Teten W. Avianto[1], Utomo Sarjono Putro[2], Pri Hermawan[3]

SYSTEM DYNAMICS APPROACH TO SUSTAINABLE FOOD SECURITY POLICY

The objective of this paper is to evaluate system dynamics as an approach to policy design, as well as the method to cope with a complex problem of food security policy. First, this paper exposes the food security concept, and food security criteria. Second, it studies the issues of modelling for food security policy, and reviews the existing models. Third, it discusses the system dynamics as one of the existing model for food security policy. Finally, it concludes how to develop system dynamics to cope with food security. This paper proposes a new method of combining system dynamics with spatial concept as applied to food security policy.

Keywords: *system dynamics; food security; sustainable policy; Indonesia.*

Тетен В. Авіанто, Утомо Сарйоно Путро, Прі Херманав

СИСТЕМНО-ДИНАМІЧНИЙ ПІДХІД ДО СТІЙКОЇ ПОЛІТИКИ ПРОДОВОЛЬЧОЇ БЕЗПЕКИ

У статті системну динаміку розглянуто як підхід до розробки політики та рішення складної проблеми продовольчої безпеки країни. Представлено концепцію продовольчої безпеки та її критерії. Описано моделювання політики продовольчої безпеки та вже існуючі її моделі. Продемонстровано, як системна динаміка може бути використана в моделюванні такого роду. Запропоновано новий метод моделювання, що поєднує у собі системну динаміки та просторову концепцію в застосуванні до політики продовольчої безпеки.

Ключові слова: *системна динаміка; продовольча безпека; стійка політика.*
Рис. 3. Табл. 2. Літ. 16.

Тетен В. Авианто, Утомо Сарйоно Путро, При Херманав

СИСТЕМНО-ДИНАМИЧЕСКИЙ ПОДХОД К УСТОЙЧИВОЙ ПОЛИТИКЕ ПРОДОВОЛЬСТВЕННОЙ БЕЗОПАСНОСТИ

В статье системная динамика рассмотрена как подход к разработке политики и решению сложной проблемы продовольственной безопасности страны. Представлена концепция продовольственной безопасности и её критерии. Описано моделирование политики продовольственной безопасности и уже существующие её модели. Показано, как системная динамика может быть использована в моделировании такого рода. Предложен новый метод моделирования, сочетающий системную динамику и пространственную концепцию в приложении к политике продовольственной безопасности.

Ключевые слова: *системная динамика; продовольственная безопасность; устойчивая политика; Индонезия.*

1. Introduction.

1.1.Background. Demand for food on the one hand, and the scarcity of food resources on the other, cause food deficit. Scarcity of food will rise its price. And then, the availability of food will determine food security. World food shortages have made food a scarce commodity, thus in some cases determining the sovereignty of a nation. National food stock in Indonesia is decreasing because of national consumption and food exports. Otherwise, the national food stock will increase because the supply of domestic agricultural product include marine fisheries products and imports (BPS, 2012).

[1] School of Business and Management, Bandung Institute of Technology, Indonesia.
[2] School of Business and Management, Bandung Institute of Technology, Indonesia.
[3] School of Business and Management, Bandung Institute of Technology, Indonesia.

Food security development program in Indonesia is aimed to operationalize the development in term of promoting food security at both national and community levels. Food in general terms covers food produced from plants, animals, and fish to fulfil the need for carbohydrates, proteins, fats, vitamins and minerals for people to be active and healthy.

Food security can be defined as sufficiency of food in terms of availability in quantity, availability at all times and in all regions, easy to get, safe to consume, at affordable prices. All of it could be achieved with implementing the subsystem of availability, the subsystem of distribution and the subsystem of consumption.

1.2. Research agenda, objectives and contribution. This paper intends to answer the questions of: 1) why system dynamics is feasible to cope with such a complex problem as policy design; 2) what factors improve system dynamics to cope with spatial problem in sustainable food security policy.

