GENERATION AND EVALUATION OF ALTERNATIVES FOR PLANNING PROBLEMS UNDER UNCERTAINTY IN SITE DEVELOPMENT

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Introduction

The users have availed themselves of water and sewer models with difficulty in generating water-distribution and sewer network alternatives. Recently the models began adding GIS. However the status of traditional models and application of GIS to the models indicates limitations in traditional models. Traditional models have limitations in generating and evaluating network alternatives. Planners and engineers may have difficulties in generating good enough water-distribution and sewer network alternatives because of three limitations in traditional models: 1) user interface and graphic display functions, 2) spatio-temporal functions, and 3) alternative generation in consideration of value engineering (VE) and life cycle costing (LCC). The paucity of graphic user interface and spatial analysis functions of traditional models can not support the generation and generation of more complicated alternatives.

Various economic evaluation criteria can be quite misleading because they lead to a different ranking and choice of alternatives. While the theory of CBA represents the ideal approach for monetizing impacts including costs and benefits, the limited market information on the willingness-to-pay for costs and benefits imposes gaps between theory and practice. Private market information for monetizing certain impacts of public projects may be sparse. This problem is a fundamental dilemma of CBA. To make matters worse, the accuracy of many monetized environmental impacts is highly questionable because the dollar values are only partial estimates (McAllister, 1980, pp.124~147). In their attempts to monetize all impacts, decision analysts have adopted sets of very technical procedures. Therefore it is common that decision-makers and the public consider with suspicion the results of CBA (McAllister, 1980, p.142). Monetization by trade-off analysis (Keeny and Raiffa, 1993; Lee, 1993) assists the PSS user through the difficulties caused by technical procedures. Especially when the user has one attribute as the object of monetization, it becomes easier.

Generation of Good enough Alternatives

Value Engineering and Life Cycle Costing

VE is a powerful tool to assist in developing alternatives objectively by its approach to understanding the problem by using analysis function and creativity and brainstorming techniques. VE focuses on the functions, identifying the essential functions and eliminating nonessential functions that represent unnecessary costs. In contrast, LCC focuses on the costs of feasible alternatives, which meet the minimal functional and technical requirements of the project, to identify a least-cost alternative (Dell'lsola, 1997; Kirk and Dell'lsola, 1995).

While some professionals perceive the two, VE and LCC, to be mutually exclusive, the others look upon the two as duplicative. The two are different and distinct. Rather than working separately, LCC can be used in VE to evaluate the costs of various alternatives to select an optimum solution.

Optimization Techniques

Mixed Integer Nonlinear Programming (MINLP) that is used as an optimization technique in capacity expansion of water-distribution and sewer networks includes 0~1 decision variables of capacity expansion increments on each link and the product of variables. MINLP problems in the past have proved to be very expensive and difficult to solve (Kocis and Grossman, 1989). There has been an increased interest in the development and application of nonlinear optimization and integer variables, especially 0~1 decision variables. The DICOPT++ (DIscrete Continuous OPTimizer) model (Viswanathan and Grossman, 1990) integrated in GAMS (General Algebraic Modeling System) (Brooke, Kendrick, and Meeraus, 1992) is available to solve such a MINLP problem.

Generating water-distribution and sewer networks using MINLP provides information about the capacity expansion sizes (sizing), expansion times (timing), expansion types, and expansion locations. It has several strengths comparing with modeling with optimal control theory (Kim and Hopkins, 1996): 1) there are a few application cases of MINLP to process scheduling, 2) interaction among models is less than that of modeling using optimal control theory, 3) there are fewer assumptions than those of modeling optimal control theory, and 4) It can handle the capacity expansion of each link. The continuity equation and the headloss equation make it possible.

Evaluation of Reasonable Alternatives

Economic Evaluation of Alternatives

Various decision criteria in Cost Benefit Analysis (CBA) have been proposed for use in evaluating alternatives: Net Present Value, Benefit/ Cost Ratio, Net Benefit/ Cost Ratio, Internal Rate of Return, Payback Period, and Opportunity Rate of Return. However each economic evaluation criterion can be quite misleading because it leads to a different ranking and choice of alternatives (Sassone and Schaffer, 1978; Freidenfelds, 1981; Mishan 1988, 1982; de Neufville, 1990).

The basic premise of CBA is that alternatives should be selected according to a systematic comparison of the advantages (benefits) and disadvantages (costs) that result from the estimated consequences of the choice (Merkhofer 1987, p.60). Each method has its own strong points and limitations. It is generally said that net present value is the best on theoretical grounds for all its limitations (Dandy and Warner, 1989, pp.75~123; Freidenfelds, 1981).

Evaluation of Alternatives with Different Planning Periods

Freidenfelds (1981) and Manne (1961) claimed that minimum present-value cost (present worth) is the optimal solution to capacity expansion, whereas Liebman (1994) insisted that minimum annual-value cost (annual worth) is sometimes preferred to minimum present worth for infrastructure problems of repeatability on the ground that alternatives may have different lifespans. He also claims that methods of conversion make it possible to use annual worth for nonrepeatable problems.

