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Reformulation and assessment of the inventory approach to urban growth boundaries

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ABSTRACT

Based on the theoretical framework, in this article we demonstrate how *Decision Network* can be used to formulate the inventory approach to urban growth boundaries (UGBs) as an application of the planning tool to a general case. In particular, in the inventory approach expansions of UGBs are considered as decision situations, land consumptions as problems, and order sizes of UGBs as solutions. We compare the time- and event-driven systems of the inventory control problem based on the decision network framework. The former in the framework is considered as making single, independent decisions in time, whereas the latter as making multiple, linked decisions in time. Our numerical example shows that the event-driven system is more effective than the time-driven system in that the former incurs less total cost than the former in the UGBs context. The implication is that making multiple, linked decisions, as manifested by *Decision Network*, would yield more benefits, such as lowering the total cost, to the planner than making these decisions independently.

Introduction

Urban planners are usually faced with making multiple, linked decisions, rather than single, independent ones. Traditional decision analytical tools for making single decisions are insufficient for planners to deal with complex urban problems. We have depicted the theoretical and conceptual framework of a planning tool, *Decision Network*, specific for planners to make multiple, linked decisions (Han and Lai, 2011). In the present paper, we will demonstrate how *Decision Network* can be used to analyze multiple, linked decisions in a planning context through a general story on expansion decisions of urban growth boundaries (UGBs). In the general story, drawing on two inventory approaches to urban growth boundaries, that is, time-driven and event-driven systems (Knaap and Hopkins, 2001), we will use *Decision Network* to demonstrate that while time-driven systems are commonly practiced, event-systems are more effective in terms of the overall cost of managing urban growth. More specifically, we argue that time-driven systems of urban growth boundaries are equivalent to making independent expansion decisions in time while event-driven systems making multiple, linked such decisions. We choose the story of urban growth boundaries as an application of *Decision Network* because UGBs involve multiple actors with complex processes, have significant effects on urban development, and are widely practiced. Though the literature on urban growth management through UGBs is large, many controversial issues still remain unresolved, including, among others, the timing and sizes of UGBs expansions. Since our purposes here are to demonstrate how *Decision Network* functions in such complex situations, we do not intend to deal in depth with policy implications of UGBs from the application. In "The conceptual framework" section, we introduce the conceptual framework of *Decision Network*. In "The inventory approach to UGBs: a general story" section, we reformulate and compare the time- and event-driven systems of the inventory approach to UGBs based on the decision network framework. In the "Discussion" section, we discuss some implications of the results from the comparison. In the "Conclusions" section we conclude.

The conceptual framework

Decision Network is composed of a network of decision nodes. Like a decision area in the strategic choice approach (Friend and Hickling, 2005), each node is a decision situation with a finite number of options in it (see Fig. 1). Like a choice opportunity in garbage can model (Cohen et al., 1972), each decision situation is associated with four inputs, that is, decision makers, problems, solutions,

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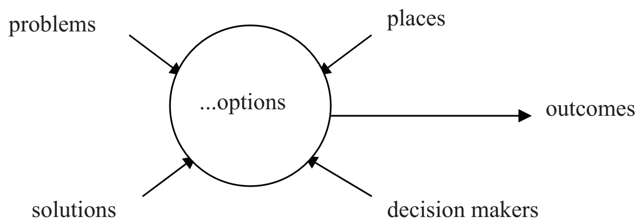

Fig. 1. A decision situation.

and places. Like an arc in decision tree (Kirkwood, 1997), an outcome emanating from the decision situation under consideration to another serves as one of the four inputs of the latter, thus forming a network (see Fig. 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 stochastic 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 as plan in the decision network that maximizes the subjective expected utility. The logic of this construct can be formalized mathematically and a hypothetical numerical example is given by Han and Lai (2011) to demonstrate how the logic works. The reader is encouraged to consult that work for how decision network functions in detail.

