Analysis of rice supply chain mechanism with simulation approach

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Abstract. Rice is the staple food consumed by most of Indonesian population, which is about 89.22 kg/capita/year during 2007-2014 with consumption percentage of 85.88%-91.73% during the year. Rice issues are a strategic issue given that food sovereignty is one of the government's strategic plans. The supply chain of rice is a complex system involving many interacting variables. Rice production exceeds its consumption, causing Indonesia to become a surplus country. Despite Indonesia's rice surplus, the government is still engaged in rice imports to ensure the availability of rice in some deficit provinces. This research aims to develop national rice supply chain model and distribution mechanism model between surplus and deficit province. The complexity of the mechanism and behavior of the system is considered in the selection of research methods using system dynamics simulation to solve the problem. The mechanism applies the principle of the transfer process in which displacement will occur if there are differences in conditions in the two adjacent materials. The result of the research shows that the built model has a MAPE value of 1.58% for wetland variables, 3.81% for rice production variables, 2.57% for population variables and 3% for rice distribution variables, with evaluation of each province availability is above zero.

1. Introduction

Rice is a staple food of most Indonesian people. According to (1), the average consumption of rice is the largest compared to other staple foods which is 89.22 kg/capita/year during 2007-2014, while consumption of corn and cassava does not reach 10 kg/capita/year. The percentage of rice consumption as staple food in Indonesia is majority compared to other staple food which is 85,88%-91,73% during 2007-2014.

In line with the government's plan to achieve food sovereignty, (2) makes achievement of rice self-sufficiency as a strategic target. Related to these targets, (3) argue that food security is a world problem that requires the attention of government and the expert community. Thus, the availability of rice as the main commodity in Indonesia is a strategic issue that needs attention.

National rice production is much higher than rice consumption should not be a problem to achieve self-sufficiency in rice. Figure 1 shows that there is a considerable difference between national rice production and consumption of around 10-17 million tonnes/year.

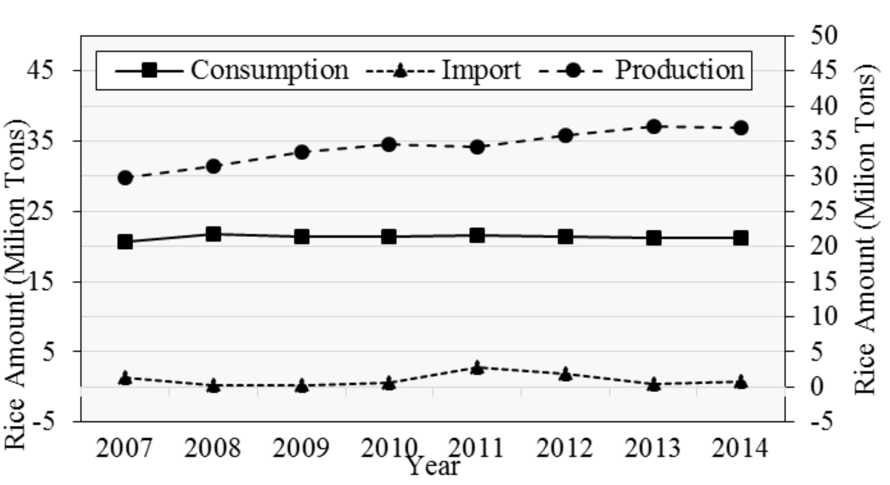

Figure 1. Production, Consumption and Import of National Rice Year 2007-2014 (1).

Several provinces experienced a rice deficit. DKI Jakarta is one of the 10 provinces of rice deficit in 2009 (4). The province of this rice deficit is a province with a small agricultural land but densely populated, so the need for rice exceeds its production capability. The rice availability in 33 provinces in 2014 is shown in Figure 2.

