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Development of Spatial-System Dynamics Model for Food Security Policy in Indonesia: A Generic Sub-Model Simulation

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Abstract. *The Indonesia has the immense geographic condition and heterogeneous condition, therefore food security issues could not be aggregated nationally, instead, they have to be described per region. In this paper, the region is defined as a province. Food security issues in every region are dynamic, and generated with complex system structure, will be described in the paper as follows. First, in order to have the comprehensive description of food security, we develop a new spatial system dynamics model that combines the concept of space and time. Previous spatial system dynamics methods could only describe the dynamics of the natural/physical system. The new spatial system dynamics proposed in this paper is designed to accommodate human decision for policy intervention. Then, we develop a decision support system, as follow. (1) After comparing characteristics of each province, we can identify the similarity of all province. We call the similarity as the generic model. (2). We propose a new method of spatial system dynamics that can accommodate the immense geographic condition and the heterogeneity. (3) By combining the generic model and the new method we propose a comprehensive model for decision support system in food security policy. Finally, from the experiments with a simulation of the comprehensive model, we could understand that a policy intervention of food security could give impact differently toward each region.*

Keywords: *System dynamics, spatial system dynamics, food security, modeling, policy*

Abstrak. *Indonesia mempunyai kondisi geografis yang membentang sangat luas dan heterogen, oleh karena itu persoalan ketahanan pangan tidak dapat diagregasikan secara nasional, tetapi harus dirinci per wilayah. Di paper ini satu wilayah itu representasi suatu provinsi. Persoalan ketahanan pangan suatu wilayah itu dinamis, dan dimunculkan oleh struktur sistem yang kompleks, yang akan dipaparkan dalam paper ini sebagai berikut ini. Pertama, agar dapat mendeskripsikan ketahanan pangan secara komprehensif, kami mengembangkan suatu model spatial-system dynamics baru yang memadukan konsep ruang dan waktu. Metodologi ini sebelumnya hanya bisa menggambarkan sistem fisik. Spatial-system dynamics baru yang diusulkan di paper ini didisain untuk mengakomodasi pemodelan keputusan manusia untuk intervensi kebijakan. Kemudian, kami membangun suatu sistem pendukung keputusan, sebagai berikut ini. (1) Setelah membandingkan karakteristik tiap provinsi, kita dapat mengidentifikasi kesamaan di antara seluruh provinsi. (2) Kami mengusulkan metode spatial-system dynamics baru yang dapat mengakomodasi kondisi geografi yang membentang sangat luas dan heterogen. (3) Dengan mengkombinasikan model generik dengan metode baru, kami mengajukan gagasan suatu model komprehensif untuk sistem pendukung pembuatan keputusan dalam hal kebijakan ketahanan pangan. Akhirnya, dari hasil simulasi model yang komprehensif kita dapat memahami bahwa suatu intervensi kebijakan pangan dapat berdampak berbeda beda dari satu wilayah dengan wilayah lainnya.*

Katakunci: *System dynamics, spatial system dynamics, ketahanan pangan, pemodelan, kebijakan*

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Introduction

The issue of food security in Indonesia is an issue that is multidimensional and highly complex and covers aspects of social, economic, political, and environmental. Food security in Indonesia is defined in the Law no.18 in 2012 on Food, (Republik Indonesia, 2012) in which include (1) food availability for all people until individual level, (2) measuring instrument for fulfillment of food needs include many aspects as follows: (a) quantitatively is sufficient, (b) qualitatively is good, safe, diverse, meet the nutritional adequacy, (c) food have to be acceptable in values of religion, and culture, (d) economically food have to be available at every region in all country with an affordable price. (3) The food availability and affordability for purpose of all people could be healthy, active, and productive (Suryana, 2014).

In Indonesia, there is a pattern of food availability. Annually, some days near religion holiday Christmas and Iedul Fitri, demand of food increase, and consequently the price of food would increase also. The scarcity of some kind of food often occurs in the days before Christmas and Iedul Fitri. This pattern has been understood by government and familiarly recognized by people, therefore government policy always makes some policies to anticipate the scarcity of food. In the perspective of structure oriented model, the pattern could be changed to behave as we desired if the systemic structure is understood.

The diversity of geographic condition in Indonesia, make disparities between surplus and deficit regions of food availability. Therefore, the food availability could not be aggregated nationally and be treated equally. Food availability condition has to be described and understood per region. Sometimes policy maker said that food availability in Indonesia is surplus, but actually, the surplus is only in terms of national aggregate. However, at the level of regions (provinces or cities or regencies), some of them may be not the surplus in food availability. This is the spatial perspective problem.

If we could understand the cause of why the pattern behaves, means we understand the systemic structure, then we could have opportunity change the path of behavior in the future. We could change the system behavior through intervention to the structure. In order to understand the complexity of systemic structure that generates systemic behavior, we could use system dynamics modeling. (Sterman, 2000), (Anderson & Johnson, 1997), (Lyneis, 1980). Which region that have to be intervened, and which region will have the impact from the intervention? In order to answer this question, we could use spatial system dynamics model as an approach. (Avianto, Putro, & Hermawan, 2016).

A previous paper, propose a new spatial system dynamics that is more appropriate for policy on sustainable food security in Indonesia. The previous spatial system dynamics methodology tend to describe natural or physical law (Avianto, Putro, & Hermawan, 2016). In order to suitable for policy design on food security, we proposed new spatial system dynamics modeling.

