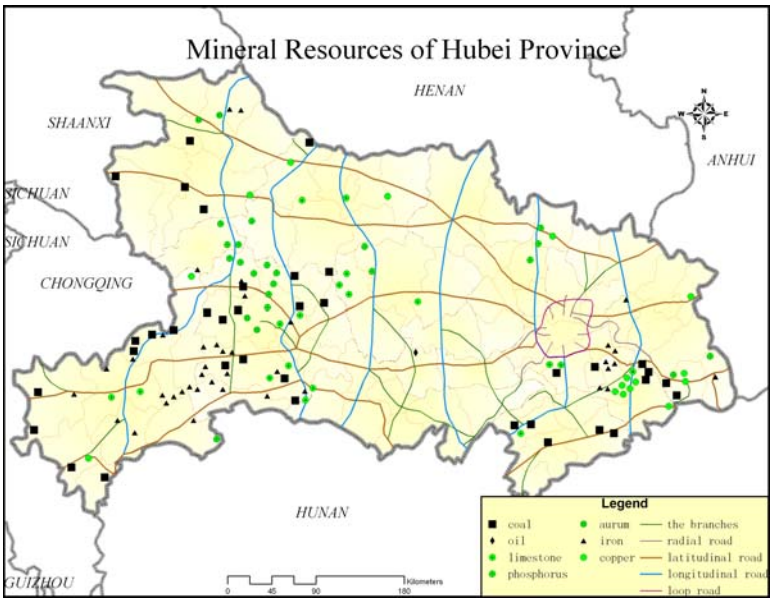


Fig. 1. Impact of Road Network Plan on Mineral Resources

4.2 Spatial and quantitative analysis

Quantitative level and authority of the SEA process can be greatly improved based on the spatial analysis function (i.e. buffer analysis). GIS is accomplished in: a) not only graphically displaying the environmental impact, b) but also automatically calculating the geographic scope of influence area, the affected populations as well as other natural and socio-economic data. For example, measures about the depletion of natural assets (ecosystem services, etc.) caused by human activities are generally called for in the SEA process. Goodland R (1997) advocated that natural resources should be incorporated into the country financial statistics system, aiming to take into account all the economic, social and natural ecological issues in the policy-making process. As we all know, depletion of natural assets is a macro-level concept, which, however, can be easily calculated using the GIS tool for its skill at dealing with large-scope geographic data. Furthermore, analysis on the extent of impacts can be also easily given in the quantitative level. In addition, considerations and comparisons with mass alternatives at different stages of policy-making processes are always regarded as the important tasks of SEA practices. Integrating with existing database, SEA could assess the alternatives through various simulation modules (Shown in figure 2). We believe that the quantitative results in the form of graphics, data and statistics can be more scientifically and convincingly accepted by the decision-makers than the irksome monograms.

