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Decision Network: a planning tool for making multiple, linked decisions

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Abstract. Few techniques exist specifically for planning analysis. Commonly used decision techniques focus on different, partial aspects of coordinating decisions. The garbage-can model focuses on the context in which decisions emerge to explain descriptively how organizational choices are made; the strategic choice approach focuses on the relationship between decisions from which rational actions can be taken; and the decision tree focuses on the causal sequence of decisions from which the optimal path of a plan can be derived. Drawing on the theoretical foundation of these three commonly used techniques, we introduce the conceptual framework of a tool for planning analysis, namely *Decision Network*, that addresses context, relationship, and sequence of decisions, with a numerical example demonstrating how the decision problem can be formulated and solved. Decision Network can be used by decision makers who are faced with more than one decision in order to make plans. Much can be built on this tool to address spatial issues.

1 Introduction

Making plans and acting accordingly are fundamental to the urban planning profession. Few would argue against the presumption that making plans is helpful in coping with urban phenomena because planning for urban development characterized by interdependence, indivisibility, irreversibility, and imperfect foresight yields benefits to planners (Hopkins, 2001). However, the question remains unsatisfactorily answered as to whether making plans can really help us in coping with complex urban systems. Instead of addressing the issue directly, we have developed an analytical planning tool called *Decision Network* on the basis of the presumption that making plans matters and yields benefits to the user in terms of his or her preferences.

Most planning situations are composed of multiple, linked decisions. The essential idea of making plans is therefore to coordinate linked decisions in order to achieve desired goals. Though this conception is crucial in making plans, little has been discussed in the planning literature about how it should be explored and how planning tools can be developed on this basis (except, for example, Hopkins, 2001). Planning and design are distinct in that the former takes into account contingencies, whereas the latter focuses on the arrangement of actions. A decision (planning) support system must therefore be capable of helping the planner to coordinate contingent decisions in context, relationship, and sequence. Commonly applied decision or planning aids enhance only part of these aspects: the garbage-can model (Cohen et al, 1972) focuses on context, the strategic choice approach (Friend and Hickling, 2005) on relationship, and the decision tree (Raiffa, 1968) on sequence. Here we present a planning tool, Decision Network, that blends the three techniques into a coherent framework, so that all three aspects of decision making are taken into account.

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In section 2, we review the three planning tools under consideration. In section 3, the conceptual framework of the planning tool Decision Network is provided. In section 4, we demonstrate how Decision Network functions using a hypothetical numerical example. In section 5, we discuss some possible applications, extensions, and limitations of the planning tool. Conclusions are given in section 6.

2 Three commonly used techniques for decision analysis

In this section, we review the three commonly used decision techniques from which Decision Network (developed in section 3) is derived, namely, the garbage-can model (Cohen et al, 1972), the strategic choice approach (Friend and Hickling, 2005), and the decision tree (Raiffa, 1968).

The garbage-can model is a description of the chaotic choice behavior in organized anarchies. It stresses how decisions are made in a particular context, or garbage can, in terms of problems, solutions, and decision makers. The model views the decision process in an organization as four independent streams: streams of problems, solutions, decision makers, and choice opportunities or decision situations. These four elements interact in an unpredictable, chaotic way and if problems, solutions, and decision makers meet in a particular choice opportunity, a decision may or may not be made, depending on whether the energy supplied exceeds that demanded. In addition to the interaction of the four streams of elements, there are structural constraints confining who are eligible for making decisions where and which problems can be brought to bear with which choice opportunities. Given the simple conception of the organizational choice behavior, the system generates extremely complex, unpredictable behavior that yields interesting, robust patterns. For example, the model predicts that most decisions are made without solving problems. However, when a structure as manifested by planning is imposed on the system, something different happens (Lai, 1998). In particular, order emerges from chaos in that the system seems tamed by the imposed structure so that problems and decision makers tend to be attached to certain fixed-choice opportunities through time. However, fewer problems are solved with planning than without planning, resulting in speedy decision making. In short, the garbage-can model focuses on the context where decisions emerge, rather than the relationship and sequence of these decisions, but it is useful in making sense of real and simulated dynamic decision processes (eg see Fioretti and Lomi, 2008a; 2008b; Kingdon, 2003) and provides a conceptual basis for the planning tool reported in this paper, as will be shown in section 3.