The inventory approach to UGBs: a general story

In arguing for the event-driven approach to UGBs in contrast to the time-driven approach, Knaap and Hopkins (2001) consider expansions of UGBs equivalent to an inventory control problem. In the time-driven approach, UGBs are usually adjusted and expanded at five-year intervals to supply sufficient land for consumption in a 20-year planning horizon, regardless of the growth rates of land for urban use. On the other hand, in the event-driven approach, the UGBs are expanded once the remaining stock of developable acres reaches a minimum threshold caused by land consumption to prevent the land market from price inflation and other negative effects on urban development, such as overbuilding and congestion. Time-driven systems are commonly practiced by local governments because they are easier to implement with less administrative cost, but susceptive of land price inflation due to monopoly pricing (Knaap and Hopkins, 2001). The event-driven systems are more flexible, on the one hand, in determining when to expand the UGBs to avoid the stock of developable acres dropping below a predetermined level, but they tend to be more costly because frequent monitoring is needed. With careful devices, such as lead-time inventory, safety-stock inventory, and market-factor inventory, Knaap and Hopkins (2001) formulate and argue for the

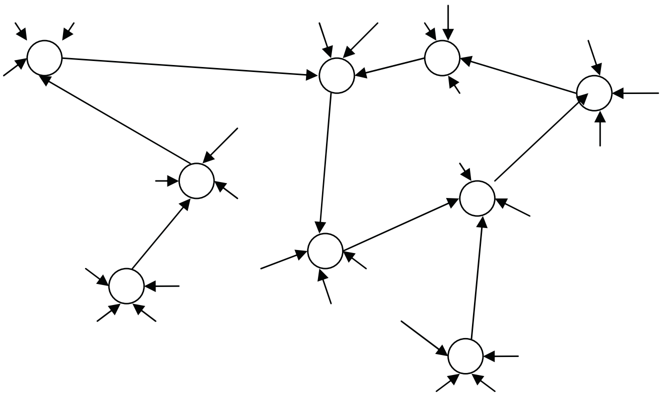

Fig. 2. A decision network.

inventory approach to UGBs of event-systems to be superior to that of time-systems as commonly practiced. The interested reader is encouraged to refer to their arguments there. In the present paper, we demonstrate that the inventory approach to UGBs of time- and event-driven systems can be reformulated as two decision networks: independent and linked respectively, and show through a numerical example, the inventory approach to UGBs based on event-driven systems is more effective than that based on time-driven systems.

Drawing on Knaap and Hopkins (2001) example, let t_0, t_1, t_2, t_3, and t_4 denote 2005, 2010, 2015, 2020, and 2025 respectively when UGB expansions are made in the time-driven system. Assume that the growth rates of urban development in five-year intervals are 2500, 1500, 2000, 1700, and 2000 acres per year, and denoted as r_0, r_1, r_2, r_3, and r_4 for the intervals from t_0 to t_1, t_1 to t_2, t_2 to t_3, t_3 to t_4, and t_4 to t_5 respectively. In order to compare the effectiveness of time- and event-driven systems, we focus here on the change in the stock of developable acres for the first 20 years, that is from 2005 to 2025. Effectiveness is determined by three factors: holding cost, order cost, and deficiency cost. Holding cost is incurred by keeping the stock of the total developable acres from being developed. For simplicity, it is assumed to be one dollar per acre and increases with the size of developable acres. Order cost is incurred by the UGB expansion decision when necessary. It is assumed to be one dollar per acre, setting aside the factor of economy of scale. Reduction of UGBs is further assumed to yield revenues at one dollar per acre. Deficiency cost occurs whenever the stock of developable acres is less than the predetermined threshold level and is assumed to be \$10 per acre because of the risk of overbuilding and price inflation in land market. Assume further that the initial designation of the UGBs includes 40,000 developable acres because the expected growth rate is 2000 acres per year in the beginning of the inventory cycle with 20 years of land consumption and the developable acres will be depleted after then. In addition, the predetermined threshold level is assumed to be 30,000 acres below which price inflation would soar.

