Use of Metaphors or Generic Systems for Formulating Models: Illustrations from Present and Distant Past

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Abstract

A metaphor, although describing a specific situation embodies basic principles and insights that are common to many diverse cases and situations. Such metaphors are widely used in every day language. They are also used in modeling methodologies and are sometimes referred to as canonical forms, archetypes, or generic systems. A few archetypes have been suggested as generic models of pervasive dynamical systems. These include capacity constrained growth, overshoot and decline, cyclical behavior, growth and cycles etc., but they are rather broad frameworks rather than being tied to metaphorical situations. On the other hand, some large models, such as limits to growth, urban dynamic, and industrial dynamics by Forrester also represent pervasive generic structures that have wide applicability, although it is difficult to conceive their alternative uses. Metaphorical structures lie in-between those two levels of abstraction. They succinctly describe a specific situation that can be applied to other contexts, yet they contain simple structures that can be easily understood. This paper briefly surveys the use of generic structures in system dynamics and develops two simple metaphorical models that have wide applicability in public policy.

Keywords: system dynamics, generic systems, public policy

1. Introduction

Metaphors in every day use are mnemonic phrases that refer to episodes relevant to a variety of situations. In the modeling contexts, they describe idealized representation with wide application. Within the field of operations research, resource allocation problems are often formalized as mathematical models, which are seen as “idealized representations” of reality (Hillier and Lieberman 1972). Some well-known metaphorical models are: the diet problem, the shortest route problem (also known as the traveling salesman problem), the transportation problem, and the assignment problem (Hillier and Lieberman 1972). The metaphorical models serve as prototypes for further extensions suitable for particular
situations. For example, the “transportation problem” can be adapted to cases outside of the field of transportation, such as production (see Hillier and Lieberman 1972: 172), or, with some additions, it can become the transshipment problem (see Hillier and Lieberman 1972: 194).

Metaphorical models are also found in other threads of modeling. As Krugman (1993) points out, economic theory is based on metaphorical models. Indeed, perfect market, competition, monopoly, equilibrium growth, etc., are all highly stylized abstract concepts that are often adapted to more complex situations when applied to address particular problems. Generic structures are also used in system dynamics, although they are not often stated as metaphors. An exception is a model by Morecroft et al. (1995) that describes the behavior of two showers that share a water source. This model, which symbolizes competition for common resource, is used to explain difficulties experienced by a real-life international manufacturing firm.

In this paper, I briefly review the use of metaphorical model structures in system dynamics that shows that unlike operations research, where the metaphorical models focus on every day life episodes, a wide variety of models have been viewed as generic forms. I also present two metaphorical models called “the stray dogs system” and “the dynastic cycle system” to illustrate my concept of how generic systems should be defined in the system dynamics. The former model is based on an illusive urban problem in many current cities of Asia; the latter is based on documented experience in distant Chinese history. These two metaphors describe pervasive latent structures in a wide range of contexts pertaining to public policy.

2. The variety of generic structures in system dynamics

Forrester, who originated the system dynamics methodology, has often stated his belief that a small number of pervasive generic structures can describe the majority of real-life situations (Forrester 1980: 18). System dynamics scholars have identified a number of such generic structures, which are expressed as canonical situation models, abstracted microstructures, and counterintuitive system archetypes (Lane and Smart 1996). Saeed and Pavlov (2007) have attempted to map the various generic systems that have been used in system dynamics. Table 1 shows examples of the three types of generic structures they found in the literature.
Table 1: Examples of generic structures in system dynamics

<table>
<thead>
<tr>
<th>Canonical situation models</th>
<th>Abstracted microstructures</th>
<th>System archetypes (Senge 1990)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Product launch (Forrester 1968)</td>
<td>• A first order positive loop</td>
<td>• Limits to growth (also known as Limits to Success)</td>
</tr>
<tr>
<td>• Urban development (Forrester 1969)</td>
<td>• First-order negative loop</td>
<td>• Shifting the Burden</td>
</tr>
<tr>
<td>• Commodity production cycles (Meadows 1970)</td>
<td>• Overshoot and oscillation</td>
<td>• Eroding Goals</td>
</tr>
<tr>
<td>• Ambitious product development (Graham 1988)</td>
<td>• Pure exploding oscillation</td>
<td>• Escalation</td>
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<tr>
<td>• Economic growth under an authoritarian regime (Saeed 1994)</td>
<td>• Pure damped oscillation</td>
<td>• Success to the Successful</td>
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<td></td>
<td></td>
<td>• Tragedy of the Commons</td>
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<td></td>
<td></td>
<td>• Fixes that Fail (also known as Fixes that Backfire)</td>
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<td></td>
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<td>• Growth and Underinvestment</td>
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<td></td>
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<td>• Accidental Adversaries</td>
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<td></td>
<td></td>
<td>• Attractiveness Principle</td>
</tr>
</tbody>
</table>

Adapted from Saeed and Pavlov (2007)

Canonical models are representative computer models that incorporate explicit stock and flow structure. Forrester produced a series of early canonical models. The market growth model (Forrester 1968) described a generalized case of new product launch and distribution. The model of urban development (Forrester 1969) was offered as a basic methodology for social analysis. The “World Model” (Forrester 1971) was a general theory of the resource use on the planet. Additional examples include canonical models of production cycles (Meadows 1970), product development (Graham 1988), and economic growth under an authoritarian regime (Saeed 1994).

Microstructures are representative computer models that also incorporate the stock and flow structure, but are smaller than canonical models. Each microstructure explains some specific mode of behavior: exponential growth, overshoot and collapse, exploding oscillations, damped oscillations, etc. Abstracted microstructures are the building blocks of larger models including the canonical models (Lane and Smart, 1996). Richardson and Andersen (1980: 99-100) offered a catalogue of abstracted microstructures (they referred to them as elementary structures). Richmond (2004) referred to them as generic systems.
Eberlein and Hines (1996) offered a set of abstracted microstructures that they refer to as molecules.

System archetypes do not include stocks and flows. They are feedback maps representing mental models (Senge 1990). They can assist in understanding the behavior of complex systems and in devising solutions to problems that arise in such systems. An archetype can also facilitate the communication of simulation results, especially to a policy oriented non-technical audience (Lane 1998). To aid in the selection of an appropriate archetype for a given situation, the archetype family tree can be used (Senge et al. 1994). For example, the limits to growth archetype can be adapted to explain the Easter Island tragedy (Mahon 1997) and the spotty performance of early peer-to-peer music networks (Pavlov and Saeed 2004).

The canonical forms category in Table 1 contains models that are often too evolved to be flexibly applicable to a variety of situations. Those in the abstracted microstructure category are widely applicable across domains, but are too detached from any meaningful situation to be able serve as metaphors. Those in the archetype category are meaningful, but have been presented as feedback loops rather than formal models. Also, they refer to the specific behavioral characteristics rather than to generalizable situational analogies. I propose that we should develop generalizable metaphorical models drawing from situations in every day life as well as distant history that should serve as a starting point for modeling more specific issues. As an example, I present in the following section models of two metaphorical systems that I think are based on interesting situations that might exist in a variety of contexts.

3. Illustrations of metaphorical systems from present and distant past

Interesting metaphors can be found both in every day experience as well as history. They can bring otherwise mundane generic structures to life and can become starting points for modeling analogous situations. I will present here two generic systems, the first that I call the stray dogs system, addresses a latent source of sustenance for a pest population or an undesirable activity. The second that I call the dynastic cycle system addresses a short sighted but pressure-driven resource allocation process that may destine, individuals, households, firms, regions, nations and the global population to a low-welfare homeostasis.
The first system arose out of my observation of Bangkok city government’s efforts into alleviating the menace of stray animals in the streets of Bangkok. The second system arose out of my efforts over many years to understand the structure of the political economies of the developing countries and later the informal structure of the university systems I worked in. The metaphorical resource allocation structure that political economies and the latent man-made organizations that I call the dynastic cycle system is documented in detail in Saeed and Pavlov (2007). These generic systems are presented below:

3.1 The stray dogs system

The metaphorical form of the first generic structure was inspired by the newspaper stories about Bangkok city government’s effort to deal with the population of stray animals roaming the city. Bangkok, with its exotic sights, sounds and smells attracts millions of tourists every year from all over the world. An important part of Bangkok is its restaurants and food vendors that serve visitors with a variety of tastes and budgets. Unlike the Western ethic, not finishing every thing on your plate is considered polite and tasteful so you are not considered a glutton. The left food is often fed to the stray cats and dogs or just thrown away in a way that it remains accessible to the stray animals. In a city of over 14 million, huge quantities of left food are generated. No wonder, Bangkok also appears to be a stray dog’s paradise. Unfortunately, stray dogs spread litter and become infected with diseases that pose a threat to humans.

General Chamlong Srimoung, was elected governor of Bangkok in the late 1980s. Chamlong came to office through a landslide victory and enjoyed wide popularity among all cross sections of people due to his impeccable honesty and personal charisma. A devout Budhist, vegetarian, and a declared celibate, Chamlong led a very simple life. He dressed in a peasant’s clothes, lived in a bare one-room apartment and slept on floor even when he was the governor of Bangkok. Chamlong sincerely wanted to improve living conditions in Bangkok. Among other things, he also wanted to alleviate the menace of stray dogs. However, being a kind man, he was not in favor of euthanizing the stray dogs as has been practiced in many cities of the world. He wanted to find a humane solution to the problem. With help from the city’s philanthropists, Chamlong set up a dog asylum. Stray gods were caught and brought to this asylum, where they were castrated and treated for any ailments they had. A small number of these castrated dogs were adopted, but most were released back into the
streets. This measure was expected to bring down the breeding rate of the stray dogs and hence reduce their population, but experience shows this did not happen.

One factor that the gracious governor of Bangkok and his philanthropist friends did not consider was that the stray dog problem was not local to Bangkok, whereas the castration program was. Stray dogs roamed all over the Kingdom of Thailand and did not need a visa to walk into Bangkok. They were attracted to a place where they could feed well and Bangkok with the same amount of food and a lower dog population created by castration would be a favorite. Dogs also spend more time breeding and less time looking for food if there is plenty of food. Needless to add that well fed dogs live longer than the malnourished ones. So, any decreases in their population, whether from euthanasia or castrations would soon be mitigated. Figure 1 outlines a simple model of this system. Model equations are placed in Annex 1.

Stray dogs population is changed by births, deaths and migration, all of which are sustained by trashed food that creates a carrying capacity. Please note, however, that carrying capacity is not given by the stock of trashed food, but by the inflow into this stock. The long run carrying capacity would be zero no matter how big the stock of trash food is if there is no inflow into this stock.
Figure 1: The stray dogs system

Figure 2 shows the behavior of this model when its equilibrium is disturbed either by reducing normal fractional births through castration reducing aggregate life expectancy through euthanasia. Either way, the population returns to the original level, which is determined by the carrying capacity that is often not obvious. The only way the stray dogs population can be decreased is by decreasing trash food generation or by creating a disposal out flow from the trash food stock.
This metaphor is relevant to the problems calling for control of unwanted populations like pests or unwanted activities like illegal immigration, crime, panhandling, terrorism, etc., where the source of sustenance of the activity is obscure and the intuitive recourse is to fight the activity, which is often ineffective. Hence such problems appear to be policy resilient. The solution of such problems lies in identifying the flows that maintain the carrying capacity of the unwanted activity and finding ways to eliminate or mitigate those flows. Policies oblivious of such structures might not only be ineffective, they sometimes might also further enhance the flows that sustain an unwanted activity.

3.2 The dynastic cycle system

The dynastic cycle metaphor was inspired by my repeated encounter with resource misallocation problem in political economies and innovation organizations that led to the context specific models I have published over the past three decades. These include, resource allocation between economic and control resources in an authoritarian political system (Saeed 1990, 1986), resource allocation between administration and faculty in a university (Saeed 1996) and between professional and administrative portfolios in an innovation organization (Saeed 1998). Such resource allocation processes are also incorporated by others in describing feast and famine cycles in consulting industry and production and sales in firms.
(Andersen and Sturis 1988). Pavlov, Radzicki and Saeed (2005) adapted the generic system presented in Saeed (1990) to understand the rise and decline of super powers in the global political economy. I have also attempted to describe in Saeed (1996) and Saeed (1998) how the latent power structure in universities and innovation organizations might effect resource allocation to constrain innovation. All these examples from different domains point to the fact that the resource allocation process can be described by a common generic system, which I have named the dynastic cycle system.

Figure 3 shows the stock and flow structure of this generic system. Farmers, bandits and soldiers are part of one conservative system. While farmers and bandits can defect to the other category based on what offers better income opportunities, soldiers are hired from and fired into the farmer pool. Farmer revenue consists of the produce created by them less, taxes paid for maintaining the soldiers and the appropriations extracted by the bandits. Both tax collections and bandit appropriations depend on farmer income. Both decline when farmer income declines. The bandit category includes those extracting rent through bribes and levies as well as those engaged in forbidden production, like gambling, gun running, prostitution and narcotic drugs. Income from both sources is accrued only to the bandits. Tax collection, together with the threat level posed by the bandits determines how many soldiers should be maintained. Soldier are hired from the farmers pool and laid off also into it. The soldiers also create a degree of deterrence for farmers to defect into the bandits category while it encourages bandits to defect to the farmers category. The model structure is shown in Figure 3. Its equations are placed in Annex 2.
Figure 3: The dynastic cycle system
(source: Saeed and Pavlov 2007)
Since this model is more complex than the stray dogs model, I have created two performance measures “freedoms” and “economic legitimacy” as indices to describe model behavior.