The strategic choice approach, on the other hand, addresses the relationship between decisions and has evolved as a practical computerized means of tackling interrelated decisions under uncertainty (Friend, 1993). It can be conceived at best as a design approach to planning in that actions are predetermined through comparing combinations of interrelated decisions derived from the relationship between decisions, without worrying about the contingencies. The technique normally starts with a shaping mode in which a decision graph is constructed to represent the relationships between decision areas. A decision area in the strategic choice approach is similar to a choice opportunity in the garbage-can model in that both represent decision situations except that a decision area only expresses options under consideration, whereas a choice opportunity specifies the context in which a decision may or may not be made. Once a decision graph is constructed, the strategic choice approach enters into a designing mode by eliminating incompatible combinations of options across decision areas. The remaining combinations of options, or decision schemes, are subject to a multiattribute evaluation analysis in the comparing mode, in order to rank these decision schemes according to a set of prespecified criteria. Once the decision schemes are ranked, in the final stage of the strategic choice approach, the choosing mode, a tentative action plan is made taking into account uncertainties and robustness of the selected decisions in relation to the ensuing ones. The four-stage process may proceed in a nonlinear fashion so the decision maker can start from any one mode working to another, without following a specified order. In short, the strategic choice approach views the planning process as continuous and focuses on the relationship between decisions, rather than the context where decisions emerge, and the sequence in which these decisions are considered, but it provides the solid logic of a rational process for the planning tool we have developed, as will be shown in section 3.

The decision tree is a widely used tool for making rational decisions. It was developed using the sound theoretical basis of the subjective expected utility model; therefore, unlike the garbage-can model, it is normative in nature. A decision tree is composed of three components: decision nodes, chance nodes, and arcs connecting these nodes. Like a choice opportunity in the garbage-can model and a decision area in the strategic choice approach, a decision node is a decision situation that is under the control of the decision maker with possible alternatives emanating from that node to represent different possible paths in the tree. A chance node is something that cannot be controlled by the decision maker, with possible states emanating from that node to represent possible outcomes of an uncertain event. The arcs connecting these nodes represent the sequential logic of these events as a manifestation of causal links of the decision problem under consideration. The arcs emanating from a chance node are assigned subjective probabilities to indicate the likelihoods that the associated states would come about. Each path of a decision tree, that is, a sequence of decision and chance nodes, is associated with a utility at the right-hand end of the tree to indicate the preference for the outcome of that path. Once a decision tree is constructed, a computational process of folding back to calculate the expected utilities associated with the decision nodes is implemented in order to determine the best path in the tree that maximizes the overall expected utility. The selected path is, to some extent, a plan that leads the decision maker to make choices along the unfolding events (Hopkins, 2001). Much has been built on the notion of the decision tree since its conception, including multiattribute utility theory (Keeney and Raiffa, 1993) and influence diagrams (Oliver and Smith, 1990). In short, a decision tree focuses on the sequential logic of decisions, rather than on the context where decisions emerge and the relationship between these decisions, but it provides a sound theoretical basis for making rational decisions for the planning tool we have developed.

3 The conceptual framework

None of the three models reviewed can alone cope completely with a planning problem of intertwined decisions. The garbage-can model is regarded as a description of how decisions come about in a certain context; the strategic choice approach focuses on figuring out the relationship between decisions, ignoring the dynamic aspects of other interacting elements; and the decision tree emphasizes the causal sequences of decisions by assuming a single decision maker. In our view, in order to take advantage of the merits of all three models, the context, relationship, and sequence of decisions are all important aspects that an effective planning tool must cover. The planning tool, Decision Network, is aimed at addressing all these considerations for a planner faced with complex, interrelated decisions. Decision Network is composed of a network of decision nodes. Like a decision area in the strategic-choice approach, each node is an emergent decision situation containing a finite number of options (see figure 1). Like a choice opportunity in garbage-can model, each decision situation is associated with four inputs, that is, decision makers, problems, solutions, and places. Like an arc in a decision tree, an outcome emanating from the decision situation under consideration

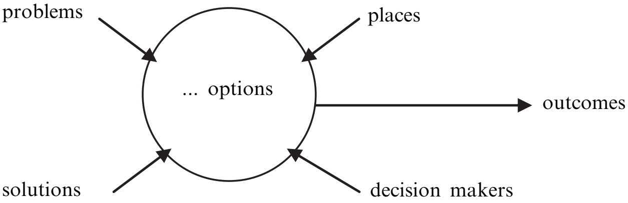

Figure 1. A decision situation.