The objectives of this paper are: 1) to evaluate why system dynamics is applicable to food security policy; 2) to develop a new method of combining system dynamics with spatial concept for more feasible food security policy in Indonesia.

2. Food security.

2.1. Food security concept. Food security definition and paradigm have been developing since the Conference of Food and Agriculture in 1943 promoting the concept of secure and suitable supply of food for everyone. There are many definitions of food security, however principally food security comprises the aspects of availability at all timeas and secure access for healthy life. This paper will refer to food security development since 1943 and the definition of the regulation of UU No. 7/1996 about food (Indonesia, 1996).

2.1.1. Development of food security concepts. In 1974 there was the World Food Summit. The international event was arranged to disscuss food security, food volumes and supply.

Until 2001, the definition of food security has been refined many times. FAO defines food security as availability of food for all people at all times their sufficient healthy physical daily life, secure access to choose their food preferences in any social and economic conditions (FAO, 2002).

2.2. Food security criteria. Basing on the chronological concept development, referring to FAO since 1943 till 2001, food security is a complex system that consists of subsystems: food availability, food access, food utilization, food stability (FAO, 2002).

Recently, the food security has been connected to global condition of the environment, and the concerns raised about sustainable development. Food security presently comprises the aspects of nutrition, health, economic development, environmental concerns and trade.

Based on the reveiew of food security concepts in chronological development, and the definition from regulation of Indonesia (Indonesia, 1996), food security policy system has to have the criteria as follows: Availability – Quantity, Availability – Quality, Access – Distribution, Access – Price, Stability – Behavior over time, Sustainability.

3. Modelling for food security.

3.1. Required model criteria for food security policy. As explained in Part 2, sustainable food security consists of 6 aspect: 1) availability in quantity; 2) availability in quality; 3) access – distribution; 4) access – price; 5) stability – behavior over time; 6) sustainability.

Availability in Quantity is that food has to be available in terms of its quantity. *Availability in Quality* means food have to be of good quality, healthy, nutricious. *Access – Distribution* is that food has to be distributed between all regions with the intention that all people can reach it easily. *Access – Price* is that food must be distributed to all parts of Indonesia under affordable prices. *Stability* is that food has to be available all time in a year period, fluctuations have to be tolerable. *Sustainability* is that food has to be, available in a longer period of time. The balance between resources and consumption is the main concern here.

Reviewing the 6 aspects above, some of them need same criteria and the others need specific criteria. Aspects of availability in quantity, availability in quality, access – distribution, access – price and stability need modelling criteria of *point prediction*. Aspects of availability of quantity, access – distribution, access – price, need modelling criteria of *quantitative detail*. Aspects of availability in quantitative, availability in qualitative, access – distribution, access – price, stability need modelling criteria of *short-term perspective*. Aspects of availability in quantity, availability in quality, access – distribution, access – price, sustainability need modelling criteria of *long-term perspective*. Aspect of access – distribution need specific modelling criteria of spatial concept. Aspects of access – distribution, sustainability need modelling criteria of holistic complexity. Aspects of access – distribution, access – price, stability, sustainability, need model criteria of *lag/time delay concept*. All of these aspects need modelling criteria of *behavior/dynamics*. The matrix of food security aspects and model criteria are shown in Table 1.

Table 1. **Matrix of food security aspects and the model criteria,** *authors'*

Desired model criteria	Food security aspects					
	Availability in Quantity	Availability in Quality	Access – Distribution	Access – Pricess	Stability	Sustainability
Point prediction	X	X	X	X		
Quantitative detail	X		X	X	X	
Short-term perspective	X	X	X	X	X	
Long-term perspective	X	X	X	X		X
Spatial concept			X			
Holistic complexity			X			X
Lag/time delay concept			X	X	X	X
Behavior/dynamics	X	X	X	X	X	X

8 criteria for modelling have been discovered for the purpose to cope with the problem in 6 aspects of food security policy. The criteria as the capability of a model to describe food security policy are as follows: 1) point prediction; 2) quantitative detail; 3) short-term perspective; 4) long-term perspective; 5) spatial concept; 6) holistic complexity; 7) lag/time delay concept; 8) behavior/dynamics

There are no ideal modelling approach capable to describe a problem as the 8 criteria listed above. Therefore, some modelling approaches have to be reviewed to find the most appropriate one to cope with food security policy problem.

