A mapping of current downstream shallot supply chain based on agent-based modeling and quadruple innovation helix: a case study at Cirebon district, Indonesia

N Sjafrina¹, Marimin¹, F Udin¹ and E Anggraeni¹

¹ Department of Agroindustrial Technology, Faculty of Agricultural Engineering and Technology, IPB Univeristy (Bogor Agricultural University), Bogor, Indonesia

E-mail: noveria_sjafrina@apps.ipb.ac.id

Abstract. Shallots have the prospect of developing value-added downstream products. Currently, the only downstream product on the market is fried shallots, so it is necessary to map the downstream product supply chain shallots in Cirebon Regency as one of the regions producing shallots. The issue in the downstream development is how to map current downstream supply chain development, including current interaction between actors, so we can make a decision for future downstream development priority. This paper designs the mapping of the downstream supply chain of shallot commodities to see the interaction between actors in the shallots agroindustry downstream supply chain network. The research method used was agent-based modeling (ABM) based modeling to determine agent behavior and its interactions in the shallots agroindustry supply chain. The structure of the agent structure in the supply chain was designed with the quadruple innovation helix (QIH) approach, which consists of 4 actors’ classifications, namely farmers, private sector, government, and universities. This research produces an interaction design that can be used as a basis for evaluating performance, added value and other aspects through the interaction behavior of each QIH actor in agent-based modeling to support downstream innovation in shallots agroindustry. Case studies in the Cirebon district of Indonesia show that the ABM and QIH models designed are able to show the form of interaction between downstream supply chain actors.

Keywords: Agent based modeling, downstream supply chain, quadruple innovation helix

1. Introduction

Shallot agro-industry downstream supply chain can be said to be the development of agro-industry that can be a way to stop the slowing down of the growth of the industrial sector. Shallot agro-industry is an agricultural sub-sector that plays an important role for economic growth, export revenues, providing employment, poverty reduction and regional development in the shallot supply chain sector. Shallot agro-industry can optimize Indonesia's comparative advantage in the agricultural sector as a country based on natural resources by increasing added value. Agro-industry down streaming is in line with the 2015-2019 National Medium-Term Development Plan (RPJMN) for Food and Agriculture, namely creating an attractive agricultural sector for young farmers / laborers through increased domestic investment in rural areas, especially in industrialization and down streaming. Shallot agro-industry is built using local raw materials so that there is a close link between the agro-industry and local onion farming. The shallots agro-industry down streaming program is also in line with the Government
Regulation of the Republic of Indonesia Number 14 of 2015 concerning the National Industrial Development Master Plan for 2015-2019 which confirms the government's seriousness in realizing the objectives of holding the industry, one of which is realizing the national industry as a pillar and a driving force of the national economy [1].

Processing of shallot products in the downstream supply chain is not only fried, powder, and paste, but there are still some processed shallot products that can be developed such as those found in shallot industry trees including fresh shallot slices, dried slices, pikelets, oleoresin, shallot oil and anti-thrombotic. The processing of shallot products must be designed not only to overcome the problem of surplus production but also directed as an effort to increase added value through product diversification using quality raw materials [2]. Industrial raw materials require large quantities of fresh produce to enable farmers to benefit. In addition, food processing can provide a high enough selling price to make it possible to buy raw materials from farmers at a price high enough if they meet the desired quality standards. This condition can provide a good bargaining position for onion farmers and guarantees of a commensurate profit. Downstreaming of shallot commodities will help the government in controlling the price of shallot commodities in addition to alternative exports. In addition, the benefits of commodity downstreaming help increase the added value of a commodity in the form of processed products so that it opens a business and new business opportunities, helps the economy, opens up new export opportunities, opens up employment opportunities and helps ensure commodity markets for shallot farmers. Downstreaming therefore becomes important for an agricultural commodity. The importance of this downstreaming certainly needs to be supported by good interaction between each component of the actors in the supply chain, especially the actors in the QIH component.

QIH is the development of the triple helix model of economic innovation. QIH adds a fourth component to the interaction framework between actors, namely universities, industry, government, and the fourth component, namely civil society and the media. QIH was first developed in 2009 for analysis that relates knowledge, innovation and the environment (natural environments) to each other [3]. The concept of QIH is important to be adopted in the development of shallot downstreaming provided that shallot is one of the commodities consumed by civil society in general so that community involvement as one of the innovations in the downstream agro-industry is important to do. The QIH framework can be used as a basis for mapping the forms of interaction of each actor in the shallot agro-industry downstream supply chain innovation system.