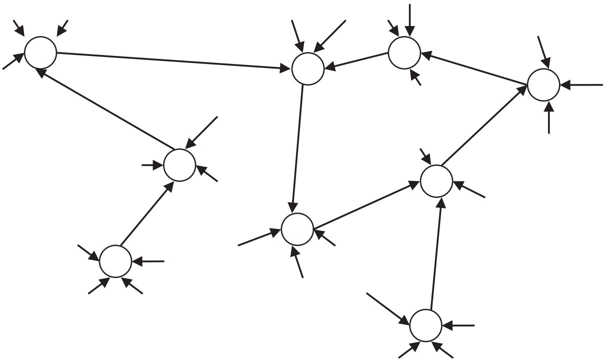

Figure 2. A decision network.

to another decision situation serves as one of the four inputs of the latter, thus forming a network (see figure 2). Each option within a decision situation is associated with a utility measurement. Each decision situation is also associated with a probability, meaning that it is emergent and that the decision situation may or may not be realized or encountered by the planner. Given the conceptual framework, the problem is then to find a path in the decision network that maximizes the subjective expected utility. The logic of this construct can be formalized mathematically and a hypothetical numerical example to demonstrate how the logic works is given in the next section.

4 A numerical example

In order to demonstrate how Decision Network works, we provide a hypothetical numerical example as an illustration. Consider a network of decisions of five decision situations, three problems, two decision makers, and four solutions or alternatives. A decision situation is an opportunity where decisions may or may not be made, reminiscent of the decision node in a decision tree or the decision area in the strategic-choice approach. The decision situation can be a formal meeting or forum or an informal gathering where problems, solutions, and decision maker(s) are brought together to discuss the issues under consideration. A meeting for deciding a zoning change or issuing a construction permit is a decision situation. A public hearing for approving urban development plans is another case in point. These decision situations can be either deterministic or stochastic in that some decisions situations can be planned and controlled ahead of time, while others are emergent depending on contingencies of the environment. We do not know when and where developers and land owners would meet to decide when and where to invest in land development, but we do know that some decision opportunities will come up where developers will discuss plans for land development with the local government. To clarify, we denote the deterministic decision situations as decision nodes and the stochastic decision situations as chance nodes. Assume that three of the five decision situations (1, 2, and 3) are deterministic decision nodes with a probability of one that they will definitely occur, while the remaining two (4 and 5) are stochastic chance nodes with various probabilities of occurrence. Assume further that the probabilities that the stochastic chance nodes of decision situations 4 and 5 will occur are 0.7 and 0.5, respectively. These probabilities are subjective rather than frequencist probabilities to indicate the decision maker's degree of belief in what would happen (Savage, 1972).

Problems incur negative utilities, or disutilities, in that they cause effects which are not desired by the decision maker. On the other hand, solutions are things the decision maker can act on and result in positive utilities, or simply utilities, in that they constitute the alternatives available to the decision maker to solve problems. Traffic congestion is a problem because it causes time delay when traveling in and between cities. Road construction is a solution to the traffic-congestion problem because it prevents the traffic flow from being congested. Decision makers bring expertise and resources to decision situations in solving problems, so their presence in decision situations incurs positive utilities. In deciding which route to construct, transportation planners make careful evaluation of alternative routes and choose the one to act on that is most effective in relieving the traffic-congestion problem. The variables and parameters of the decision-network problem are summarized in table 1.

Table 1. Variables and parameters of the hypothetical decision-network problem.

Terminology	Notation	Probability	Utility
Decision situations			
Decision node 1	d_1	1.0	not applicable
Decision node 2	d_2	1.0	not applicable
Decision node 3	d_3	1.0	not applicable
Chance node 4	d_4	0.7	not applicable
Chance node 5	d_5	0.5	not applicable
Problems			
Problem 1	p_1	not applicable	−0.6
Problem 2	p_2	not applicable	−0.5
Problem 3	p_3	not applicable	−0.7
Solutions			
Solution 1	s_1	not applicable	0.6
Solution 2	s_2	not applicable	0.3
Solution 3	s_3	not applicable	0.7
Solution 4	s_4	not applicable	0.5
Decision makers			
Decision maker 1	m_1	not applicable	0.7
Decision maker 2	m_2	not applicable	0.3

In addition to the variables and parameters as shown in table 1, there are three structures in which these variables are related to each other: access structure, decision structure, and solution structure. The access structure specifies which problem is associated with which decision situation. Some problems can only be attended to in certain decision situations. In the land-development context, for example, acquisition of land, at least in China, can only be brought about in decision situations in which the local government is involved. A matrix is used to identify this structure with rows as problems and decision situations as columns. A '1' in the matrix denotes that the problem in the corresponding row can be considered in the associated decision situation in the corresponding column, whereas a '0' denotes that it cannot. In our numerical example, the access structure is given below. Note that problem 1 can be attended to in either decision node 2 or chance node 5, but not both simultaneously.