Various parameters can be used to measure the performance of food security. Kinds of major commodities are often used as benchmarks. In this paper, the availability of rice will serve as performance benchmarks of sustainable food security in Indonesia. In the context of national development, rice is a commodity that has strategic value, both economic, cultural, political, and environmental. In the field of national economy in Indonesia, rice is always treated as a commodity of economic, social, and political. (Suryana, Rachman, & Hartono, 2014); (Irianto, 2014).

Research Methodology

Methodology for the purpose of better understanding of the issue of sustainable food security is spatial-system dynamics. Spatial-system dynamics is the combination of system dynamics methodology and spatial modeling methodology.

In the previous research (Avianto, Putro, & Hermawan, 2016), we described that the existing policy on food security in Indonesia require a model that could explain the dynamics of food availability, therefore we select system dynamics after comparing with others modeling methods. However, system dynamics could not explain the food distribution, therefore we select spatial system dynamics modeling as the methodology. The existing spatial system dynamics need to be improved for food security policy in Indonesia.

System dynamics is a computer simulation modeling methodology. System dynamics describe the structure of the system of real-world problems that are rich of feedback. As with the issue of sustainable food security, and other social issues. The real world systemic structure cause behavior over time. In the modeling process, real world behavior over time is represented with computer simulation. (Sterman, 2000; Anderson & Johnson, 1997; Lyneis, 1980).

Intervention into the system structure of an issue will change the pattern of behavior over time. Therefore, system dynamics is a model for policy design. (Sterman, 2000; Saeed, 1986; Saeed, 1994).The issue of the use of spatial - system dynamics modeling arises when the issue of food security distribution disparities between regions to be questioned. System dynamics need to be combined with spatial models in order to describe the problem space.

This article proposed an integrating spatial concept to system dynamics approach. The effort to combine spatial modeling and system dynamics modeling has been found in some article in the journal, with the different method and different level of perspective. (Avianto, Putro, & Hermawan, 2016)

Spatial modeling involves the use of disaggregated spatial data and relationships in order to understand spatial forms and processes. By spatializing system dynamics model, we can explicitly: (1) Simulate system structure that is heterogeneous over space. (2) Consider how spatial interactions affect systems themselves. (BenDor & Kazz, 2012)

Development of spatial system dynamics implemented in various field of study, such as in coastal area (Ruth & Pieper, 1994) in fisheries management, in invasive species spread (BenDor & Metcalf, 2006), in interregional diseases control (Rich, 2008) in a theory of spatial system archetypes (BenDor & Kazz, 2012).

Spatialized system dynamics development principally is combining between system dynamics concept and spatial concept. However, the methods of combining are different each other. Different in depth from philosophy to technical tools. Different in term of methods and tools. (Avianto, Putro, & Hermawan, 2016).

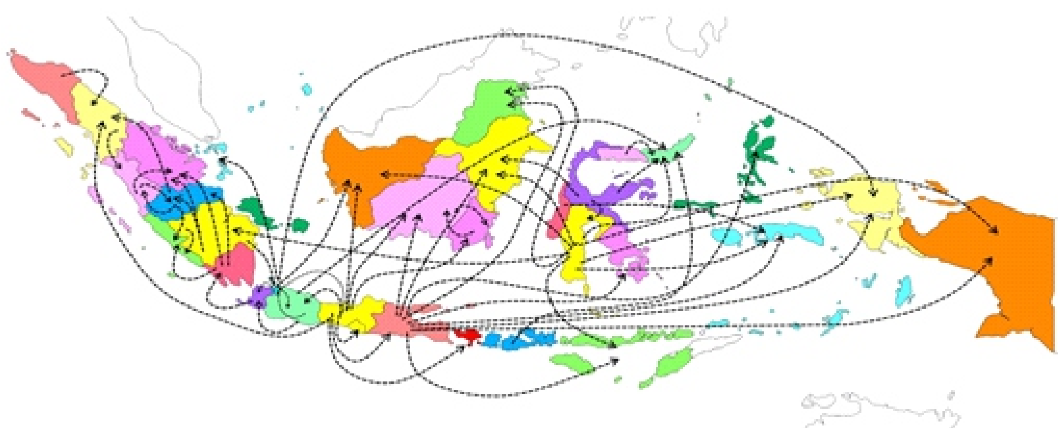

Figure 1. Distribution of Rice Trade in Indonesia (modified from BPS, 2015)

Previous spatial system dynamics methods generally describe the dynamic of natural phenomena, such as coastal, fisheries, disease, and so on. (Ruth & Pieper, 1994; Rich, 2008; BenDor & Metcalf, 2006; BenDor & Kazz, 2012). The new method proposed by Avianto et.al (2016) emphasize to describe the decision making for policy design on food security. Food security in Indonesia has to be provided with this method because it requires the explanation of food availability over time and food availability in certain regions. (Avianto, Putro, & Hermawan, 2016). In the new method, food security has to be represented in each region all around a country. In the case of Indonesia, rice distribution and rice trading traffic among provinces as shown in Figure. 1, (Badan Pusat Statistik, 2015) could be referred as a portrait of the existing condition for the modeling process.

Generic Sub Model and Interconnecting between Sub Model in Causal Loop Diagram as the Principle of Spatial System Dynamics for Food Security

This paper elaborates the concept of spatial system dynamics, that is proposed by Avianto, Putro, & Hermawan, 2016, to the form of spatial system dynamics model and simulation. In this paper, a region represents a province. The systemic structure of rice availability in a region (province) is defined as a sub-model of food security model of Indonesia. The specific differences this new method compare to previous metods are (a) this method design for accommodate human decission model, such as we often found in policy. (b) this methods accommodate for policy in Indonesia which has imense and heterogenous regions.