3.2. Reviewing the existing modelling methods for food security. With relation to food security policy, we review 7 modelling approaches. They are selected here because they are widely recognized, and have robust theoritical foundations: 1) statistical regression; 2) econometrics; 3) input-output modelling; 4) optimization; 5) agent-based modelling; 6) causal model; 7) system dynamics.

The 7 existing models are reviewed by comparing them with modelling criteria as described in Section 3.1. The required model criteria for food security policy are reviewed as applied to the selected approaches (see matrix in Tabel 2).

Table 2. **Matrix of model criteria and selected approaches,** *authors'*

Model	Required model criteria for sustainable food security policy							
	1	2	3	4	5	6	7	8
	Point prediction	Precision	Short-term	Long-term	Spatial concept	Holistic complexity	Delay concept	Dynamics
Regression	x	x	x					
Econometrics	x	x	x					
Input-output modelling	x	x	x					
Optimization		x	x	x				
Agent-based modelling		x	x	x				x
Causal model			x	x				
System dynamics				x		x	x	x

In the context of food security policy, econometric and regression models could be developed based on the availability of time series data. It could be used for point prediction by extrapolation from time series data. The precision of a prediction depends on how far back the data could be retrieved. The length of prediction in the future is determined by how long historical data could be collected. In food security policy, this model is widely used. It could predict the availability of food in quality, quantity, prices, productivity etc.

Input-output model uses histroical data rather than describes causal interdepencency among factors, therefore it could not expalin why the problem happens. This model could descirbe whether performance was typical, optimal, efficient, or desirable, not whether the system was in equilibrium (Meadows and Robinson, 2007; Sterman, 2000).

Optimization model is the explanation of system conditions, which is to be maximized, or of the cost to the system to be minimized. Control variables are all policy choices available to decision makers (Meadows and Robinson, 2007).

Agent-based modelling (ABM). As compared to other models under review, agent-based modelling is relatively new. ABM is the modelling of interacting agent with other agents and the environment in a dynamic system. ABM describes a theory construction in a simulation approach (Jaccard and Jacoby, 2010).

J. Jaccard and J. Jacoby (2010) stated that the most prominent approach to the theory construction in social sciences is causal thinking and causal modelling. By thinking in causal terms, we are able to identify systematic relationships between variables and manipulate those variables so as to produce change in phenomena that are scientifically or socially desirable to change (Jaccard and Jacoby, 2010).

System dynamics model describes the structure of a system that determines behavior over time. Structure always contains feeback. Understanding the mechanism of change in a system is more important than precise forecasting of events (Saeed, 1994). Management controls organization's behavior by first understanding what causes that behavior, and then designing policies to change behavior as desired (Lyneis, 1980). In this paper we select system dynamics due to its capability to describe long-term perspective, holistic complexity, delay concept and dynamics.

4. System dynamics as methodology for policy design.

4.1.Level of perspective. Characteristics of policy design methodology is categorized in described by (Senge, 1990). There are 3 levels of perspective: 1) event; 2) pattern of behavior over time; 3) systemic structure (Anderson and Johnson, 1997; Kim, 2000; Senge, 1990).

Events are occurrences that we usually meet day to day. It often apears as a symptom of a problem. Decision-making in response to *events* are *reactions*. Naturally, we made reaction decision to events that occur.

Patterns of behavior over time are the series of events recorded in a span of time. It could be time series data. It could reveal a trend. Decision-making in response to the *pattern of behavior over time* is *adaptation or anticipation*.

Systemic structure means interrelations and interconnections between all elements of a system to achieve its goal. Structure generates patterns and events. Decision-making in response to systemic structure is *creative*.