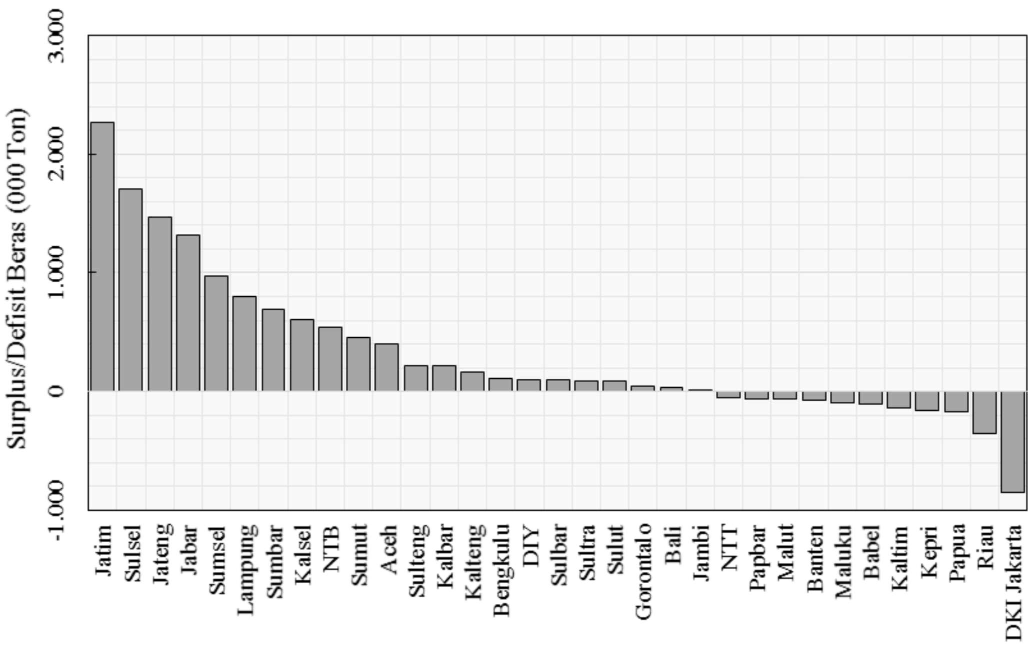

Figure 2. Rice Surplus and Deficit in 33 Provinces by 2014 (5).

Rice issues are a strategic issue given that food sovereignty is one of the government's strategic plans. Rice production exceeds its consumption, causing Indonesia to become a surplus country. Despite Indonesia's rice surplus, the government is still engaged in rice imports to ensure the availability of rice in some deficit provinces. The purpose of this research are develop the dynamics model of rice supply chain system, establish inter-province distribution mechanisms of surplus and deficit, and develop policy of rice supply chain mechanism to achieve rice self-sufficiency.

2. Research Method

2.1. Defining System

The rice supply chain system that is influenced by the government as a policy maker causes rice problems to be viewed top-down, so it can know the effect of the policy on the behavior of the system. The type of simulation that is close enough to the characteristics of the rice supply chain system is system dynamics simulation. System dynamics has top-down properties with homogeneous agents, and can describe stock flow in complex systems.

System dynamics is a concept that can be used to understand the structure and dynamics of complex systems over time (6). This method can explain the interrelationships between the variables contained in the system. The purpose of modeling system dynamics is to improve understanding of organizational performance related to the internal structure and the policies it contains. The basic principle of system dynamics is the structure of the system will give impact to the behavior of the system. Author (7) mentions that the dynamics of the system can accommodate the complexity, nonlinearity, and feedback structures contained in physical and social systems.

2.2. Research Objects and Tools

The object of this research is the national rice supply chain system and rice availability in six provinces in Java Island. The tools used in this research are Vensim Software PLE for Windows Version 6.4 b (x32) and Software Powersim Studio 10 Academic (Service Release 5).

2.3. Verifying and Validating Model

Tests on the simulation model are done to ensure that the model has been built in accordance with the objectives and limits. Tests conducted are boundary adequacy test, extreme condition test, and behavior reproduction test.

3. Results and Discussion

The model certainly has certain limitations covering all the variables involved. The variables are then grouped into three types of endogenous, exogenous, and exception. Endogenous variables are interacting variables in the system (19 variables). Exogenous variables are the variables that affect the behaviour of the model but not influenced by other variables (11 variables).

