IMPROVING ROAD NETWORK CONSIDERING RICE SUPPLY CHAIN NETWORK

Andrean Maulana
Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jl. Ganesha No.10, Bandung 40132, Indonesia.

Ade Sjafruddin
Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jl. Ganesha No.10, Bandung 40132, Indonesia.

Russ Bona Frazila
Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jl. Ganesha No.10, Bandung 40132, Indonesia.

Febri Zukhruf
Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jl. Ganesha No.10, Bandung 40132, Indonesia.

Abstract

The stakeholders involved in the rice supply chain, who rely on transportation networks, have a shared objective of enhancing their operational efficiency to maximize surplus. This paper presents a model that aims to evaluate the impact of road network improvement on the stakeholders involved in the rice supply chain network. The entities considered as related stakeholders in this context encompass collectors, wholesalers, and retailers, that have a distinct logistics cost structure and profit ratio. The model is developed within the framework of bi-level optimization, in which the upper level decides the road network improvement action and the lower level describes the optimality conditions of the rice supply chain network. The method of successive averages (MSA) is proposed to solve the lower-level problem, where a full enumeration-based approach is conducted in the upper-level problem The case study is situated in the Cugenang District of the Cianjur Regency, an area renowned for its productivity value in the rice farming sector, surpassing other sectors in economic significance. The numerical experiment evaluates three alternatives for road development, with the alternative consisting of solid connectivity to stakeholders yielding the greatest surplus, refer to Alternative 1 with the highest surplus investment ratio (0.0000232).

Keywords: method of successive averages, rice supply chain, stakeholders, supply investment ratio

INTRODUCTION

As of 2020, Indonesia's logistics performance has shown improvements compared to previous years. According to the World Bank's Logistics Performance Index (LPI) 2018, Indonesia's overall LPI score was 2.79, indicating a moderate level of logistics performance (Beysenbaev & Dus, 2020). Empirical evidence indicates that the costs associated with transport costs in Indonesia remain elevated. The logistics costs associated with shipping goods from Surabaya to Makassar are comparatively higher than those incurred when shipping goods from Surabaya to Singapore. A similar occurrence transpired in the context of transporting a 40ft container from Padang to Jakarta, necessitating a sum of 600 USD, however, the expense incurred for shipping the same container size from Jakarta to Singapore amounted to 185 USD. Transportation costs are identified as a significant factor influencing logistics costs. The factors influencing transportation costs (José & Julio, 2022;

Liu et al., 2023), encompass various aspects such as operations, products, geography, infrastructure, customer requirements, inventory, production decisions, locations, hazards, and agreements among stakeholders. Therefore, enhancing factors that impact transportation costs will undeniably enhance the efficacy of the logistics infrastructure in Indonesia.

A significant aspect of strategic logistics in Indonesia pertains to agricultural commodities. The availability of rice may be influenced by factors such as the geographical extent of paddy fields and the market price of rice (Elpawati et al., 2017). In the year 2020, the total expanse of paddy fields amounted to 10.786 million hectares, exhibiting a growth of 1% in comparison to the previous year, 2019. The potential for expanding the extent of paddy fields is substantial since the agricultural land has the capacity to encompass around 15.9 million hectares (Pertanian, 2020). The prices of rice are subject to the influence of both rice production and public consumption (Perdagangan, 2014). The data indicates that there was a marginal growth (0.08%) in rice production, amounting to 54.65 million tonnes, for the year 2020 (Statistik, 2020). One consequence of significantly reduced rice production is the conversion of paddy land to alternative agricultural uses, resulting from the financial constraints faced by low-income agricultural stakeholders (Islam et al., 2020). Table 1 presents a comparative analysis of the surplus generated by stakeholders for each product. Hence, the revenue generated by those engaged in the rice industry has a direct impact on the annual supply of rice.