Freedoms is a ratio of farmers to the sum of bandits and soldiers:

\[
\text{Freedoms} = \frac{\alpha \times \text{farmers}}{\text{soldiers} + \text{bandits}}
\]

Where, parameter \( \alpha \) is a normalization constant, which ensures that the value of the index is one in the steady state.

The economic legitimacy index compares the volume of economic activity by farmers to the scope of the economic activity of bandits:

\[
\text{Economic legitimacy} = \frac{\beta \times \text{produce of farmers}}{\text{bandit disposable income}}
\]

Again, normalization factor \( \beta \) ensures that the index is equal to one in the steady state. A phase plot of these two indices defines the economic and political health of a society or an organization. The lower left corner of the phase plot represents low economic welfare and low level of freedoms; the upper right corner of the plot represents higher economic welfare and higher level of freedoms. The transition from one homeostasis to another may exhibit better-before-worse or worse-before-better behavior when we simulate this model.

The model is initialized in equilibrium which is disturbed in two ways for simulation experiments: 1) by infusing a fixed number of additional members into the various population stocks; and 2) by changing the parameters representing the various productivities and scaling factors. While the first set of experiments is primarily aimed at understanding the internal dynamics of the resource allocation system, the second set provides insights into the key entry points for change. Both sets can, however, be interpreted in terms of the related policy interventions.

Figure 4 shows the phase plots resulting from infusing new members into the respective population stocks. Although, these disturbances are mainly aimed at understanding how the
system recovers from disequilibrium, they may correspond also to real events. For example, farmer infusion would correspond to population growth with fixed resources in a political economy or use of overtime in a company with fixed capitalization. Soldier infusion would imply expansion of government’s role in a political economy or an expansion of administration in an organization. Bandit infusion would imply an externally supported growth in insurgent activity, a growth of parasitic subeconomies (such as businesses receiving special concessions or privileges supported by public funds) in a political system, or recruitment of people to cook books, and exploit customers, employees or shareholders in a company.

Figure 4: Phase-plot showing behavior of the dynastic cycle system with infusion in the various populations (source: Saeed and Pavlov 2007)

Economic legitimacy index is plotted against the horizontal axis and the freedom index against the vertical axis. The system is in the initial equilibrium in point (1, 1). The end equilibrium for all cases is independent of the stock where the infusion was made and depends on the volume of the infusion. Each infusion, however, creates a unique path to the new equilibrium. We observe that the organization is worse off in the new equilibrium, since both freedoms and economic legitimacy are reduced.
An increase in any population beyond equilibrium, *ceteris paribus*, yields suboptimal conditions. Increase in control beyond an optimal level warranted by the resources – the case of soldier infusion – may create economic growth in the short run, but this growth cannot be sustained. Likewise, an expansion in legitimate production portfolio, i.e. farmer infusion, may increase general welfare in the short run, but the economy would return to a suboptimal equilibrium. Lastly, an increase in non-legitimate activity due to an influx of bandits may drastically reduce the welfare; but this will be a temporary condition and the system will partially recover by reaching a new suboptimal equilibrium. Thus another lesson to be learnt is that expansion beyond the state afforded by the system will always lead to a suboptimal condition, no matter what path of growth is adopted.

Figure 5 illustrates the sensitivity of the model to the following policy related parameters: productivity of farmers, land, typical loot per bandit, productivity of bandits, and cost per soldier. Productivity of farmers may be affected in several ways, such as, introduction of modern technology, improvement in plant varieties, and land reforms (Gillis *et al.* 1996). Factors outside of policy control, such as climate change and inclement weather, may also have an impact on agricultural output. Parameter land, which signifies the availability of some relatively fixed but important resource, may increase due to the discoveries of additional resources or their acquisition through colonization. Examples of such a resource are arable land and oil (Yergin 1992). Typical loot per bandit might rise due to weak and inadequate enforcement of property rights (Bandiera 2003). The productivity of bandits imitates yields in the non-legitimate production processes. It can increase through bandits’ collusion with the government or external assistance. The cost per soldier is the compensation and other privileges of the ruling personnel or capital costs of the control infrastructure. It also subsumes cost of equipment and infrastructure provided per soldier.
Each simulation in Figure 5 starts in equilibrium. Increasing produce either through improvements to the productivity of farmers or through acquisition of land will increase the size of the legitimate economy providing greater economic legitimacy. This is the reason why the graphs for experiments with parameters land and productivity of farmers start to the right of the original equilibrium point. Greater produce adds to the disposable income per farmer, which in turn increases loot per bandit and aggregate bandit appropriations. For a short period of time, this causes the economic legitimacy to retract some. Improved farmer income resulting from increase in legitimate production, however draws bandits into farming. A reduction in the number of bandits also decreases the need for the control instruments and some of the soldiers can be released into the farmer’s pool. Thus, the economy subsequently moves towards offering both greater freedoms and more economic legitimacy. The crowding of the farmers sector, however, reduces income in it making banditry attractive again. As farmers move back into banditry, more soldiers need to be hired, which takes away more of the production. The system comes to a new balance at a higher level of legitimacy and freedoms than the initial level. The new homeostasis depends, of course, on the degree of technological growth achieved or the volume of additional resources acquired.

The effects of an increase in productivity of bandits and typical loot per bandit almost coincide since both make banditry more attractive while also increasing the relative size of
the non-legitimate economy. When either of the parameters is increased, a corresponding sudden jump in disposable income of bandits lowers the economic legitimacy index, which sets the starting points for the respective graphs to the left of the initial equilibrium point in Figure 5. Subsequent defections into banditry require hiring of soldiers to maintain control, which further reduces farmer income because of the hike in taxation. As a result, economic legitimacy and freedoms are reduced, which explains why corresponding graphs move downwards. Crowding of the bandits sector and a reduction in bandit appropriations due to diminishing produce turn things around – moving the economy to a new equilibrium at a lower level of welfare in terms of freedoms and economic legitimacy.

An increase in the cost per soldier will move the system to a lower level of legitimacy and freedoms. Increased soldier cost reduces disposable income per farmer making banditry relatively more attractive than farming. As a result, some of the farmers are drawn to banditry. This requires hiring more soldiers to control the bandits, which further reduces farmer income. The society or the institution in question is worse off in the new equilibrium.

This metaphorical model can be applied to the resource allocation process in a variety of situations ranging from personal time management, latent structure of firms, markets, regions, and nations. For example, the dynastic cycle system can be identified in Saeed (1990) in a model of the tradeoff between allocating resources for economic and control uses. Economic uses improve the social welfare of the population. Unless the political structure of a country is able to protect civil rights, the analysis suggests that the need to increase control over the population will eventually require excessively high level of scarce resources. Concomitantly, the lack of economic resources will force the government to abandon its welfare agenda. Policy levers that are available to decision-makers in this context are productivity of economic resources, productivity of control and the statues and institutions for protection of civil rights. Productivity of economic resources affects production of social goods. Productivity of control determines the effectiveness of resources put into such institutions as the military and the police in stabilizing the political situation in the country. Civil rights is a political decision to allow democratic institutions in the country, which may alleviate the need for control and, hence, indirectly channel more resources to economic use.

The dynastic cycles framework can also be recognized in a model of a superpower dominated global economic systems presented in Pavlov, Radzicki and Saeed (2005). Their
model assumes that an economic and military superpower may allocate some limited resources, such as Congress-appropriated budget for a foreign mission, either to the productive economic activity that benefits the foreign population or to building up the stock of resources to control the possible foreign dissent. The resources are continuously redistributed between economic and control sectors based on the perceived need. Inadequate economic production and the inability of the population to express its frustration about the status quo may lead to insurgency. Greater levels of insurgency lead to greater levels of desired control, which triggers a redistribution of total resources in favor of control resources. Case-specific policy levers are effectiveness of economic assistance, effectiveness of the military and the development of international agreements and institutions for preserving political freedoms.

As pointed out in Saeed and Pavlov (2007), another example is from Bandiera (2003) who develops a framework, which can be interpreted as a dynastic cycle structure. The author explains the role of mafia in the 19th century Sicily at the time of land reforms. Before the reforms, large feudal landowners employed peasants to work on the land and maintained adequate armies of soldiers for protection. As the land was redistributed, the armies of the few large landlords were disbanded. In the presence of the weak state, predatory attacks on new landowners became a serious problem. Former soldiers, who turned into *mafiosi*, were recruited by new landowners to enforce property rights. Some bandits were also hired as guards. The author notes that thieves often came from the ranks of poor peasants. Even though Bandiera does not offer any policy experiments, several parameters in her model can be viewed as policy levers.

A similar structure can be identified in Saeed (1996), and Saeed (1998) addressing resource allocation process respectively in a university and in an innovation organization in general.

4. Conclusion

The two metaphorical models proposed in this paper outline the structure of the latent organizations that may support unwanted activity in case of the stray dogs system, and low welfare and instability in case of the dynastic cycle system. Any interventions into addressing
the symptoms created by the latent structures will be defeated by the internal tendencies of these systems. Understanding the latent structure underlying each system points to the root cause of the respective problems that must be addressed to create system improvement. Application of these metaphors to specific cases will call for rebuilding the models to subsume the situations of the specific cases being addressed, but having the metaphors available will facilitate the process of modeling.

Creating an inventory of metaphorical models can simplify the task of modeling specific situations as a small number of metaphors might be applicable to a large variety of situations. Although a variety of generic systems have been proposed in system dynamics, very few can be called metaphors since they often do not describe a story that can be used as an analogy for a variety of situations. Developing such metaphors is a new frontier for system dynamics methodology.
References


Annex 1

Equation for the stray dogs system

Bangkok_stray_dogs(t) = Bangkok_stray_dogs(t - dt) + (dog_births + imig - dog_deaths) * dt

INIT Bangkok_stray_dogs = 100

INFLOWS:
dog_births = Bangkok_stray_dogs*fr_births
imig = (potential_dog_pop-Bangkok_stray_dogs)/4

OUTFLOWS:
dog_deaths = Bangkok_stray_dogs/life_expectancy
trash_food(t) = trash_food(t - dt) + (trash_food_generation - trash_food_consumption_by_dogs - trash_disposal) * dt

INIT trash_food = 100

INFLOWS:

trash_food_generation = 100

OUTFLOWS:

trash_food_consumption_by_dogs = Bangkok_stray_dogs*per_dog_consumption
trash_disposal = trash_food*fraction__disposed
fraction__disposed = 0
fr_births = normal_fr_births*food_av_effect
life_expectancy = normal_life_exp*food_av_effect
normal_fr_births = .2
normal_life_exp = 5
per_dog_consumption = 1
potential_dog_pop = trash_food/per_dog_consumption
trash_food_availability = trash_food/Bangkok_stray_dogs
food_av_effect = GRAPH(trash_food_availability)
(0.00, 0.01), (0.2, 0.307), (0.4, 0.54), (0.6, 0.713), (0.8, 0.87), (1.00, 1.00), (1.20, 1.14), (1.40, 1.24), (1.60, 1.33), (1.80, 1.41), (2.00, 1.47)

Annex 2

Equations for the dynastic cycle system

bandits(t) = bandits(t - dt) + (bandit__recruitment_and_attrition + bandit_infusion) * dt
INIT bandits = 10

INFLOWS:

bandit__recruitment_and_attrition = 
  (farmers*.01/(farmer_relative__income*state__control))-
  (bandits*.1*(farmer_relative__income*state__control))

bandit_infusion = PULSE(bandit_additions,0,10000)

farmers(t) = farmers(t - dt) + (farmer__infusion - soldier_recruitment__and_attrition - 
  bandit__recruitment_and_attrition) * dt

INIT farmers = 100

INFLOWS:

farmer__infusion = PULSE(farmer_additions,0,10000)

OUTFLOWS:

soldier_recruitment__and_attrition = .01*farmers*(desired__number__of_soldiers/soldiers)-
  .1*soldiers/(desired__number__of_soldiers/soldiers)

bandit__recruitment_and_attrition = 
  (farmers*.01/(farmer_relative__income*state__control))-
  (bandits*.1*(farmer_relative__income*state__control))

perceived_disposable__income_per_bandit_bandit(t) = 
  perceived_disposable__income_per_bandit_bandit(t - dt) + 
  (chng_in__disposable_per_bandit) * dt

INIT perceived_disposable__income_per_bandit_bandit = 1

INFLOWS:

chng_in__disposable_per_bandit = (disposable_income__per_bandit-
  perceived_disposable__income_per_bandit_bandit)/2

perceived_disposable__income_per_farmer(t) = perceived_disposable__income_per_farmer(t - dt) + (chng_in_disposable__income_per_bandit) * dt

INIT perceived_disposable__income_per_farmer = 1

INFLOWS:

chng_in_disposable__income_per_bandit = (disposable_income__per_farmer-
  perceived_disposable__income_per_farmer)/2

soldiers(t) = soldiers(t - dt) + (soldier_recruitment__and_attrition + soldier_infusion) * dt