Given these initial parameters, the inventory approach to UGBs can readily be translated into a decision network problem. For the time-driven system, UGBs expansions are made at t_0, t_1, t_2, t_3, t_4, and t_5, whereas those for the event-system are uncertain depending on when the amount of developable acres in the UGBs falls below the threshold level, that is 30,000 acres. Each expansion can be considered as a decision situation with land consumption as problems, land supply or UGBs expansions (or order size in terms of the inventory control problem) as solutions, and mayors, public officials, landowners, developers, and planners as decision makers. Though expansions of UGBs are apparently a complex process involving multiple actors and because our focus here is on formulating and comparing the time- and event-driven systems of the inventory cycle using *Decision Network*, we set aside here the complex process as a topic in “Discussion” section by treating contributions of decision makers as negligible compared to the problems of land consumption and the solutions of UGBs expansion. That is, to simplify we ignore the elements of decision makers in the following decision network frameworks.

Decision network formulation of the time-driven system

Fig. 3 depicts the decision network formulation of the inventory approach to UGBs based on the time-driven system. There are four decision situations of UGBs expansion occurring at different times of t_0, t_1, t_2, and t_3 and denoted as d_0, d_1, d_2, and d_3 respectively, all of which being deterministic with a probability of one. Decision maker i is denoted as dm_i, solution j as s_j, and problem k as p_k. Note that in this decision network, problems, solutions, and decision makers are connected to one and only one decision situation,

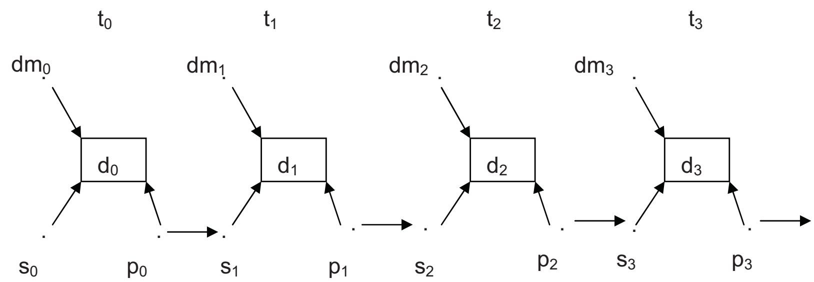

Fig. 3. Decision network formulation of time-driven inventory approach to UGBs.

so the network is unique to be the only solution to the inventory control problem. An arrow emanating from p_k to s_{k+1} shows that the size of UGBs expansion at t_{k+1} depends on the consumption rate at t_k. Note that the decision situations of UGBs expansion are independent in time in that the previous decision situations have no effect on the timing of the occurrences of the ensuing decision situations. In other words, when d_{i+1} would occur does not depend on d_i.

In order to compare the effectiveness of the time- and event-driven systems of the inventory approach to UGBs, we need to calculate the total cost of solving the inventory control problem. As depicted earlier, the total cost is composed of three factors: holding cost, order cost, and deficiency cost. The holding cost is equivalent to \$1 times the amount of the stock of developable acres across a particular interval. The order cost is equivalent to \$1 times the amount of the size of UGBs expansion in the beginning of a particular interval. The deficiency cost is equivalent to \$10 times the amount of the difference between the stock of developable acres under 30,000 acres and that threshold level during any period(s) in the 20-year time frame. In order to calculate these costs, we need to estimate the amounts of s_j (order size in the beginning of an interval), p_k (land consumption at the end of the interval), and m_l of the minimum inventory (remaining stock of developable acres at the end of the interval).

