Land Use Decision-Making Strategy in Bandung: An Agent-Based Modeling Approach

Ilham Fadhil Nurdayat and Manahan Siallagan

Abstract Land system science as a complex system has been explored by using various approaches such as remote sensing, economics, ecology, and geography. Agent-based modeling (ABM), as a third way of doing science, enables researchers to explore the complex system deeper on land science. Interdisciplinary approach has brought land use science into agent-based modeling. Bottom-up view and inclusion of agent as real-life representation brought a powerful method to analyze land use change and cover (LUCC) and explore coupling between human and natural system. Land use decision-making is a function of interaction between internal models of the land manager with its environment. This study incorporates two variables, commercial and farm expectation, as a representation between productivity farmland and other commercial objectives of the land. Agents have the ability to alter land use based on rational and irrational decision-making process. The objective of this paper is to capture the behavior of the agent and observe land use change that resulted from agent decision-making.

Keywords Agent-based modeling • Decision-making strategy • Land use change and cover

1 Introduction

Java Island, in the early 1990s, has been experiencing the beginning of change of land use, especially the agricultural land. City expansion caused to shift the agricultural land into other cover, such as settlement and industrial area. Economic growth has been a catalyst for urban growth in Java Island [1, 2]. The economic

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growth that centered in urban area demanded goods and services other than food. Food production moves farther relative to urban area. Average return of agriculture is lower than other opportunities in urban area; thus, farmers change their activities that resulted from land trade or land use change. Aggregation of those phenomena has driven lower agricultural production which in the long term becomes vulnerable to national food security [3]. In addition, stagnant productivity in agricultural production cannot increase regional and national production capacity. Study about land use change and cover (LUCC) is important to understand its land use impact and study the impacts.

Bandung is the capital of Jawa Barat province. Established in the colonial era, Bandung was developed to become a plantation hub. This plantation hub grew becoming the center of economic activity in present day. Based on the government's statistics agency, in the end of 2014, Bandung was inhabited by 2,470,802 people. This figure reflected a slight decrease from previous year, where 2,483,977 people were registered in Bandung area. Meanwhile, Bandung Regency recorded an increasing number of residents, from 3.415.700 in 2013 to 3.470.391 in 2014. A decreasing number of residents in Bandung city are accounted by the rapid development of city center, thus resulting in high rent land. Residential and mostly agricultural lands drive to move into fringe of Bandung city. This could have an effect on shrinking agricultural land, thus decreasing the food production [4]. Concentrated urban area, such as in Indonesia, needs to develop sustainable urban development. Sustainable food production is one of them. The study about the land conversion in urban area, especially in Bandung, would give insight to Bandung policy makers for a better understanding of the behavior of LUCC in Bandung area.

Previous approach has been focusing on macro level by analyzing the factor that affected the LUCC. This approach allows the researcher to study the detail of the factors and make decision based on that information. Hence, an intervention will be developed based on that factor. Land system science is needed for interdisciplinary approach to describe the situation [5, 6]. Interdisciplinary field concerning climate change, food security, urban planning, and ecological studies has been studied using various approaches such as mathematical modeling, econometrics model, and remote sensing. Most of the approach focuses on top-down approach of the subject. Each modeling approach has different purposes and goals [7]. Top-down approach advantage enables the decision-maker to make general action, although the dynamics of the situation is less captured in this approach. In complex situation such as LUCC, capturing the situation dynamics will improve the understanding of actual situation.

Agent-based modeling (ABM) on decision strategy can offer alternative explanation in LUCC. The dynamics of the situation of the agent-based model can give a richer picture to the land system science. The dynamics of the situation in LUCC is captured by the interaction among agents. This agent is defined as landowner whom can change the purpose of their land use based on their strategy in decision-making. Difference in decision-making strategy results from their mental model, availability of information, and expected utility value of each agent. This dynamic interaction aimed to be preliminary studies for household decision-making regarding their land use decision.