Food availability subsystem in a province has a specific characteristic, therefore, have to be represented with a specific sub-model also, however, all region have generic characteristics that could be represented with a generic sub model. The generic sub model is similar to a template, that could represent the condition of each region in Indonesia, in a causal loop diagram is described in Figure 2.

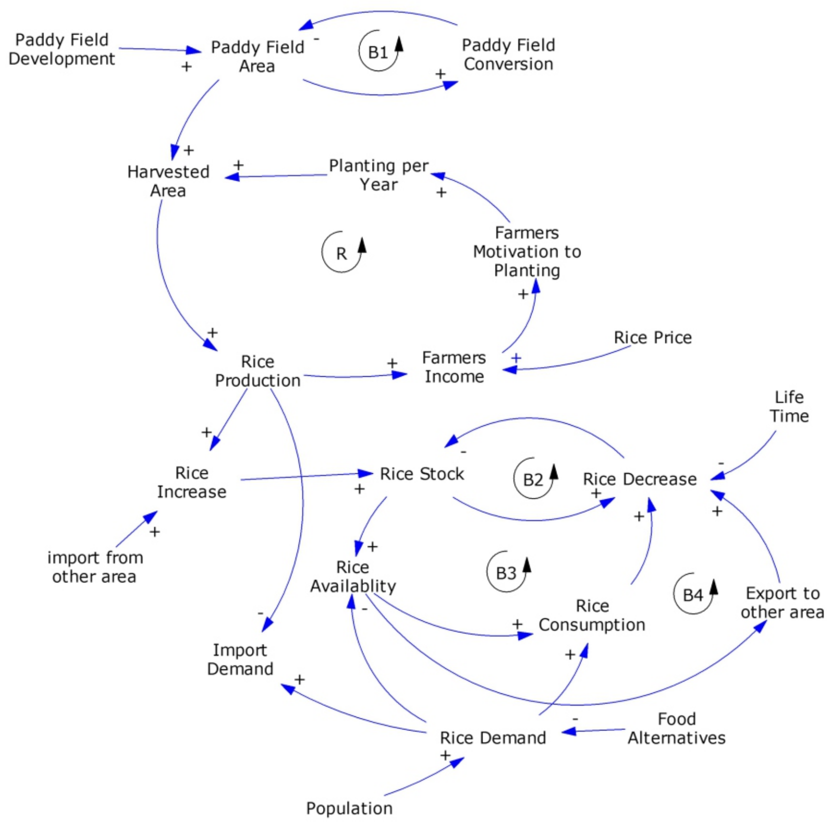

Figure 2. Causal Loop Diagram of Generic Sub-Model of Food Security in A Region

The step of the building of generic model is important because it will help the modeler to interweave the sub model more clear and easy to understand. The generic model could be replicated as many as the number of provinces in Indonesia.

Figure 2 is the causal loop diagram (CLD) of the generic systemic structure. Rice Availability in a province is a ratio between Rice Stock and Rice Demand. Rice Demand is determined by Population. Rice Stock increase because of Production from the internal region, and Import from other areas. Import means rice supply from out of its region, domestic or foreign countries.

Rice Production determined by Harvested Area. Harvested Area is derived from Paddy Field Area. Paddy Field Area could be increase and decrease. Rice Stock decrease is determined by Consumption, Rice Life Time, and Export. Consumption depends on Rice Demand and Rice Availability. Consumption equal to its Demand if Rice is available. There are 4 balancing loop, B1, B2, B3, and B4. Loop B1 determined by the external factor, or exogenous variables, that impact on paddy field conversion to others function. Loop B2, explain rice decrease generally, and particularly because of the life time of rice or natural decay. Loop B3 describe that Rice Consumption cause Rice Decrease and Rice Consumption determined by Rice Demand and Rice Availability. Loop B4 figure out Rice Decrease because of Export or transport to other provinces. The Export itself determined by Rice Availability and by Demand from other provinces.

Rice Production together with Rice Price will generate Farmers Income, and the Farmer Income will be a source of motivation to plant as a farmer role. This motivation will drive farmers to increase Harvested Area. And then the Harvested Area will increase Rice Production. It will form a reinforcing loop (R). The reinforcing loop in Figure 2 will be triggered by Rice Price. (Perdana & Avianto, 2007)

Rice trading interrelation among region could be represented with interconnection among sub model, in form of causal loop diagram is represented in Figure 3. Figure 3 describe an example of interconnecting between Province A and Province B. Province A is an exporter or supplier of rice to Province B, and Province B as importer or receiver of rice trading from Province A. Province A will send rice to Province B based on rice demand of Province B, and the availability of rice in Province A.

In Figure 3, this relationship is described with bold arrows connections. The interconnecting method could simulate interdependence among provinces or other region scales, not only in an adjacent each other but also among region that is separated by space.

Simulation of Generic Model and Interconnecting between Sub-Model as the Principle of Spatial System Dynamics for Food Security

In order to simulate the dynamics of food security in each province, the CLD in Figure 3. will be translated into stock and flow diagram as described in Figure 4, which contain mathematical equation. In this simulation step, only part of region characteristic is simulated, those are the feedback loop of B2, B3, B4, B6, B7 and B8 as shown in Figure 3. Remain feedback loop R1, R2, B1, dan B5 will be discussed in the next paper. The software tools for this simulation is Vensim PLE. Up to this time, Vensim PLE is free and could be download from http:// www.vensim.com

For the purpose of building of valid model structure, we made two dummy provinces, name Province A as exporter or supplier, and Province B as importer or receiver of rice from Province A. Both Province A and B have the same population, however Province A has surplus of rice, and Province B has deficit of rice. Province A sends rice to Province B. At the first step, the model is set up to behave in the equilibrium condition. Province A has rice surplus as much as demanded by Province B. The equilibrium condition is the reference condition.