INIT soldiers = 10

INFLOWS:
soldier_recruitment_and_attrition = .01*farmers*(desired_number_of_soldiers/soldiers)-.1*soldiers/(desired_number_of_soldiers/soldiers)
soldier_infusion = PULSE(soldier_additions,0,10000)
bandit_additions = 0
bandit_appropriations = bandits*loot_per_bandit
bandit_disposable_income = bandit_appropriations+nonlegit_produce_by_bandits
cost_per_soldier = 1.5
desired_number_of_soldiers = (tax_collection/cost_per_soldier)*threat_to_society
disposable_income_per_bandit = bandit_disposable_income/bandits
disposable_income_per_farmer = farmer_disposable_income/farmers
economic_legitimacy = (produce_of_farmers/bandit_disposable_income)/(120/10)
economic_well_being_of_a_farmer = perceivedDisposable_income_per_farmer/normal_farmer_income
farmer_additions = 0
farmer_relative_income = perceivedDisposable_income_per_farmer/perceivedDisposable_income_per_bandit
farmer_disposable_income = produce_of_farmers-tax_collection-bandit_appropriations
farmer_productivity = 1.2
freedoms = (farmers/(soldiers+bandits))/(100/20)
labor_elasticity = 1-land_elasticity
land = 100
land_elasticity = .7
loot_per_bandit = typical_loot_per_bandit*economic_well_being_of_a_farmer
nonlegit_produce_by_bandits = bandits*productivity_of_bandits
normal_farmer_income = 1
produce_of_farmers = farmer_productivity*((farmers)^labor_elasticity)*((land)^land_elasticity)
productivity_of_bandits = .5
soldier_additions = 0
state_control = (soldiers/(bandits+farmers))/(10/(110))
tax_need = soldiers*cost_per_soldier
tax_collection = tax_need*economic_well_being_of_a_farmer
threat_to_society = (bandits/(farmers+soldiers)/(10/110))
typical_loot_per_bandit = .5
Dynamical Systems, Cellular Automata, Urban Models and SLEUTH: Anticipating the Future Urban System

Keith C. Clarke
Department of Geography
University of California, Santa Barbara
http://www.geog.ucsb.edu/~kclarke
Models of Dynamical Systems

• Have inputs and outputs
• Simplify and reduce
• Relate system to basic behavior of phenomenon (process, change)
• Recreate structures over time (form)
• Generate forecasts
• Propagate errors (Calibration, validation)
Modeling simple systems

\[
\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) =
\]

\[
\rho g_x - \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left[ 2 \mu \frac{\partial u}{\partial x} + \kappa \nabla \cdot \mathbf{v} \right] + \frac{\partial}{\partial y} \left[ \mu \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] + \frac{\partial}{\partial z} \left[ \mu \left( \frac{\partial u}{\partial z} + \frac{\partial v}{\partial y} \right) \right]
\]

\[
\rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) =
\]

\[
\rho g_y - \frac{\partial p}{\partial y} + \frac{\partial}{\partial y} \left[ 2 \mu \frac{\partial v}{\partial y} + \kappa \nabla \cdot \mathbf{v} \right] + \frac{\partial}{\partial z} \left[ \mu \left( \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right] + \frac{\partial}{\partial x} \left[ \mu \left( \frac{\partial v}{\partial x} + \frac{\partial w}{\partial y} \right) \right]
\]

\[
\rho \left( \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) =
\]

\[
\rho g_z - \frac{\partial p}{\partial z} + \frac{\partial}{\partial z} \left[ 2 \mu \frac{\partial w}{\partial z} + \kappa \nabla \cdot \mathbf{v} \right] + \frac{\partial}{\partial x} \left[ \mu \left( \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right] + \frac{\partial}{\partial y} \left[ \mu \left( \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z} \right) \right]
\]
Laminar vs. Turbulent flow
Stock Market Crashes
Properties of Complex Systems

- Sensitivity to initial conditions
- Self regulation
- Scaling
- Emergence
- Self-organized criticality
- Phase transition
- Edge of chaos (chaos-linear-non-linear[Complex])
- Threshold
- Resilience
Urban systems
A Review and Assessment of Land-Use Change Models
*Dynamics of Space, Time, and Human Choice*
(2000) C. Agarwal, G. L. Green, M. Grove, T. Evans, and C. Schweik

![Diagram showing space (Y), time (X), and human decision-making (Z).]

**Table 2.1 Resolution and Extent in the Three Dimensions of Space, Time and Human Decision Making**

<table>
<thead>
<tr>
<th>Resolution or equivalent</th>
<th>Space</th>
<th>Time</th>
<th>Human Decision Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution or equivalent</td>
<td>Resolution: smallest spatial unit of analysis</td>
<td>Time step: shortest temporal unit of analysis</td>
<td>Agent and decision-making time horizon</td>
</tr>
<tr>
<td>Extent or equivalent</td>
<td>Extent: total relevant geographical area</td>
<td>Duration: total relevant period of time</td>
<td>Jurisdictional domain and decision-making time horizon</td>
</tr>
</tbody>
</table>
Models in the Framework

Key

A- Time series statistical models, STELLA models with no human dimension
B- Time series models with human decision-making explicitly modeled
C- Most traditional GIS situations
D- GIS modeling with an explicit temporal component (e.g. Cellular Automata models)
E- Econometric (regression) and Game Theoretic models
F- RBSim, Swarm and SME: Spatial Modeling Environment

The ultimate goal of human-environment dynamic modeling: high in all three dimensions
Models surveyed

- 1. General Ecosystem Model (GEM) (Fitz et al. 1996)
- 2. Patuxent Landscape Model (PLM) (Voinov et al. 1999)
- 3. CLUE Model (Conversion of Land Use and Its Effects) (Veldkamp and Fresco 1996a)
- 4. CLUE-CR (Conversion of Land Use and Its Effects – Costa Rica) (Veldkamp and Fresco 1996b)
- 5. Area base model (Hardie et al. 1997)
- 6. Univariate spatial models (Mertens et al. 1997)
- 7. Econometric (multinomial logit) model (Chomitz et al. 1996)
- 8. Spatial dynamic model (Gilruth et al. 1995)
- 10. CUF (California Urban Futures) (Landis 1995, Landis et al. 1998)
- 11. LUCAS (Land Use Change Analysis System) (Berry et al. 1996)
- 12. Simple log weights (Wear et al. 1998)
- 13. Logit model (Wear et al. 1999)
- 14. Dynamic model (Swallow et al. 1997)
- 15. NELUP (Natural Environment Research Council [NERC]–Economic and Social Research Council [ESRC]: NERC/ESRC Land Use Programme [NELUP]) (O’Callahan 1995)
- 16. NELUP - Extension, (Oglethorpe et al. 1995)
- 17. FASOM (Forest and Agriculture Sector Optimization Model) (Adams et al. 1996)
- 18. CURBA (California Urban and Biodiversity Analysis Model) (Landis et al. 1998)
Cellular automata

- Framework for systems experiments
- Simplest way to demonstrate complex systems behavior
- Wolfram: Formal framework
  - {Cells, States, Initial conditions, Neighborhood, Rules, Time}
- Conway’s LIFE
The game of life

• Grid of square cells extending infinitely in every direction.
• A cell can be *live* or *dead*.
• Each cell in the grid has a neighborhood consisting of the eight cells in every direction including diagonals.
• To apply one step of the rules, we count the number of live neighbors for each cell.
  – A dead cell with exactly three live neighbors becomes a live cell (birth).
  – A live cell with two or three live neighbors stays alive (survival).
  – In all other cases, a cell dies or remains dead (overcrowding or loneliness).
Some examples
More examples
Emergence in CA

- Growth (many types)
- Decline and extinction
- Stable: Static and Dynamic
- Oscillators
- Gliders (Rabbits, etc)
- Glider gun
- Self replication sequences
Urban Cellular Automata

- Cells are pixels
- States are land uses
- Time is “units”, e.g. years
- Rules determine growth and change
- Different models have different rule sets
- Many models now developed, few tested
- Requiem for large scale models (Lee)
The Approach

- Use cellular automata
- Use real data for cities
- Use hindcasting
- “Train” the model to a specific city
- Use the model for simulation
- Do “what if” planning
Project Web Site

- Set of background materials, e.g. publications
- Documentation as web pages in HTML
- Source Code for model in C
- Version 3.0 plus patches on web for download
- Uses utilities and GD GIF libraries
- Parallel version requires MPI
- Set of sample calibration data demo_city
- Web-based discussion forum with FAQ
How does SLEUTH work?
Spontaneous Growth

- urban settlements may occur anywhere on a landscape

- \( f \) (diffusion coefficient, slope resistance)
Creation of new spreading centers

- Some new urban settlements will become centers of further growth.
- Others will remain isolated.

\[ f \text{ (spontaneous growth, breed coefficient, slope resistance)} \]
Organic Growth

- The most common type of development
- occurs at urban edges and as in-fill

- \( f \) (spread coefficient, slope resistance)
Road Influenced Growth

- Urbanization has a tendency to follow lines of transportation

- \( f \) (breed coefficient, road_gravity coefficient, slope resistance, diffusion coefficient)
Deltatron Land Cover Model

**Phase 1: Create change**

- **Select random pixel**
- **Create delta space**
- **Transition Probability Matrix**
  - YEL | ORN | GRN
  - YEL | 0.9 | 0.05 | 0.05
  - ORN | 0.05 | 0.9 | 0.05
  - GRN | 0.1 | 0.1 | 0.8
- **Change land cover**
- **Check the transition probability**
- **Of the two: Find the land class most similar to current slope**
- **Average slope**
  - YEL: 1.20%
  - ORN: 3.30%
  - GRN: 5.60%
- **For n new urban cells**
- **Select two land classes at random**
- **Change land cover**
- **Spread change**

**Average slope**

- YEL: 1.20%
- ORN: 3.30%
- GRN: 5.60%

**Transition Probability Matrix**

<table>
<thead>
<tr>
<th></th>
<th>YEL</th>
<th>ORN</th>
<th>GRN</th>
</tr>
</thead>
<tbody>
<tr>
<td>YEL</td>
<td>0.9</td>
<td>0.05</td>
<td>0.05</td>
</tr>
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<td>0.05</td>
<td>0.9</td>
<td>0.05</td>
</tr>
<tr>
<td>GRN</td>
<td>0.1</td>
<td>0.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Check the transition probability**

Deltatron Land Cover Model
Phase 2: Perpetuate change

- search for change in the neighborhood
- find associated land cover transitions

Transition Probability Matrix

<table>
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<tr>
<th></th>
<th>YEL</th>
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<th>GRN</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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</tr>
<tr>
<td>GRN</td>
<td>0.1</td>
<td>0.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- Age or kill deltatrons
- Create deltatrons
- Impose change in land cover
Behavior Rules

For \( i \) time periods (years)
Forecasting (the future from the present)

- Probability Images

- Alternate Scenarios (Exclusion, roads)

- Land Cover Uncertainty
Project Web Site: Shareware C code and Documentation

Gigalopolis is the growing urban structure containing billions of people worldwide. Urban settlements and their connectivity will be the dominant driver of global change during the twenty-first century. Urbanizing land, atmosphere, and hydrological resources, urban dynamics has now surpassed the regional scale of megacities and must now be considered as a continental and global scale phenomenon. Project Gigalopolis extends and refines the Charles urban growth model enabling predictions at regional, continental, and eventually, global scales.
Santa Barbara Study Area: UCIME (Integrated modeling)

- Coastal California, 90 miles from Los Angeles
- Intense physical constraints to new growth
- SLEUTH is one of a set of models being used to envision Santa Barbara’s urban future.
- A voluntary urban growth boundary is currently in place

$1,000,000$ question...
- How does the growth boundary affect urbanization?
Two review documents are on-line as PDFs.
The South Coast
Planning Tools: Coupling

- **GIS**
  - Access to regional and accurate data on the South Coast
  - Key role is integration, not data collection

- **SLEUTH Urban Growth Model**
  - Visualize changes to the South Coast footprint overtime

- **SCOPE model**
  - Examine relations among indicators that effect quality of life on the South Coast
  - Web enabled

- **UCIME Urban Change Integrated Modeling Environment**

- **Scenario composition and visualization**
Data for the models

- 1929
- 1943
- 1954
- 1967
- 1976
- 1986
- 1997

Air photo mosaics used for historical growth inputs
Santa Barbara Historic Growth
Historical growth of Santa Barbara
2040 Probabilities and Scenarios

Urban Growth Boundary Exclusion

Only Parks are Excluded
SCOPE focuses on the interrelationships among five sectors.
Stella version of SCOPE
SLEUTH and Scenarios

- Urban pattern in the future
- Transportation network
- Exclusion layer
- Change parameters “Cross-breeding”
- Can couple with other models
Part 2: Input Images
Tulare excluded. Wac. (Used for the Williamson Act Excluded Layer)
Scenario 1. Business As Usual (Current Administration)
Westernport Project: DPI Parkville
Conceptual Framework

Stakeholders

Define a problem

Evaluate Solutions

User Interface (Maps, Tables and Graphics)

Model Management System

Input

Output

Scenario Management Model

Terrestrial Component

Land Use change Model (SLEUTH)

Hydrological Model

Marine

Marine Models

Multi-criteria Model

(Spatial) Database Management System (GIS-based)

Land Use

Soil Attributes

Topography (Slope, Elevation, Orientation)

Vegetation (EVC – Native Plantation)

Species (Animal Habitat)

Climate (Rainfall, Temperature)

Socio-economic characteristics
Scenario 2

- Land development is not controlled by any statutory regulation.
- Land use change follows past trends
- [Google Earth](#)
SLEUTH Model Output
A decade of SLEUTHing

- Approximately 100 papers on applications
- Used on every continent except Antarctica
- Applied at scales from 1m to 1km
- Many lessons learned: recent reviews
- 20 years of IJGIS book (Taylor & Francis)
- Harvard Lincoln Inst. Book on *Planning Decision Tools*
- Australia book on *Place and Purpose*
SLEUTH lessons learned

- Open source works
- Sensitivity testing essential
  - Units
  - Overfit
  - Landscape metrics
  - Temporal
  - LU aggregation
  - Resolution
  - Monte Carlo
SLEUTH lessons learned

• Toward optimal calibration
• Coupling is powerful
• Link models to scenarios
• Visualization important
• Need link to urban evolutionary theory
Unsolved issues

• Variables versus constants e.g. PRN
• Calibration: impact on results
• Data preparation and uncertainty
• Scalability
• Versioning
• Scenarios
  – Future plans
  – Future transportation
  – Zoning weights
  – Change parameters (GE)
  – Coupling
• Validation
Validation vs. Verification

SanSac 2007
Base data 1900-1990
Forecast to 2100 made in 1996
Characteristics and Practical Use of SimCity

Yeon Joon Kim
Simcity Expert
kjguns@lplus.or.kr

1. What is SimCity?

1.1 Summary of SimCity

SimCity is a strategy simulation game of city management, which designs and manages a city. Users should design roads, traffics, water supply and drainage, electric power, and land use as if they constructed a real city, and in the course of time they should manage the city through the decision-making process in tax, law, exchange, consultation, and statistics. SimCity is a masterpiece of game developing company, Maxis\(^1\), which has developed original SimCity (1989, SimCity Classic), SimCity 2000 (1993), SimCity 3000 (1999), SimCity 3000 Unlimited (2000), SimCity 4(2003), SimCity 4 Rush Hour (2004), and SimCity Society (2007). However, recently released SimCity Society version is a graphic-centered Sims\(^2\) version rather than a strategy and management simulation evaluated as a little different from existing SimCity. Currently, the version containing more city-planning factor than anything else will be SimCity 4 Rush Hour (2004)\(^3\).