In the beginning of the inventory cycle at t_0, by assumption s_0 is equal to 40,000 acres with p_0 equal to an estimated amount of $5 \times 2000 = 10{,}000$ acres as the estimated total land consumed in five years. However, the realized land consumption is actually $5r_0 = 5 \times 2500 = 12{,}500$ acres. The minimum inventory, m_0, at the end of this interval is equal to $s_0 - 5r_0 = 40{,}000 - 12{,}500 = 27{,}500$ acres. After five years at t_1, s_1 is estimated based on the growth rate during the previous interval, that is 2500, projected into another five years in the future so that the ordered size of developable acres together with the minimum inventory at the end of the previous interval would suffice to cover the total amount of land consumption in the next 20 years. Therefore, s_1 is equal to $20r_0 - (s_0 - 5r_0) = 20 \times 2500 - (40{,}000 - 5 \times 2500) = 22{,}500$ acres, with the total amount of developable acres equal to 20×2500 or the order size plus the minimum inventory at t_1, that is, $22{,}500 + 27{,}500 = 50{,}000$ acres. Though the estimated amount of land consumption p_1 is $5r_0 = 5 \times 2500 = 12{,}500$ acres, the realized amount of land consumption is, however, $5r_1 = 5 \times 1500 = 7500$ acres, and the minimum inventory m_1 at the end of this interval of t_1 is $20r_0 - 5r_1 = 50{,}000 - 7500 = 42{,}500$ acres. Similarly, at t_2, $s_2 = 20r_1 - (s_1 + m_0 - 5r_1) = 20 \times 1500 - (22{,}500 + 27{,}500 - 5 \times 1500) = -12{,}500$ acres. Note that the order size is negative because the growth rate is relatively low in this interval causing the amount of developable acres included in UGBs decreases. The estimated (p_2) and realized amounts of land consumption are $5r_1 = 5 \times 1500 = 7500$ acres and $5r_2 = 5 \times 2000 = 10{,}000$ acres respectively. The minimum inventory m_2 at the end of this interval of t_3 is $20r_1 - 5r_2 = 20 \times 1500 - 5 \times 2000 = 20{,}000$ acres. At t_3, the beginning of the fourth interval, $s_3 = 20r_2 - (s_2 + m_1 - 5r_2) = 20 \times 2000 - (-12{,}500 + 42{,}500 - 5 \times 2000) = 20{,}000$ acres. A close examination will show that the estimated amount of land consumption p_3 is equal to 10,000 acres and the realized amount 8500 acres. The minimum inventory m_3 at t_4 is $40{,}000 - 8500 = 31{,}500$ acres.

In order to estimate the total cost of the time-driven system with the given parameters and necessary derivatives as depicted, we first calculate the holding cost for each of the four interval, that is, t_0 to t_1, t_1 to t_2, t_2 to t_3, and t_3 to t_4, denoted as hc_{01}, hc_{12}, hc_{23}, and hc_{34} respectively. The holding cost for each interval is equal to one dollar per acre times the cumulative amount of developable acres held in the UGBs during that period, which in turn is equal to the cumulative amount of developable acres minus the cumulative amount of land consumption for the five-year interval. For hc_{01}, since the amount of developable acres at t_0 is equal to 40,000 acres and the realized amount of land consumption at t_1 is 12,500 acres, the cumulative amount of land consumed is equal to the triangular area[1] with the base of 5 years and the height of 12,500 acres, which is equal to $12{,}500 \times 5 \times 0.5 = 31{,}250$ acres. Consequently, the cumulative amount of developable acres during the first five-year period is equal to $40{,}000 \times 5 - 31{,}250 = 168{,}750$ acres. Similarly, for hc_{12}, since the amount of developable acres at t_1 is equal to 50,000 acres and the realized amount of land consumption at t_2 is 7500 acres, the cumulative amount of developable acres during this time interval is equal to $50{,}000 \times 5 - 7500 \times 5 \times 0.5 = 231{,}250$ acres. Since the unit holding cost is one dollar per acre, hc_{12} is equal to \$231,250. A close examination will find that $hc_{23} = 1 \times (30{,}000 \times 5 - 10{,}000 \times 5 \times 0.5) = \$125{,}000$ and $hc_{34} = 1 \times (40{,}000 \times 5 - 8500 \times 5 \times 0.5) = \$178{,}750$.

There are four order costs, that is oc_0, oc_1, oc_2, and oc_3, at t_0, t_1, t_2, and t_3 respectively. Since the order cost is equal to the unit cost of one dollar per acre times the order size, it is equal to the order size in the beginning of a particular five-year time interval. In other words, $oc_i = 1 \times s_i$, for $i = 0, 1, 2$, and 3; we have $oc_0 = \$40{,}0000$, $oc_1 = \$22{,}500$, $oc_2 = -\$12{,}500$, and $oc_3 = \$20{,}000$. As for the deficiency cost, it can be shown that at t_2 or the year of 2015, the amount of developable acres drops to 30,000 acres and from that time the amount of developable acres is below the threshold level until the year of 2020 or t_3 when the UGBs are expanded. At t_2, the amount of developable acres is equal to $m_1 + s_2 = 42{,}500 - 12{,}500 = 30{,}000$ acres, the threshold level and the deficiency cost is exactly the same as the cumulative realized amount of land consumption which is equal to the triangular area with the height of 10,000 acres and the base of 5 years, or $5 \times 10{,}000 \times 0.5 = 25{,}000$ acres. Because the unit cost of deficiency is \$10 per acre, the deficiency cost is $10 \times 25{,}000 = \$250{,}000$. The