When the planning periods are identical, the comparison of alternatives provides same result irrespective of using either present worth or annual worth. However planning periods of alternatives may be variable. In addition, each alternative may be repeatable or nonrepeatable.

When the alternatives have different planning periods and repeatable, present worth and annual worth can be used for comparison of alternatives. When present worth is used, common planning periods must be sought and all costs must be discounted. When annual worth is used, “we can avoid calculating the value of the extra life of the longer-lived alternative” (Liebman 1994, p.44). However alternatives can be nonrepeatable. The simplest method for nonrepeatable problem (Liebman 1994, p.44) is to set a common life and compare alternatives by present worth. However this method is exposed to the difficulty of determining cash value for the extra life of longer alternative. Therefore Liebman (1994) asserts that some method of using annual worth assuming repeatability of alternatives is necessary.

Evaluation of Alternatives with the Same Planning Periods by Nonnormalized Cost Benefit Analysis Criteria

There are three identified decision-making situations in economic evaluation of alternatives: (1) the decision whether or not to pursue an alternative; (2) the choice of a most economically desirable alternative among a number of alternatives; (3) the choice of several alternatives from a number of feasible alternatives within a fiscal constraint (Sassone and Schaffer, 1978, p.25; Dandy and Warner, 1989, p.88; Lund, 1992).

Figure 1. Decision Tree of Alternatives Selection

Design	Constraint	Criterion
1. Accept one alternative		NPV > 0
2. One of several alternatives		Maximize NPV
3. Several of many alternatives	1. Capital constraint	Rank alternatives by B/C > 1
	2. No capital constraint	Rank alternatives by NPV > 0

Adapted from Sassone and Schaffer, 1978, p.28).

Sassone and Schaffer (1978) recommended NPV for three of these situations of economic evaluation of alternatives (Figure 1). NPV is used in the case of accepting one alternative or not and choosing one among several alternatives. The choice of one alternative of highest net present value and the exact same initial cost as the capital constraint prevents a set of alternatives with less net present value and less initial cost from being chosen, which would result in a lower net present value.

On the branch for which several alternatives have to be selected among many independent alternatives, subject to a capital constraint, the rule is to adopt projects based on the B/ C Ratio ranking. Ranking by B/ C Ratio in this case is equivalent to maximizing the sum of the NPV from all feasible sets of alternatives. A hypothetical example by Sassone and Schaffer (1978, pp.20~21) gave an example to explain that B/ C Ratio has a place in considering several independent alternatives to be chosen, given some capital constraint. The example assumes that among alternatives one has highest net present value, lower benefit cost ratio, and cost as same as available finance. The highest NPV of the alternative is less than NPV of a set of alternatives with lower NPV and higher B/ C Ratio within financial constraint..

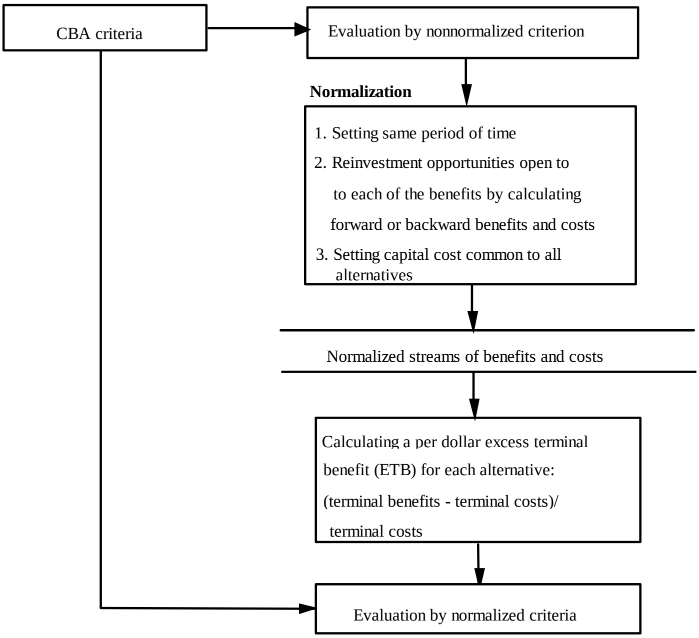
Normalization and Normalized Cost Benefit Analysis Criteria

The normalization technique (Mishan, 1988) (Figure 2) addresses the limitation that each economic evaluation criterion suggested may lead to a different choice of alternatives. Normalization produces revised streams of costs and benefits through three stages: (1) setting a common investment period; (2) identifying reinvestment opportunities open to each of the benefits; (3) setting capital cost common to all alternatives. These three conditions are sufficient to ensure a unique ranking of alternatives in question irrespective of the cost benefit analysis criterion. The first stage of normalization technique addresses the issue that different planning periods among alternatives should still result in consistent rankings. The second stage of normalization makes the capital cost of each alternative equal and the third stage reinvests the benefit at the private discount rate.