2 Literature Review

2.1 Complexity of Land Use Change and Cover (LUCC)

LUCC have different sources of complexity in relation to human land use decision from human decision-maker to potential global-scale influences [8]. Complexity science focuses on disorder, instability, and change. This complexity can emerge from nonlinear interaction among land's stakeholders. Complexity of the interaction aimed to capture the progression of LUCC based on landowner's decision. In human decision-maker level, individual land manager can employ different strategies. Individuals can make their own strategy based on their preferences, beliefs, information, behaviors, and expectations.

Recent development in land use science enables us to incorporate the behavior of human and the society, the multilevel characters of decision-maker and land units, and how are they connected to a broader world [9, 10, 11]. That opens the opportunity to study interdisciplinary aspect in land use. Previous studies have attempted to combine land use, geographic information system (GIS), human behavior [11], food security, and climate change [12]. This development opens the opportunities for social science to develop strong social simulation [13].

Previous model explicated the causality of the land use change by modeling the trade, supply, and demand that are connected by endogenous price mechanism. Deeper understanding of LUCC different approach. Land use change caused by supply and demand process is not included in the model. Remote sensing is used to focus on land supply and spatial pattern data. This model is beneficial when explaining about spatial limitation and land resources. But this modeling approach cannot capture endogenous supply, demand, and trade [10].

LUCC rely on the decision-making of the land manager for productive, rent, or other purposes. The decision is affected by the environment, economic opportunity, social aspects, and government regulation. This research focuses on farmers as land managers, because household farmer is the backbone of the agricultural production in Indonesia. Despite its important role, the numbers keep decreasing. From agriculture census data in 2013, the number of household farmer decreases 16, 32% compared to 2003. This event resulted in decreasing agricultural production.

2.2 Driving Forces and Actors

Previous studies focus on identification of driving forces in land use change. Ecological field has seen natural factors as driving forces especially that alter environmental condition [14, 15]. In the development, driving factors alone cannot cause land use change, in order to create decision of the land use. Driving factors need to interact with the decision-maker. Natural, politics, social economy, culture, technology, and society were the main driving factors in interdisciplinary studies of land use change. Each of the driving factors has different ways of influencing the decision-maker.

Interaction between actors and driving factors is summarized into four models [16]. The first (DF-C) model is that driving forces are directly related to land use change. Causal relationship is not of prime interest in this model. The second (DF-A-C) model represents that driving forces have an influence toward actors' motivation and therefore actors' actions. The third model (DFA-C) focuses on the close relation and interaction between actors and driving forces that caused land use change. Change occurs as a result of that interaction. The last model (AC) depicted that actors have central role in land use change; this model represents the situation where driving forces are elements of the environment in which actors make decision. Each type of model has a different approach to capture the situation. AC model type represents that actors have central role suitable with research objective. Agent-based modeling was appropriate to describe this type of model because in ABM the modeler focuses on the actor and actors' actions, motivations, decisions, and discouragements. Different types of actors result in heterogeneous and more dynamic interaction of the problem.

2.3 Strategy of Decision-Making

The strategy is a process of taking decisions by the agent, from how he gets his information to how to use that information to make decisions. The fundamental assumption of decision in microeconomics is that the people maximize their benefit and minimize the cost. This way of thinking is also described as rational decision-making. People assume they have adequate information and analyze it to get maximal outcome. The strategy is a process of rational strategies applied by taking into account the profit and loss as a result of the action.

On the other hand, other disciplines suggested people are rational decision-makers, even when they are facing a variety of limitations. Based on Kahneman's work, people cannot take rational decision if they are facing incidental risks, making them prone to intuitive decision. At the stage of decision-making, the rational assumption might be useful, but to see the dynamics resulting from interactions need enter the presence of irrational strategy.

In everyday interactions, the two strategies above may occur for personal decision-making depending on whether it has enough information and what mental model that he had. Lack of information can lead to people taking decisions based on the available data, even if it has no relevance. This paper aims to see how the dynamics between the two strategies in the related land use decision-making (Fig. 1).