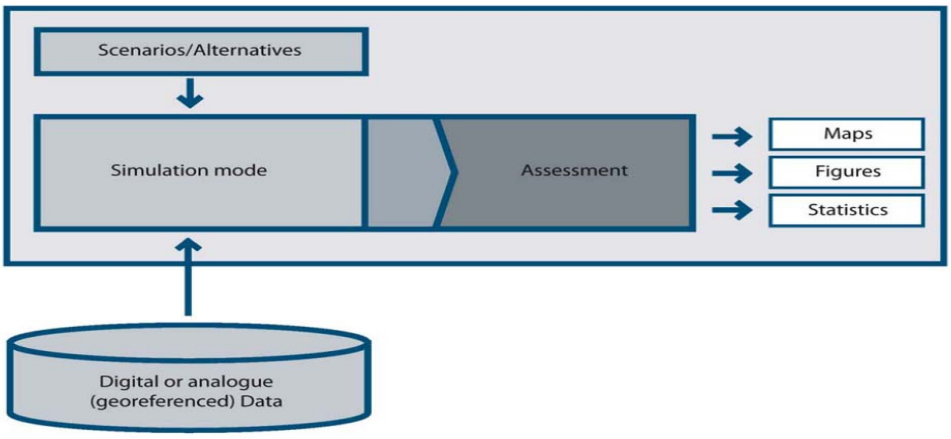
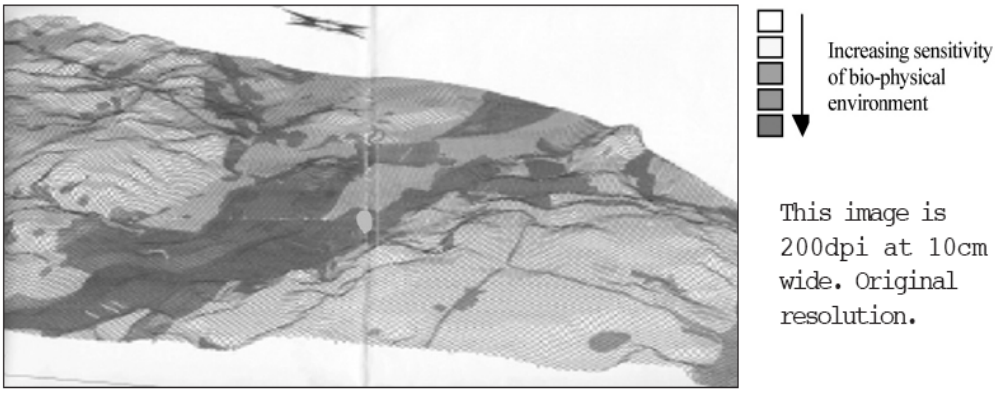


Fig. 2. GIS-based Evaluation Process to Alternatives

4.3 Cumulative effects evaluation

It is the concept of "layer" that helps GIS able to comprehensively evaluate the cumulative impact of the possible effects through the layered expression and overlaying of the sorts of impacts. On the basis of overlaying different factors and characteristics in the same region, changes in environmental quality, including the affected extent and its geographical distribution, are able to be analyzed to help operators identify the factors that might have been overlooked and the sensitive areas that are needed to be more focused on. This technique is so-called Overlay Mapping Method used frequently in the current SEA cases. Figure 3 shows a GIS-based overlay map indicating environmentally sensitive areas. The map was prepared based on a range of underlying themes, including water, soils, biodiversity and others. In this case, the use of GIS would have also allowed the evaluation of impacts by comparing site sensitivities with impact magnitudes of different proposed alternatives.(Fischer et al, 1994)



Source: Fischer et al (1994)

Fig. 3. A GIS overlay map showing sensitivities

4.4 Decision support

The GIS system has endowed SEA operators with stronger spatial decision-support function. As we know, SEA is a tool for decision-making aiming to provide timely and effective information to policy makers. Accordingly, GIS can provide easily-acceptable graphical expression, three-dimensional or even multi-dimensional spatial display, dynamic model support based on the secondary development, as well as convenient result-query function and other functions. So SEA operators can be given a hand to display their evaluation results from various perspectives and the adverse effects could be understood and accepted by decision-makers even more easily. For example, scenario analysis is a common mean of dealing with uncertainties in the existing SEA process. With its visualization tools, GIS can compare the development status under different scenarios, helping decision-makers to make optimal decisions. Based on ArcGIS, figure 4 demonstrates the possible geographic distribution of nitrogen oxides linear sources in one of scenarios in Hubei. The clear display of air pollution trends both in 2010 and 2020 contributes the government to take preventive measures as soon as possible. In addition, using data integration techniques, the information about all the stakeholders could be collected and transformed into GIS data. With the supplement of satellite remote sensing, GPS field surveys and ecological "sample" field verification and other means, a real and effective digital SEA result---SEA information system might be established. These results are not only a report but also a more convenient tool for government departments in long-term decisions-making.

4.5 Forecast function

Forecast analysis in the SEA process would go better along with the help of database analysis function and visualization tools as well as different forecasting modules. According to the forecasting principle of other disciplines, GIS also supports the secondary development based on different languages. Using programming language (e.g. VC, .NET), the operators can design specific models suiting to their objects. On the basis of the environmental geographic information database, the change trend of certain environmental elements could be forecasted effectively. Figure 5 is a GIS process model framework designed by Yao (2005).