Refering to P. Senge (1990), the more we understand going down towards the structure the more we have in leverage to change the system. The most powerful understanding to change the system is the systemic structure of problem understanding. In general, for policy design models based on pattern of behavior over time and models based on systemic structure are mostly used (Senge, 1990).

4.2.Methodology based on pattern of behavior over time. Methodology based on pattern of behavior over time is generaly developed for point prediction in the future. To this category fall the methods of statistical regression, that consist of linear and multiple regression. This category of models is developed from a series of data (real world behavior), then a model is constructed to have simulation (model behavior) similar with real world time series data (real world behavior) (Meadows and Robinson, 2007; Saeed, 1986; Sterman, 2000).

4.3.Methodology based on problem structure. Systemic structure is more than the sum of elements in its interrelationship. Structure causes pattern of behavior. P. Senge (1990) wrote that understanding of structure gives an opportunity to know how to create change in a system.

4.4.System dynamics for policy design. System dynamics is one of modelling methodologies based on structure, or structural model. System dynamics is more of a philosophy rather than a technique. A philosophy on the role of management in controlling of organizational behavior by first understanding what causes this behavior, and then designing policies to change behavior as desired (Lyneis, 1980).

Output of system dynamics modelling is computer-based simulation of behavior over time. We select system dynamics as the approach to cope with sustainable food security policy. However, system dynamics modelling on food security policy could not embrace all the criteria of food security. The criteria that could not be modeled is food distribution aspect. System dynamics could represent the dynamics of all aspect of food security overtime, however it could not describe the spatial aspect of food distribution.

5. Spatial – system dynamics. Based on the journal articles we have reviewed, spatial – system dynamics is a method or an approach combining system dynamics and spatial concept (Bendor and Kazz, 2012).

5.1. Review of methods combining geospatial and system dynamics. Various methods of combining spatial/geospatial and system dynamics are being used, from simple to quite sophisticated. The methods chosen from some of journal articles are listed as follows.

1. S.S. Metcalf and T.K. Bendor (2006) use Spatial Modelling Environment (SME). This platform is a tool for combining system dynamics and spatial concept model. This method could work effectively in a homogenous space, therefore could not be implemented in a wide region and or heterogenous terrains. Indonesia is a big country with very heterogenous surfaces. This method could not be feasible in Indonesia.

2. M. Ruth and F. Pieper (1994) created a model of sea water level impact on growth and decrease of coastal areas. This method is more specific in expressing changes of land or surface condition. It could be effectively implemented in specific land condition. It is not feasible for food security policy, especialy in Indonesia which has very diverse conditions.

3. M. Ruth (1995) combined system dynamics model and natural resources model with the purpose to assess natural resources existing condition, inital condition, and estimated condition for policy-making. The model was constructed as mathematic equation and the behavior of the model is ploted in Cartessian graph. The graph defines space with certain direction. However, this method did not show explicit spatial concept in an ordinary map. Without ordinary map, spatial concept is difficult in application on policies overall or for food security policy in Indonesia specifically.

5.2. Proposed spatial – system dynamics method. T.K. Bendor and N. Kazz (2012) were comparing some methods to represent spatial concept in system dynamics, trying to make generalization in the way of making system archetype in the relation with spatial modelling. In our observation and experience, combination of dynamics aspect and spatial aspect is mostly executed in a way of combining system dynamics software tools and GIS software tools. Integrating spatial concept with system dynamics approach have not been done before in a way the authors of this article are suggesting.

In the context of sustainable food security policy, system dynamics requires colaboration with spatial concept in a way different from the mentioned methods in Section 5.1. This colaboration as expected could improve modelling capability in the aspect of food distribution. Constructing the collaboration expressed in a conceptual model is temporarily named as "the platform". The platform is illustrated in Figure 1.

The platform describes that every model structure, or sub-model structure, or even a variable have own address, or geo coding, or coordinate X-Y. Every sub-model or variable in different position could be connected or have causal relation with each other to form a whole system. For example, the conceptual model of spatial – system dynamics as applies to Indonesian regions is shown in Figure 2.