The system dynamics model has many interrelated variables and has a reciprocal relationship. Causal Loop Diagram (CLD) in this study is shown in Figure 3. There are 5 loops on the CLD.

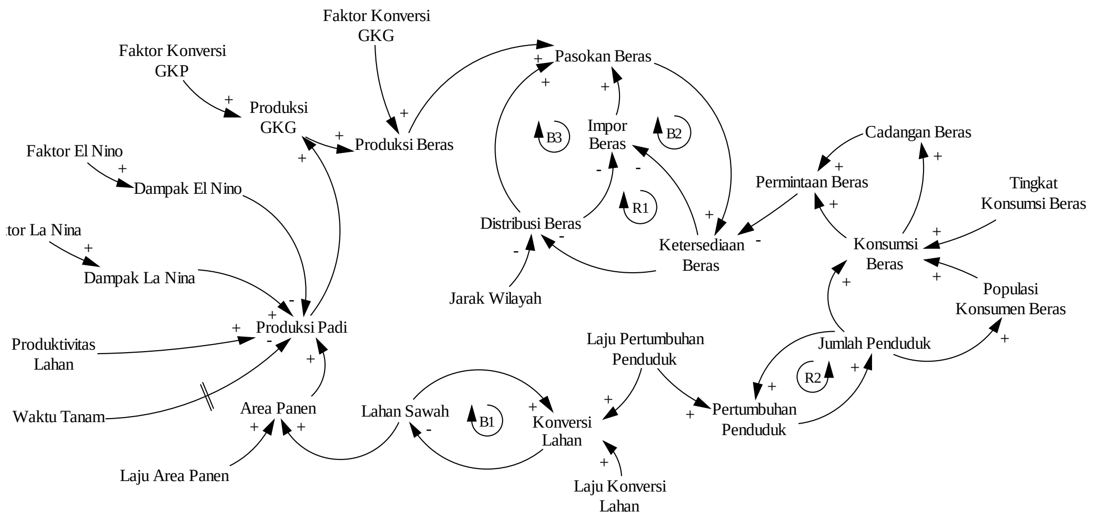

Figure 3. Causal Loop Diagram (CLD)

Stock Flow Diagram (SFD) is a diagram created by quantizing the variables contained in Causal Loop Diagram (CLD). Author (6) mentions that SFD consists of stock, flow, and auxiliary.