Table 1 Surplus in Agricultural Sectors

Agricultural Sector	Production Cost (Million IDR)	Surplus (Million IDR)
Rice/Paddy	12.7	4.5
Corn	9.1	2.9
Red Chilly	52.1	25
Red Onion	67.2	10

The rice supply chain is an additional factor that can impact the accessibility of rice. In 2020 (Statistik, 2020), the survey encompassed several stakeholders involved in the process, including rice farmers/millers, wholesalers, retailers, and the demand market. The predominant practice among farmers is to engage in direct sales of their agricultural produce to retailers, accounting for around 22.93% of the total. A portion of farmers, approximately 8.23%, engage in the practice of selling their products directly to the demand market, bypassing intermediary corporate entities. Most farmers (about 14.67%) opt to distribute their products through wholesalers, who thereafter sell to retailers and demand the market. The proportion of rice sales from farmers and rice mills to other cities and provinces is substantial, amounting to 37.08%. Farmers and rice millers engage in the sale of rice to commercial entities that offer the most potential for financial gain. Similarly, this principle applies to various entities within the commercial realm, specifically wholesalers and retailers. Every stakeholder in the business sector will strive to optimize their individual surplus. An optimally functioning supply chain has the potential to create optimal financial returns for all stakeholders, including the farmers participating in the network. The potential for increased rice availability can be enhanced through the optimization of farmers' advantages and the establishment of an effective supply network.

Supply Chain Network Equilibrium (SCNE) models can be used to solve supply chain case optimization problems. SCNE models capture the interactions and decision-making of various stakeholders in the supply chain, including manufacturers, retailers, and consumers, and aim to find an equilibrium state where all stakeholders have achieved optimality (Yamada & Febri, 2015b). The SCNE model provides a benchmark for evaluating price and product flows in the supply chain and can be used to analyse the efficiency and effectiveness of different supply chain configurations and strategies. By formulating the problem as a variational inequality or optimization problem, SCNE models can be solved using mathematical programming techniques, heuristic algorithms, or simulation-based optimization (Nagurney, 2021).

The equilibrium state obtained from the SCNE model represents an optimal solution that balances the conflicting objectives of different stakeholders and considers various constraints and uncertainties in the supply chain. It provides insights into the optimal allocation of resources, inventory levels, production quantities, transportation routes, and pricing strategies (Nagurney & Toyasaki, 2005).

These measures can help assess the effectiveness of infrastructure developments in improving supply chain performance. One of the infrastructure developments is road network development. This research aims to assess road network improvement considering rice supply chain network.

METHODOLOGY

Overall, SCNE models offer a comprehensive approach to supply chain optimization by considering the interactions and dynamics of the entire supply chain network. They provide a framework for analyzing and improving the performance of supply chains in terms of cost efficiency, service level, and overall supply chain coordination(Yamada & Febri, 2015b). The Minimum Successive Average (MSA) method is one of the methods that can be used to fulfill the objective function (Maulana et al., 2023).

Lower-level stages to maximize surpluses for all stakeholders. Various methods could be used to solve this optimization problem (Frazila & Zukhruf, 2017; Yamada et al., 2009; Yamada & Febri, 2015a). This research will use the MSA method to complete the lower-level stages. By using the MSA method, it will be obtained that the rice movement conditions are in an equilibrium state. The MSA method is considered suitable because it can produce the optimum global solution, as has been done in the case of transportation (Mounce & Carey, 2015). The stages of working on the MSA are as follows.

Step 0: Initialization.	Do all-or-nothing assignment in supply chain network $\{q_a^0=1\}$
Step 1: Update.	Set $z_a^n=z_a(q_a^n)$, $\forall a$
Step 2: Direction finding	Do assignment in supply chain network based on current flow $\{q_a^n\}$.
Step 3: Line search	Find $\alpha_k=\frac{1}{k}$.
Step 4: Move.	$q^{k+1}=q^k+\alpha_k d^k$
Step 5: Convergence test.	If convergence criteria fit, then stop calculate $\{\omega_a^{n+1}\}$, else if use value $n:=n+1$ and continue to step 1.

$$\frac{\sqrt{\sum_a (q_a^{n+1}-q_a^n)^2}}{\sum_a q_a^n} \leqslant \kappa \tag{1}$$