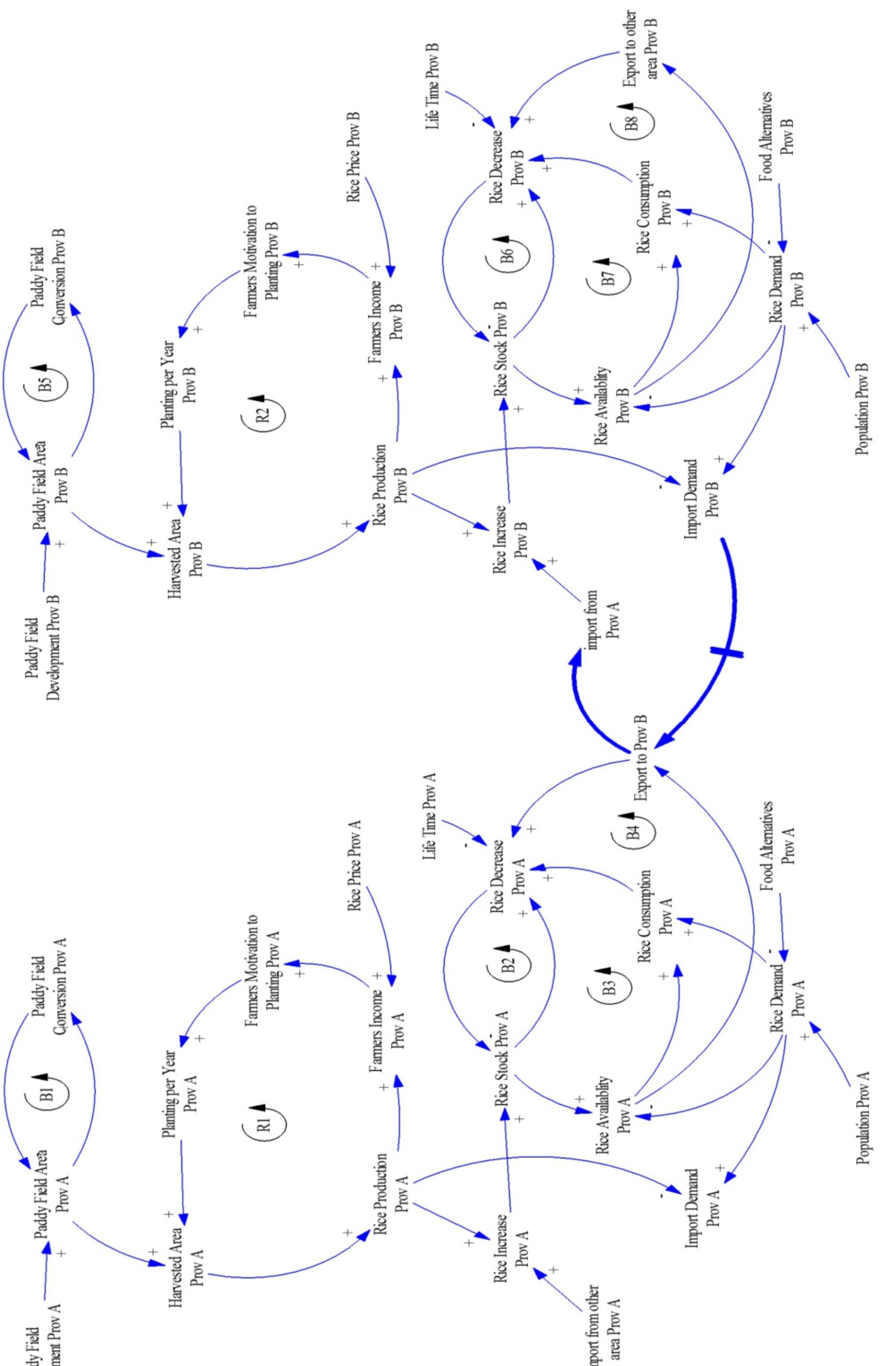

Figure 3. Interconnection Between 2 Sub Model

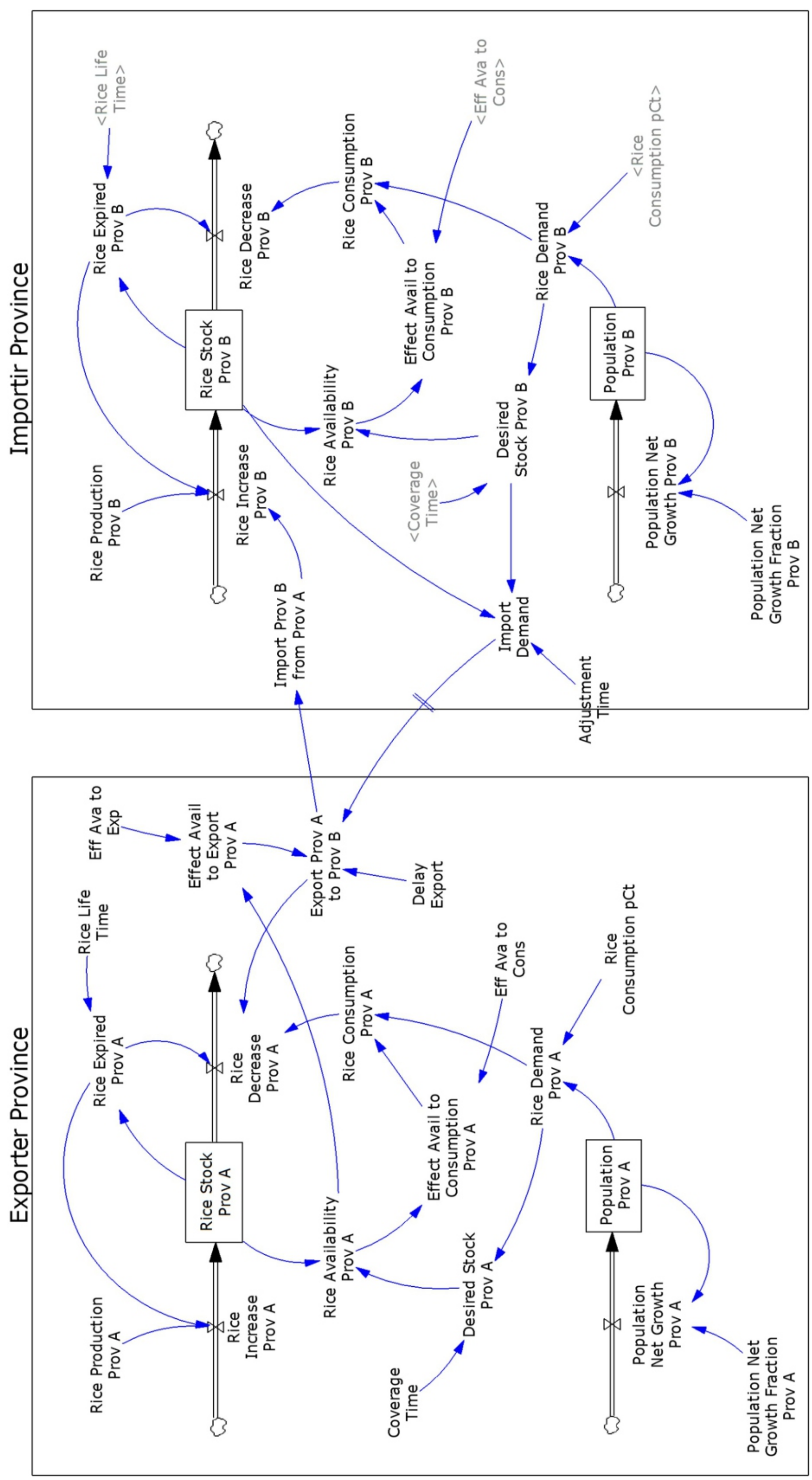

Figure 4. Stock & Flow Diagram Model of Exporter and Importer Provinces

Table 1.
Parameters of Simulation

Parameter	**Unit**	**Value**			
		Equilibrium	**Scenario 1**	**Scenario 2**	**Scenario 3**
i	ii	iii	iv	v	vi
Population Initial Prov A	Pop	10,000,000	10,000,000	10,000,000	10,000,000
Population Initial Prov B	Pop	10,000,000	10,000,000	10,000,000	10,000,000
Pop Net Growth Frac Prov A	1/Year	0	*0.02*	*0.02*	*0.02*
Pop Net Growth Frac Prov B	1/Year	0	*0.02*	*0.02*	*0.02*
Rice Production Prov A	Ton/Year	1,710,000	1,710,000	*2,000,000*	1,710,000
Rice Production Prov B	Ton/Year	570,000	570,000	570,000	*1,300,000*
Rice Stock Prov A	Ton	570,000	570,000	570,000	570,000
Rice Stock Prov B	Ton	285,000	285,000	285,000	285,000
Adjustment Time	Year	0.5	*0.25*	*0.25*	*0.25*
Coverage Time	Year	0.5	0.5	0.5	0.5
Rice Life Time	Year	2	2	2	2
Rice Consumption per Capita	Ton/Year/Pop	0.114	0.114	0.114	0.114

Table 1 contains parameters of system dynamics simulation models that described in Figure 4. The column iii contain the value in the model in the condition of equilibrium or everything is steady, and when is simulated will behave linear and equilibrium as shown in Figure 5. This step is taken because of this model has not yet used real data from the real world. This step also helps modeler to understand the validity of the model. Indicators of Rice Stock and Rice Availability could be used as the general indicator of system behavior.

Figure 5 is a simulation result when all surplus productions from Province A, were sent to Province B, and all were consumed.

The column iv of Table 1 is Scenario 1, that assumes the population of Province A and Province B are growing with the fraction of growth is 0.02 per year. Adjustment time change from 0.5 years to 0.25 year, means that response of Province B to import the rice from Province A is more reactive than before condition. Changing of model structure from equilibrium to scenario 1 will result from the simulation as shown in Figure 6.

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Column v of scenario 2 contain values that scenario 1 condition plus change on rice production at Province A as exporter or supplier province, from 1,710,000 ton per year to 2.000.000 ton/year. This condition will results behavior as shown in Figure 7.

Column vi of scenario 3 contain values that similar with Scenario 1, however, change on rice production of Province B as the importer of rice from Province A, from 5.700 ton per year to 1.300.000 ton per year. This condition assumes that rice production of Province B is sufficient and does not need import any more. This structure will result in a simulation as described in Figure 8.