Impact Monetization by Trade-off Analysis

As one of the fundamental concepts of multiattribute utility theory is that of utility independence (Keeney and Raiffa, 1993), one of the main concepts of monetization by trade-off analysis is additive utility independence. The additive utility function allows us to add the separate contributions of two attributes to obtain the total utility.

Figure 2. Evaluation Procedure by Normalization and Normalized Criteria



The interrelationship between economic evaluation and trade-off analysis should be considered in the context of incommensurable impacts. While some observers would argue that all impacts should be converted into dollar value, others oppose this opinion. In its attempt to monetize all impacts, CBA has adopted a set of very technical procedures that are difficult for the decision-maker and the public to understand (McAllister, 1980). CBA that fails to convert impacts into dollars can be aided by trade-off analysis in the PSS for capacity expansion. Examples of incommensurate impacts are resource supplies such as water supply, and water excess capacity. These incommensurate impacts can be monetized by two methods: traditional technical procedures and trade-off analysis.

Monetization by trade-off analysis uses midvalue splitting technique, exponential function, or direct determination, which were used by Lee (1993) and Lai (1990) in value determination of attributes for alternatives. The midvalue splitting technique is an approximation method to derive value function of attributes (Keeney and Raiffa, 1993). In the first place, this midvalue splitting technique asks the decision maker to monetize the largest and smallest values of given, incommensurate attributes. In addition, the PSS user is asked to choose three midpoints (0.25, 0.50, 0.75) of the attributes and is allowed to iterate as many as midpoints as appropriate. Like the midvalue splitting technique, the exponential function asks the PSS user to monetize largest and smallest values of given incommensurate impacts. The exponential function, a modified version of the midvalue splitting technique, asks the PSS user to specify one midpoint (0.50), which then provides three points to which the exponential function is fit. In direct determination, the PSS user assigns values directly to the corresponding attribute. The PSS user can edit the results of other methods with this direct determination.

Revisiting for The Modeling of The Generation and Evaluation of Alternatives in Site Development

Planning Support System for the Generation and Evaluation of Water-Distribution Network Alternatives Using GIS, VE, LCC, MGA, and Optimization Techniques

A capacity expansion model for water-distribution network alternatives seeks to find the capacity expansion of water-distribution at each stage (year) to meet changing needs and to manage urban growth. One behavioral simplification in the capacity expansion modeling using a mixed integer nonlinear programming (MINLP) is that water demand increases exogenously and independently of capacity expansion decision. In particular, pricing effects are not considered.

Capacity expansion by the dynamic water-distribution network optimization model using MINLP includes three advantages over capacity expansion using optimal control theory (Kim and Hopkins, 1996): 1) finds capacity expansion alternatives including future capacity expansion times, sizes, locations, and pipe types of a water-distribution network provided, 2) has the capabilities to do the capacity expansion of each link spatially and intertemporally, and 3) requires less interaction between models.

We make the following assumptions pertinent to the installation of water capacity over time in order to simplify the dynamic capacity expansion model:

- Capacity once installed has an infinite life.
- Negative demand increments are not allowed.
- Demand is deterministically forecasted.
- There are no lag times from decision to service provision.

Dynamic Network Optimization Model

We extend a static network optimization model (Brooke, Drud, and Meeraus, 1985) to include time. The objective function of variables for dynamic water-distribution network optimization model for capacity expansion can be formulated as follows.

$$\text{Minimize } Z = \sum_{t=0}^{nt} e^{-rt} \cdot \{unit \cdot \sum_{ij} length_{ij} \cdot (D_{ij}(t) \cdot NY_{ij}(t))^{cpow} + om \cdot unit \cdot \sum_{ij} length_{ij} \cdot D_{ij}(t)^{cpow}$$

$$- sv \cdot \sum_{ij} length_{ij} \cdot (D_{ij}(t-1) \cdot NY_{ij}(t))^{cpow}\}$$

where r : discount rate,

nt : number of planning periods,

i, j : from-node and to-node of link $(i \neq j)$,

$unit$: cost per unit of length and diameter,

$length_{ij}$: the length of link ij (m),

$cpow$: power on diameter for cost, an economies of scale parameter,

om : operation and management factor to construction cost,

sv : salvage value factor per length and diameter,

$\Delta D_{ij}(t)$: pipe increment of pipe from-node i and to-node j at time t (m),

$D_{ij}(t)$: pipe diameter from-node i to-node j at time t (m).

$NY_{ij}(t)$: continuous surrogate decision variable of $Y_{ij}(t)$.