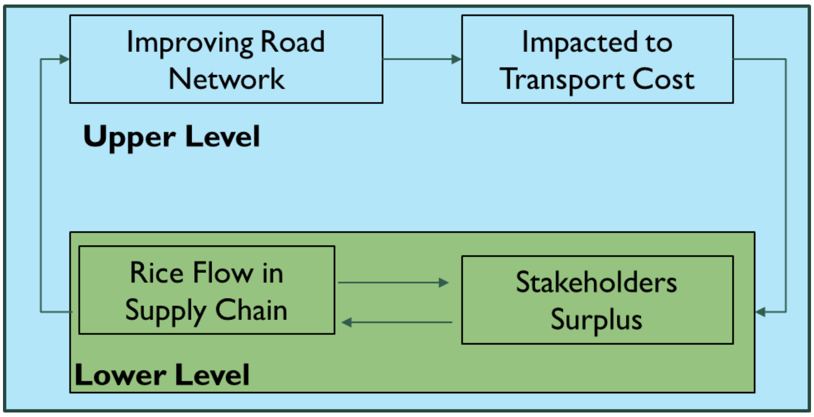


Figure 1 Upper and Lower-Level Optimization Steps

Figure 1 shows the relation between upper level and lower level, called bi level optimization. This approach is often used when the problem is embedded within another, such as hazardous freight transportation (Song et al., 2023), truck operation and storage (Tao et al., 2023) and industrial supply chain(Silva et al., 2022). Once the system reaches a state of equilibrium, the subsequent computation at a lower level involves discretely testing all potential stakeholder's profit percentages. The profit (%) refers to the desired level of surplus that each stakeholder entity aims to attain, determined by the computation of costs. The profit portion is discretely determined and fixed. Therefore, a state of equilibrium will be achieved for every potential profit. At the advanced stage in upper level, the model finds the optimal combination of road network improvement. This is achieved by maximizing the ratio of total surplus for all stakeholder players and investment in transportation network expansion.

The surplus investment ratio metric $(P(y,\vartheta,q^*,b^*))$ employed to assess supply chain performance is the surplus ratio $H(q)$ generated by each business entity to the investment value allocated for road network improvement (ϑ_m). The pursuit of the highest surplus value $H(q)$ is conducted discretely, relying on the predetermined optimal profit percentage (b^*). The calculation of surplus value $H(q)$ is performed for each individual link $(z_a(q))$. The link surplus's form $z_a(q)$ is determined by the link flow inside the path l that connects nodes r

and s. Within the framework of the supply chain, there exists $z_a(q)$ a notable benefit that arises from the facilitation of rice transportation. The $z_a(q)$ values are both positive and $dz_a(q)/dq$ finite when considering z_a values within a certain range. This statement is a component of the proof $F(\cdot)$ pertaining to convexity.

$$P(y,\vartheta,q^*,b^*)=\frac{H(y,q^*,b^*)-H_0(q^*,b^*)}{\sum_{m\epsilon W_2}\vartheta_m y_m} \quad (2)$$

$$H(q^*)=\sum_{k=1}^{K}\rho_{jk}^{3*}q_{jk}*b^*+\sum_{l=1}^{L}\rho_{jl}^{4*}q_{hjl}*b^*+\sum_{l=1}^{L}\rho_{kl}^{5*}q_{hkl}*b^*-\sum_{a\in A}\int_0^{q_a}z_a(q^*)dq \quad (3)$$

$$z_a(q)=\sum_{rs\in D}\sum_{l\in Q_{rs}}j(q)_l^{rs}\delta_{al}^{rs}\forall a\in A \quad (4)$$

Table 2 presents a comprehensive depiction of the cost function $j(q)_l^{rs}$ associated with each actor participating in the study. The cost function pertaining to wholesalers, retailers, and logistic cost costs is derived based on the findings of the study, containing collection cost $f_i(Q)$, handling cost $(c(Q))$, inventory cost $(g(Q))$ and transportation cost (w_h). Transportation cost is calculated from vehicle rent cost and vehicle operation cost (Marufuzzaman et al., 2015). Needs of vehicle number is estimated based on operational time per day (T), vehicle capacity (s), rent vehicle unit (η) and travel time for each zone (t_a).