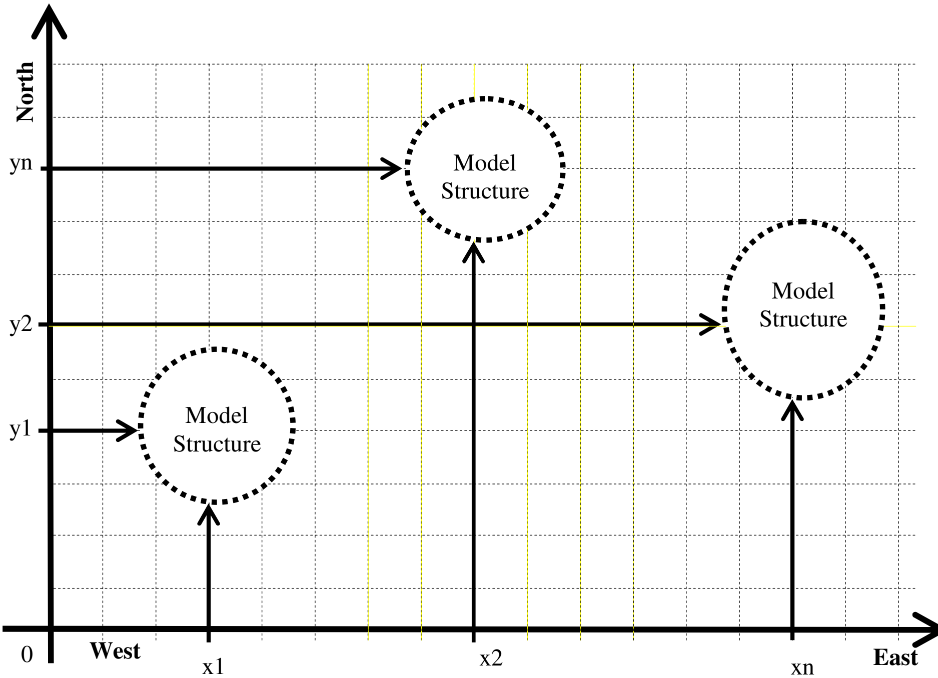

Figure 1. **Conceptual model of "the platform" for collaboration of system dynamics and spatial concept,** *authors'*

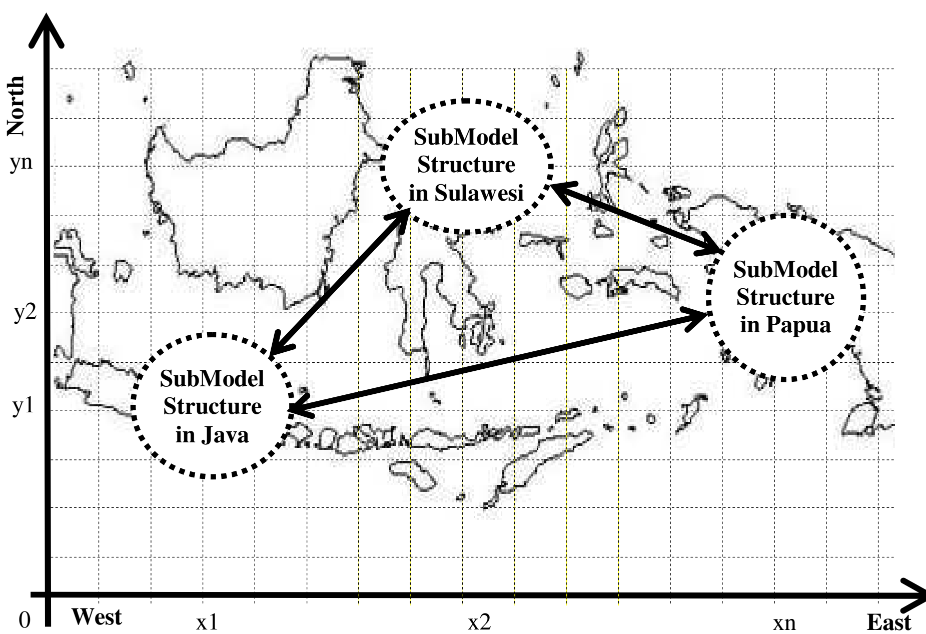

Figure 2. **Example of a conceptual model of spatial – system dynamics: submodel has own address,** *authors'*