The objective function is to minimize the total discounted costs of the networks associated with the expansion process. Cost is composed of construction cost, the first term, O & M (operation and maintenance) cost, the second term, and salvage value, the third term. The first implies that construction cost is considered only in the case that there is any change in pipe size at the time, that is, if pipe size at time t is the same as that at time t-1, construction cost is not added in objective function. The continuous surrogate decision variable $NY_{ij}(t)$ is used in place of the integer decision variable $Y_{ij}(t)$ because the integer decision variable can not be used in nonlinear equations (Brooke, Kendrick, and Meeraus, 1992). The third term implies that salvage value of old pipe is considered whenever pipe size is changed at the time.

Water-distribution Network Analysis Model

The water-distribution network analysis model simulates flow and water pressure for a single point in time, in order to determine the water pressures at nodes and flows in links given a distribution network and pipe sizes assigned from the network optimization model. Cesario (1991) provides an excellent description about the network analysis models.

The network analysis model improves on analysis included in the dynamic network optimization model and capacity expansion MGA by four ways: 1) analyzing discrete pipe sizes of model defined alternatives, 2) analyzing discrete pipe sizes of MGA defined alternatives and calculating construction cost, 3) analyzing discrete pipe sizes adjusted and edited by the user and calculating construction cost, and 4) analyzing user defined alternatives and calculating construction costs. In addition to water pressure head at nodes, the network analysis model analyzes the water velocity and the head loss gradient, which are not checked in the optimization model, for velocity and head loss gradient criteria in links.

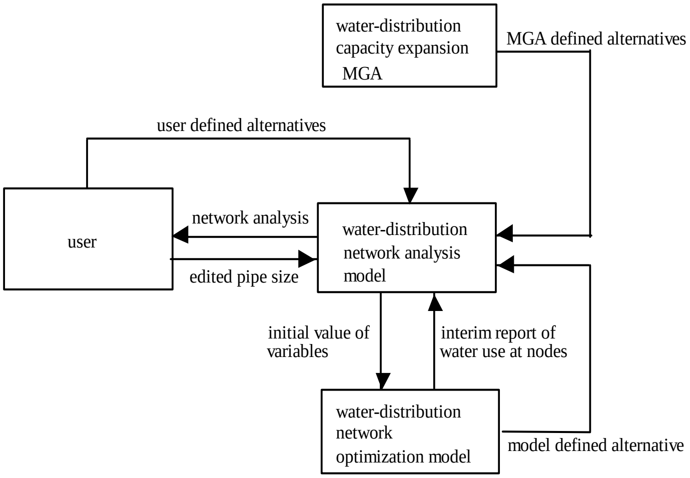
Modeling-to-Generate-Alternatives

While there are several studies about sewer network MGA (Chang, Brill, and Hopkins, 1982), there are few studies about water-distribution network MGA. The difficulty of generating water-distribution alternative networks accounts for the paucity of related studies. Some streets do not have sewer pipes, which makes it feasible to generate sewer alternative networks. Generating alternatives of water-distribution networks is rather difficult because water-distribution pipes are placed under every street and it is not feasible to make alternatives by changing origin and end nodes (from-node and to-node) as it is in sewer MGA.

There are no perfect tools to generate alternatives, but some heuristic approaches with modeling can be used to generate good enough alternatives. In this study, the method of manipulating model parameters (Dickey, Leone, and Schwarte, 1973) is applied to generate capacity expansion alternatives. In order to get alternatives, the capacity expansion MGA changes either the bounds or initial values of variables in the network optimization model.

Figure 3 illustrates the relationship among the user, the dynamic water-distribution network optimization model, the capacity expansion MGA, and the water-distribution network analysis model. The dynamic optimization model provides the network analysis model with an interim report of water use at nodes over time. The network analysis model returns initial pipe sizes over time after simulation utilizing the network analysis model. The water-distribution network analysis model analyzes the dynamic optimization model defined, user defined, and MGA defined alternatives. The PSS user evaluates the analysis results, edits the pipe size, and returns them to the network analysis model again until acknowledging that the network is reasonable.

Figure 3. The Generation of Alternatives with MGA and Water Models



Manipulating model parameters may generate different alternatives using optimization techniques (Dickey, Leone, and Schwarte, 1973). The possibility of generating water-distribution alternatives involves change of pipe size by changing the bounds of variables in the dynamic water-distribution network optimization model. Changing the lower bound of water pressure head at nodes provides alternatives.

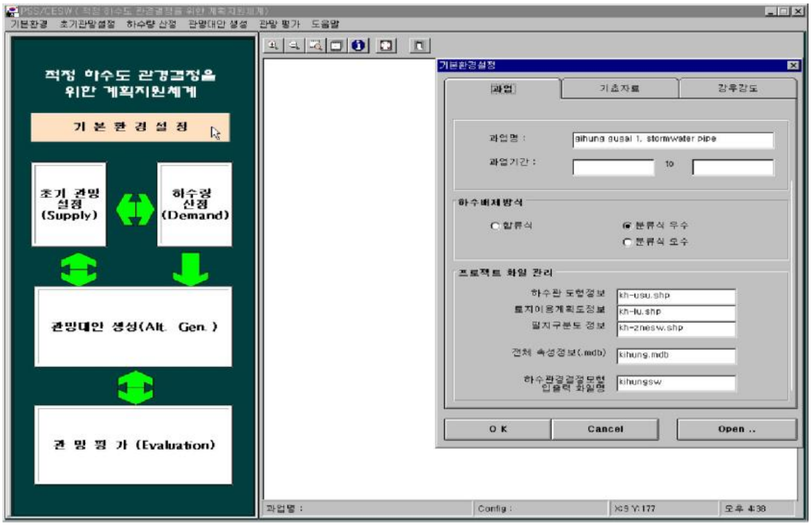
Planning Support System for the Generation of Satisficing Sewer Alternatives Using GIS, MGA, and Simulation Techniques