[1] The traditional graphic representation of the inventory control problem is framed by a vertical axis of the amount of developable acres and a horizontal axis of time or year, as presented by Knaap and Hopkins (2001). The dynamic fluctuations of the amount of developable acres over time can be shown easily in this graph and calculated using elementary geometry.

Table 1
A summary of the key values of the parameters in the time-driven system.

Time	t_0 (2005)	t_1 (2010)	t_2 (2015)	t_3 (2020)	t_4 (2025)
p_i					
Expected	10,000 acres	12,500 acres	7500 acres	10,000 acres	N.A.
Realized	12,500 acres	7500 acres	10,000 acres	8500 acres	N.A.
s_i	40,000 acres	22,500 acres	−12,500 acres	20,000 acres	N.A.
m_i	27,500 acres	42,500 acres	20,000 acres	31,500 acres	N.A.
hc_{ij}	$168,750	$231,250	$125,000	$178,750	
oc_i	$40,000	$22,500	−$12,500	$20,000	
dc_i	$0	$0	$250,000		

total cost for the time-driven system of inventory cycle for the first 20 years is the sum of the overall holding costs, order costs, and deficiency costs across the 20-year time frame, which is equal to ($168,750 + $231,250 + $125,000 + $178,750) + ($40,000 + $22,500 − $12,500 + $20,000) + $250,000 = $1,023,750. Table 1 summarizes the key steps for deriving p_i, s_i, m_i, hc_{ij}, oc_i, and dc_i.

Decision network formulation of the event-driven system

We now turn to the case of the event-driven system of the inventory approach to UGBs. Fig. 4 shows the decision network representation of the event-driven inventory control problem. Compared to the time-driven system in Fig. 3, the decision network for the event-driven system is exactly the same as that for the time-driven system except that an outcome arrow emanates from each decision situation to another in the inventory sequence, implying that the timing of the latter depends on that of the former. For example, the timing of the decision situation at t_{i+1} depends on the timing of the decision situation at t_i when the amount of developable acres included in the UGBs drops to the predetermined threshold level of 30,000 acres. Therefore, unlike the fixed timing of the decision situations in the time-driven system, which is the five-year interval, the timing of the decision situations in the event-driven system is uncertain and subject to the order size determined in the previous decision situation, the realized growth rate of land consumption during the five-year period, and the predetermined threshold level. One might argue that since the timing of the decision situations is uncertain in Fig. 4, the decision situations after t_0 should also be stochastic and represented as circles of chance nodes rather than squares of decision nodes. We would argue that in hindsight, these decision situations would not have occurred if the amounts of the developable acres would not drop to the threshold level, and therefore once included in the decision network, they are deterministic. Note that since the timing of the decision situations here, that is t_0, t_1, t_2, and t_3, is variable rather than fixed, these notations have different meanings from those in Fig. 3 Otherwise, the meanings of all other notations and symbols in Fig. 4 remain the same as those in Fig. 3.