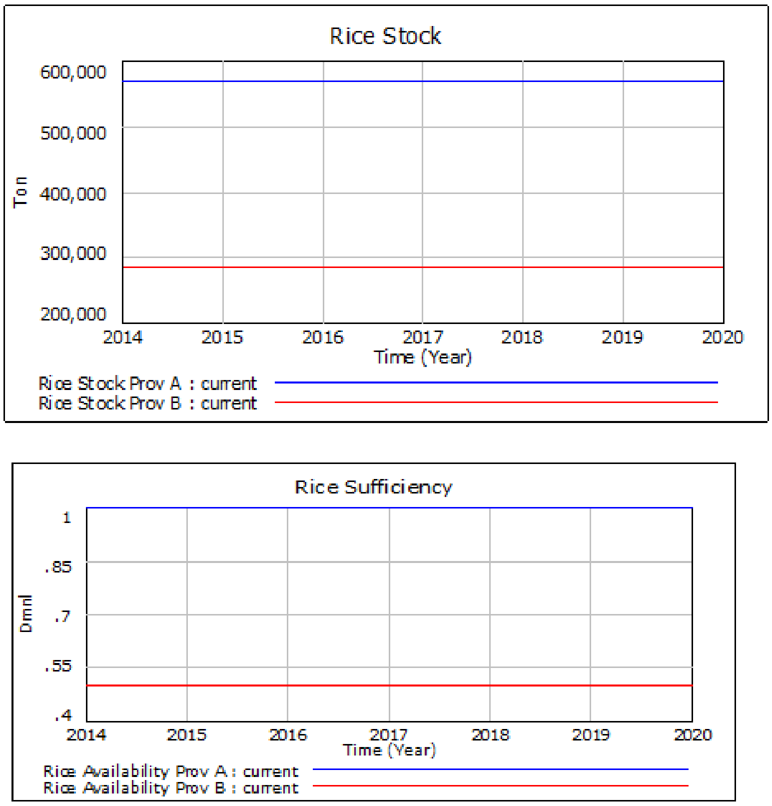

Figure 5. Scenario resulting equilibrium condition, parameter in column 3 of Table 1