3 Methodology

This research focuses on a high-level abstraction model by incorporating individual land manager strategies into the simulation model. This model was built using two decision strategies which constitute in this paper as "rational" and "irrational."

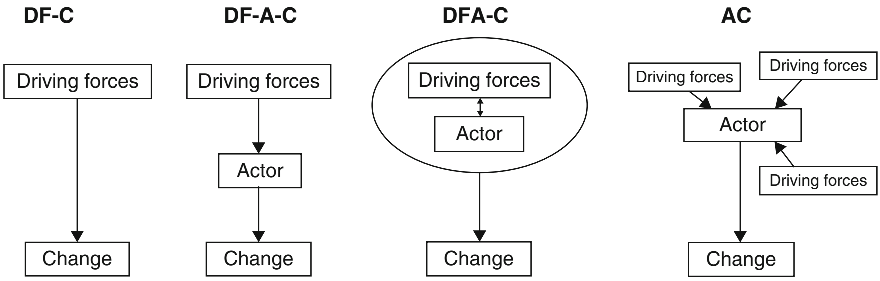

Fig. 1 Driving force and actor linkage

Rational decision-making strategy is described as decision-making strategy to maximize outcome of the landowner. Each agent has production function to produce to fulfill the demand. Irrational decision-making strategy is explicated as human behavior to make decision based on the rule of thumb and decide land use based on relative valuation, although it's not symmetric information. Several assumptions and limitations will be applied in this model; a more detailed explanation is included in simulation model section.

Agent-based modeling (ABM) is used in this study to capture heterogeneous condition in individual decision-making strategy. ABM has the advantage to incorporate the behavior aspect to agent decision-making strategy. These studies observe interaction between agents that have different decision strategies.

Individual decision-making is affected by extensive factors, internally and externally. Internal factors such as personal belief, culture, and past experience have been studied using the theory of planned behavior, factor analysis, and qualitative analysis. On the other hand, external factors, such as the environment, information access, and policy, have been studied in the macro-focused discipline. In microeconomics, the decision-maker is the center of studies. Individual behavior and action are theorized and hypothesized. The fundamental theory of microeconomics suggests that human decides based on rational aspects, in other words, maximize the benefit and minimize the cost. This hypothesis affected the decision-maker's view to develop an understanding of the problem and the solution of it.

4 Simulation Model

Overview, design concepts, and details (ODD) protocol was developed as structured design for an agent-based design process, to overcome barrier in the specification and explanation of the model. Thus, the model could avoid misunderstanding among other researchers and create bigger opportunity to replicate, refine, and redesign for further research [17]. Application of ODD protocol has not been widely used, but there are an increasing number of researchers attached to their ODD protocol in their paper. Critiques for the proposed ODD protocol were the methodology generated from ecological perspective, and some adaptation was needed to be accommodated that includes human decision-making process [18]. The organization of section will follow section and elements in ODD protocol.

4.1 Overview

4.1.1 Purpose

This model was intended to explore and understand land use change decision-making strategy. This research will look at agent's decision-making strategy regarding their land use. Decision-making strategy was divided into two types: "rational" and "irrational" ones. Both interact with each other in order to decide what decision they take for their land. Targeted users of this model are academicians, researchers, and decision-makers.

First, strategy is derived from farmer economic strategy in making decision to use their resource [3]. Land is assumed as one of the farmer's resources; thus, "rational" strategy was selected to represent landowner behavior. Second, strategy selection is based on basic human behavior to mimic other decisions with limited information. Further process will be explained in the next section.

Emergent properties of the model intended to see which strategies generate disparities among land use. Land use is simplified into two categories: the first is agriculture and the second is nonagriculture to support the model intention. Model intention does not make prediction or projection, but means to study decision strategies that have influence over land use decision of the land manager. Individual-level decision in aggregation will drive change in macro-level properties (Fig. 2).