Will Wright\(^4\) SimCity has been developed by Will Wright, the founder of game development company Maxis and game designer, Will Wright started to develop SimCity based on the great interest in various, impromptu, and complex behavior patterns of people using simple system, Jay Forrester, the originator of System Dynamics centered on time serial change of complex system, inspired him to develop SimCity (David Kushner, Technology

---

1. It is a computer/video game development company in US, jointly founded with Jeff Brown in 1987, as of today, Max studio has been undertaken by EA company.

2. “Sims” is a simulation game played by deciding behavior pattern of people, creating environment, enjoying the results through the avatar called ‘Sims’ in 3D living space.

3. The descriptions in this study are based on SimCity 4 Rush Hour version.

4. He is regarded as big three in the world with Peter Molyneux, and Sid Meier.
Jay Forrester was an MIT professor who was independent of city planning, serving as a cornerstone of modern computer simulation through the work 'Urban Dynamics' in 1969, trying to simulate a city with different variables including population, birthrate, real estate, crime, and pollution. Will Wright intended to make the city simulation Jay Forrester tried out a kind of game. On the basis of such a System Dynamics, he planned SimCity by linking complex and various factors occurring in cities such as tax, law, crime, pollution, population, and the connection with neighboring cities with the passage of time.

Christopher Alexander, an architect of Berkeley and mathematician, is another influential in Simcity creation. He took an activity part in 1960s and 1970s, advocating ideal separation from modernism style city model in top-down way popular at that time, emphasizing the city design and development based on interaction between men and cities (Joh, Choonman,, 2005). These factors helped to construct developmental cities through the interaction between computers and users by allowing users to receive the various information and statistical data on the city while developing SimCity. Besides these theoretical factors, Will Wright has got more interest in producing topography since the mid-development. The rapid progress of computer and the subsequent advent of various software enabled SimCity to represent the space in virtual reality similar to the real world, which naturally drew attention to topography production, the basic factor of city constitution. It allowed users to design their desired city by providing different topography of cities in the world, moreover, it has attained the stage in which they produce and edit the topography with their own hands by applying GIS (Geographic Information System).

The game goal of SimCity is not to simply construct and design a city, but to manage the city as a mayor. Users need to have strategies and goals for what kind of city will be constructed, designing a city, managing it through the analysis and monitoring on various external factors. The user becomes a mayor and official managing a city, expert of city planning, architecture, landscape architecture, traffic, environment, finance, facilities, and disaster prevention, and a citizen constructing the city and living in it at the same time. Eventually, the ultimate goal of SimCity is to construct a city with enough finance and excellent environmental conditions, and competitive through the differentiation from other cities, as all the cities of today dream. Thus, the advent of SimCity has had repercussions in the game industry, and had an effect on the city-related fields of at the same time. The city planning related theory and the simulation applying it made possible indirect experience of
city construction and management, which was applied to city planning related study and research simulation at universities in and out of the country. By making it possible to overcome the space and time factors that can be obstacles when simulating a real city, it helped us a lot in understanding a city, though still indirect.

Figure 1: Screen configuration of SimCity

1.2 The Advent of SimCity and Development Process

SimCity has developed for nearly 20 years from 1989 to 2008. From early original version to SimCity Society, it has gradually evolved step by step, by integrating the various fields including strategy, management, and design in constructing cities rather than simple game factors.

1) SimCity Classic (1989)

It is an early version of SimCity series first released in 1989, which might be the basis of present SimCity. At that time, it could be driven in MS-DOS and Machitosh, but it has been developed being used in various types such as X-Box, Nintendo, and Playstation. Its graphic is so flat and infra to be built
is restricted to roads, railroads, electric power, harbors, and airports. Facilities appearing on it are also restricted to basic ones and police stations and fire stations were all. However, the concept of disaster, accident, and budget is so advanced and especially the cell concept setting unique view and region, regarding a city as three main factors of residence, commerce and industry, has served as the most important factor that composes SimCity until now.

![Figure 2: Scenario selection and screen configuration in SimCity Classic](image)

2) SimCity 2000 (1993)

It is the second version of SimCity series released in 1993. Compared to SimCity Classics, it represents cities more three-dimensionally, thus the concept of ‘topography’ and ‘altitude’ appeared first. As infra needed for cities got diversified, the concept of ‘subway’, ‘water supply’, ‘education’, and ‘health’ appeared newly, and it was possible to build various power plants, foundation establishment, and buildings in housing, commercial and industry areas. Also, cities in the game allowed users to make various decisions by providing main issues and information occurring in cities in the form of news items. Considering the conditions of 1993, it presented a new paradigm of strategy and management simulation in the games area.
3) SimCity 3000 (1999)

It is the third version of SimCity series released in 1999. In planning stage this version would be manufactured in 3D, but there was a problem that the specifications of most computers marketed at that time couldn’t support this. So it was supposed to be produced in the most advanced type in the 2D category. This version, released with the fad-word, “2.5D”, was remarkably improved at least in graphics. Also, as news items shown in earlier version has developed into the form of expert advisers and petitions, users could form a mutual organic relationship between computers and them by receiving more concrete technical materials and city information. In addition, it reflected the effect of environment on cities by adding the concept of ‘waste’ and ‘pollution’ in the downtown area. Considering it applied and reflected the coexistence issue of development and environment, which is the greatest issue in city planning, in the game aspects in 1999, we can estimate social aspect at that time and the importance of environment. It emphasized landmark part and allowed actually built famous buildings in the world, such as ‘pyramid’ ‘the Eiffel Tower’ and ‘Empire state buildings’ to be embodied in the game. However, in spite of remarkable development in graphics, internal factors including topography and editing has hardly advanced compared to the early version: rather, it was retrograded in some factors.

4) SimCity 3000 Unlimited (2000)

It is the expanded version of SimCity 3000 released in 1999. It accepted considerable complaints of existing users and reflected them in it by adding new and various buildings and restoring the function of topography edition that was problematic in SimCity 3000. Due to the advent of Building Architect Tool (BAT), the tool for building various buildings, users could use their own made building in games, Through this, users could participate in more civil engineering and construction fields in
5) SimCity 4 (2003)

It is the fourth version of SimCity released in January 2003. The advent of SimCity 4 was amazing enough. Not only did it make rapid progress in epoch-making 3D graphics, it created a virtual space similar to the real city construction as well, by adding various factors for managing city and making decisions. In addition, actually users could move city topographies of the world’s leading cities into the topography needed for city construction and freely edit them. Tools for building construction showed in earlier version could be used in constructing and using more realistic building due to the advance of 3D edit program. The ‘Sim’ concept introduced in this version is a citizen in games, living there with house and work place, providing detailed information with users. Like this, SimCity 4 reflected all the design factors constructing real cities most realistically.

6) SimCity 4 Rush Hour (2004)

It is the expanded version of SimCity 4 released in September 2003, much upgraded in ‘traffic’ field compared with existing version. In this version, ‘waterborne traffic’ appeared at first, and infra facilities including avenue, highway, and connection roads were provided in various forms. Also, new and high-tech transportation like monorail and elevated trains appeared and the function for checking congestion and traffic volume according to the flow of traffic was added. With the advent of view for observing cities through the transportation such as cars, ships, and planes, users could make more realistic city and look around.

Figure 4: City composition and information in SimCity 3000
7) SimCity Society (2007)

At 3 years after release of SimCity4 version, Society, the seventh version of SimCity was released in November 2007. Since the release of SimCity4 version, many users have anticipated SimCity5. Their main interest was that how many epoch-making factors would be complemented in the progress of epoch-making graphics, topography edition, city management and decision-making progress of SimCity4. However, the functions of land use setting and topography edition disappeared, and the factors of traditional city planning to which SimCity had adhered almost disappeared. It just stayed on the level of objectives achievement by user-centered simple game constitution and disposition of graphic-centered city model rather than connections of complex system.
2. The Functions and Components of SimCity

2.1 Topography Selection

The most basic factor that composes SimCity is topography selection. Users should select appropriate topography before constructing a city. In the past SimCity, scenario was progressed to the history of topography, but now it provides only city topography to the exclusion of scenario. Basically, topographies of New York, San Francisco, Berlin, and London are provided, and users can download the topography of famous cities in the world through the relevant website. Recent SimCity4 version allows users themselves to produce topography in detail using DEM (Digital Elevation Model). Users can easily download this topography material made elaborately through network due to the development of Internet. Topography consists of large map, middle map, and small map. These many maps constitute a map and users can choose the desired Map type.

![Topography of New York city and Suwan metropolitan city](image1)

Figure 7: Topography of New York city and Suwan metropolitan city(top), the size of topography(bottom)
2.2 City Construction

This is the part that determines the real shape of a city in SimCity. Users properly arrange infra facilities for electric power, water supply and drainage, roads, and waste according to the population and city scale and then make land use plans for housing, commerce, industry, and green. Each land use consists of three stages, that is, low, medium, and high density, for green, various park items like neighborhood parks, children’s parks, and public parks can be selected. They should also arrange education, welfare, crime, public security, medical facilities on the proper scale, and they can establish public facilities like mayor mansion, national library and government buildings when reaching the proper scale and population of city. Users can construct world famous landmark buildings as occasion demands. These factors like parks, public facilities, and landmarks enhance the quality of citizens’ life, being useful for city finance through the inducement of foreign tourists. However, noxious facilities like casinos, army camps and radioactivity laboratories contribute to city finance but can be a factor for reducing population and degrading environment and the quality of life, as in the real cities. Since all the factors needed for city construction accompany costs, they should be arranged and established properly considering budget and finance situations. Also, they can make new land use plans by removing unwanted areas. This part of city construction in SimCity is the most important factor in designing city, when accompanying land use and arrangement of infra facilities appropriate for population and city scale, the desired city can be constructed. Otherwise, users will see slum city view and eventually expelled by citizens.

Figure 8: Developed city(left) and slum city(right)
2.3 City Management

City management in SimCity is the most basic factor to maintain, manage, and develop a city and the most important component that composes an axis of SimCity, with the city construction part. Through this, users can grasp city population, finance situation, mayor’s approving rating, demand of housing, commerce, and industry at present, receiving the latest information including traffic problems, expansion of education facilities which are the issues of the city. Users decide design mode of buildings, control budget, examine and control various legislative bills on the basis of this information. It can be a luxurious housing complex or middle-class city, financial and commercial city or high-tech industrial city depending on user’s choice. It can be a safe city through law enactment, but citizens can address petitions because of excessive suppression. It can overcome city problems and finance situation through the business with neighboring cities, grasping past and present information on the education, public security, traffic, and land use through the city statistical data and graphs. Users should operate and manage the city on the basis of various news and expert consultations provided in real time. City management factors of SimCity lead to various results depending on the budget operation and interchange with neighboring cities, and users should present optimum alternative conforming to city basic plans and goals and set strategies through the proper decision-making process according to these complex situations.

Figure 9: Various information and statistical data
2.4 Residents’ Participation and Monitoring

SimCity allowed residents’ participation and city monitoring, which are regarded as important in making city plans. It has up to five Avatar\(^5\) citizens called ‘SIMS’ inhabit in a city, monitoring traffic, environment, employment, and the quality of life around the habitat in real time, providing the information with users. When clicking residents living in the city and cars, besides these SIMS, it provided information on pending problem at the present position. Also it allowed users to look closely at all the areas in the city by boarding cars, waterborne traffic, and plane. Through the residents’ participation and monitoring, users can make a city richer and desirable to live in and it helped a lot in decision-making process through the interaction with computers.