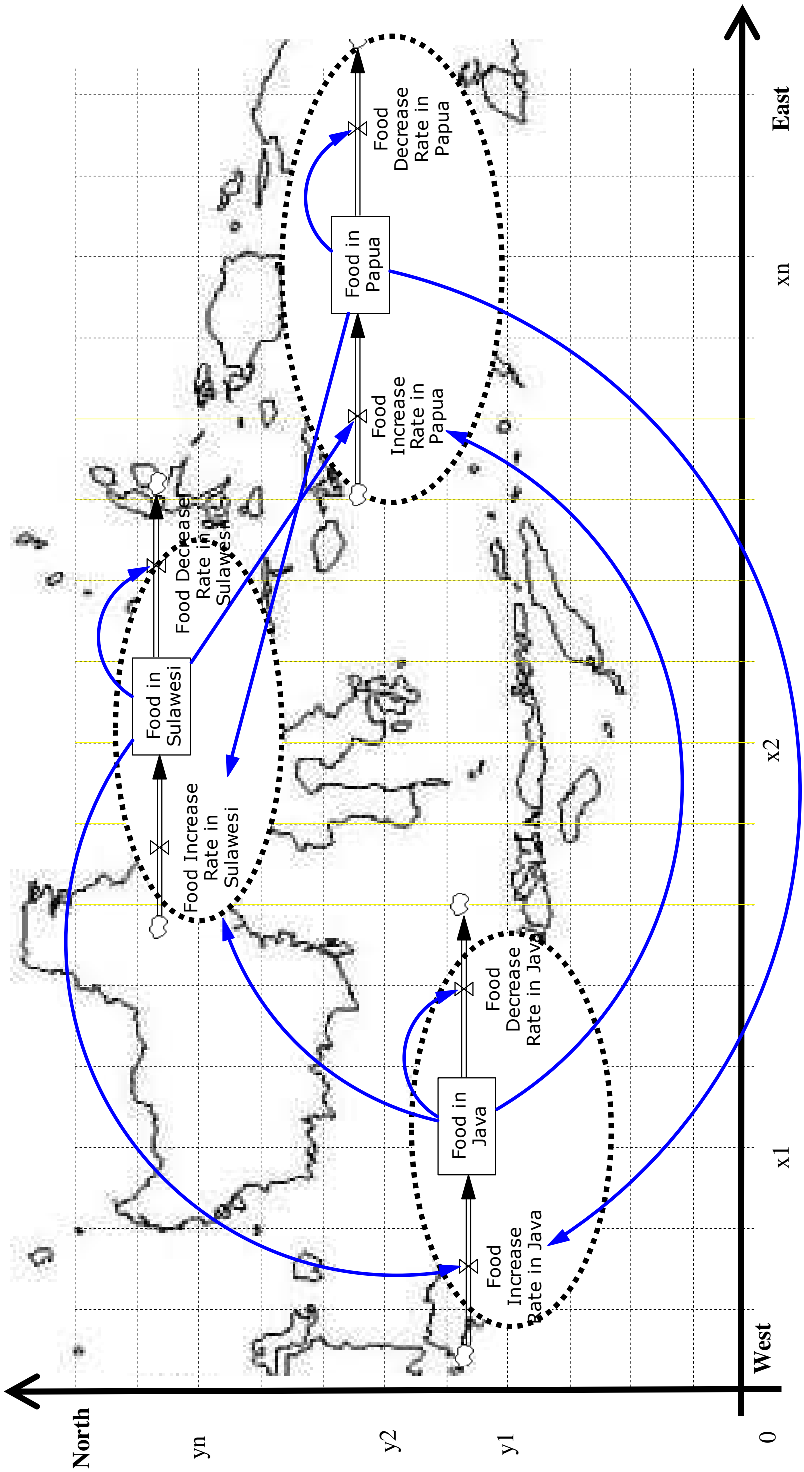

Figure 3. **Example of a generic model of spatial – system dynamics,** *authors'*

At the stage of stock and flow of system dynamics modelling, causal relation among submodels in different positions could be elaborated with model connection. The example of generic model is shown in Figure 3. Connection has been shown in more detail, from a variable to other variable in different submodels in different positions.