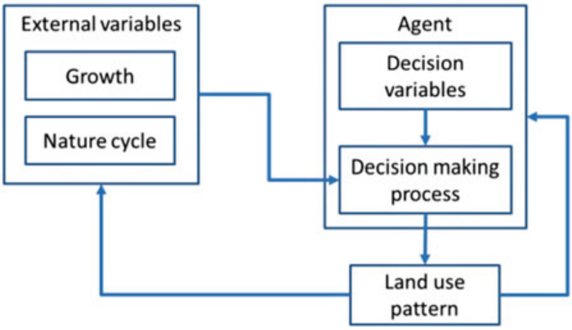

Fig. 2 Conceptual framework

4.1.2 Entities, State Variables, and Scales

The model will consist of two main entities: the environment and the agent. Current model represents human decision-making strategy. This model excludes spatial aspect and only focuses on decision strategy aspects. Agent will interact with the environment and other agents that consequently influence agent's decision-making attribute and process. Each agent is assumed to own a land without considering the dimension and characteristic of the land. Each agent has decision toward the use of their own land.

Landowner agents have state variables as follows (Table 1).

The environment has state variables as follows (Table 2).

4.1.3 Process Overview and Scheduling

Every time step, agent's land use decisions were determined by a decision-making strategy they were assigned. For agent irrational-type decision-making strategy, information sharing and asymmetric information were included in this process. Two spots were provided for the agent to exchange information within the spot. Information sharing is restricted to only in their spot. The spot in this model is named komunitas. Komunitas is an Indonesian language for community or in this paper defined as a place or activity for information sharing with other agents.

A probability of 0.5 is randomly assigned in the beginning of each time step to komunitas 1 or komunitas 2. Komunitas acts as an institution for agents to share their information about their productivity. Information sharing is represented by forming average productivity.

Table 1 Agent's state variables

Variable	Brief description
Productivity	Level of agent production rate given to resources
Capital	Starting and accumulated resource for production activity
Probability to change	Agent willingness to change, represented by a number between 0 and 1
Satisfaction	State of agent's satisfaction to their condition. Satisfied or dissatisfied
Decision strategy	Which decision strategy the agents chose. Rational or irrational

Table 2 Environment's state variables

Variable	Brief description
Demand	Demand that should be fulfilled by agent production
Average land use	Calculated average
Agricultural growth	Rate of agricultural land use resource
Nonagricultural growth	Rate of nonagricultural land use resource

$$\text{averageproductivity} = \frac{n_1 + n_2 + n_3 + \cdots + n_i}{\sum i\text{komunitas}} \tag{1}$$

$$\text{productionfunction} = \text{capital} \times e_i \tag{2}$$

$$\text{random}(x) < \text{probability} \tag{3}$$

Each agent will use average productivity as benchmarking standard. If their productivity is below average, they will increase probability to change the land use; otherwise, if their productivity is above average, they will increase the probability to unchange the land use.

Rational agent type has a different decision-making strategy; this type doesn't rely on other information to make decision. The agent relies on production activities that resulted from Eq. (2). The outcome of the equation will be used to fulfill external demand. If they cannot fulfill the demand, the probability to change land use will increase.

After the agent updates their probability, land use change process is triggered by random number generation between 0 and 1 to run Eq. (3). If probability of the agent is larger than random number, then the agent will change their land use from farm to commercial and vice versa. After each conversion the probability will reset to 0.1 to represent wait-and-see action after they convert their land.

4.2 Design Concepts

The emergence of this model is only represented by structural change in land use, excluding spatial aspects. Interaction between agent and driving forces holds central role in this research to capture an idea of how different decision-making strategies result in different land use patterns. Driving forces that shape land use are categorized into political, economic, cultural, technological, and natural. Economic and natural driving forces are included in the model. Economic forces in the urbanization argument are central to attract people and activities. Natural aspect represented resources of the land, and agricultural use accounted for the land quality. For each production activity, land quality decreases, but periodically land could update the resources, thus simulating season in Indonesia.