In order to assess the effectiveness of the event-driven system, we first determine t_1. Since the stock of developable acres should not be below the threshold level, the realized amount of land consumption starting from t_0 should be more than or equal to 30,000 acres. That is, *delta* $t \times 2500 = 10{,}000$ acres, and we have *delta t* equal to four years, meaning that at 2009 the UGBs should be expanded. The order size s_1 at t_1 should cover the expected amount of land consumption over 20 years; therefore, s_1 is equal to $20r_0 - (s_0 - 4r_0) = 20 \times 2500 - (40{,}000 - 4 \times 2500) = 20{,}000$ acres. The expected (p_0) and realized amounts of land consumption are $4 \times 2000 = 8000$ acres and $4 \times 2500 = 10{,}000$ acres respectively. The minimum inventory at the end of the fourth year is 40,000 − 10,000 = 30,000 acres, the threshold level. At t_1, the stock of the developable acres is 30,000 + 20,000 = 50,000 acres, and at t_2 the amount of developable acres is expected to deplete again to 30,000 acres. Assume that the growth rates remain the same as those in the time-driven system and are estimated in five-year intervals. We have, between 2009 and 2010, the realized amount of land consumption is $1 \times 2500 = 2500$ acres; between 2010 and 2015, it is $5 \times 1500 = 7500$ acres; and between 2015 and 2020, it is $5 \times 2000 = 10{,}000$ acres. The three amounts of land depletion together result in the stock of developable acres dropping to 50,000 − 20,000 = 30,000 acres, the threshold level. Therefore, in the beginning of 2020, that is t_2, the UGBs must be expanded again to prevent the stock of developable acres from being below the threshold level. Similar to the calculation of s_1, s_2 is equal to $20r_2 - (s_1 + m_0 - 20{,}000) = 20 \times 2000 - (50{,}000 - 20{,}000) = 10{,}000$ acres. The expected (p_1) and realized amounts of land consumption during the 15 years are $11 \times 2500 = 27{,}500$ acres and 20,000 acres respectively. The minimum inventory m_1 at the end of 2019 or t_2 is 50,000 − 20,000 = 30,000 acres. In order to determine t_3, starting from t_2, we need to estimate the time when the amount of developable acres drops to the threshold level of 30,000 acres. Therefore, between 2020 and 2025, the realized amount of land consumption is $5 \times 1700 = 8500$ acres and between 2025 and 2030, it is $5 \times 2000 = 10{,}000$ acres. The total amount of land consumption during the 10 years is 18,500 acres, causing the stock of developable acres to drop to 40,000 − 18,500 = 21,500 acres, well below the threshold level. Therefore, t_3 must lie between 2025 and 2030. This implies that $5 \times 1700 + \textit{delta}\, t \times 2000 = 10{,}000$ and *delta t* is equal to 0.75 and t_3 is at the end of the third quarter of 2025. This means that at t_3, the UGBs must be expanded to prevent the amount of developable acres from dropping below the threshold level, and the order size s_3 is

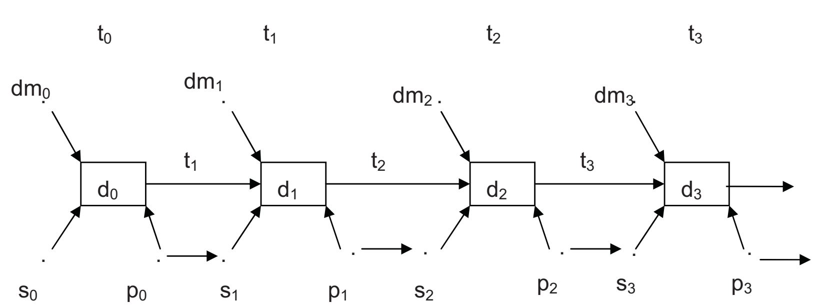

Fig. 4. Decision network formulation of event-driven inventory approach to UGBs.

Table 2
A summary of the key values of the parameters in the even-driven system.

Time	t_0 (2005)	t_1 (2009)	t_2 (2020)	t_3 (2025.75)
p_i				
Expected	8000 acres	27,500 acres	11,500 acres	N.A.
Realized	10,000 acres	20,000 acres	10,000 acres	N.A.
s_i	40,000 acres	20,000 acres	10,000 acres	N.A.
m_i	30,000 acres	30,000 acres	30,000 acres	30,000 acres
hc_{ij}	\$140,000	\$441,250	\$178,750 (till 2025)	
oc_i	\$40,000	\$20,000	\$10,000	
dc_i	\$0	\$0	\$0	