A PSS for the Generation of Satisficing Sewer alternatives (PSS/ GSS) (Kim and Kim, 1998) seeks to find a set of sewer networks to meet changing wastewater demand.

User Interface Design

The user interaction with PSS/ GSS is categorized into four stages (Figure 4): 1) Supply, 2) Demand, 3) Alternative Generation, and 4) Evaluation. Arrows indicate the flow of information and process. A user can start at any point in the process or move around among steps in any way that is possible and valid in terms of necessary data being available.

Figure 4. User Interface Configuration



과업명 : gihung gusal 1. stormwater pipe

과업기간 : to

하수배제방식

○ 합류식

● 분류식 우수

○ 분류식 오수

프로젝트 화일 관리

하수관 도형정보: kh-usu.shp

토지이용계획도정보: kh-lu.shp

필지구분도 정보: kh-znesw.shp

전체 속성정보(.mdb): kihung.mdb

하수관경결정모형 입출력 화일명: kihungsw

Supply

User procedures including Create Virtual Network, Define Initial Network, and Modify Land Use Pattern invoke a GIS environment. The user can generate virtual network coverages based on street coverages. Virtual network coverages encompass all possible links including existing links. Virtual network coverages for considering changes of land use should include existing sewer networks. From the virtual network, the user can generate one or several initial networks depending upon the situation. Given the user's definition of an initial network, the system derives information needed to define alternatives from the initial network.

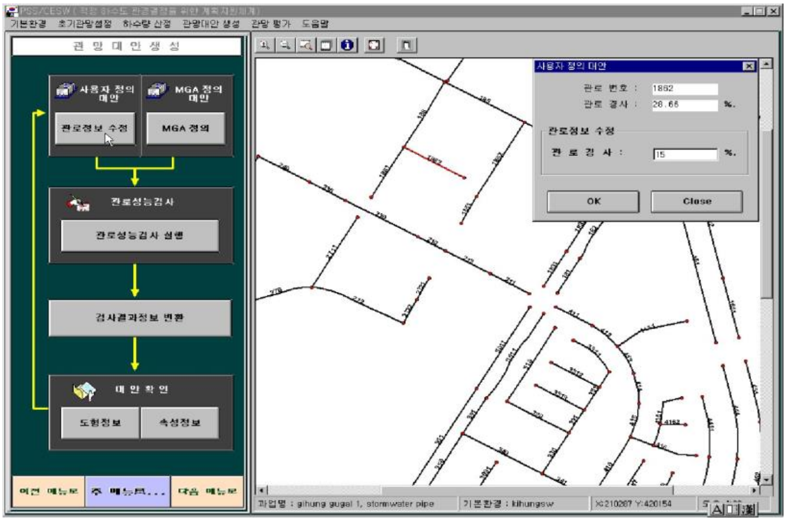
Demand

The user can create a land use plan for new development or modify a land use plan for changes of land use. The user also inserts or edits consumption parameters. As a result of created or modified land use patterns and consumption parameters, the system calculates the quantity of wastewater to be charged at lines of the initial network. Considering the wastewater at lines, the user can modify the land use pattern again.

Alternative Generation

Alternative Generation generates and analyzes alternatives. If no alternatives have yet been generated, the user can choose one of three alternative generation methods: sewer model, user, and MGA. Once alternatives have been generated and analyzed, the user can edit parameters to generate edited alternatives or manipulate networks (Figure 5). The sewer model utilizes the initial network and information from the previous steps. With this detailed analysis the user can edit pipe sizes. The user can edit parameters in the sewer model, creating the sewer MGA. The parameters to be edited are earth depth and drop height in a manhole. The system generates and analyzes MGA defined alternatives. The adjusting process continues until analyzed results are satisfactory to the user.

Figure 5. Manipulation of Pipe Slope



관로 번호 : 1862
관로 경사 : 28.66 %.
관로 경사 : 15 %.