Agricultural type of land is used by the owner as a farm to produce crops or as a green space. This type of land has been decreased in effect of urban development that directly and indirectly pushes the land use change. Nonagricultural land includes land for commercial purposes such as service or manufacturing activities. This type of land has been increasing in urban area recently. But the generalization of nonagricultural land may be considered too broad, because residential lands were included in this type although this is not a productive type of land. Agricultural activity relies on the availability and the quality of the land as production factors, thus resulting in competition of land. Interaction among stakeholders affected governance structure, production, consumption, technology, ecosystem services, and global environmental change in human activity in regional and international scale.

4.3 Details

4.3.1 Initialization

Initialization phase begins with generating agent decision variables and external information. Decision variables for agents consist of economic and natural productivity. Selection of these variables was based on five categories of driving forces in land use change. Economic and natural driving forces were selected to represent competition between agricultural and nonagricultural land use. Further research is needed to comprehend this selection of decision variables.

This model begins with high level of abstraction. All agent variables are set to 0.2 to assume similar productivity in the land. Productivity will differ from several scenarios. Each productivity represents different types of land; economic productivity is for non-farmland which in the real world is used for commercial activities such as trade, manufacturing, and service. Natural productivity in this model represented agricultural production in farmland.

4.3.2 Scenario

Describing different decision-making strategies in this model was done using several scenarios in order to give clearer distinction to each process. The following are the scenarios that were implemented in this model (Table 3).

Scenario 1, 2, and 3 emphasis on irrational and rational decision-making strategy focuses on each decision-making strategy and how they interact with each other. The total number of land used for farm or commercial will be used as emergence properties to view these two decision-making strategies.

Table 3 Model scenario

Name	Description
Scenario 1	Irrational decision-making strategy
Scenario 2	Rational decision-making strategy
Scenario 3	Irrational and rational decision-making strategy

5 Result and Conclusion

In this section, we will describe and discuss the simulation result. First, we look at decision-making strategy change, and second, we analyze the relation between the two decision-making strategies in deciding land use.

In scenario 1, agents were assigned to have irrational decision-making strategy, and the result seemed the land use did not have distinctive patterns. They change their land use according to the information they have in the community, and the land manager is constantly adjusting the land use to the information they have.

In scenario 2, agents that are assigned to rational decision-making strategy inclined to convert their land into commercial land. This pattern emerges from the beginning part of the iteration. In Fig. 3 total land use number in scenario 1 showed that land use change rate is very rapid; in less than half of the total 200 iterations, almost all landowners have convert their land to commercial land (Figs. 4 and 5).

Different rules were adapted to natural and economic productivity to capture real-world condition. For natural productivity, each time step in this productivity will decrease for six periods for 0.1 per each time step, and then at the sixth time step, the productivity will rise to 0.3. This rule meant to capture farming cycle due to natural condition of soil quality, season, etc. On the other hand, economic productivity was designed to adjust to the demand with 5% standard deviation.

Scenario 3 incorporates between irrational and rational decision-making strategy. The result of this scenario captures the interaction between those. Total land use number in scenario 1 has emerged but with some volatility in all iterations. Although nonagricultural land type has been the most land use, the number of farmland in this scenario is significantly larger than scenario 2. This evidence could show us that