equal to $20r_4 - (s_2 + m_1 - 10{,}000) = 20 \times 2000 - (40{,}000 - 10{,}000) = 10{,}000$ acres. The expected (p_2) and realized amounts of land consumption from t_2 to t_3 are $5.75 \times 2000 = 11{,}500$ acres and $5 \times 1700 + 0.75 \times 2000 = 10{,}000$ acres respectively. However, the expected (p_3) and realized amounts of land consumption starting from t_3 are subject to the determination of t_4, but we can be sure that the realized amount of land consumption must be equal to $40{,}000 - 30{,}000 = 10{,}000$ acres at which the UGBs must be expanded again. The minimum inventory m_2 immediately before t_3 is again equal to the threshold level of 30,000 acres.

Given the calculation depicted above, we can assess the holding costs, order costs, and deficiency costs from which to derive the total cost of the event-driven system. For hc_{01}, the holding cost between t_0 and t_1, it is equal to the unit cost of one dollar per acre times the difference between the cumulative amount of order size and the cumulative amount of land consumption across the first four years, which is $1 \times (4 \times 40{,}000 - 4 \times 10{,}000 \times 0.5) = \$140{,}000$. For hc_{12}, the holding cost between t_1 and t_2, it is equal to the unit cost of one dollar per acre times the cumulative amount of developable acres across the next 11 years. Between 2009 (t_1) and 2010, there are $50{,}000 - 2500 = 47{,}500$ acres of developable land. For each of the next two five-year periods, the cumulative amount of developable acres is equal to the minimum inventory in the beginning of the five-year period times five years minus the triangular area of the cumulative amount of land consumed. Thus we have, between 2010 and 2015, there are $5 \times 47{,}500–5 \times 7500 \times 0.5 = 218{,}750$ acres and between 2015 and 2020, there are $5 \times 40{,}000 - 5 \times 10{,}000 \times 0.5 = 175{,}000$ acres. Therefore, the total amount of developable acres held between t_1 and t_2 is equal to $475{,}00 + 218{,}750 + 175{,}000 = 441{,}250$ acres and the holding cost for that period h_{12} is $1 \times 441{,}250 = \$441{,}250$. Since we only compare the total costs of the time- and event-driven systems across 20 years, starting from t_2, we only need to calculate the cumulate amount of developable acres held till 2025, which is $5 \times 40{,}000 - 5 \times 8{,}500 \times 0.5 = 178{,}750$ acres. Therefore, the holding cost between t_2 and 2025 is \$178,750. From 2005 (t_0) to 2025, there are three UGBs expansions at t_0, t_1, and t_2 with order sizes of 40,000 acres, 20,000 acres, and 10,000 acres respectively, and therefore the order costs for the three expansions are \$40,000, \$20,000, and \$10,000 respectively. Since all the amounts of developable acres are kept greater or equal to the threshold level of 30,000 acres, no deficiency cost is incurred in the event-driven system. The total cost for the event-driven system for the first twenty years is the sum of the overall holding costs, order costs, and deficiency costs, which is equal to $(\$140{,}000 + \$441{,}250 + \$178{,}750) + (\$40{,}000 + \$20{,}000 + \$10{,}000) + \$0 = \$830{,}000$, which is less than the total cost of \$1,023,750 for the time-driven system. Table 2 summarizes the key steps for deriving p_i, s_i, m_i, hc_{ij}, oc_i, and dc_i.

Discussion

The main difference between the time- and event-driven systems of the inventory approach to UGBs is that the decision situations in the former are independent in time, whereas those in the latter are interdependent or linked. In general, considering linked or interdependent decisions yields more benefits than considering them independently, as shown in "The inventory approach to UGBs: a general story" section in that the time-driven system incurs a total cost of \$1,023,750, whereas the event-driven system incurs a total cost of \$830,000. Hopkins (2001) provides a numerical example of a land development case showing that in a decision tree, considering infrastructure and housing decisions at the same time yields more net benefits than considering them independently. He argues that in essence making plans is equivalent to making multiple, linked decisions in space and time, which is consistent with the effect of the event-driven system compared to the time-driven system as presented here. In addition, the difference between the total costs of the two systems, \$1,023,750 − \$830,000 = \$193,750, can be viewed as the value of making plans of multiple, linked decisions compared to making no plans of independent decisions.