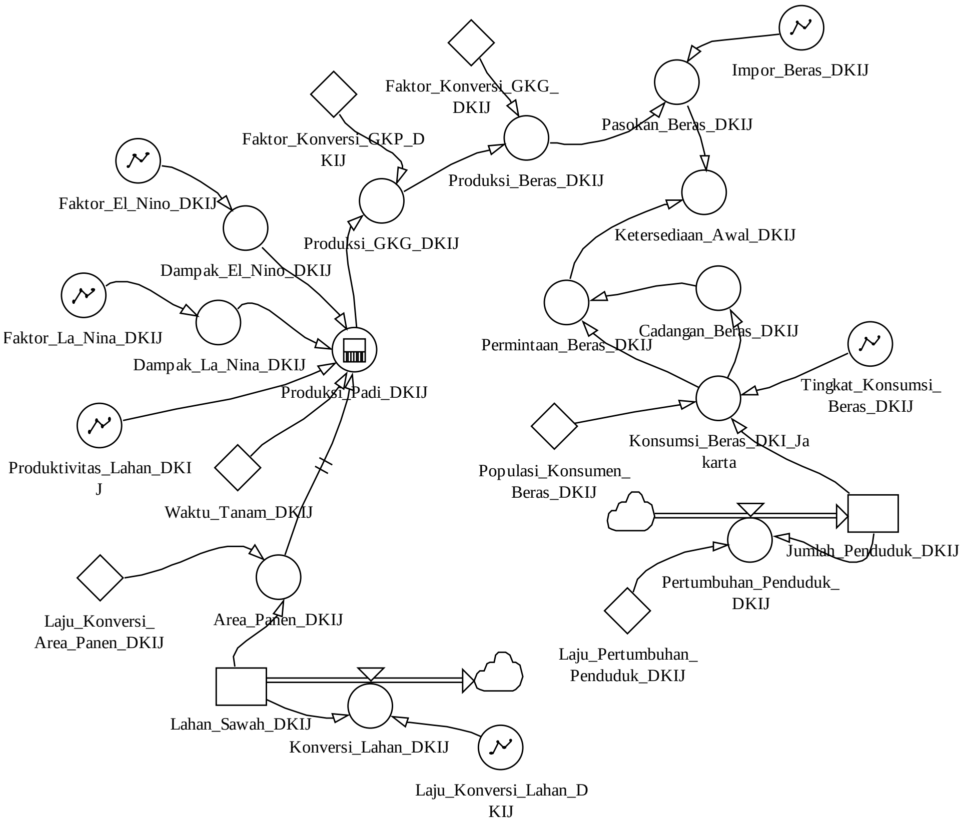

Figure 4. Stock and Flow Diagram of Province Rice Supply Chain

After model development and model testing is conducted, then the model is simulated. The simulation results will show the behaviour of the model. The simulation results from the behavior of rice supply chains are indicated by the rice availability (Figure 5) in 6 provinces in Java Island. The simulation is done in 2011-2020 by eliminating the variable of rice import.

According to Figure 5, it can be seen that from 6 provinces in Java Island, there are 3 provinces with rice surplus throughout the year, West Java Province experienced deficit in the last years, and DKI Jakarta Province and Banten Province which experienced rice deficit throughout the year. This condition led to the need for a rice distribution mechanism that would link provinces with surplus and province deficits.

The rice distribution mechanism is carried out in order to meet the demand for rice in all provinces with the highest availability of rice. To build the model of distribution mechanism of rice, in this research conducted a distribution mechanism.

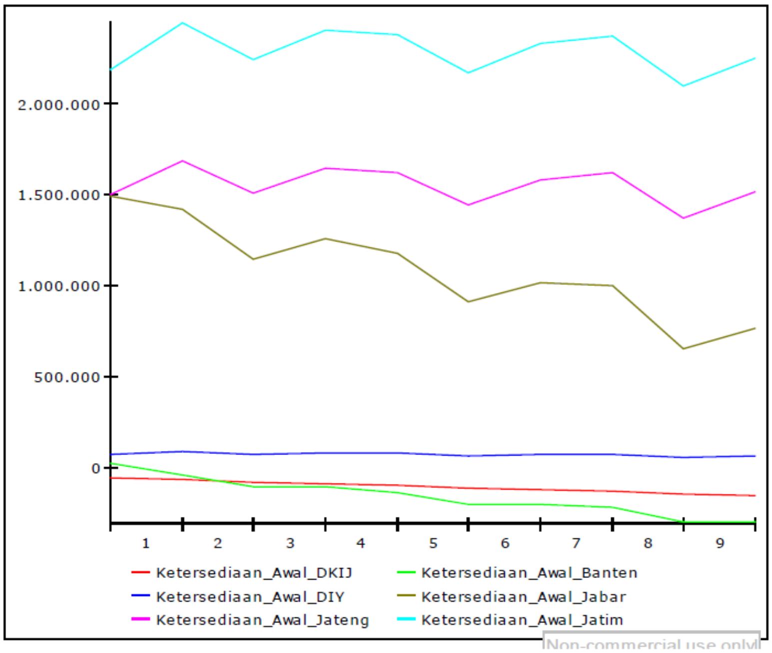

Figure 5. Rice Availability in 2011-2020 (Before)

The distribution mechanism adopts the principle of Transfer Process theory (8) where if there is a difference of condition between the two adjacent planes, there will be a flow from high to low so that the same final condition is obtained. The expected final condition of this distribution is that all provinces have no rice deficit. The flow principle contained in the Transfer Process was then applied to the rice distribution system from the surplus province to the rice deficit province with the analogy shown in Table 1.