4.6 Visible display

Except of the advantages discussed above, the visible display function of GIS is also in favor of public participation in the SEA process. Generally speaking, the primary indicator of public participation validity is the openness and public understanding of information. However, compared with the theoretical emphasis on information disclosure, the forms of public participation in current SEA process

is still relatively simple. Using the GIS, SEA results can translated from the simple text into data visual form of graphical display, which can draw more interests and attentions of officials from the relevant departments and the experts, making results with easier acceptance for the general public.

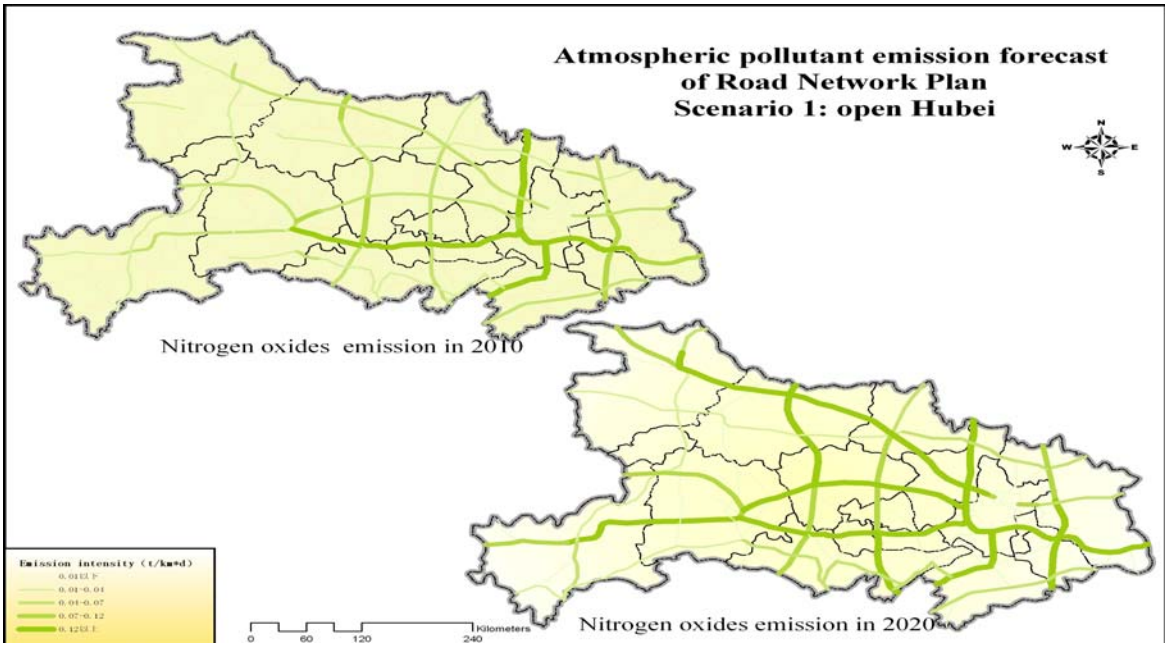


Fig. 4. Nitrogen oxides linear sources emissions forecast in Hubei province

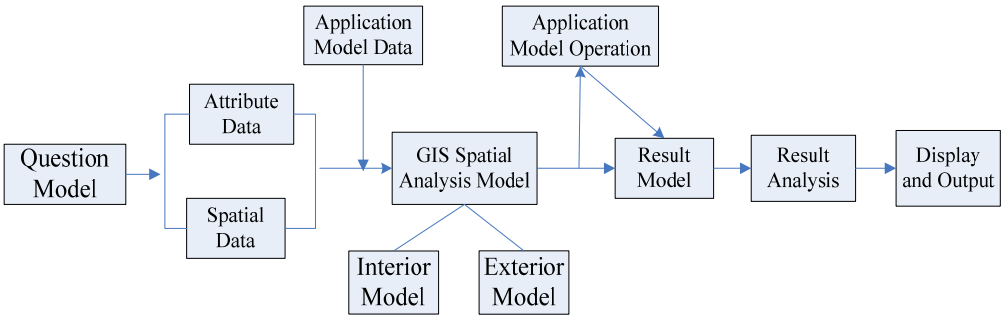


Fig. 5. GIS Process Model Framework

5. CONCLUSION

Nowadays, GIS is being encouragingly introduced into more and more SEA cases as their analysis and evaluation tools, which has been proved considerable success. However, There are still sorts of obstacles and shortcomings in the process of GIS application in SEA practices. For present purposes, these are grouped into seven issues discussed below:

- There is discipline gap existing between the GIS technology and the SEA fields. Firstly, SEA

operators do not quite understand the GIS functions, in particular the latest technological advances, and there are still a large number of innovative technologies of GIS that are not been fully understood and used in the SEA process. Secondly, the GIS experts do not understand the SEA process as well as its technical requirements, so the applied pertinence is limited for the development of GIS functions, which leads to many failures of GIS applied in SEA.

- As a new business, SEA will be faced with tremendous difficulties in the GIS data collection work. Apart from the obstacles of national institutional systems, the GIS data standardization is more required, as well as the improvement of data transmission efficiency and the integration of information sharing.
- 2-D plane map used in most of the current SEA cases is not enough to analyze the multi-dimensional environmental impact. 3-D model should be drawn more attentions in the future SEA processes. On the other hand, GIS field needs improve its functions of describing three-dimensional, or even four-dimensional geographical entity to better express complex, dynamic changes in the environment process.
- Spatial analysis functions in current GIS are very limited in the analysis of abstract matter. It is the environmental impacts of a policy, plan or program and its alternatives that SEA will evaluate, which contains many humanities elements. Unfortunately, the abstract social, economic and environmental phenomenon needs exact and troublesome digitization to be incorporated into geographic information systems. In order to applied better in the SEA process, GIS needs greater breakthrough in the abstract analysis.
- So far, GIS has little able to express the causal relationship between the "source" and "receptor", which is more concerned in the SEA process. At present, the dynamic display of spatial data and time model are being studied, which are anticipated to further strengthen the GIS analysis capabilities on the causal relationship.
- Combined with RS, GPS and other information technology, GIS is anticipated to continuously update its database to achieve spatial data dynamic changes, thus helping the work of SEA forecast.
- SEA is essentially a decision-support tool. Unluckily, current GIS has been unable to provide substantive decision-making intelligence other than the GIS data support. Knowledge-based expert system (ES) is being developed in the GIS field to simulate the human brain’s heuristic reasoning. Combination of GIS and RS, ES can help resolving the unstructured problems that SEA often encounters.

Despite so many shortcomings, the key factors discussed above, which have impeded the better application of GIS in the SEA process, are being identified and solved by both GIS experts and SEA operators. It is convincingly demonstrated that GIS will play a more and more important role in the future SEA processes.

REFERENCES

Bina, O. *Strategic Environmental Assessment of transport Corridors: Lessons Learned Comparing the Method of Five Member State*. Brussels: European Commission. Directorate General for Environment, 2001.

Burde, Michael, Jackel, et al. Environmental impact assessment for regional planning with S A F Ra N.IFIP Transactions B: Computer Applications in Technology.1994(B-16):245-256.

Chen Z, Huang G H, Chakma A. et al. Application of a GIS-based modeling system for effective management of petroleum-contaminated sites. *Environmental Engineering Science*, 2002, 19(5):291-303.

Chen, M. Strategic environmental assessment is the starting point of constructing an environmentally-friendly society–an interview of Pan Yue, deputy director general of the Chinese SEPA. *Environmental Protection*, 2005, 11: 6~12.

Cicero-Fernandez, Winer, Arthur M, et al. Preliminary assessment of human exposure to ozone in Mexico City using a GIS-based methodology. Proceedings of the Air & Waste Management Association's Annual Meeting & Exhibition. 1998(98-TP57.07):8pp.

Coenen, Beattie, Diaz, et al. Temporal reasoning using tesseral addressing: towards an intelligent environmental impact assessment system: Knowledge-Based Systems,1996,9(5):287-300.

Colqan, Anja, Hankard, et al. Closing the loop: A spatial analysis to link observed environmental damage to predicted heavy metal emissions. Environmental Toxicology and Chemistry, 2003,22(5):970-976.

Daniel, R., Leonard, O. Air quality impacts of Tokyo’s on-road diesel emission regulations. Transportation Research part D, 2003, 13: 239—254.