과업명 : gihung gugal 1, stormwater pipe
기본환경 : kihungsw
X:210287 Y:420154

Economic Evaluation

Economic evaluation can be used to choose one or compare several alternatives with or without a financial constraint. The user can select a value of social discount rate and CBA. Streams of benefits and costs can be illustrated in graphics and numerically. An inconsistent CBA criterion results in an inconsistent ranking of alternatives graphically and numerically. The user can normalize the streams of benefits and costs to ensure valid use of any benefit cost criterion. The information of common initial capital cost, common planning period, and private discount rate is prerequisite for normalization of streams of benefits and costs (See e. g. Mishan, 1988). Calculating by normalized CBA criteria results in a consistent ranking of alternatives graphically and numerically.

Implementation

The PSS is intended to support exploration of alternatives using the set of models to consider and create alternatives. The PSS was applied to a case site, Gihung-Gugal housing site, which is located south of Seoul, Korea. Four storm sewer size alternatives and one sewer network alternative were generated using the sewer model, the sewer MGA, and user definition (Table 1). Each alternative shows a rather big difference in construction cost and earthwork.

Table 1. Summary of Storm Sewer Alternatives

	alt #1	alt #2	alt #3	alt #4	alt #5
	sewer model defined size alternative	MGA defined size alternative	MGA defined size alternative	MGA defined size alternative	user defined network alternative
construction cost (thousand $)	2576	3116	3481	2500	2996
Earthwork (m^3)	21,432	23,778	24,998	23,318	21,787
no. of manhole (ea)	233	240	240	183	232

Modeling of A Planning Support System for The Generation And Evaluation of Alternatives Under Uncertainty

Conceptual Design

There are several strategies and approaches for the integration of DSS and GIS (Kurt, 1993). The major shortcoming of GIS in integration with other models is that they do not easily incorporate existing urban and regional models (Budic 1994).

The simplest strategy for this problem is to just exchange files, which is called “shallow coupling through common files” (Kurt, 1993). In spite of its merit that it requires little software modification, the user is likely to make errors if it contains a significant amount of manual, time-consuming tasks. The other way is “deeper integration by deep coupling in a common framework” (Kurt, 1993). A common graphic user interface is provided in addition to transparent file or information sharing and transfer between the respective modules.

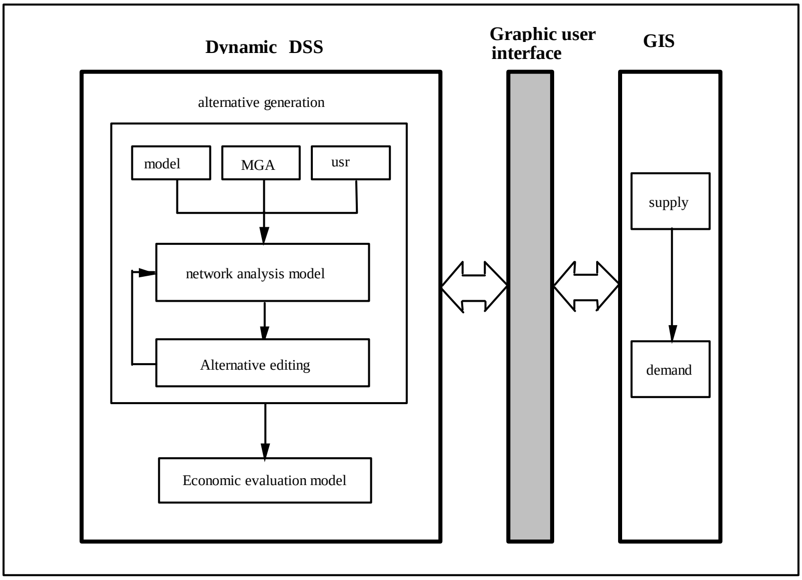
The melding together of a DSS and a GIS in PSS that follows is based on “deeper integration.” Figure 6 shows a conceptual design framework of PSS for the generation and evaluation of alternatives (PSS/ GEA), in which the dynamic DSS that has advanced spatial analysis functions and intertemporal functions is linked to the GIS, through a graphic user interface (GUI).

The dynamic PSS in this study includes seven models (Figure 6): 1) dynamic water-distribution and sewer network optimization models, 2) water-distribution and sewer network analysis models, 3) water-distribution and sewer MGAs, and 4) an economic evaluation model. While the dynamic network optimization models address the issue of intertemporal functions, the remaining ones address spatial analysis functions. The user can calculate the quantity of water and wasterwater demand at nodes and generate virtual and initial networks utilizing GIS. The dynamic network optimization model, the user, and capacity expansion MGA can generate good enough network alternatives. The network analysis models analyze the alternatives. Considering the analysis results, the user can edit link sizes. The economic evaluation model identifies reasonable ones among good enough capacity expansion alternatives.

PSS Specifications

PSS/ GEA should have the following specifications, which respond to the explanation of the gap in knowledge in the capacity expansion of water-distribution and sewer models .