Access structure

		Decision situation				
		1	2	3	4	5
Problems	1	0	1	0	0	1
	2	0	0	0	1	0
	3	0	0	1	0	0

Similarly, the decision structure specifies which decision maker has authority to participate in which decision situation. Some decision makers have greater authority in that they are eligible to participate in more decision situations than others, though in reality higher-level decision makers only have time for more important decisions. The higher profile officials in local government are eligible for participating in a wider range of forums, such as public hearings and household associations, than those of lower rank. The decision structure can be represented by a matrix similar to the access structure and for our numerical example this is given below. Note that decision maker 1 has more access to decision situations (three in total) than decision maker 2 who is associated with only two decision situations.

Decision structure

		Decision situation				
		1	2	3	4	5
Decision maker	1	0	1	1	0	1
	2	1	0	0	1	0

Unlike problems which can be present in only one decision situation, we further assume that a decision maker can participate in more than one decision situation because problems disappear once resolved, whereas decision makers persist over time.

Viewing the solutions as alternatives available in solving problems, the solution structure specifies which solution is available to which decision situation. Solutions are usually specialized and generated specifically for particular decision situations. For example, shelters constructed for the homeless cannot be used as schools. Therefore, similar to the access structure where problems are decision specific, solutions can be associated with more than one decision situation, but they can be used in only one decision situation. The solution structure for our numerical example is given below. Note that solution 1 is available to either decision node 2 or decision node 3, but not both at the same time. Note also that, for simplicity, we do not consider here the relationship between problems and solutions, assuming that all problems can be solved by any solution.

Solution structure

		Decision situation				
		1	2	3	4	5
Solutions	1	0	1	1	0	0
	2	1	0	0	0	0
	3	0	0	0	1	0
	4	0	0	1	0	1

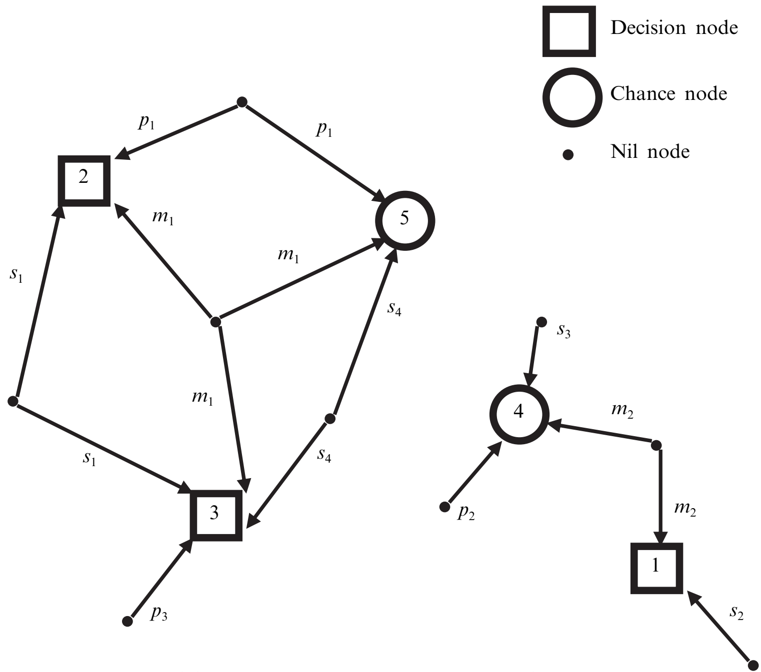

Figure 3. The decision network of G_0 for the numerical example.

Given the variables and parameters in table 1 and the access, decision, and solution structures depicted, the decision maker is faced with a planning problem of multiple, linked decisions in determining which problems and solutions should be associated with which decision situations in order to maximize the overall expected utility. This problem can be represented by a decision network denoted as G_0 as shown in figure 3.