Table 2 Cost Function Description $\mathbf{j(q)_l^{rs}}$

No	**Name**	**Cost Function Description $\mathbf{j(q)_l^{rs}}$**
1	Collectors (i)	$f_i(Q)+c_i(Q)+g_i(Q)+w_h$
2	Wholesalers (j)	$c_j(Q)+g_j(Q)+\sum_{j=1}^{J}\rho_{ij}^{1*}q_{ij}+w_h$
3	Retailers (k)	$c_k(Q)+g_k(Q)+\sum_{k=1}^{K}\rho_{jk}^{3*}q_{jk}+\sum_{k=1}^{K}\rho_{ik}^{2*}\sum_{h=1}^{H}q_{hik}+w_h$
4	Transportation Cost (w_h)	$\frac{q}{(s)(T)}\eta\sum_{a=1}^{A}t_a\delta_a+length\times vehicle\ operation\ cost\ each\ km$

CASE STUDY

The constituents of the transportation network model inside the supply chain encompass supply chain systems, network models, and zoning models. The supply chain system in Cianjur Regency commences with the agricultural producers and concludes with the end customers. Farmers predominantly select collectors, also known as middlemen, as the primary institutions in this paradigm. Consequently, the collectors assume the role of upstream economic actors in this context. Moreover, the second phase of the study involves the inclusion of both wholesalers and small-scale traders as key stakeholders in the business landscape. One distinguishing factor between the two categories of dealers lies in the magnitude of rice transactions they engage in. Lastly, we have customers, who will afterward be referred to as the demand market. The network and zoning model representation is depicted in Figure 2.

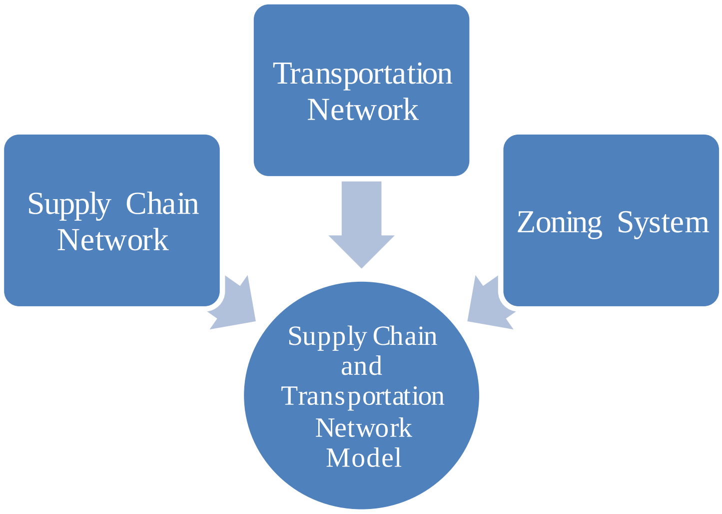
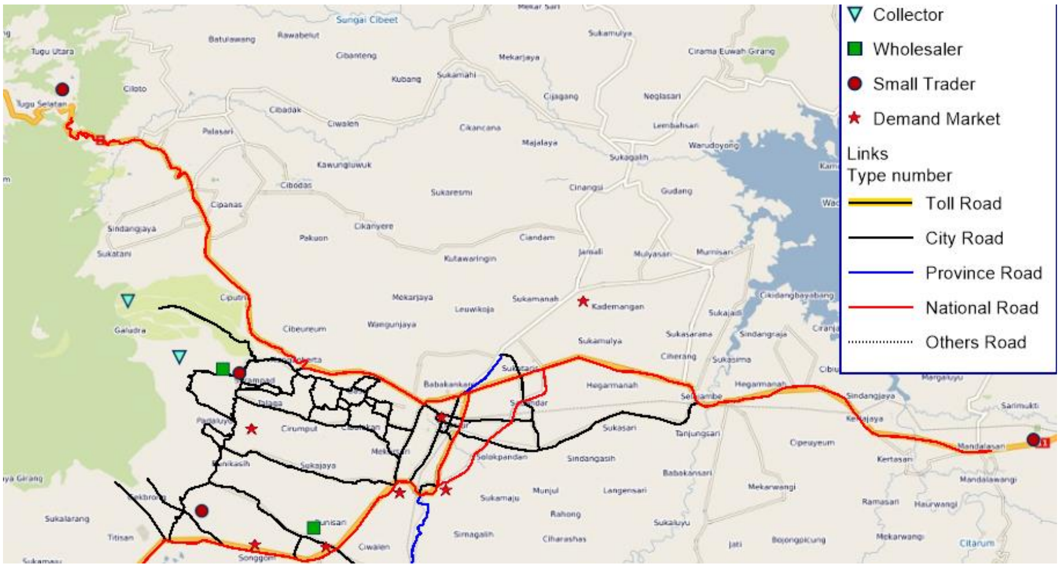
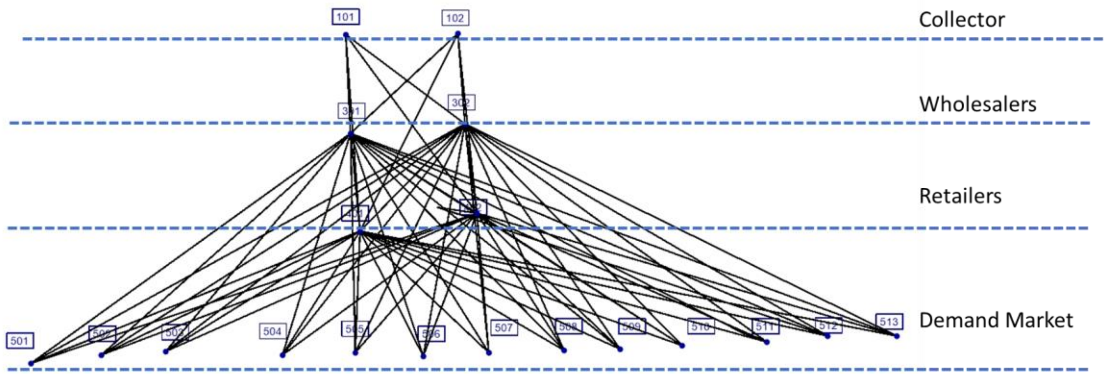