Table 1. Application of transfer process theory on rice distribution system**.**

Comparison	Transfer Phenomena	Rice Distribution
Formula	$q = k \cdot A \cdot \frac{\Delta T}{\Delta X}$	$q = (k_0 + k_1 . a_1) \cdot A \cdot \frac{\Delta T}{\Delta X}$
q	Heat flow through the surface	Rice distribution flow
A	Surface area	Wide provincial border
k	Thermal conductivity	Provincial connectivity
ΔT	Temperature difference	availability difference of provincial rice
ΔX	Distance between plates	Distance between province

If there is a province with a rice deficit, the system will check the condition (surplus / deficit) of the adjacent provinces. A distribution status of 1 means that there are provinces with deficit and surplus provinces, so that distribution between these two provinces can be done. If the availability of rice in the adjacent province is not able to meet each other's needs, then this mechanism will be implemented in the next closest province.

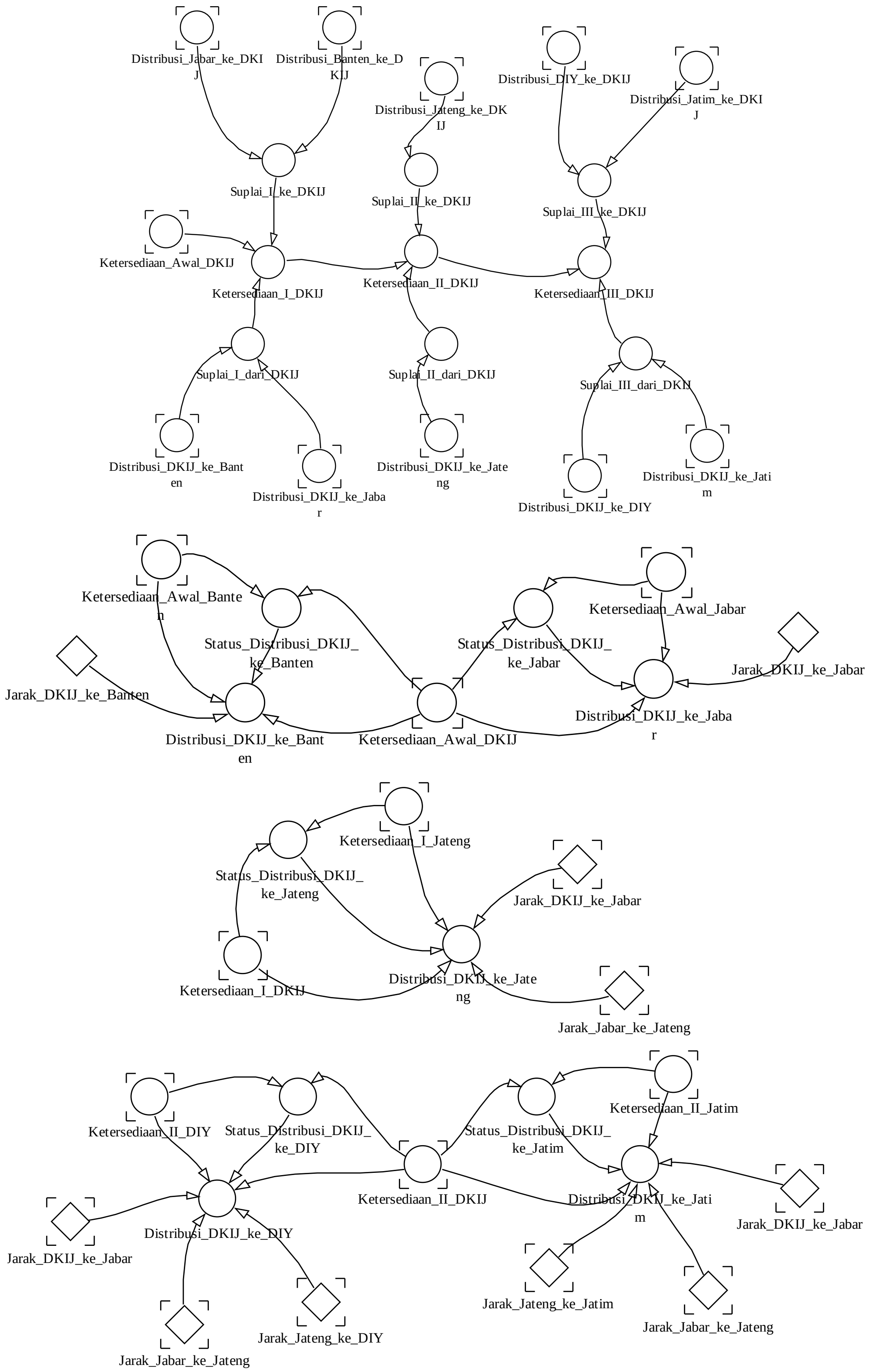

Figure 6. Stock and Flow Diagram of Distribution Mechanism

This model is then used to simulate the availability of rice for each province and the distribution of rice between provinces. Validation on this test is done using MAPE (Mean Absolute Percentage Error) calculation with hypothesis:

H_0: there is no significant difference between simulation data and actual data (valid)

H_1: there is a significant difference between the simulated data and the actual data (not valid)