The directed graph in figure 3 is composed of nodes that specify decisions and arcs that connect these nodes. There are three types of nodes: decision nodes, chance nodes, and nil nodes. Decision nodes (squares) are deterministic decision situations with probabilities of occurrence equal to one; chance nodes (circles) are stochastic decision situations with probabilities of occurrence greater than zero and less than one; and nil nodes (dots) are auxiliary ones for analytic purposes. The arcs emanating from the nil nodes represent the associative relationship in the matrices of the structures. For example, in figure 3, there are two arcs labeled as p_1 emanating from a nil node to decision node 2 and chance node 5, respectively, which means that in the access structure problem 1 has two 1's associated with decision node 2 and chance node 5, respectively. Note that the graph is not completely connected in that decision node 4 and chance node 1 form an independent cluster. Note also that although the decision situations are not directly connected with each other, they are interdependent indirectly through the connection of problems, solutions, and decision makers.

Because problems and solutions can only be connected to one decision or chance node, to solve the network problem is to seek a combination of how p_1, s_1, and s_4 are connected to respective single decision or chance nodes. Since the number of such possible connections for each of p_1, s_1, or s_4 is two, there are totally $2 \times 2 \times 2 = 8$ combinations of such connections. Let $u(d_i)$ denote the expected utility by summing up all utilities that are associated with the elements connected to decision situation i; $p(d_j)$ the probability that decision situation j would occur; $u(s_k)$, $u(p_l)$, and $u(m_m)$ the utilities associated with solution k, problem l, and decision maker m; and $u(G_n)$

the overall utility for graph n by summing their expected utilities across all the decision and chance nodes. We can compute the respective overall utilities for the graphs derived from the eight combinations of the p_1, s_1, and s_4 connections as follows. Since $u(d_1)$ and $u(d_4)$ remain fixed across these eight graphs, we can first calculate them as:

$$u(d_1) = p(d_1)[u(s_2)+u(m_2)] = 1.0(0.3+0.3) = 0.6\,,$$

$$u(d_4) = p(d_4)[u(p_2)+u(s_3)+u(m_2)] = 0.7(-0.5+0.7+0.3) = 0.35\,.$$

The calculation for the overall utility of each graph proceeds as follows: for G_1, p_1 is connected to d_5, s_1 is connected to d_2, and s_4 is connected to d_5.

$$u(d_2) = p(d_2)[u(s_1)+u(m_1)] = 1.0(0.6+0.7) = 1.3\,,$$

$$u(d_3) = p(d_3)[u(p_3)+u(m_1)] = 1.0(-0.7+0.7) = 0.0\,,$$

$$u(d_5) = p(d_5)[u(p_1)+u(s_4)+u(m_1)] = 0.5(-0.6+0.5+0.7) = 0.3\,,$$

$$u(G_1) = 0.6+0.35+1.3+0.0+0.3 = 2.55\,.$$

Similarly, for G_2, p_1 is connected to d_2, s_1 is connected to d_2, and s_4 is connected to d_5. A close examination will find that

$$u(G_2) = 0.6+0.35+0.7+0.0+0.6 = 2.25\,.$$

For G_3, where p_1 is connected to d_5, s_1 to d_3, and s_4 to d_5,

$$u(G_3) = 0.6+0.35+0.7+0.6+0.3 = 2.55\,.$$

For G_4, where p_1 is connected to d_2, s_1 to d_3, and s_4 to d_5,

$$u(G_3) = 0.6+0.35+0.1+0.6+0.6 = 2.25\,.$$

For G_5, where p_1 is connected to d_5, s_1 to d_2, and s_4 to d_3,

$$u(G_5) = 0.6+0.35+1.3+0.5+0.05 = 2.80\,.$$

For G_6, where p_1 is connected to d_2, s_1 to d_3, and s_4 to d_3,

$$u(G_6) = 0.6+0.35+0.1+1.1+0.35 = 2.50\,.$$

For G_7, where p_1 is connected to d_2, s_1 to d_2, and s_4 to d_3,

$$u(G_7) = 0.6+0.35+0.7+0.5+0.35 = 2.50\,.$$

Finally, for G_8, where p_1 is connected to d_5, s_1 to d_3, and s_4 to d_3,

$$u(G_8) = 0.6+0.35+0.7+1.1+0.05 = 2.80\,.$$

Apparently, G_5 and G_8 yield the highest overall utility of 2.80, and are thus the solutions to the decision network problem. More specifically, problem 1 should be considered in chance node 5, solution 4 in decision node 3, and solution 1 in either decision node 2 or decision node 3. Note that there are four pairs of overall utilities in the eight graphs because with the connections for p_1 and s_4 as given, the connection choice to a deterministic decision node for s_1 does not affect the overall utility due to linearity of the decision rule. Figures 4 and 5 show the graphs of decision networks for G_5 and G_8, respectively.