Figure 2 The Transportation Network and Zoning Model

The study was carried out in the Cugenang District, located in the Cianjur Regency. The figure and table below provide a comprehensive presentation of the input data used in the study. The subsequent data pertains to the transportation of rice during a span of season/four months. Figure 3a shows the road network model representing link and zone in the spatial model. The scope of the link includes city road, province road, and national road. The zone system represents each stakeholder, as shown in Table 3. Figure 3b notes the supply chain network model, that explains rice flow between zones. Zones represent the location where stakeholders are. The stakeholders consist of two collectors, two wholesalers, two retailers, and 13 demand markets.



a) Road Network Model



b) Supply Chain Network Model

Figure 3 Road Network and Supply Chain Network Configuration

Table 3 Zone Description

Zone No	Zone Name	Stakeholders	Zone No	Zone Name	Stakeholders
101	Bangbayang	Collector	507	Cikaroya	Demand Market
102	Buni Kasih	Collector	508	Ciwalen	Demand Market
301	Buni Kasih	Wholesalers	509	Jambudi PA	Demand Market
302	Jambudi PA	Wholesalers	510	Mekarwangi	Demand Market
401	Buni Kasih	Retailers	511	Pamuyanan	Demand Market
402	Buni Sari	Retailers	512	Sirnagalih	Demand Market
501	Eksternal Barat	Demand Market	513	Sukamulya	Demand Market
502	Eksternal Timur	Demand Market			
503	Buni Kasih	Demand Market			
504	Buni Sari	Demand Market			
505	Ciendeur	Demand Market			
506	Ciherang	Demand Market			

The establishment of a supply chain network, as depicted in Figure 3, is being undertaken. The input of movement data involves the processing of rice movement data in response to market demand, as seen in Table 3. Zone system in Origin/Destination in Table 4 is referred to Table 3. Table 5 displays more data setting parameters.