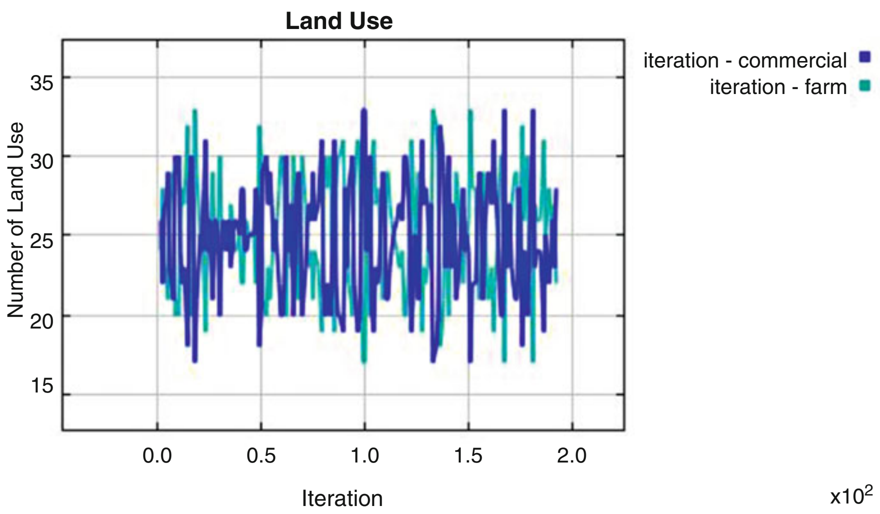

Fig. 3 Total land use number in scenario 1

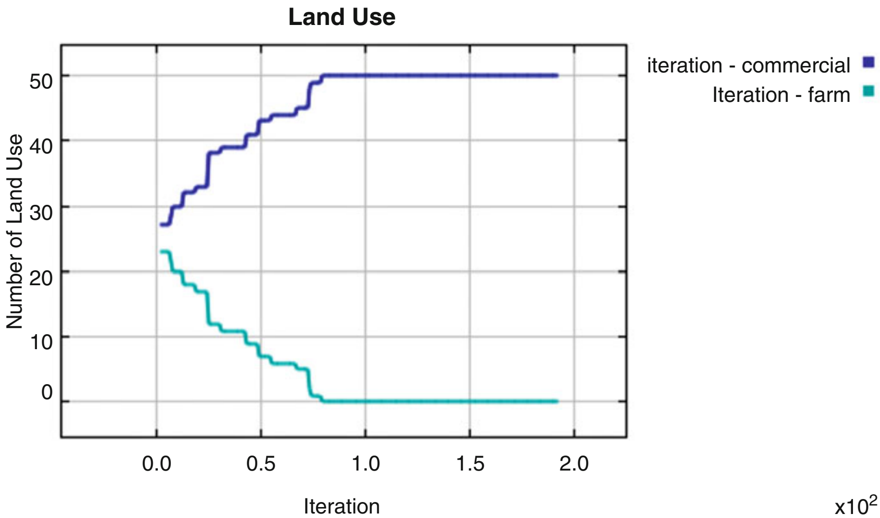

Fig. 4 Total land use number in scenario 2

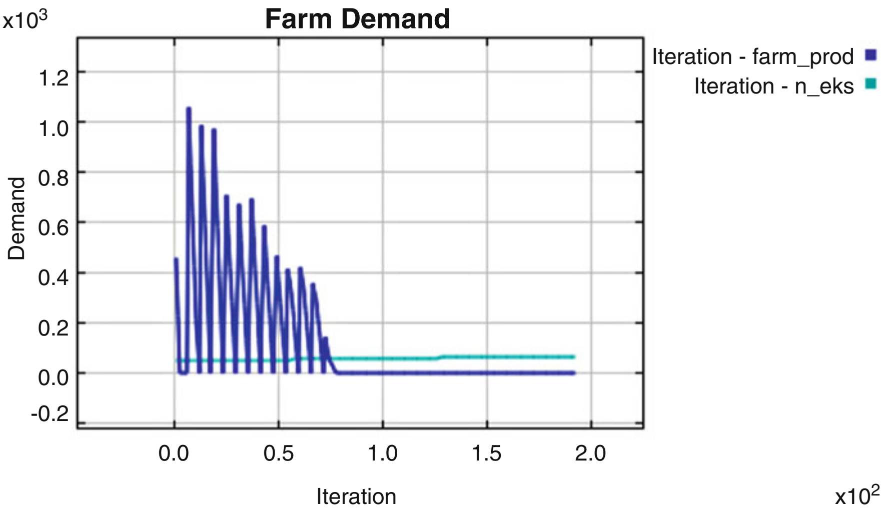

Fig. 5 Total land use number in scenario 3

the irrational decision-making strategy has increased farmland in the model. Main driving irrational and rational agent type sharing their information about their land use that increase volatility of the land use change and increase number of farmland (Fig. 6).