The proposed spatial system dynamics method has more advantages than the previous methods, such as: 1) this method combines dynamics and spatial concepts, but not the tools; 2) spatial concept in the proposed method could be applied in any map, from simple to sophisticated one (GIS); 3) the proposed method is feasible to food security policy in a large country and archipelago countries just likes Indonesia.

6. Conclusions and recommendations for further research. Modelling of food security policy has been approached by various authors methods, from behavioral modelling to structural modelling. We review here 7 and modelling approaches as follows: statistical regression, econometrics, input-output modelling, optimization, agent-based modelling, causal model, system dynamics. Considering to understanding complexity, dynamics over time, and systemic approach, we select system dynamics as the key approach.

As described in the review of modelling approaches, system dynamics could not simulate the aspect of food distribution because distribution is a spatial aspect. Otherwise, system dynamics simulate dynamic behavior over time. This paper proposes to combine system dynamics and spatial aspect. The combining proposed here is different from spatial-system dynamics that have been published before us.

The proposed spatial – system dynamics emphasizes on combining the concepts of time and space, therefore this method could be implemented with any software tools and any media of spatial mapping. The proposed method is designed specifically for policy in very diverse surface of space similar with Indonesia.

The recomendation for next research is developing a spatial – system dynamics model and simulation with an appropirate software tool. The simulation expected could express the "counter intuitive" phenomena that is hard to find without a structural model and simulation.

References:

Anderson, V., Johnson, L. (1997). Systems Thinking Basics: from Concept to Causal Loops. Massachusetts: Pegasus Communication.

Bendor, T. K., Kazz, N. (2012). A theory of spatial system archetypes. System Dynamics Review, April–June: 109–130.

BPS (2012). Indonesia in Figures. Jakarta: BPS.

FAO (2002). The State of Food Insecurity in The World 2001. Rome.

Indonesia G.o. (1996). Undang Undang No. 7/1996 Tentang Pangan. Jakarta: Government of Indonesia.

Jaccard, J., Jacoby, J. (2010). Theory Construction and Model-Building Skill: a practical guide for social scientists. New York; London: The Guilford Press.

Kim, D.H. (2000). Introduction to Systems Thinking, Innovation in Management Series. Massachusetts: Pegasus Communication.

Lyneis, J.M. (1980). Corporate Planning and Policy Design: A System Dynamics Approach. Massachusetts: The Massachusetts Institute of Technology.

Meadows, D.H., Robinson, M.J. (2007). The Electronic Oracle: computer models and social decissons. New York: System Dynamics Society.

Metcalf, S.S., Bendor, T.K. (2006). The spatial dynamics of invasive species spread. System Dynamics Review, 27–50.

Ruth, M. (1995). A system dynamics approach to modeling fisheries management issues: Implications for spatial dynamics and resolution. System Dynamics Review, 233–243.

Ruth, M., Pieper, F. (1994). Modeling spatial dynamics of sea-level rise in a coastal area. System Dynamics Review, 375–389.

Saeed, K. (1986). Minds over Methods. System Dynamics Review, Summer: 150–156.

Saeed, K. (1994). Development Planning and Policy Design, a system dynamics approach. Vermont: Avebury.

Senge, P.M. (1990). The Fifth Discipline: The Art & Practice of the Learning Organization. New York: Currency Doubleday.

Sterman, J.D. (2000). Business Dynamics: Systems Thinking and Dynamics Modeling for a Complex World. New York: Irwin / McGraw Hill.

Стаття надійшла до редакції 30.08.2015.