Table 4 Input Data for Origin Destination Matrix for Rice Movement (ton/season)

Origin/Destination	301	302	401	402	501	502
101	408	480	0	0	0	0
102	0	100	0	0	0	0
301	0	0	15	6	24	130
302	0	0	7.8	20.4	24	48
401	0	0	0	0	0	0
402	0	0	0	0	0	0

Origin/Destination	503	504	505	506	507	508	509	510	511	512	513
101	0	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0	0
301	0	0	0	0	0	0	0	0	0	0	16
302	0	0	0	0	0	0	0	0	0	0	3
401	0	0	0	0.8	0	0	1.6	0	4	1.6	0
402	0.60	2.52	1.92	0	1.2	0.6	1.2	2.28	0	0	0.24

Table 5 Data Parameters Settings

Parameter	Data
Collection Cost	4,000 IDR per kg
Rent Vehicle Unit (η)	300,000 IDR per vehicle-day
Operation Time (T)	18 hours daily
Vehicle Capacity (s)	15 ton per vehicle-day
Vehicle operation cost per km	1,000 IDR per km

The primary objective of the lower-level model is to optimize the surplus value, aiming to get the maximum possible outcome. Once the equilibrium condition is achieved, the calculation is subsequently extended to encompass each discrete profit percentage that has been determined. There exists a group of six stakeholders, comprising two collectors, two wholesalers, and two retailers. The total number of possible combinations among these actors may be calculated using the formula is 4095. Enumeration is conducted for every computed combination (4095 combinations). It needs a total of 581 seconds of computational time is required to successfully execute all combinations utilizing the Matlab software.

Figure 4 shows all combinations (4095 combinations) surplus for each stakeholder. Each alternative possesses a distinct combination of surplus that contributes to the attainment of the maximum total surplus. The demand market has constraints for rice purchasing standards, which are set at 11,000 IDR per kilogram. The optimal condition for the base condition is achieved in combination no. 1636 (have profit percentage (b) 20%), it is imperative that the criteria for maximum surplus. Noted in combination no 1636, all zones have a profit of 20%. Figure 5 depicts the procedural steps involved in attaining the convergence point. Combination no 1636 (shown in Figure 5) reaches the convergence value of 0,1% on iteration no 39, with a surplus value of 3,136,266 IDR.