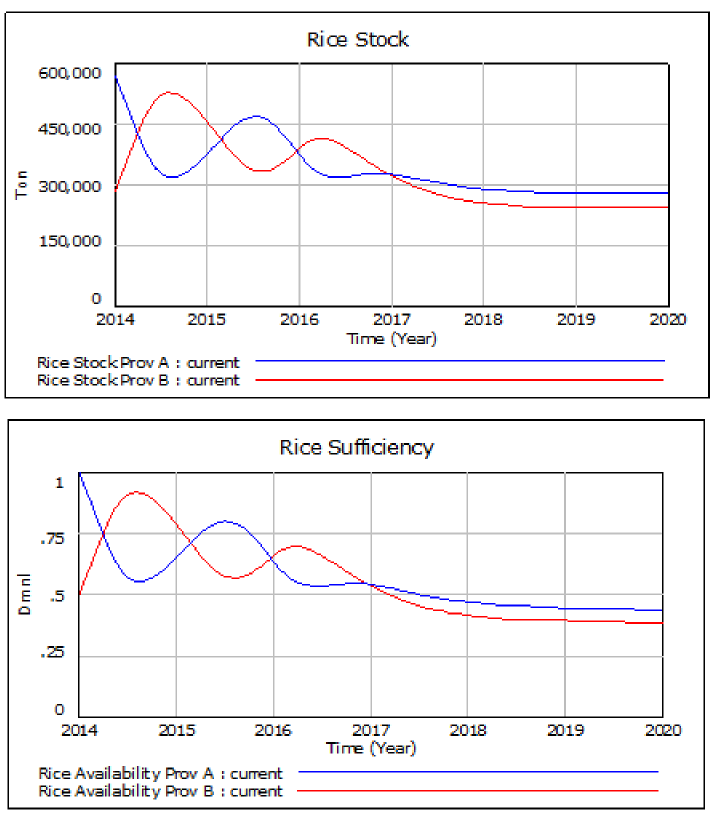

Figure 6. Scenario 1, parameter in column 4 of Table 1

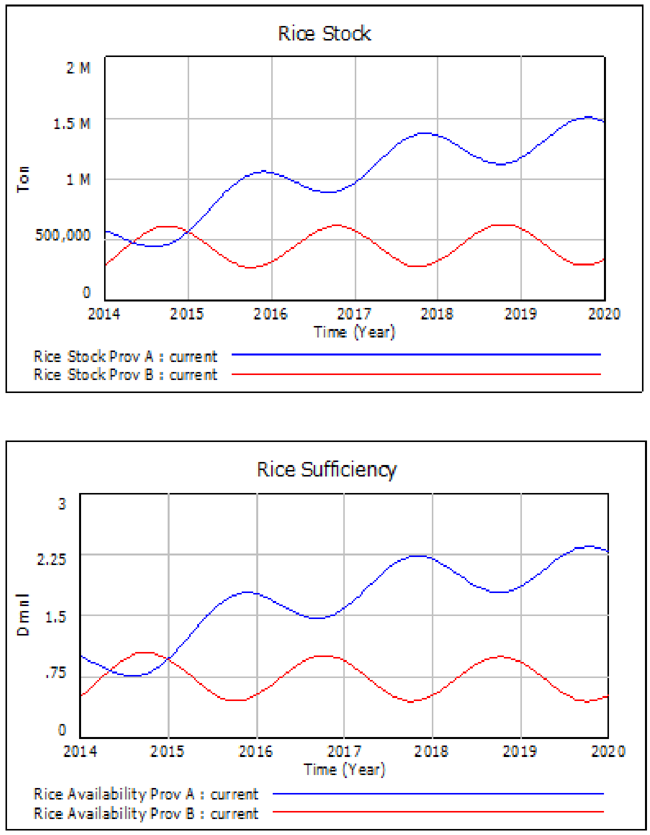

Figure 7. Scenario 2, parameter in column 4 of Table 1

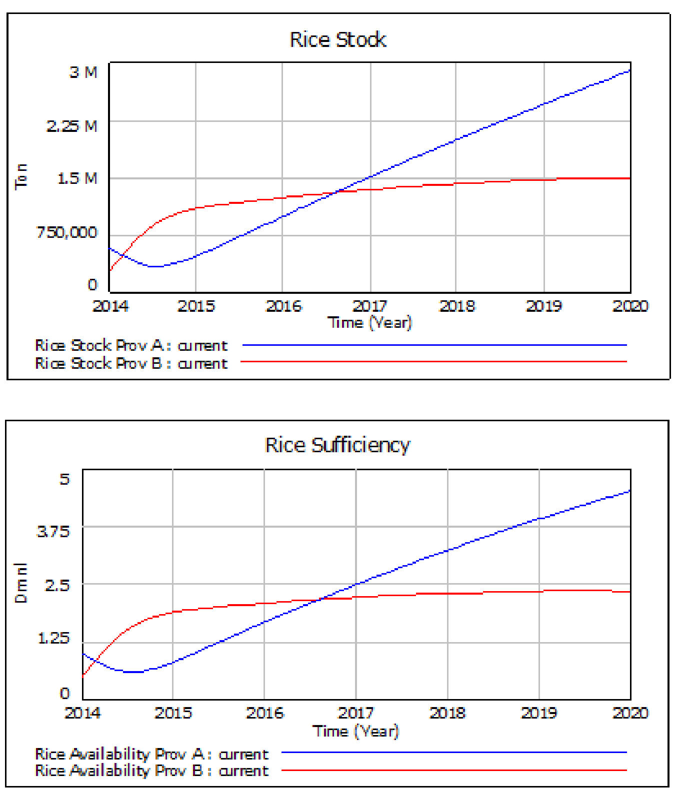

Figure 8. Scenario 3, parameter in column 4 of Table 1

Result and Discussion

The advantage of system dynamics compare to other methodologies, and the reasons why system dynamics have to combine with the spatial concept is described in the previous paper (Avianto, Putro, & Hermawan, 2016). This paper discusses developing of generic structure of sub model that is a building block of the complete model of food security in Indonesia. The sub-model represents a province. This paper also discusses connecting method from one submodel to another. The connecting among sub model represent traffic of food and the demand from one province to another.

In the example, above, only two dummy province and one food traffic model, and one food demand traffic model. Only one direction food traffic. However, in the complete model, a sub model could be connected to two or more others sub model, describe that one province could interact with two or more others province in the real world. Integration of all sub model to a completed model could generate emergence properties.

Reasons why have to develop generic structure. Food availability is one of the factors of food security. Measuring of food availability in Indonesia, in this method, means that food availability in all province must be measured, and could be compared from one province to another province. Food availability may be various from one province to another province. Identification of factors that exist in all province, and identification interrelationship among those factors, means developing a generic structure model. A generic structure has to represent a province. A generic structure model is a sub-model of the comprehensive model, similar with a province as sub system of Indonesia. The generic structure is figured out in form of causal loop diagram in Figure 2 and then elaborate in form of simulation model in Figure4. The factors and its interconnection that form generic structure is the first finding of this paper.

Interrelation among province is represented with rice traffics and demand traffics. In the generic structure, Figure 3 and Figure 4, the traffics is represented with factors of Import Demand, Import from other areas, and Export to other areas. Demand in one province could create export and import traffics with others province. Those traffic of rice would change the state of food security in the level of the province. The interrelation and interconnection between two provinces as explain above, expected to be the improvement of spatial system dynamics methods. This method accommodates human decision to determine rice flow from one province to other provinces. This method is the second finding in this paper.

Food security policy model that could be developed. System dynamics assume that structure generates behavior over time. Each of sub-model structure represents a province, in this discussion, therefore the behavior simulation could be displayed together with a map that displays per province. It could help policy maker to understand systemically the dynamics of food security condition and space where the dynamics are taking place. Figure 9 is an example of display and could be developed and combine with GIS and other tools. Because of the Province A and Province B is only an example, Figure 9 could not clearly point out which province is describing with the Province A and Province B. However, it is an example that could be expected could explain the dynamic of a province, and where the position of the province is.

Simulation of behavior over time in all province in Indonesia could be linked with spatial display or map of Indonesia. This link represents that the dynamics over time have own address in Indonesia. Policy intervention to a certain of time and space could result in one or more effects in other time and space. This method could be expected to support decision maker to make more appropriate decisions.