One might argue that the result favoring the event-driven system over the time-driven system is subject to the hypothetical values of the parameters, in particular the unit values of the holding cost, order cost, and deficiency cost. A simple sensitivity analysis will show that when the unit deficiency cost drops to \$2.25 per acre or the unit holding cost rises up to \$4.44 per acre, other cost being held constant, the two systems are equivalently effective in terms of the total cost. Compared to the unit holding cost or order cost of \$1, this deficiency cost of \$2.25 is unreasonably low because the cost of price inflation, overbuilding, and other urban ills caused by inadequate provision of developable acres included in the UGBs should be much higher than the administrative cost of managing the UGBs. The same logic applies to the rise of the unit holding cost up to \$4.44, compared to the deficiency cost of \$10 per acre. Note that holding costs include the opportunity costs of capital, which may be negative under conditions of rapid land value appreciation which may be intertwined with deficiency costs of housing inflation. In addition, these costs are set in relative terms, so the comparative result should have some realistic connotations even with adjustments of these figures, such as considering the factor of economy of scale in the order costs. Regardless, a more formalized, rather than algebraic, assessment through modeling would yield a more conclusive result.

We demonstrate in the present paper how *Decision Network* can be used to deal with the whole inventory cycle of managing UGBs. In more specific cases, it can also be used at the time when expansion decisions are made. For example, the process is complex of making expansion decisions of urban construction boundaries (UCBs) in Beijing (Han et al., 2009), which are equivalent to UGBs in the U.S. *Decision Network* could be used to make clear the complex situations faced by planners and help them to make multiple, linked decisions on the expansions of the UCBs. Decision makers could be the mayor, planners, landowners, and developers; problems could be the overbuilding in rural areas as well as land consumptions of large, private projects and public infrastructure constructions outside the UCBs; solutions could be the status quo, small scale expansions and large scale revisions of the UCBs; and decision situations could be formal and informal meetings of these decision makers triggered by routine or unexpected events, such as changing growth rates of land development inside or outside the UCBs, failures in managing the UCBs, deteriorating urban conditions, and land and housing price inflation. Given appropriate utility measurements of gains and losses in these interacting elements, *Decision Network* can help the planners to make clear when, where, by how much, and by whom to make expansion decisions on the UCBs.

The decision network formulation of the time- and event-driven systems of the inventory approach to UGBs is to make sequential decisions in time, but decision network is most powerful when problems, solutions, decision makers, and decision situations are linked as a network of which the sequential formulation as depicted here is a special case. We argue that most decision processes in planning situations are complex that involve multiple actors interacting with multiple problems, solutions, and decision situations. Though decision makers are abstracted from the current formation, they can be included in the model as depicted by Han and Lai (2011). More specifically, decision makers incur positive utilities in decision situations, in addition to solutions. A decision is made when the net amount of utilities in a decision situation is positive. The numerical example presented here demonstrates that, unlike other network approaches to solving specific operations research problems, such as transportation, *Decision Network* provides a planning framework sufficiently general to formulate and solve a wide range of problems as a useful planning tool. In particular, building on the garbage can model in which decision situations, decision makers, problems, and solutions meet in a random fashion, the model presented here provides a normative way of looking at the garbage can model in that these elements are recombined through structured control in order to yield an optimal outcome. Computer simulations have been done in this line of thought (Lai, 1998, 2003), but we formulate here an algebraic model. More general formulations beg future work.

Conclusions

We have shown how *Decision Network* can be applied to solving the inventory control problem by telling a general story of managing UGBs. In particular, the inventory approach to UGBs as proposed by Knaap and Hopkins (2001) is translated into a decision network formulation. The algebraic calculation shows that the event-driven system is more effective than the time-driven system by incurring a lower total cost. The implication is that the event-system as manifested by making multiple, linked decisions, the main objective of *Decision Network*, is more effective than the time-driven system of making these decisions independently. Many issues of managing UGBs remain unresolved, but our purpose here is to demonstrate that *Decision Network* provides a framework sufficiently general as a useful planning tool for a wide range of applications.

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