5 Spatial application and possible extensions

The comprehensive planning approach to managing growth as manifested by limiting cities to compact forms is being widely applied. Urban growth boundaries (UGBs) are probably the best known approach in the US. In contrast, urban construction

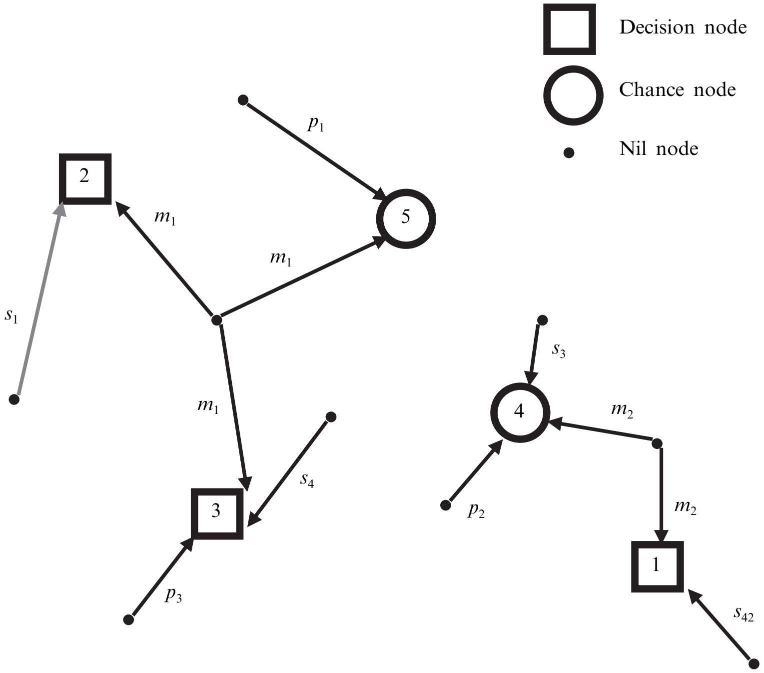

Figure 4. The decision network of G_5 for the numerical example.

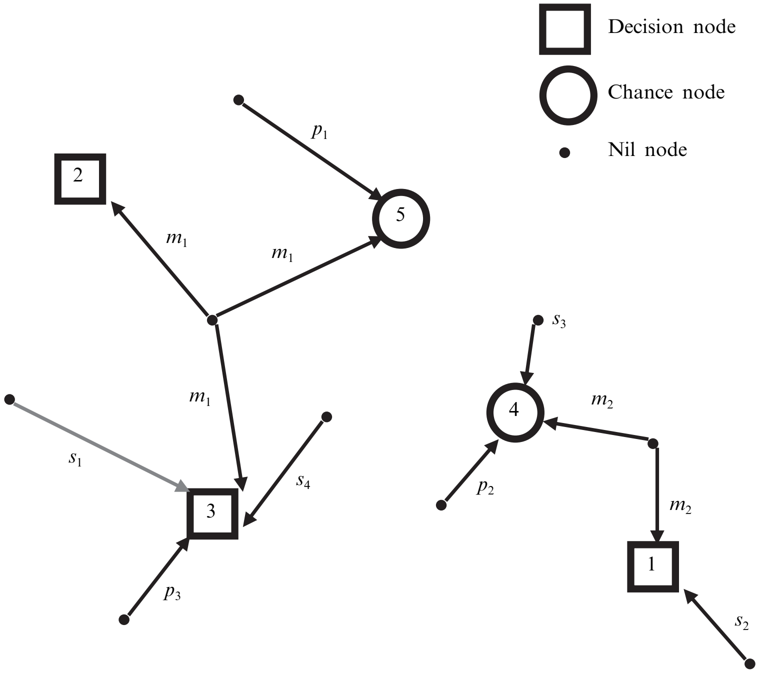

Figure 5. The decision network of G_8 for the numerical example.