EI-Raey M, Fouda Y, Gal M. GIS for environmental assessment of the impacts of urban encroachment on Rosetta region, Egypt. Environmental Monitoring and Assessment, 2000,60(2):217-233.

Elsa, J. A research agenda for data and scale issues in Strategic Environmental Assessment. Environmental Impact Assessment Review, 2007, 27: 479—491.

Gao Jianxin. Overview on GIS development trend. Journal of Geomatics, 2003, 28(5):15~18

Goodland R, Mercier JR. The evolution of environmental family. EA-Magazine IEA EARA, 1997, 5(3): 17~19

He Yan, Xu Jianming, Shi Jiachun, Current situation and development of application of GIS in environmental protection. Environmental Pollution & Control, 2003, 25(6): 359~361.

Hu Chunhua, Wang Wenpeng, Li Xiongwen, et al. Development trend of GIS in environmental field. Geospatial Information, 2005,3(2):17~19

K. Dharanirajan, P. Kasinatha, B. Gurugnanam, et al. An integrated study for the assessment of tsunami impacts: a case study of south andaman island, india using remote sensing and GIS. Coastal Engineering Journal, Vol. 49, No. 3 (2007) 229 – 266

Lu Liang, Ming Luping. Application of GIS technique to environmental impact assessment. Shanghai Environmental Science, 2000,19(5):208~210

Marino, Alessandra, Pecci, et al. Remote sensing and GIS techniques for the environmental management of areas exposed to industrial pollution events. Proceedings of SPIE-The International Society for Optical Engineering.1999,3853:87-93.

Partidario M R , Strategic environmental assessment: key issues emerging from recent practice. Environmental Impact Assessment Review , 1996, 16: 31~55

Partidario M R. Elements of an SEA framework improving the added-value of SEA. *Environmental Impact Assessment Review*, 2000, 20: 647~663

Puliafito E, Guevara M, Puliafito C. Modeling air pollution in an industrial area using GIS as an assessment tool.Air Pollution IX[C], 2001:529-537.

Rosciqno, Pasquale, McNiff, et al. Use of geographic information system technology to compare the environmental impacts of human development on Mobile bay, Alabama, and Galveston bay, Texas. Source: Coastal Zone: Proceedings of the Symposium on Coastal and Ocean Management.1993,1:825-837 .

Rose, Michael, Hodqes, et al. Computerized system for the performance of Environmental Impact Assessments. Proceedings of the Air & Waste Management Association's Annual Meeting & Exhibition.1997:10.

Therivel R, Wilson E, Thompson S, et al. Strategic environmental assessment. London: Earthscan Publication, 1992.

Therivel R. Strategic environmental assessment of development plans in Great Britain. Environmental Impact Assessment Review, 1998, 18: 39~57

Therivel, R. Strategic environmental assessment in action. London: Earthscan Publication, 2004.

Thomas B Fischer . The Theory and Practice of Strategic Environmental Assessment Towards a More Systematic Approach . London: Earthscan Publication , 2007

Thomas, B., Fischer. Strategic Environmental Assessment in post-modern times. Environmental Impact Assessment Review, 2003, 23, 155—170.

Wang Lu, Zhai Yixin, Wang Fei. Development of theory and application in agriculture of GIS. Joumal of Agr-Environmental Science, 2005, 24: 362~366

Wang Xinhao, Stauffer, Bruce. Application of GIS for environmental impact analysis in a traffic relief study.Computers, Environment and Urban Systems,1995,19(4):275-286.

Xu He, Zhu Tan, Dai Shugui. Study on the development of strategic environmental assessment. Shanghai environmental Science, 1999, 18(8):348~351

Xue Xiongzhi, Lin Tao, Hong Huasheng. International research trend in strategic environmental assessment. Shanghai Environmental Science, 2004, 23(2): 75~80

Yao Yongling, Hal G Reld. Application of GIS in the city management. Renmin University of China Press, 2005

Zhao Jinping, Jiao Shuqiang. Progress of domestic and international research on GIS based environmental impact assessment. Xinjiang Geology, 2004,22(4):395~399