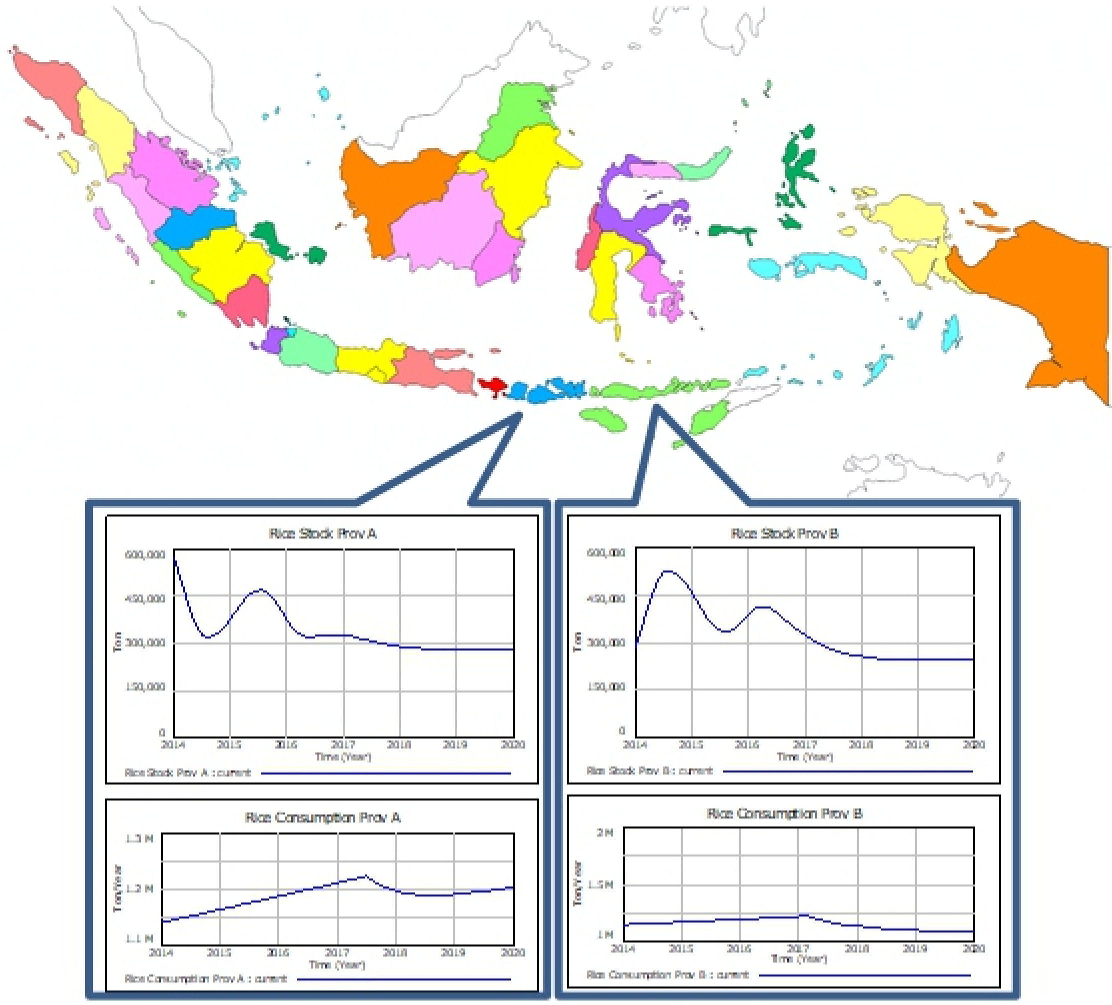

Figure 9. Condition of Province A and Province B in a Display of Map for comparison, an example

Food security dynamics over time and space could be simulated in spatial system dynamics, and this paper discusses spatial system dynamics simulation on food security policy in Indonesia. However, spatial system dynamics in this paper is developed for decision making and policy design. The differences from previous methods are that this method could describe cause and effect relation among regions, both between the region adjacent each other and between the region that is separated in space. The model of food security policy that could be developed is the third finding of this paper.

Recommendation

There are many aspects should be discussed, however, this paper could not yet comprise all of the aspects. Therefore we propose some recommendation for next research are:

Completing simulation of the generic model. We recommend developing a simulation model for feedback loop (R) as seen on causal loop diagram in Figure 3. The loop R is the farmer decision to plant or not to plant depending on the price of rice, and production. The motivation of farmer to plant has not yet included in the simulation model.

After recommendation point 1, generic model has been completed for the application. The next completion is the development of sub-models for 34 provinces and the interconnecting among provinces. This completed simulation could describe food security in Indonesia.

The next improvement is the development of methods of combining GIS and system dynamics software tools. This step of improvement will include more software development content and database than system dynamics itself.

Conclusion

From the explanation above, we made the conclusion as follows. Food security policy in Indonesia need a method that could describe the cause of the problem, therefore the policy could be intervened on the right province and at the right time. Factors and interrelation among those factors that cause problems of food security policy are described in form of causal loop diagram as shown in Fig.2., and then named as generic structure. The generic structure then will be the building block of the comprehensive model. The generic model is the first finding of this paper. The generic model could describe differentiation of food security among province.

This paper offers the new method of spatial system dynamics. This method is designed to describe and simulate food behavior over time and space, based on the human decision and natural law. The method is the second finding of this paper. These findings allow us to make a policy of food distribution when the food situation is changing dynamically. An interweaving of the generic structures that represent interrelation among province in Indonesia, will form the comprehensive model, and present the simulation of food security dynamic in each region. Spatial system dynamics on food security in Indonesia could be used as tools for national policy.

And we expected that this spatial system dynamics modeling could help ministry of agrculture, national planning body, food scurity council, etc. It can help policy maker to understand the food security as whole and detail at once. This model that could be developed is the third finding of this paper.

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