![City monitoring through the residents’ participation](image)

**Figure 10**: City monitoring through the residents’ participation

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\(^5\) It means one’s other self and incarnation, indicating an animation character representing an individual. It is used especially on Internet, and users can select characters according to their personalities and tastes. Avatars can move freely in screen space and express feelings.
3. The Method of Space Composition and decision-making process in SimCity

3.1 The Method of Space Composition in SimCity

Two large areas that compose SimCity are city construction and management. City construction composes spaces and management is decision-making process. The bases of this space composition are topography and 3D modeling.

1) Topography Production

Users can produce desired topography with their own hands, besides basically provided topography in SimCity, one is to use production tool provided in SimCity itself, and the other is to use Degital Elevation Model(DEM) for producing more detailed topography.

In basically provided production tool in SimCity itself, users can edit topography with five icons through the god mode tap. Topography edition is possible only once before constructing a city, they must pay extra costs for engineering work once city construction has started. The basic tools for topography production are topography making, topographic effect making, altitude alignment with surrounding areas, disaster control, and day/night coordination. In the tap of topography making, they can level mountains and valleys topography and plant trees. Mountain, as a tool for elevating topography, it can form a mountain and a mountain range by making mesa, flat topography with huge mountain ranges, gentle hills, rapid hills, cliffs with sharp ridge, and more than one steep slopes. Valley is a tool for lowering topography, by using this users can produce great valleys, deep valleys with steep slope, shallow valleys with gentle slope, gorges whose edges are cliffs, shallow gorges whose edges are descending, craters in volcano or resulted from the meteorite fall. Topography leveling is a tool for leveling with surrounding topographies, there are corrosion function changing wanted areas into rough mountainous districts, shorelines, and plains, flat function hardening rough topographies evenly, hardening function for all the topographies within the reach of mouse conforming to the topography of center arrow rapidly and evenly, the function making shoreline or gentle slope by leveling topographies evenly, and table land function making mountain topographies flats by leveling. In addition, they can plant trees and raise wildlife all over the areas. Tap of topographic effect making is a tool for editing topographies by applying weathering of wind, which makes plains or adjusts sea level. This tap adjusts whole topography uniformly rather than edits parts of topographies, having functions of weathering, flattening whole topography, elevating or lowering the level of whole topography. Also, there are functions of
leveling with surrounding areas composed of squares in all directions, making earthquake
topography, volcano topography, and meteorite topography through disaster creating, and
coordinating day and night. Topography production basically provided has demerits that elaborate
topography production is impossible as it is intended to produce proper topography with design
sense of users or mouse handling rather than produce with special numerical values, but it can be
useful for detailed edition of model produced in DEM.

Figure 11: Tools for topography production of SimCity

To produce a topography using DEM, users should basically understand DEM and Config
file. DEM is a digital elevation material representing the states of topography with numerical
values, recording height value by dividing topography into the grid of specific size and its
measurement standard is height from sea level. It is most widely used in GIS, especially elevation
analysis of topography is used for technology project including hydrological application, 3
dimensional analysis of topography surface, landscape analysis and design, and road design, and
statistical analysis and comparison of various types of topography\(^6\). However, since SimCity can’t recognize the DEM in itself, it needs separate correction. SimCity is made to recognize only through ups and downs of shadow (brightness) in topography production, and so needs conversion of topography image made with digital elevation model to 2bit image\(^7\). With GIS related software\(^8\) and image enhancement program, it can make the same topography as real one. This DEM should be made personally using satellite image, but it can also be downloaded through the sites producing it for use in SimCity and providing it free or charged for. There is also a website providing detailed material for DEM and guiding manufacturing method\(^9\).

![Figure 12: Digital Elevation Model](source)

Config file constitutes the size of SimCity topography. The resolution of DEM should be determined conforming to the size of this config file. SimCity largely consists of three stages of maps, they are large map, middle map whose size is a quarter of large map, and small map whose size is a sixteenth of large map. Large map of config file classifies and recognizes large map as blue, middle map as green, and small map as red. Many of these three cells are mixed and

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\(^7\) When converting DEM file into image file, the image mode should be Grayscale

\(^8\) There are programs like Global Maper, Terragen, and Micro DEM


compose one config file. In case image pixel values of config file are 16×16, there are 16 large maps, 64 middle maps, and 256 smalls on screen. Constant values connecting this config file with DEM are ‘64+1’, in case of 16×16 config file, it can create the desired topography when correcting resolution values of DEM into 1025×1025, which added 1 to each (16×16)×64=1024×1024 pixel value

Figure 13: Composition of Config file(16x16)

When compounding DEM.jpeg file of Suwan metropolitan city where image mode was set to Grayscale and Pixel Demension was corrected into 1025×1025, resolution value into 72 with config.bmp file where Pixel Demension was corrected into 16×16, resolution value into 72, and composed as a large map on SimCity, detailed topography production as shown in <Figure 14> is possible with internal program.

11 Users can feely select and set pixel value of Config file but its maximum is 25x25, should adjust the aspect ratio of pixel value of DEM file according to the Config pixel value. (in case of 25x16, DEM is 1601x1025).
Topography produced in this way has coordinate information\textsuperscript{12}, which allows to identify the coordinates of $X,Y,Z$ axis of each cell. In the end of all four directions, the values of $X,Y$, and $Z$ axis are indicated as 0. $X$-axis means direction from west to east, $Z$-axis from north to south, and $Y$-axis represents altitude. As the size of one cell that coordinate information represents is 16m, each time moving by a cell, $X$-axis and $Z$-axis increase by 16\textsuperscript{13}, and values of $Y$-axis\textsuperscript{14} vary

\textsuperscript{12} It means coordinates on SimCity, not coordinates representing latitude or latitude in real world.

\textsuperscript{13} As length and width of a cell is 16cm, values of $X$-axis and $Y$-axis in cell are indicated differently.

\textsuperscript{14} In case of DEM, maximum height of $k$ value is up to 255, but on SimCity, height value more than 10 times can be indicated.
according to the DEM values. There are also Cell values identifying the position on cell, they are indicated as Cell X value and Cell Z value, and inform location information of cells by increasing by 1.

![Coordinate information on SimCity](image)

**Figure 15: Coordinate information on SimCity**

2) 3-dimensional Modeling

Once selecting produced topography and starting program, users should arrange or establish infra facilities like loads, water supply, power plant, and transmission tower or city planning factors like structures, public facilities, and parks. The model of public facilities needed to form a city is provided in various forms, types and sizes according to the determined design on SimCity. However, unlike these standardized public facilities, in case of the style of city construction for housing, commerce and business, users can reflect historical construction trend including Chicago style in 1980s, New York style in 1940s, Huston style in 1990s, and modern European style in 2000s on SimCity spaces and model them depending on every year or fixed period. Also, SimCity allows users themselves to reflect building and engineering work factors needed on SimCity by
providing Lot editor program. Through this program, they can appoint detailed attribute value for reflecting population and tax factors as well as external rendering. Lot editor allows connection with other programs including CAD or 3D-Max, and users can construct and reflect not only stated above housing buildings, commerce buildings, and business buildings but also elaborate buildings like laboratories, power plants, dams, parks, canals, and underground roadways, and public facilities, parks and civil engineering facilities. In fact, using this program, famous buildings like Burj Dubai building or Petronas towers are constructed and opened to the public on the network. These factors allowed users themselves to participate in city design, showing the possibility of building virtual spaces similar to real ones, as 3 dimensional GIS.

![Figure 16: 3-dimensional building modeling and an air-view of complex plan](image)

3.2 SimCity and Decision Making Process

Design and planning are very important in building a city. Support from the aspects of operation and management, however, is necessary in the process of shaping and developing a city. A city operator should present a suitable solution through various decision making processes within the organism of a city where complex systems are related one another.

1) Decision Making Process

SimCity involves unilateral decision making process and the one through mutual exchanges.
The unilateral decision making process is the part that a user establishes strategies and designs a city without external opinions or advisory. Meanwhile, the decision making process through mutual exchanges is the part that a user judges and decides every moment by acquiring news, city statistical data and residential, commercial and industrial demand, along with experts’ advisory opinions provided by SimCity. External factors do not greatly affect the unilateral decision making process, and the flow of time is not important. A user can build the city through already decided policies. City form, shape and architectural type can be categorized into the unilateral decision making process.

However, in the decision making process through mutual exchanges, surrounding situations that change, depending on the flow of time, and complex systems become the most important variables and factors deciding and judging decisions. Probably, these factors are the part produced on the basis of system dynamics. A characteristic of an approach based on such system dynamics is basically concerned with how specific variables for research dynamically change according to the change of time. That is, the approach is interested in how dynamic changes take place and how they will take place according to the time flow of research variables. Therefore, system dynamics is more concerned with what dynamic change trend of research variables is shown depending on the flow of time (Meadows, 1980:31-36). In SimCity, the concerned variable is city, that is, the factors for operation and management of a city, such as finance, laws, crime rates and traffic volume. The system dynamics needs to be understood from the perspective of internal circulation feedback structure of all phenomena. In other words, the system dynamics is not forming a simple relationship between a dependent variable corresponding to a certain result and an independent variable that becomes a cause to affect the dependent variable. Dynamic change of a certain variable is identified as taking place by ring form of dynamic interaction that exists in the inside of the system. Variables are interlocked one another in terms of the ring structure of the feedback. The system dynamics focuses on empirical and factual thinking, as thinking is unfolded by the feedback structure.

Accordingly, the system dynamics is the thinking focusing on change process regarding how changes actually take place, rather than on what values do the variables, which belong to feedback structure, have at specific time. Such a feedback process is repeated so many times in SimCity. In other words, the empirical and factual feedback process repeats so many times in SimCity. In decision making on one variable, so many influencing factors exist; thus, a user needs to present the most optimal alternative solution through his/her own experiences, and should present a new
alternative solution through feedback process, when the outcomes are different. Though more scrupulous analysis is possible concerning how, how much and what degree does each information exchanges influences has been exchanged through internal programming source interpretation, there is limitation in that actual values cannot be mentioned, because no internal programming source is obtained. However, in the simulation process, public facilities, such as parks, schools and police stations, provide good environment to residents, and thus, premium housing is located, or technology-intensive industries are located within the city, or high rise buildings are built in commercial zone: In this manner, they exchange mutually close influences in city development, and feedback process through redevelopment and reconstruction explains the relevance between SimCity and system dynamics most properly.

In real world, although decision making structure chart in city system takes on really complex relationships, this study categorized the structure into five categories: Public facility, transportation, environment, population and finance sectors in order to look into the system dynamics structure chart in SimCity.

![System Structure Chart in SimCity](image)

**Figure 17: System Structure Chart in SimCity**

Since each sector moves in interaction, without a start and an end one another, it is very difficult to explain which sector starts first. This study examines the supply of public facilities for public benefits in a city in the first place. When public facility increases, population increases, but finance declines. However, population increase causes financial increase, due to tax revenue increase. In
this process, financial balance can be made, or positive or negative finance can take place. Also, traffic jam can be generated, and thus favorable traffic conditions decline, and environmental conditions, such as air and water quality, decline. Decline of traffic and environmental conditions brings about the increase of public facilities, and forms a circulating structure of feedback. Though it is difficult to explain the structure simply, since each sector contains comprehensive contents, outline can be as follows: the supply of public facility and population and financial increase are the factors that make a city grow, and the decline of traffic and environmental conditions and financial reduction are the factors deteriorating a city. A city can grow, stay as it is and deteriorate in such a circulating structure.

2) Operation and Management

The basic factors composing a city are residence, commerce, industry and green area in SimCity. By planning such basic factors in certain space and allocating them with zones, functions are set within the city. By installing various facilities (roads, public facilities, etc.) necessary for residents’ living, the environment where humans can live within the city is provided. Since these factors move according to the principle of demand and supply, the quantity balance needs to be properly adjusted, based on a variety of information provided by SimCity. That is, decision is made through mutual exchanges, therefore, a city manager should look at a variety of information provided by SimCity with great interest by opening eyes and ears all the time.

The zones classifying functions in a city (land use) are divided into residence, commerce and industry, and decisions are made through RCI demand indicator classified into high class, middle class and low class or agriculture, pollution-generating industry, manufacturing industry and high-tech industry. If demand is high, a city should be extended by newly designating zones, and if demand is low, proper response should be made in consultation with other information. When the number of zones is decided through demand, location is designated by confirming compatibility by zone. If a zone has a low compatibility, the concerned function may not be located, despite designation of a zone.
For traffic, each zone needs to be connected well. The information provided is traffic jam data and road traffic volume data by each transportation means, such as cars, public transportation means and monorail, and passage path is provided. Based on the provided information, commuting time (rush hour) is given. Based on the information above, city administrator must decide the kinds and volume of general roads, expressways, general passage roads, avenues and so on, depending on the city size and associated characters, and build them. Moreover, the provision of public transportation, such as subway and bus, and the period to build them, location, etc. are decided.
Figure 19: Traffic-related Information

(Traffic Jam Data <Left>, Road Traffic Load Data <Right>)

Of the public facilities, the number of police stations, fire stations, schools, hospitals to be built is set according to the scope of their influences. Consequently, weak points need to be identified and proper allocation/assignment needs to be placed through information marked on the map. Electric power and tap water need to be built as much as needed in consideration of entire amount consumed within the city. However, here comes the most difficult thing. Finance is required in operating and managing all those things, and thus they must be built in order with time interval in consideration of urban income and expenditure.
Figure 20: Public Facility-related Information

For environment, only two types of information, that is, air pollution and water pollution are provided. The area with high pollution affects compatibility and residential environment, and thus, the degree of potential needs to be reduced. Air pollution is high in the roads where many pollution-generating industries and great traffic load exist; in this case, an effort to induce the existing industry into cutting-edge industry and to reduce car use is necessary. High water pollution is demonstrated in the pollution-generating industries, and it needs to maintain good water quality in the surrounding area by installing water treatment facilities.