boundaries (UCBs) in China have an implementing mechanism similar to the UGBs and have been implemented as legal boundaries for managing urban growth. However, the effectiveness of UCBs in containing urban growth in China has been criticized (Han et al, 2009) partly because UCBs, once derived from city master plans (CMPs), are not capable of controlling land development through the existing planning system. We do not intend to delve into the issues of UCBs here, but in order to illustrate spatially and realistically how Decision Network works as depicted in the previous section, we consider the making of the UCBs expansion decisions in a hypothetical scenario as shown in figure 6 and table 2. Figure 6 shows the urban development patterns before and after the setting of the UCB for a hypothetical city. It is assumed that, because of the UCB's ineffective control of land-development behavior, newly developed areas could fall inside (A1) and outside (A2) the UCB, with some vacant land left unused (A3). Table 2 depicts the elements of the decision-network problem and the corresponding variables and parameters with descriptions of the implications and situations of the decision and chance nodes. For example, decision node 1 is the decision situation where routine meetings are held with the mayor and participating planners to determine whether to issue a development permit to a developer for a site within the UCB, under the conditions that the area of land developed outside the UCB is greater than that inside and that the area of vacant land left undeveloped is greater than or equal to the area of land developed outside the UCB. The three chance nodes are simply the decision situations in relation to the revision of the UCB based on different possible futures of the urban-development pattern. Three distinct problems include overdevelopment in the rural area, lack of land for large investment within the UCB, and infrastructure expansion outside the UCB. Three levels of solutions are considered: status quo, moderate revision of the UCB, and significant revision of the UCB. Decision makers include the mayor, developers, and planners, each of whom is associated with a distinct utility. Note that a utility could be defined in relation to property rights (Barzel, 1997) and that the relationship between the elements requires the model to specify the structural constraints as depicted earlier, that is, access, decision, and solution structures. Once these structures are specified, the remaining task is to compute the optimal connection of these elements in order to find the best actions as depicted in the numerical example.

The decision-network tool presented in the present paper is still in its initial stage, but the conceptual framework and the numerical example depicted here illustrate

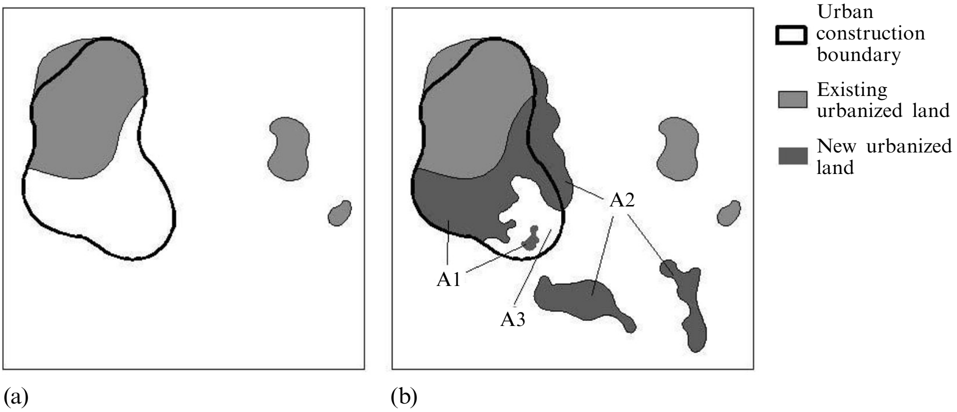

Figure 6. A hypothetical example of delineating an urban construction boundary. (a) Beginning of the planning period; (b) end of the planning period.

Table 2. The variables and parameters for the hypothetical example of delineating an urban construction boundary (UCB).

Terminology	Notation	Probability	Utility	Actual conditions	Implication	Situation
Decision situations						
Decision node 1	d_1	1.0	na	$A2 < A1$ and $A2 \leqslant A3$	Currently slow growth outside the UCB and the UCB is large enough	Routine meeting for better control
Chance node 1	d_2	0.5	na	$A3 < A2 < A1$	Relatively fast growth outside the UCB and the UCB is too small	Meeting about whether the UCB should be expanded
Chance node 2	d_3	0.25	na	$A1 \leqslant A2 \leqslant A3$	Ineffective implementation, but the UCB is large enough	Meeting on how to control urban growth outside the UCB
Chance node 3	d_4	0.25	na	$A1 \leqslant A2$ and $A3 < A2$	Ineffective implementation and insufficient size of the UCB	Meeting about whether the UCB should be revised comprehensively
Problems						
Problem 1	p_1	na	−0.6	Overexpansion of rural settlements		
Problem 2	p_2	na	−0.5	Need for large private projects for large area of land which cannot be found within the UCB		
Problem 3	p_3	na	−0.7	Inevitable occupation of land outside the UCB by large public infrastructures such as roads and airports		
Solutions						
Solution 1	s_1	na	0.3	Status quo		
Solution 2	s_2	na	0.5	Small revision of the UCB without comprehensive change in the CMP[a]		
Solution 3	s_3	na	0.7	Reestablish the UCB by comprehensively revising the CMP[a]		
Decision makers						
Decision maker 1	m_1	na	0.7	Urban planners		
Decision maker 2	m_2	na	0.3	Developers		
Decision maker 3	m_3	na	0.4	Mayor		

Note: na—not applicable.