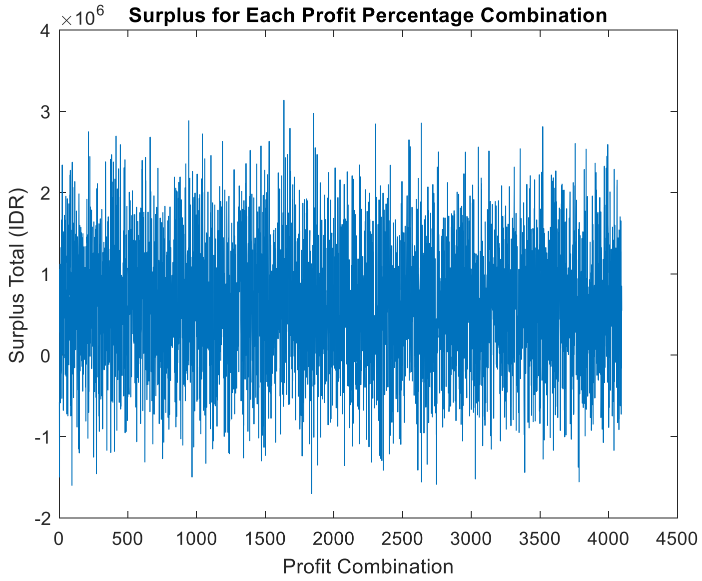


Figure 4 Surplus for Each Profit Percentage Combination

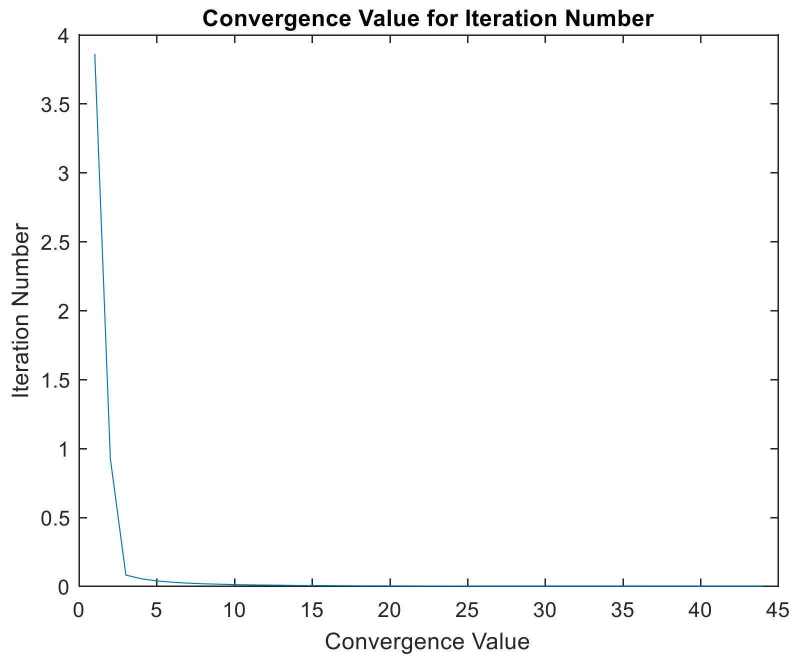


Figure 5 Convergence Value Iteration for Profit Combination No 1636

RESULT ASSESSMENT

Validation of the supply chain model is necessary to ascertain if the output of the model accurately reflects the current conditions. The model proposed by Maulana (2023) has been empirically validated, namely in terms of the resemblance between the selling prices of rice. Moreover, the decision to prioritize the construction of the road network is contingent upon the constraints imposed by the restricted budget.

Transportation development and policy are carried out based on the condition of transportation infrastructure and facilities. The table below describes the alternative road development network transportation policy descriptions. Figure 6 and Table 6 show alternative descriptions. Alternatives 1 and 2 show an improvement in the condition of the transportation infrastructure, with the unit price of road widening IDR 5 billion per km, which is located in Cugenang District. Those two alternatives are needed to increase connectivity between Cugenang District and Cianjur District or the city center in Cianjur. Alternative 3 shows a combination of the two alternatives.

Table 6 Road Development Network Alternative Description

Name	Description	Investment Cost
Alternative 1	Road widening 11 km into 10 m (4/2 UD)	59.18 IDR Billion
Alternative 2	Road widening 18 km into 10 m (4/2 UD)	95.3 IDR Billion
Alternative 3	Both Alternative 1 and Alternative 2	154.48 IDR Billion

In the previous section, the optimal condition reached by stakeholders in Combination no 1696. While assessing Alternative 1,2 and 3, we have an optimality condition in a different combination number, shown in Table 7. Table 7 also displays the earnings and return on investment ratios that have been acquired. Each alternative has a different stakeholder's profit combination. Among the available alternatives, Alternative 1 emerges as the most appealing option for rice company stakeholders due to its highest surplus $H(q^*)$, which is 4.51 million IDR. Refer to Table 6, alternative 3 has the most expensive investment cost. From the surplus investment ratio, Alternative 1 is the optimum road network improvement, which stands at 0.0000232.

Figure 6 Alternative 1 and 2 Locations

Table 7 Surplus Assessment for Each Alternative

Name	Surplus (IDR)	Ratio Surplus and Investment Cost
Alternative 1	4,510,519	0.0000232
Alternative 2	3,568,199	0.0000045
Alternative 3	4,929,479	0.0000116

CONCLUSION AND RECOMMENDATION

This paper presented a model for enhancing the road network by considering the rice supply chain network. The stakeholders (i.e., collectors, wholesalers, and retailers) in the rice supply chain network persistently pursue maximizing their surplus. The optimal condition of the rice supply chain network was solved by invoking a method of successive averages, where the road improvement decisions were examined by testing three combinations. A numerical experiment showed that the road expansion (Alternative 1) significantly increased the surplus of rice supply chain stakeholders by up to 0.0000232. Additionally, it is noteworthy that increasing the number of road expansions does not inevitably lead to improving stakeholder surpluses. Further research can then be expanded by exploring the additional commodities impacted by the expansion of the road network.

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