Figure 6. Conceptual Design Framework of PSS/ GEA



User Interface functions

Well managed, flexible, and sophisticated user interfaces are one of the objectives of PSS. Users want to be informed and make choices and decisions because of semistructured or unstructured nature of planning problems (Langendorf, 1985). For human-machine interaction, two types of translation should be performed to facilitate the human-machine interaction process:

translating the human's thoughts into physical actions that the machine understands; and translating the output of the machine into the format that the human can understand (Hutchins, Hollan, and Norman, 1986; Schneiderman, 1983).

Data Import and Export Functions

The data to be used in this PSS are layers from other sources, which can be used without the process of converting. Digitizing and scanning are conventional methods of importing data. In the PSS for capacity expansion, urban planners and civil engineers sometimes require data from a variety of formats, such as DIME, ASCII, and AUTOcad. In addition to scanning and digitizing methods, the PSS for capacity expansion must have functions for importing information related to infrastructure planning and exporting the same data into the original format after checking for consistency topologically (Dangermond, 1988). As a result, PSS/ GEA becomes an interface system between different software systems, different hardware systems, and different data formats.

Graphic Display Functions

Graphic display is more effective and efficient than a data sheet in persuading and communicating with people in other disciplines. GIS with graphic display functions make up for the deficiency of the conventional water and sewer models without graphic functions by displaying result. Graphic capabilities enhance users' judgment of inputting, editing, and deciding their choices.

Data Edit Functions

Users are able to edit attribute data in two ways: first, editing in text format, which is used in the conventional water models; second, editing on the screen, which is used in GIS environment. When it comes to spatial data, users can edit those data on the screen under GIS environment. It is however impossible in the conventional models.

Analytic Functions

One common problem in many existing water-distribution and sewer network models and pure GIS is their lack of analytic functions. The combination of GIS and DSS makes up for the limitation of analytic functions. The analytic functions of GIS are very helpful in overlaying layers to get the land use of every parcel and calculating the amount of water and wastewater per node.

Spatial Database Management Functions

Spatial database management function of GIS enables users to integrate information of water planning and utilize information in other fields such as land use planning. Query functions, a kind of spatial database management function, make it possible for users to find the attribute data of links, nodes, and parcels.

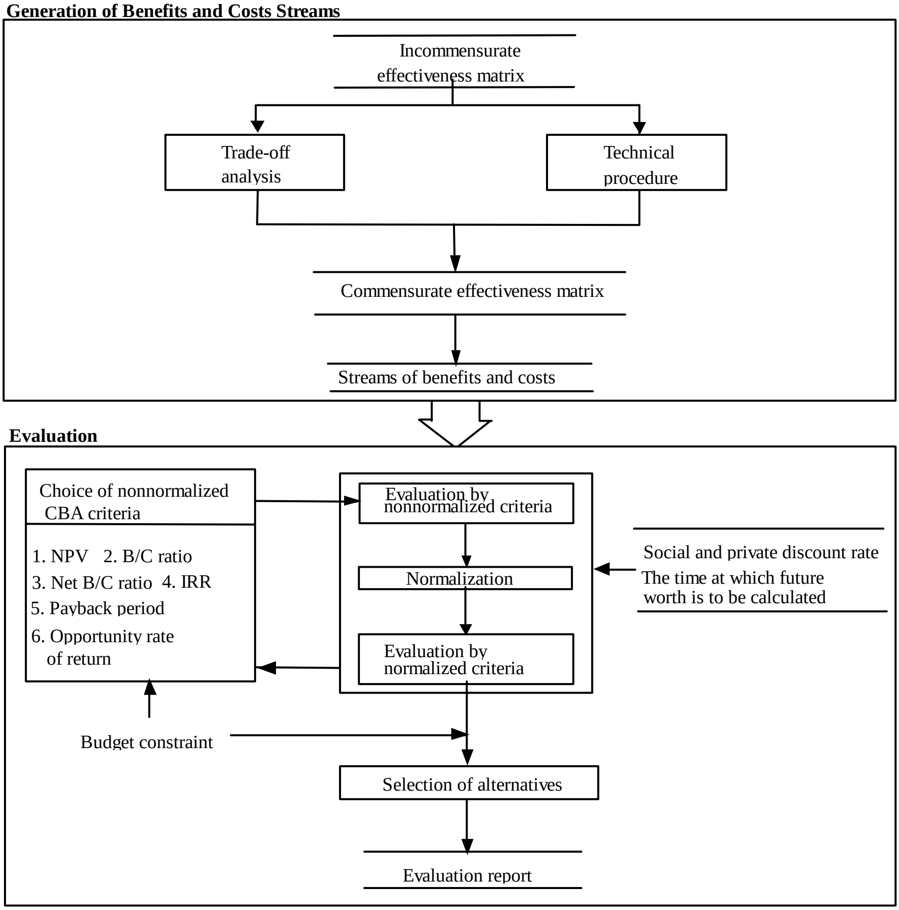
Capacity Expansion Analysis Functions

Generally, fixed design periods have been used in the case of water-distribution and sewer networks. However, this does not result from consideration of discount rate, economies of scale and staged development strategies but is a rule of thumb. Economic design periods of water-distribution and sewer networks depend on discount rate, the ease of capacity expansion, and initial construction costs. The capacity expansion model provides curves of future water consumption and wasterwater production and allows for the consideration of excess capacity. These curves become the basis for capacity expansion analysis functions.