Figure 21: Environment-related Information
(Air Pollution Information <Left>, Water Pollution <Right>)

Stability in finance is essential to build and maintain such facilities. Therefore, positive finance
needs to be maintained in consideration of tax income and expenditure in managing a city. To keep positive finance, investment should be made in a planned way in consideration of time and amount.

Figure 22: Finance-related Information
(Monthly Budget <Left>, City Income and Expenditure Graph <Right>)

Various information on the factors constituting a city, including zoning, traffic, public facility, environment and finance provided in SimCity, plays a role of each indicator interpreting and evaluating the city. A decision should be made through mutual exchanges with such information. However, such information must not be classified into an independent variable. The reason is that a city grows with each information being associated one another and exchanging influences, as seen in the system structure chart from the perspective of system dynamics: A comprehensive decision making process is required.
4. Use of SimCity in the National Land Research Field

4.1 Application of Urban Planning

SimCity is a simulation game developed by combining a variety of urban planning theories mentioned above. In view of the features of SimCity, land use plan is simulated to greatly affect city growth. For this reason, SimCity has been used for efficiency verification of land configuration criteria closely related to the land use plan.

For land configuration criteria, under the premise that it is more advantageous when the configuration of land is simple and concentrated, rather than when it is complex and linear, the indicators demonstrating the complexity and linearity of land configuration have been the criteria of land configuration. From the aspect of use of land configuration, the value of land configuration criteria becomes larger, as land is not complex and simple and is concentrated, rather than lining long. In this manner, the land configuration criteria have been defined (Junghoon Kim, 2005)

Various research methods have been used for the efficiency verification of the land configuration criteria, and the following have been assumed for three scenarios for the criteria through SimCity:

First, as land configuration is better, the area of public facilities is less needed and maintenance/management expenses are spent less. Second, as population increases more and the class distribution will show stable distribution like this: middle class> high class> low class.

Third, in case of commercial zone in the industrial structure, premium services and offices will be located, and the tertiary industry ratio of cutting-edge IT industry will be high. Based on these assumptions, the scenario 1 is the square land configuration equal to Yongin Jukjeon region in terms of area, and the scenario 2 is the Yongin Jukjeon region, which becomes the criterion of area (3.59㎢). In the scenario 3, the area was revised in order to make Gimpo Yangchon region same as Yongin Jukjeon region in terms of area (3.59㎢). The land
configuration by scenario was produced by recomposing the config. file needed for SimCity topography production, after editing the same size of topography calculated using ArcGIS 8.3 to 129×129 pixels and resolution 72 through Photoshop 7.0. The produced models are shown in Figure 23.

Figure 23: Land Configuration of Each Scenario and Topography Produced in SimCity

Junghoon Kim et al. (2005), Research on the Introduction of Land Configuration Criteria for Rational Selection of
The analyses of population and industry distribution and differences of management expenses for public facility area by scenario were carried out during the same target period (after 50 years), after land use and major facilities are laid out in the same manner for each scenario. For an objective land configuration analysis, simulation was conducted by making the residential land, commercial land, industrial land and park land equal in terms of area. To eliminate external influential factors, land configuration was all island form. The city size, along with tax, law and environmental factors, was applied in the same manner to all scenarios, based on the scenario 3 of which land configuration is worst. The conditions provided in the same manner in the three scenarios are exhibited in <Table 1>.

**Table 1: Commonly Applied Factors in Each Scenario**

<table>
<thead>
<tr>
<th>Residential zone</th>
<th>498 kan (a unit of floor space)</th>
<th>Commercial zone</th>
<th>279 kan</th>
<th>Industrial area</th>
<th>288 kan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park</td>
<td>Tennis court, basketball court, football field, baseball field, church, cemetery park, city park</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the public facilities in SimCity, more management expenses are spent, as the sizes of roads and water supply and sewerage are bigger. For police station and fire station, the number and expenses will be calculated according to their influential scope. For power plant, maintenance/management expenses are different depending on consumed amount of power.

According to the analysis results of the three scenarios, the city in the scenario 1, whose land configuration was best, as assumed above, showed area distribution showing the most efficient distribution of public facility influences and lowest maintenance/management expenses. The scenario 3 demonstrated the most inefficient area distribution and highest maintenance/management expenses. As for total population and population structure, the scenario 1 with the best land configuration showed the most population with 11,223 people, the scenario 2 showed 10,422 and the scenario 3 with the worst land configuration demonstrated the least population of 9,892. Looking into population structure, the scenario 1 and 2 showed stable structure in the order of middle class, high class and low class in terms of population number. The scenario 3 showed the order of low class, middle class and high

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Development-Possible Land, KRIHS
Concerning industrial distribution, cutting-edge IT industry was located in the scenario 1 and 2 with good land configuration, while pollution-generating industry was mostly located in the scenario 3. However, for commercial location, premium commercial services and offices were mostly located in all scenarios, regardless of land configuration. Consequently, the following results have been drawn through SimCity analysis: land configuration affects a city, and as land configuration is better, smaller area of public facilities and less maintenance/management expenses are used. Also, eco-friendly, cutting-edge IT tertiary industry-oriented efficient city configuration is demonstrated with stable population structure and population increase.

### Table 2: Industrial Structure Analysis Results of Each Scenario

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential zone (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low class area</td>
<td>25.0</td>
<td>24.9</td>
<td>42.5</td>
</tr>
<tr>
<td>Middle class area</td>
<td>40.9</td>
<td>42.8</td>
<td>31.6</td>
</tr>
<tr>
<td>High class area</td>
<td>34.1</td>
<td>32.3</td>
<td>25.9</td>
</tr>
<tr>
<td>Commercial zone (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low class commercial services</td>
<td>2.0</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>Middle class commercial services</td>
<td>1.5</td>
<td>2.0</td>
<td>9.3</td>
</tr>
<tr>
<td>High class commercial services</td>
<td>56.3</td>
<td>64.7</td>
<td>51.8</td>
</tr>
<tr>
<td>Middle class commercial services</td>
<td>6.1</td>
<td>3.5</td>
<td>11.2</td>
</tr>
<tr>
<td>High class commercial services</td>
<td>34.1</td>
<td>28.1</td>
<td>27.7</td>
</tr>
<tr>
<td>Industrial zone (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollution-generating industry</td>
<td>40.7</td>
<td>37.3</td>
<td>85.3</td>
</tr>
<tr>
<td>Manufacturing industry</td>
<td>8.8</td>
<td>4.7</td>
<td>11.9</td>
</tr>
<tr>
<td>Cutting-edge industry</td>
<td>50.5</td>
<td>58.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Public facilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roads</td>
<td>159</td>
<td>163</td>
<td>172</td>
</tr>
<tr>
<td>Water supply and sewerage</td>
<td>21</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>Police station</td>
<td>1 (250)</td>
<td>2 (500)</td>
<td>3 (625)</td>
</tr>
<tr>
<td>Fire station</td>
<td>1 (250)</td>
<td>2 (500)</td>
<td>3 (625)</td>
</tr>
<tr>
<td>Power plant</td>
<td>2(456)</td>
<td>2 (506)</td>
<td>3 (514)</td>
</tr>
</tbody>
</table>
Figure 24: SimCity Analysis Results of Scenario 1

Figure 25: SimCity Analysis Results of Scenario 2
Figure 26: SimCity Analysis Results of Scenario 3

4.2 Model Simulation

Graphic software support of high specifications of graphic software support is possible from SimCity 4 version, due to remarkable development of computer technology. It, however, does not show perfect 3D graphics, and thus, 2.5D graphic is possible in between 2D and 3D. 2.5D is not suitable for architecture or complex design that requires scrupulous and detailed factors, but is widely used for the production of bird’s eye view that shows entire city and examines topography.

KRIHS held a “Virtual City Construction Contest for New Administrative City” to enhance citizens’ interest in the construction of administrative city and to provide an opportunity to participate in the contest to the public, as well as experts, in November 2003. In the contest with duration of 3 months, the topography similar to the administrative city, based on SimCity 4, was provided, and thus the concept and design direction of the administrative city could be freely presented, before the administrative city is actually built. About 40,000 people visited the official Web page of the contest and 394 people presented their works. Screening was conducted in three stages. Through the evaluation of 7 judges, 14 candidate works (7

16 The name changed from new administrative capital construction to administrative city construction.
high class works and 7 beginner class) with the highest average scores were selected. In the third stage and final screening, 11 awarded works were selected by comprehensive assessment of 11 judges. A variety of information and statistical data provided by SimCity make the qualitative and quantitative evaluations of urban planning factors possible, and thus, objective and fair screening can be carried out <Table 3>.

**Table 3: Screening Criteria and Detailed Evaluation Criteria**

<table>
<thead>
<tr>
<th>Qualitative evaluation</th>
<th>Idea</th>
<th>City landscape, urban planning, urban design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Added score</td>
<td>Urban design strategy and after note</td>
</tr>
<tr>
<td>Quantitative</td>
<td>Environment</td>
<td>Water pollution, air pollution, waste generation volume</td>
</tr>
<tr>
<td>evaluation</td>
<td>Traffic</td>
<td>Transportation use rate, traffic congestion</td>
</tr>
<tr>
<td></td>
<td>Welfare</td>
<td>Average income, life span, education level, crime rate</td>
</tr>
<tr>
<td></td>
<td>City operation</td>
<td>Mayor’s city Mgt performance, city finance, public opinion poll, number of population</td>
</tr>
</tbody>
</table>

**Figure 27: Awarded Work in the Virtual City Construction Contest for New Administrative Capital: Presentation of a ring structure concept**
Among the simulation models, there were some works that presented the ring structure concept similar to the basic concept of the administrative city, which is currently underway. The basic concept of the administrative city construction was decided through the international design contest in November 2005. This can be a case shown through the SimCity model simulation ahead of two years. Likewise, SimCity can be used by producing a bird’s eye view prior to building a city through the 3D embodiment ability of SimCity. Compared to the production of a bird’s eye view requiring much expense and time, the basic concept, land use and future image of a city can be outlined with less time and expense using SimCity.

The following <Figure 29> shows topography and a bird’s eye view, based on the satellite photo and land use in the Saemangeum Land Reclamation Project shaping 40,100ha of land by building a 33km-long sea wall located in Gunsan, Gimje and Buan in North Jeolla Province. The topography was edited based on the basic plot to be formed in the future using the current satellite photo. Moreover, international business zone, new renewable energy zone, industrial zone and international conference halls have been formed and embodied in SimCity. However, the housing development in the Saemangeum Project was produced in a plane
structure, and thus altitude via DEM is not demonstrated.

Figure 29: Bird’ Eye View of Saemangeum
5. Conclusion (SimCity for Time and Spatial Integrated System)

SimCity has shown a possibility to be used for national land and urban planning, based on spatial portraying ability and various decision making processes, through 3D graphic topography production with the sense of the real. Through topography production using DEM and city building using 3D modeling, SimCity has made users easily access the unlimited potential of spatial expression using GIS via a means of game. Though SimCity has limitation in that it does not provide coordinates system showing latitude and longitude and precise scale used in maps, it provides a coordinates system produced in its own way for location check in the topography, distance information using cells and various city statistical data. Such location and attributes information are the basic factors constituting GIS, and will become an important part connecting the real world and SimCity, that is GIS and SimCity. The final objective of SimCity’s spatial portraying ability can be found in Google Earth. Quick support and precise location information of 3D graphics are provided by a game. The developer of SimCity, Will Wright, easily solves complex system structure in daily life, including physical factors like interior and landscape, as well as emotional expression like love and jealousy, through a human of Avatar on the virtual space, in a game of Sims through a decision making process. These decision making processes are a factor connecting system dynamics and SimCity, and can measure urban phenomena in SimCity similar to the real world through the addition of various items and introduction of variables in city operation and management. When measured urban information data are converted into attribute value, the connection with GIS will also be possible. However, that the disclosure of concrete development source is impossible as a game can be limitation. As a developer of SimCity and Sims, that Will Wright tried to combine Sims and SimCity through resident participation and monitoring in SimCity 4 has great implications.

SimCity is a strategy game of city management simulation. Although SimCity was produced based on urban planning, business administration, GIS and system dynamics, anyone who is not the expert in such areas can build and manage a city and produce topography and make diverse decisions. Ultimate objective of the time and spatial integrated system at visualization level was sought in SimCity, because SimCity can be used like a game and reflects the real world (Youngpyo Kim, 2007). If SimCity is developed as simply entertaining factors, it would stay in the society version released in 2007. However, if SimCity is developed by combining spatial and time factors like GIS and system dynamics,
based on Google Earth and Sims, overcoming the current limitations, not only the embodiment of time and spatial integrated system, but also the use in various research fields, may be expected in the future SimCity version.
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Directions to Formulation of Integrated SD-GIS System

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1. Three Fundamental Elements in the Universe:
   Three Kans Time(Si-Kan), Space(Gong-Kan) and Human(In-Kan)

   What is the most important thing God created at the beginning of the Universe? The answer may be achieved from the Thousand-Character Text (千字文), the Huai Nan Tzu (淮南子), and the Old Testament.