Testing is done with 95% confidence level. H_0 is rejected if MAPE value is> 5%. The value in Table 2 shows that there is no significant difference between the simulated data and the actual data, or it can be said that the built model is valid to represent the real system.

Table 2. Distribution of rice from West Java to DKI Jakarta 2011-2015

Year	Actual (Ton)	Simulation (Ton)	Error
2011	607.601	604.426	1%
2012	507.475	566.833	12%
2013	501.127	448.684	10%
2014	484.994	491.839	1%
2015	548.516	453.610	17%
	MAPE		3%

The overall simulation model for 6 provinces is shown in Figure 7. On the graph it can be seen that some of the availability of West Java Provincial rice is distributed to DKI Jakarta and Banten, so in the end the availability of rice in 6 provinces can be guaranteed.

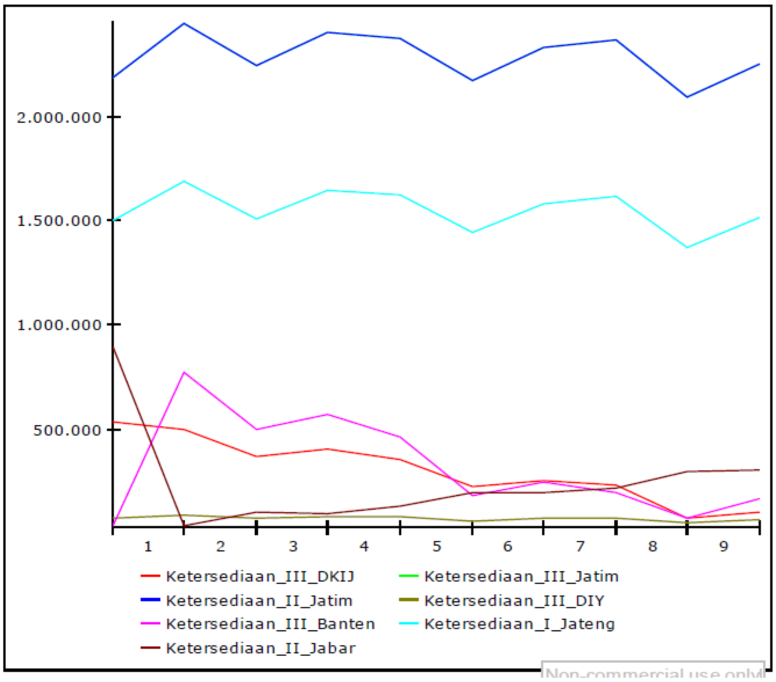

Figure 7. Rice Availability in 2011-2020 (After)

4. Conclusion

Based on the research that has been done, it can be concluded that the real system and has been tested Boundary Adequacy Test, Extreme Condition Test, and Behavior Reproduction Test. The inter-province distribution mechanism of surplus and deficit is built using the principle of transfer process, where the distribution of rice will occur if there are surplus and deficit conditions in the adjacent province. The built model has a MAPE value of 1.58% for wetland variables, 3.81% for rice production variables, 2.57% for population variables, and 3% for rice distribution variables, with evaluation of the availability of each province zero (guaranteed).

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