Modeling of Economic Evaluation of Alternatives

Economic evaluation of alternatives encompasses 1) Generation of Streams of Benefits and Costs Streams and 2) Evaluation (Figure 7). In the first part, Generation of Streams of Benefits and Costs, an incommensurate effectiveness matrix is transformed to a commensurate effectiveness matrix and streams of benefits and costs.

Figure 7. Modeling of Economic Evaluation of Alternatives



Monetization and conversion to time discounted values are necessary for every attribute and alternative. For example, for NPV, all impacts must be discounted and transformed into present worth. For B/ C Ratio, all impacts must be discounted and transformed into present or annual worth. The difference between commensurate effectiveness matrix and streams of benefits and costs is that each impact in the commensurate effectiveness matrix is transformed into streams of benefits and costs. If it is assumed that positive and negative value impacts mean benefit and cost respectively, this transformation is not necessary.

Lund (1992), Bruggink (1992), and Sonnen (1992) argued about the instability of the B/ C Ratio, i. e., B/ C Ratio varies greatly depending on how the benefits and costs are classified. Lund, an engineer, (1992) showed that different classifications of impacts could even result in negative and zero value of B/ C Ratio for alternatives with positive NPV. He recommended that NPV and annualized NPV as a replacement for B/ C Ratio generate fewest computational and economical pitfalls. In responding to Lund (1992), Bruggink (1992) and Sonnen (1992), economists, insisted that a universal rational classification exist, i. e., positive and negative value impacts mean benefit and cost respectively.

In the second part, Evaluation, after normalization of streams of benefits and costs, conventional CBA criteria are executed to get consistent results. This system makes use of the techniques of Mishan (1988) and Sassone and Schaffer (1978) in normalizing and selecting alternatives. Before the normalization of streams of benefits and costs, each of the alternative selection criteria of Sassone and Schaffer (1978) is available to users (Figure 1). Normalization techniques of Mishan (1988) are also available (Figure 2). Even though users may wish to stay with their accustomed evaluation criterion, this system will show results from all six criteria, thus highlighting inconsistencies that imply inadequate problem specification. This information provides the decision maker with “cognitive feedback” (Sengupta and Abdel-Hamid, 1993) and improves performance for selecting alternatives by giving clues to the normalization procedure.

Sengupta and Abdel-Hamid (1993) showed that subjects provided with “cognitive feedback” performed best in a dynamic environment, followed by those provided with “cognitive feedforward” and “outcome feedback.” The conceptual difference of “cognitive feedback,” “cognitive feedforward,” and “outcome feedback” is as follows: 1) “Cognitive feedback” improves decision making by enhancing the decision maker's comprehension of the decision structure, his or her cognitive system, and the fit between the two (Hammond et al., 1975). “Cognitive feedback” is information provided to the decision maker about the relations in the decision environment, relations perceived by the person about the environment, and relations between the environment and the person’s perception; 2) “Cognitive feedforward” seeks to improve the decision maker’s decision making by providing him or her with a model of the task prior to performing the task; 3) “Outcome feedback” does not provide enough information from which decision makers can form suitable models of dynamic systems.

Conclusions

PSS/ GEA of water-distribution and sewer networks provides users with several tools: 1) aggregating the amount of water and wastewater by nodes and generating a virtual network and several user defined networks using GIS; 2) identifying water-distribution network alternatives by user definition, the dynamic optimization model, or MGA; 3) evaluating the performance of networks using the network analysis model; 4) showing the results of capacity expansion model using GIS; and identifying reasonable ones among good enough alternatives.

However the modeling using MINLP is limited in addressing the relationship between cost, price, and demand, which the optimal control approach can consider. Strictly speaking, the construction and O & M costs of water-distribution and sewer networks influence the price charged for the served water and wastewater, which in turn influence the demand. This limitation can be justified in rather small area because price per unit water and wastewater in the area must be same as that of neighboring area, i. e., the price is determined administratively. The users can put emphasis on capacity expansion without consideration of the relationship between cost, price, and demand.

The capacity expansion model shows GIS, VE, LCC, MGA, water-distribution and sewer network models and economic evaluation models can complement each other in generating and evaluating alternatives. Some extensions for future research are:

- Some of several assumptions for the network capacity expansion model should be relaxed.
- The combination of MINLP and optimal control theory in capacity expansion modeling of network alternatives can make up for the limitations to generate alternatives in consideration of expansion sizing, expansion timing, expansion types, expansion locations, and the dynamic relationship between cost, price, and demand.
- As decision rules in decision analysis, the usage of AHP (Analytic Hierarchy Process) and MAUT (Multi-attribute Utility Theory) should be studied furthermore.

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