   The Thousand-Character Text(a primer of Chinese characters) is the poem book containing exactly one thousand unique characters, 250 phrases of 4 characters each(四言古詩). This book was composed by Zhou Xingsi in Liang Country, one of the ancient Chinese countries around 1500 years ago. This book includes important contents for human life such as 'cosmos theory'(which is accord with current scientific explanations), 'provision of nature', 'human geography', 'history', 'ethics', 'politics', and 'economics'. For example, the first phrase, ‘heaven is black and earth is yellow(天地玄黃)’ contains the secret of the universe creation. 'Heaven and earth(天地)' does not mean current heaven and earth but the chaos(混沌), not divided into heaven and earth, before the big bang(開闢). And 'black and yellow(玄黃)’ implies the status and the color of the chaos. The second phrase of the Thousand-Character Text is ‘the cosmos is large and coarse(宇宙洪荒)’. The cosmos was defined by the ‘Huai Nan Tzu’ written in early Han dynasty around 2,100 years ago. According to the Huai Nan Tzu, the cosmos(宇宙, Wu-Zu) was defined like following. Wu(宇) is three dimensional space(四方上下) and Zu(宙) is time networked by past-present-future(古往今來). Therefore, the cosmos is a house which is composed of space and time. Therefore, ‘the cosmos is large and coarse(宇宙洪荒)’ can be interpreted more detail like following: 'The cosmos is spatially boundless and temporally continuous'. First two phrases in the Thousand-Character Text explain the meaning of the chaos before the big bang and the cosmos after the big bang. Adding human to space and time, these three fundamental elements are so called 'Three
Kans(三間) in the universe'.


In the oriental philosophy, Heaven(天) corresponds to time, Earth(地) to space, and Man(人) to human. These three terms, Heaven, Earth, and Man, are so called ‘Three Foundations(三才)’ as on academic term. The ideological system based on ‘Three Foundations’ is ‘Three Foundations Thought(三才思想)’.

The universe, the largest system, is constituted of 'Three Foundations'. Therefore, the fundamental and confident system in any field such as politics, economics, sociology, culture, science, technology, literature, art, or religion can be formulated and analyzed by the integration of 'Three Foundations'.

In the process of abstract modeling for the experiment and the analysis of real world, it is necessary to consider 'temporal factors' for the prediction of the future, 'spatial factors' for the analysis of spatial locations, distributions, and connections, and 'human factors' for the decision making of finding the best strategies in given conditions. Being the operation of gathering various factors of time, space, and human in one framework based on the cause-effect rule, modeling can be the procedure of creating the microcosmos.

Therefore, this article considers time, space and human, or the ‘Three Kans’, as the foundation factors of every system. And, the 'Harmony Principle of Three Kans' is defined as the approach principle to the systematic formulation of concepts or the construction of modeling with the harmonious integration of three Kans.

3. Approach to the System Construction for the Three Kans Integration

The best way to construct the dynamic model with time concepts is 'System Dynamics(SD)', the best technology for the spatial analysis and spatial modeling is 'Geographic Information System(GIS)', and the most suitable way for the decision making is 'Optimal Control Method'. It is difficult to integrate and to utilize all three approaches because of the time consuming and large effort to learn and understand each approach even though each approach is excellent.

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1 Young-Pyo Kim, Seon-Hee Han, Mi-Jeong Kim, Rin-Gon Moon, 2001, Cyber Territory Construction in Digital, KRIHS. [Korean]
2 Young-Pyo Kim, Seon-Hee Han, Mi-Jeong Kim, Ho-Jeong Kim, 2007, Development of Simulation System for Financial Investment Impact Assessment and Set-up of National Development Index(I) : Based on System Dynamics Approach, KRIHS. [Korean]
However, the world is an interrelated 'Complex System' of three factors (time, space, and human) like a web. Therefore, in order for a clear examination and effective measure on the present situation of the world, what is required is an integrated model utilizing simulation technologies such as the game engine, as well as the approach to the ‘Consilience’ that deals with the three factors altogether. In the past, technical problems and obstacles made difficulties to find solutions or construct systems out of models similar to this integrated model. With the help of theoretical foundations and technical progress, the model is now feasible to be constructed through combining various approaches with progressed technologies.

4. System Dynamics Techniques: Time Based Approach

4.1 The Progress of System Dynamics

With the background of the mathematics including simultaneous calculus equations and control theories, System Dynamics is the approach to comprehensively understand dynamic systems constituted of many complicated variables.

In general, a system, whether natural phenomena or social phenomena, is constituted of interrelations with various factors in the system and cause-effects of complicated networks. The structure of simultaneous calculus equations, mixed with 'integral equations' of conditional variables such as 'differential equations' of rate variables, and 'various logical or mathematical subsidiary equations' of other variables, can be achieved to express the changeable dynamic relations among various factors by mathematics. Therefore, it may meet many difficulties to get analytical solutions and modeling constructions to analysis dynamic systems with general compute languages.

To overcome these difficulties and to analysis dynamic systems conveniently, MIT engineers developed DYNAMO as a special simulation language in 1959. Professor J. Forrester, the project P.I, developed 'Industrial Dynamics' model in 1962, 'Urban Dynamics' in 1969, and 'World Dynamics' in 1971. After that, these approaches have used for quantitative and qualitative analyses of various social and economic phenomena including

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3 ‘Complex System’ is constituted of many components and these components interact with each other. More than the independent unique characteristics of each component, the interaction with each other in the system can produce new micro phenomena and cosmos. Components in one complex system produces constitute the other complex system and adapts to that system continuously. The interrelationship with each component is usually 'non linear' relationship and it constitute 'feedback loop'. And, 'complex system' is open system to connect the outside world. Therefore the boundary of complex system is sometimes vague.

4 ‘DYNAMO’ is the abbreviation for 'DYNAmic MOdel'.
societies, economies, educations, environments, resources, politics, foreign policies, and militaries.

The analytical methodology with system simulation languages, one of the methodologies to understand dynamic systems comprehensively in various fields, has been widely used since the beginning of 1960s. All methodologies related these approaches are so called "System Dynamics" because fundamental approaches do not have differences among each other.

4.2 Complex World vs. Simple Structure

A newly coined word, ‘six degrees of separation’ was popular around 2003. The meaning of this word was "anyone on earth can be connected to any other person on the planet through a chain of acquaintances that has no more than five intermediaries". It has same meaning of "small world". Likewise, things appear complex in this world, but the inherently fundamental structure and the relations are surprisingly simple. In natural phenomena or social phenomena, every component constituting phenomena can be categorized by five different types like 'conditional variables', 'rate variables', 'auxiliary variables', 'time variables', and 'constants'. Figure 1, briefly, illustrates the relationship between state(stock, level) and rate(in or out) variables.

![Figure 1: Relationship between State and Rate Variables](image)

As shown above, it is not difficult to express the complicated process, status, and cause-effect relations in the dynamic system with various mathematical function systems including calculus equations, as shown in figure 2. But, the easy expression with mathematical functions does not guarantee to achieve analytic solutions. A little more complicated dynamic systems may not be solved only with analytics. 'System Dynamics' can be the most useful tool to solve complicated dynamic systems with numerical solutions from the simulation.
4.3 Tools for the development of System Dynamics Modeling

The Simulator, DYNAMO had been widely used for the realization of System Dynamics modeling from 1959 to 1980s. In 1990s, the STELLA\(^5\) followed 'DYNAMO' with more strengthen graphic functions and operation availability in Window. Nowadays, VENSIM and PowerSim are popular. Especially, PowerSim is more powerful to solve optimization problems and to use practically control variables, and to be compatible with MS EXCEL data. It has also various expression methods of simulation results.

4.4 Formulating Process of System Dynamics Modeling

As can be seen in Figure 1, the formulating process of simulating modeling with System Dynamics is 7 steps like followings: ① Problem statement, ② Drawing the causal relationship chart, ③ Drawing the system flow chart, ④ Formulating modeling, ⑤ Behavior analysis of model, ⑥ Validity evaluation of the model, and ⑦ Policy analysis and decision making.

Figure 3 also shows the detail modeling development procedures and the related functions of PowerSim like followings;

First, one of related functions is to open initial data for modeling as an EXCEL file format, and to export the simulation results as EXCEL file format. Second, managing confidence intervals of simulation results with probabilities through the 'risk assessment' and the 'risk analysis' using various probability distribution functions, PowerSim can achieve analytic solutions of Optimal Control Problems. Dynamic optimization problem is also called as

\[ y(t) = y(0) + \int_0^t \left[ B(t) + M(t) - D(t) - OM(t) \right] dt \]  \hspace{2cm} (1)

\[ \frac{dy(t)}{dt} = B(t) + M(t) - D(t) - OM(t) \]  \hspace{2cm} (2)

\[ \frac{dy(t)}{dt} = \lim_{\alpha \to 0} \frac{\Delta y(t)}{\Delta t} \]  \hspace{2cm} (3)

\[ y(t + \Delta t) = y(t) + \frac{\Delta t}{\Delta t} \left[ B(t) + M(t) - D(t) - OM(t) \right] \]  \hspace{2cm} (4)

\[ y(t + \Delta t) = y(t) + \Delta t \left[ B(t) + M(t) - D(t) - OM(t) \right] \]  \hspace{2cm} (5)

\(^5\) STELLA is the abbreviation for "System Thinking Environmental Laboratory for Loop Analysis."
'Optimal Control Problem'. Third, PowerSim contains various useful 'Control Tools' for input and output. There are Switch, Slider, Gauge, Table, and Chart for the input and output control devices. And, there are also Time Table and Time Graph only for output control devices. Forth, PowerSim includes various intrinsic functions to deal with any logic of the situation. Functions can be classified by Logical Function, Mathematical Function, Statistical Function, Array Function, Complex Function, Conditional Function, Control Function, Conversion Function, Delay Function, Financial Function, Flow Function, Graph Function, History Function, Random Function, Time-related Function, Trigonometric Function, Miscellaneous Function, and so on. Fifth, performing Web Based Simulation connected with Internet through SDK(Software Development Kit), PowerSim can connect to other external Platform such as GIS softwares.

Source: Young-Pyo Kim, Seon-Hee Han, Mi-Jeong Kim, Ho-Jeong Kim, 2007, Development of Simulation System for Financial Investment Impact Assessment and Set-up of National Development Index(I) : Based on System Dynamics Approach, KRIHS. [Korean]

Figure 3: The Formulating Process of Simulation Model with System Dynamics
4.5 Simultaneously Solving from the Prospect of Future to the Measurement of Policy Efficiency

1) Simple Prospect of Future
There are many approaches to estimate and to prospect the future of national societies such as Time Series Analysis. In general, System Dynamics is known for the most comprehensive and practically useful method. The reason of the usefulness for the future prospect is because this method contains all variables including conditional variables', 'rate variables', and 'auxiliary variables' as not x type but x(t) type. X(t) type variables include time variables in themselves. Values of type x(t) variables contain time parameter. Therefore, values of variables reflect the time difference. The changing values according to the time difference can be prospects of future. The most important strength of System Dynamics is to estimate the prospect of every variable in the model. Therefore, System Dynamics can be possible to estimate various prospects and comprehensive outlooks. Moreover, System Dynamics can be used for prospects of the national future and establishments of strategies in many different social fields.

2) Prospect of Future and the Measurement of Policy Efficiency Together
The simulation model based on System Dynamics does the dynamic analysis more than simply static summing of various national projects or national policy results. System Dynamics can estimate not only the future prospect of previous policies but also the future prospect of new policy. So, researchers can estimate the efficiency of new policy through the comparative study of previous and new policy. They also prospect the ripple effect in each point of time in the future.

3) Solution of the Optimal Control Problem
System Dynamics before the advent of POWERSIM was used only for the measurement of policy ripple effects and future prospects. After the advent of POWERSIM, System Dynamics is developing to the level of the perfect preparation method deriving the dynamic optimal control condition with considering time flows. Adding to this, PowerSim provides the confidence interval of the potential power of the goal achievement and the probability of riskiness with the risk evaluation and the analysis. System Dynamics can clarify the best and the worst substitute scenario through the risk evaluation and analysis. It also automatically change variables' values to help the derivation of the possibility to achieve the best substitute and provide the new result.
4.6 KRIHS Accomplishments in System Dynamics Research

1) In the 1980’s

KRIHS published three research reports applying system dynamics technique between 1986 and 1989. In 1986, it carried out a research titled, ‘A System Dynamics Model for Impact Analysis of Planning and Investment on Socio-economic Changes in the Seoul Capital Region’. The research divided the capital region into a total of 31 cities and counties, and forecast the future of the six sectors of population, households, housing, land, industrial structure, and regional income, assessing the policy impact.


Figure 4: Flow Chart of Population Sector
In 1988, KRIHS performed the research on ‘System Dynamics of Investment Impacts : An Inter-regional Simulation Model’. The study classified the entire country into 28 regions, and forecast the population, households and housing, along with labor, capital, gross regional domestic product and landuse by industry. Also, it carried out the assessment on the impact of individual regional development projects. Lastly, in 1989, KRIHS performed ‘A Study on Land Price Forecasting Model’.