[a] CMP = city master plan.

in effect how the tool works. In order for Decision Network to solve the real-world problems, more complicated network structures could be added to the simple version. For example, an outcome structure could be created that relates one decision situation to another so that the decision outcome from the former can serve as an input element, such as a problem or a solution, for the latter. In this way, decision situations are directly connected. In addition, a spatial structure that relates decision situations to places can be considered so that the tool can be applied to solve spatial planning problems. Furthermore, the relationship between problems and solutions can be specified in the solution structure so that solutions are problem specific.

The numerical example shows the detailed, but cumbersome, steps to search for the optimal solution to the decision-network problem algebraically. A more efficient solution algorithm can be found by formulating the problem in a more rigorous, general way [eg Kirkwood's (1993) approach to the sequential decisions of influence diagram]. Once the decision-network problem is formalized and efficiently solved, it can be implemented through computer programming languages serving as a decision-support system, or even better, if coupled with geographic information systems, serving as a planning-support system.

In the current formulation, uncertainties are narrowly assumed to be captured by subjective probabilities to indicate the decision maker's degree of belief in the occurrence of decision situations. This notion of uncertainties is derived directly from subjective expected utility theory (Savage, 1972). A broader interpretation of contingencies would include different types of uncertainty, including uncertainties about the environment, values, and related decisions (Friend and Hickling, 2005). Hopkins (2001) argues that there is also uncertainty about available alternatives when making plans. These contingencies could be captured by decision weights in place of probabilities. For example, Kahneman and Tversky (1979) propose a weighting function that transforms probabilities into decision weights to capture the decision maker's attitude in relation to the impact of events on the desirability of prospects, not merely the perceived likelihood of these events. Krantz and Kunreuther (2007) suggest a plan – goal approach in contrast to the traditional strategy – event approach to decision making under uncertainty and also interpret probabilities in the strategy – event approach as decision weights. These different interpretations of contingencies could be incorporated into the current formulation of Decision Network to enrich the content of the tool and enhance its usefulness.

In short, Decision Network can provide advice not only on which actions to take now in the light of other related decision situations, but also the scope of the plan if we take into account decision cost. Robustness can be analyzed in a similar way to the strategic choice approach so that the action taken now can remain optimal within several possible futures. One of the limitations of Decision Network in the current formulation is that the model is static. In a world full of uncertainties, a dynamic model may represent more realistically how the world works. In principle there may be three possible ways to address the dynamics of the world. Firstly, following the strategic choice approach, the formulation of the decision-network model could be revised when new information arises to incorporate the flow of and the relationship between decision makers, problems, and solutions. For example, some problems drop out of the decision-network formulation after they have been solved, whereas some higher level decision makers remain in the picture even after decision situations have changed. Secondly, computerized simulations could be constructed to complement the decision-network formulation in order to emulate the dynamic characteristics of the complex decision processes in the real world (eg Lai, 1998; 2003; 2006). Thirdly, the current formulation of Decision Network presented here can readily be transformed into a linear programming problem with the maximization of the overall expected utility as the objective function. Dynamic-programming techniques could be used to extend the current linear-programming formulation in order to address a sequence of decision-network formulations that cope with the changing conditions over time (eg, Cooper and Cooper, 1981). None of these three ways of addressing the dynamic world is easy, but they serve as a starting point for Decision Network to attain more realism. Note in particular that linear programming cannot be used directly as a model for urban development (Hopkins, 1979); rather it should be considered as a metaphor for the logic of design, or plan for that matter, in the face of complexity (Simon, 1996).

6 Conclusions

Planners of urban development and decision makers in complex environments are faced with multiple, linked decisions at the same time. Making single, independent decisions as commonly perceived in decision analysis is insufficient for dealing with the complexity. Decision Network is aimed at providing a planning tool for making multiple, linked decisions. The potential applications of Decision Network are not limited to urban planning. It can be a useful planning tool if the decision maker is faced with making more than one decision. Therefore, Decision Network is most effective in a complex environment in which decisions are interrelated. The potential clients who might use Decision Network to seek advice may include urban planners, city managers, policy analysts, and business managers. In addition, Decision Network can serve as the kernel for a larger planning-support system that addresses spatial problems by coupling them with geographic information systems. In this paper we have depicted a conceptual framework with a numerical example of an analytical tool for planning that takes into account the context, relationship, and sequence of decisions. Much can be built on this framework in further work.

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