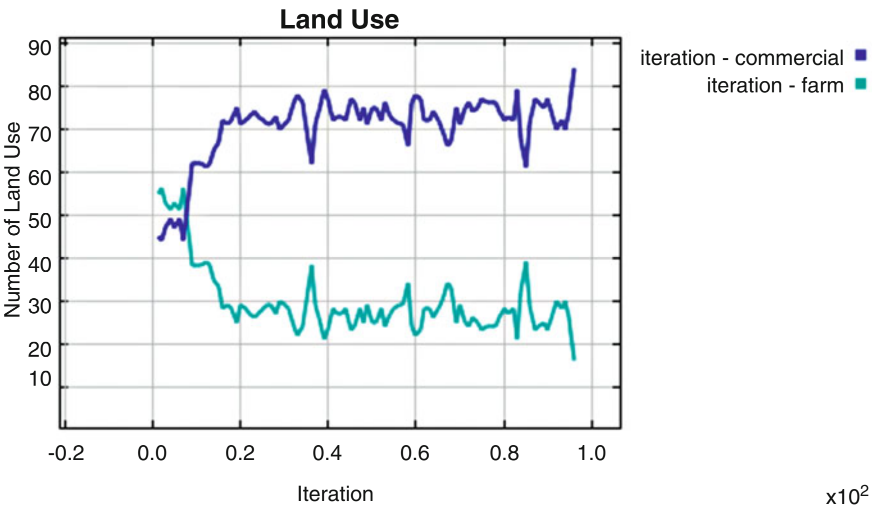

Fig. 6 Demand fulfillment comparison in scenario 2

This model showed in the broad sense that different decision-making strategies of the agent could result in different land use types and patterns. Irrational decision-making only relies on other information not regarding the truth and completeness of the information. This kind of agent decision-making strategy can be observed in the real world. In land market, rumor, gossip, and word of mouth have important roles to shape people's decision.

The opposite decision-making strategy was described in the rational strategy. The agent ignores information from other agents and relies only on external environment driving forces. Decision-making strategy has a close resemblance, based on our analysis, with the fundamental approach in capital market. Rather than using relative valuation tool, they studied about the business process and prospectus of the company. This decision-making strategy was considered more rational because the process agent could maximize the opportunity.

Economical and natural decision variables in this model are claimed as the beginning phases in the model building. Each driving force only affects one land type, and in the future several driving factors could be included in one equation to represent a decision-making result of intertwined several driving factors that cannot be separated. This view supports the fact that in Bandung, based on National Institute of Aeronautics and Space (LAPAN) satellite imaging, agricultural lands have been decreasing more than 90% since early 2000. Several studies argue the decreasing process is due to Bandung economic growth that shifts the main activities to factory, craft, and service. Increasing demand for settlement has driven up land price, thus shifting benchmarking process with agricultural production result. Short-term high land price creates incentive for land managers to change their land use for more optimum outcomes.

In understanding build complexity, we must build a complex model. But to build this model that could represent complex model is a long road we take step by step. Comprehension and a deep understanding of the model result in the better model. This is the main objective of this study: to develop high-level abstraction model to represent decision-making strategy, excluding spatial aspect in land use change. Decision-making strategy, the object of the study, is an important aspect to consider in land use change modeling. The pattern that emerges from land use change is not only caused by actor and driving forces but also from decision-making strategy in the individual level. Aggregation of individual level will create properties in, national and international stage. Agent-based modeling enables researcher to explore that particular objective and area of study.

Further research is needed to add more decision variables and driving forces into agents and decision-making strategy. Interplay between variables and different kind of decision making strategy in deciding land use change is important aspect in developing model and policy. Parameterization of data using real-world data to add verification process will strengthen the result of the study.

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