2) In the 2000’s

In 2003, KRIHS restarted the system dynamics related researches. The major research results are as follows. KRIHS researched SD-GIS integration methodology performing the research ‘A Study on GIS based Spatial Analysis Methodology’ in 2003 and 2004, and ‘Integrated Spatio-temporal Simulation Model for National Territorial Policy’ in 2005 and 2006. KRIHS began to develop large scale system dynamics model through the research ‘Pilot Simulation Model for Balanced Development Impact Assessment: Based on System Dynamics Approach’ in 2006. Now, KRIHS has been tried to develop the SD-GIS integrated model, for budget authority use, by the research of ‘Development of Simulation System for Financial Investment Impact Assessment and Set-up of National Development Index’ since 2007. Figure 6 shows several accomplishments of KRIHS in the system dynamic related research in the 2000’s.
Figure 6: KRIHS Accomplishments in SD Research in the 2000’s
Figure 6: KRIHS Accomplishments in SD Research in the 2000’s
5. GIS Techniques: Space Based Approach

5.1 Outline

Geographic Information System (GIS) is the most suitable tool to treat problems of spatial dimension. GIS is the computer based technique and methodology to collect, manage, analyze, modeling, and visualize spatial data. In here, spatial data include the geographic information to show locations and related attribute data. GIS is the technique and method to apply comprehensively and academically to many space related fields such as geography, computer science, remote sensing, demography, education field, spatial planning, geology, engineering, ecology, water resource fields, geodesy, archeology, and marketing.

In the early year, GIS technology focused on Informatization of maps. As GIS related technology developed, the usefulness of GIS is widely known. Supported by space related academic fields, GIS achieved the fame as the excellent spatial analysis tool.

Recently, GIS focused on the methodology development for 3D spatial visualization and analysis including the natural color and 3D visualization of spatial information, the construction of virtual cities, the simulation of urban management analysis, the construction of Cyber Territory, and the analysis of local investment policies.

5.2 Database Construction of Spatial Geographic Information

Data for GIS are collected from various resources such as maps, satellite images, CD-ROM or Internet. But, it is difficult to integrate data from various resources to one place. The construction of systematic integrating database for the flexible use of various spatial geographic information is prerequisite for making full use of GIS. In here, spatial geographic information database is defined as the table which has necessary information for the system construction or GIS analysis such as coordinate system, location, regional information in a row(or record), and attribute values suitable for each row such as variables and relevant data in each column(or field). The structure of database should be the relational database structure for connecting and interacting each record or attribute value with other record or attribute value. Of course, each database should be connected with relevant maps.

5.3 Construction of GIS Application System

It is possible to construct the GIS Application System in every field dealing with spatial geographic information. The field of the largest number of GIS Application Systems is
Underground Facility Management System field of local governments and the largest using GIS Application System is the 'Land Management Information Systems(LMIS)'. The 'Korea Planning Support Systems(KOPSS)' conducted by the 'Ministry of Land, Transport, and Maritime Affairs(MLTM)' and the 'Korea Research Institute for Human Settlements(KRIHS)' is considered as the successful project which improves the standard of GIS Application Systems. KOPSS provides 'multi-dimensional analysis model', 'urban renewal/regeneration model', 'land use planning model', 'urban facility supply suitability assessment model' 'public facility location allocation model', and 'landscape planning model'.

5.4 GIS Spatial Analysis

There are a lot of GIS spatial analyses from 'simple overlay', 'map algebra', and 'buffer' to more complicated spatial analysis such as 'proximity analysis', 'spatial operation', 'location analysis', 'location-allocation analysis', 'land use-transportation analysis', and 'dynamic model of regional population growth'. Combining more than two analyses together as occasion demands, it is possible to analyze target areas much better.

6. Optimal Control Methods: Human Based Approach

6.1 Overview

In general, there are two approaches to analyze certain phenomena; 'Static Approach Method' and 'Dynamic Approach Method'. Depending on approaches, optimization problems are also classified by 'Static Optimization Problem' without considering time and 'Dynamic Optimization Problem' with the distribution resources in considering time flow for matching objects of decision makers.

Previous one is called as 'Mathematical Programming Problem' and later one is 'Control Problem'. Control problems are usually found in socio-economic phenomena. Examples are 'Regional Investment Policy', 'Agricultural Product Price Policy', 'Regulation of the Money Supply', 'Control of the Interest Rate', and 'Reasonable Maintenance Cost and Removal Time of Apartment House Problem'.

Usually, control problems are constituted of 'time', 'condition variables', 'control variables', 'equations of motion', 'the end of time duration', and 'objective function'. The function relation of these components is like following formulas from equation 1 to equation 5 in Figure 7. Approaches to solve control problems are three different ways; calculus of variation, dynamic programming, and maximum principle.
6.2 Calculus of Variation

Calculus of Variation is the field of mathematics that was first developed through the procedure of the problem solution for the brachistochrone by G. Galileo in 1630s. J. Bernoulli expanded this to a theory in 1696. After that, this field had performed the important role to solve control problems in the field of natural sciences and social sciences till 1950s with efforts of many mathematicians such as L. Euler.

Control problems of classic calculus of variation is usually to get time path of condition variables to maximize integral calculus values of intermediate function constituted of condition variables, rates of change, and time variables within the scope of the given time. However, control problems of calculus of variation, unlike the general control problems, do not have independent control variables and the part of final functions in objective functions. Therefore, this approach has the weakness to deal with general control problem which has the restriction on one control variation from the given group of control variables. But, this weakness can be solved with 'Dynamic Programming' or 'Maximum Principle'.
6.3 Dynamic Programming

Dynamic Programming was developed by R. Bellman in 1950s. This method can directly apply to general control problems with maximum principle. Dynamic programming can solve control problems derived from Bellman equation based on the 'Principle of Optimality'\(^6\). Dynamic Programming is a more general approach than Calculus of Variation. But, it is usually impossible to get analytic solutions but possible to get a mathematical solution through computer simulations because Bellman equation, the prerequisite of Dynamic Programming, is 'partial differential equation'. In the case of big size models, time consuming efforts are necessary.

6.4 Maximum Principle

Maximum Principle, developed by L.S. Pontryagin in 1950s, and Dynamic Programming are similar both directly applied to general control problems but the difference is the prerequisite of Maximum Principle is 'ordinary differential equation' while Dynamic Programming is 'partial differential equation'. Therefore, the approach to control problems with Maximum Principle is much easier than Dynamic Programming. Maximum Principle is more useful approach than other two approaches. The optimal decision-making available on some of system dynamics software is none other than the application of this Maximum Principle.

7. Game Techniques: Simulation Approach

The three technologies reviewed in previous chapters, or time-oriented system dynamics technique, space-oriented GIS technology, and human-oriented optimal control technique, are not sufficient enough to completely construct the Integrated Three Kans System. Only after the 3-D expression technique and the game engine are added to the three techniques and technologies can a cyber geospace(territory) similar to the real world be produced. A simulation of a complete form can be carried out on this basis.

Of existing game engines, the one that is the most similar to the game engine this article pursues in the long run is the SimCity, the simulation of urban construction and management. Ultimately, the Integrated Three Kans System should evolve so much so that it can actualize the 3-D animation exactly reflecting the actual 3-D visualization, while distributed as a game, as the SimCity does.

\(^6\) Principle of Optimality' has the meaning "to make every efforts in current condition". As a mathematical expression, whatever initial statuses and decisions are, current decision making should select the best solution in current condition".
8. Approach to the Integrated Simulation System for Space, Time and Human Factors

8.1 World Interrelated with Time, Space, and Human

Fundamental elements of whether nature or human society are time, space, and human. The direction of Nature and human society in the interrelated world with three Kans is the balance and harmony. In analyzing natural phenomena or constructing human society, the harmony of three Kans leads to the most natural and the perfect result. Same result can be achieved for the government management or other activities such as science, literature, and art.

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7 Young-Pyo Kim, Seon-Hee Han, Mi-Jeong Kim, Rin-Gon Moon, 2001, Cyber Territory Construction in Digital, KRIHS. [Korean]
Young-Pyo Kim, Eun-Sun Im, Dong-Bin Shin, 2004, Strategies for Creating Cyber-National Territory toward the Ubiquitous World(I), KRIHS. [Korean]
Young-Pyo Kim, Seon-Hee Han, Mi-Jeong Kim, Ho-Jeong Kim, 2007, Development of Simulation System for Financial Investment Impact Assessment and Set-up of National Development Index(I) : Based on System Dynamics Approach, KRIHS. [Korean]

8 Phrases of ‘Chuang Tzu’, based on three-Kans, are introduced:

井蛙不可以語於海者 拘於虛也 [The frog in a well doesn't understand the sea, because it is bound to SPACE]
夏蟲不可以語於氷者 拘於時也 [The summer insect doesn't understand the ice, because it is bound to TIME]
曲士不可以語於道者 末於數也 [The stupid scholar doesn't understand the truth, because he is bound to REDECENSOR' dogma]
It is same to analyze social phenomena\textsuperscript{9} and to investigate government policies. The starting point to develop approaches or models for examining and understanding world interrelated with time, space, and human is to integrate three elements of Three Kans. The direction of every academic development is toward the approach or integrating model for the integration of three Kans in each field.

### 8.2 Establishment Plan for the Integrated System of Time•Space•Human Factors

1) Overview

As seen above, Phenomena of real world are results of interrelated time factors, spatial factors, and decision making factors of human. Therefore, the ultimate end of academic fields has developed to the establishment of frames and models for integrating time, space, and human factors. In the same manner, investigating natural rules, analyzing social phenomena, or dealing with government policies within the frame of temporal dimension, spatial dimension, and human dimension is necessary to derive the most suitable information and knowledge. It is necessary to develop the integrated system of 'System Dynamics' for the temporal dimension, 'GIS technology' for the analysis of the spatial dimension, and 'Optimal Control Methods' for the derivation of the reasonable decision making. To develop the model, the link to connect three different methods is important.

2) Connecting way for the integration

There are two different ways to get this link. As can be seen in Figure 9, the link can be achieved from the MS EXCEL or from the SDK (Software Development Kit). MS EXCEL is one of the most popular softwares for data management. Therefore, if a software can input and output of EXCEL type data, this software with MS EXCEL as mediation can construct the integrated or connected system.

\textsuperscript{9} ‘Revolutionary Wealth’ by Alvin Toffler deals with time, space, and human in Part Three "Rearranging time", Part Four "Stretching Space", and Part Five "Trusting Knowledge."
For applying the connection of this way, various variables ($x$) in the System Dynamics model should not restrict variables [$x(t)$] of time ($t$) but expand to variables [$x(t,s)$] of space ($s$), time ($t$) and further, probability. At this time, spatial units can be from administrative districts to regional districts, lots of land, or even pixel. Larger size of spatial units makes project easier but more difficult to achieve the objective of the project. On the contrary, smaller size of spatial units provides more detail analytical contents but more difficult to collect data and more time consuming and costly. Therefore, it is important to decide the suitable size of spatial units considering the objective and the cost of the project.

System Dynamics approach was just for the estimation of the future and the ripple effects evaluation of policies before the advent of PowerSim. After the advent of PowerSim, System Dynamics approach reaches to the level of the preparation method deriving the dynamic optimal control condition with considering time flows. Some GIS software also contains the method to solve the optimization problems.

If solutions in optimization problems are included in the System Dynamics or GIS software, it is easy to solve problems. If not, the program to solve optimization problems from the outside environment should be developed or obtained to link outside functions. But, it may need additional expert knowledge of optimizations.
Figure 10 is a comprehensive conceptual map of one single integrated model to be formulated by combining the aforementioned components of time, space, and human, and the simulation technique using a game engine altogether. In order to help understand, the five key cases in which the integration is partly taking place have been illustrated all at once in the figure, with the causal relationships with each other indicated. The hexagon five key cases include the UrbanSim, the Cellular Automata, the KOPSS and the $S^2F^2A$, as well as the SimCity.

Note: OCT: Optimal Control Theory  
SD: System Dynamics  
GIS: Geographic Information System  
SAP: Statistical Analysis Package  
CA: Cellular Automata  
KOPSS: KOrea Planning Support System  
$S^2F^2A$: Simulation System for Financial Investment Impact Assessment

Figure 10: Comprehensive Conceptual Map of the Grand Integration
Figure 11 shows the specific methods of connecting the system dynamics and the GIS by means of the SDK. Here, the connection between the PowerSim of the system dynamics softwares and the ArcGIS of the GIS softwares has been presented as an example.

In addition, in the long term, the time, space and human-integrated model requires a 3-D visualization of the simulation outcome. Also, it is necessary to turn the model into a component so that it can be easily utilized by unit model for the built large system when needed. The 3-D visualization should evolve to realize a 3-D animation exactly reflecting the real world while distributed as a game like the SimCity. In addition, the efforts of turning the unit model into a component should be also made at the same time in order to enhance flexibility in using the model. Figure 12 shows the conceptual map of the component methodology, and Figure 13 examplifies a component type SD-GIS integrated model.
Figure 12: Conceptual Map of the Component Methodology

Figure 13: Component Type SD-GIS Integrated Model
9. Conclusions

As explained in previous chapters, it is not a simple task to construct a multiple-use time, space and human-integrated simulation system based on the system dynamics and the GIS. Still, it is possible to achieve the task in the mid- and long-term. This is because the related technologies are advancing rapidly, and because there are a lot of data accumulated so far. However, even if the construction is initiated immediately, the use of the time, space and human-integrated system is expected to reach the level the GIS is currently used by 2020 as suggested in Figure 14, given the speed the GIS technologies and information, and system dynamics techniques spread in the past in the nation.

In other words, it is desirable that this task promoted in collaboration among stakeholders under a mid- and long-term plan from now on. The academic circle should develop related theories, with state-run research institutes presenting related policies and directions, and private enterprises making ceaseless efforts for developing relevant technologies. In particular, the government should recognize that this business can grow to become a future growth engine of the country to lead the development of cutting edge technologies, and provide related laws and institutions, along with financial support.

Figure 14: Project for Time-Space-Human Integrated System Construction
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