Downstream mapping is an important aspect of the study that must be modeled on a downstream innovation of an agricultural commodity. In Indonesia, shallots, as one of the strategic commodities of the community, have an important role to downstream to increase the added value of these commodities. Interaction between agents in the downstream industrial supply chain is important to be mapped and modeled to determine the shape of the organization's network interaction so that we can determine the supply chain value-added and the appropriate future downstream strategy design. The most appropriate approach for modelling the interaction behaviour between actors in the downstream agro-industry supply chain of shallots is the agent-based model. An agent-based computer model to succeed the fair counteract in the added value for each of the POSC(Palm Oils Supply Chain) actors [4] to balance of profits between cacao supply chain actors [5]

Agent-based mapping (ABM) integrated with QIH [6] as actors/objects conducting interactions that occur within the downstream supply chain of shallots is important to be carried out in the downstream agro-industry mapping model to see the form of interaction that occurs in it so that it can be used as a basis for the development of further research in the field of supply chain strategy model for the agro-industry shallot [7]. Previous studies have focused on assessing the performance of the shallot supply chain and the products produced in the downstream process. In designing a shallot downstream supply chain innovation, there is a gap in the form of interaction of each actor involved in it as well as a map of the shape of their interactions that affect the behaviour of the supply chain system in the downstream supply chain design in the future. Therefore the downstream supply chain mapping model research based on innovation is important to do.
But the challenge that must be answered is to model the behaviour of actors in the downstream supply chain of shallots and the form of their interactions based on the interaction of quantified agents so that performance, behaviour, and other calculated aspects can be determined. Based on this challenge, research on mapping the shallot downstream supply chain innovation based on agent-based modeling and QIH becomes important to do to fill the gaps in the modeling of shallot downstream supply chains. This mapping study also opens up opportunities for the development of new research on the downstream design of shallot commodities ranging from short, long, and medium-term as well as other innovation studies, including technology transfer, value-added, and appropriate strategic decisions based on variables that affect the performance of the chain supply shallots.

This research objectives are to design and review a downstream mapping of the shallot supply chain based on agent-based modeling integrated with the QIH framework by analyzing the interaction between actors, design actors and deploy the mapping downstream supply chain into a simulation so as to produce a mapping in the form of a comprehensive interaction between actors and become the basis for modeling the downstream supply chain going forward. We claim the novelty in the form of integration between ABM and QIH in becoming a new approach to assessing innovations and forms of interaction between quantified actors so that the process of innovation in agricultural commodities can be measured from various aspects.

2. Methodology
Mapping is an important initial stage in a strategy formulation. Mapping allows researchers to see existing conditions from a variety of perspectives before entering the stage of the downstream supply chain model and the formulation of a shallot supply chain strategy. This study mapped the current condition of the shallot agro-industry supply chain with an agent-based modeling approach. Agent-based modeling allows researchers to be able to do current downstream supply chain simulations so that they get a calculation of the performance and behavior of each agent. This simulation approach can be carried out considering the complexity of field conditions and full area coverage, so it requires a huge cost. In addition, this design can be the basis and initiation of the next red shallot supply chain design proposal. Agent-based simulations reinforce the simulation results more comprehensively so that they can be analyzed based on agent behavior in the model. Furthermore, the simulation results are adjusted to the conditions on the ground.

The concept of the quadruple innovation helix (QIH) framework [6] was adopted as the basis for compiling agents in agent-based modeling concerning the national/regional innovation system framework consisting of four groups of actors interacting to run an innovation system. The four actors are collaboration and interaction between academics and industry and the government as the coordinating and facilitation of top-down policy instruments based on views and perspectives on the of innovation in the future. The fourth actor in QIH is the community which forms bottom-up interactions.

This gives the view that innovation is a socio-technical, socio-economic and socio-political phenomenon so that civil society plays a central role as a driver of innovation based on the user-centred interaction consisting the community itself and the economy.

The agent interaction is described by using state chart, the agent attributes and task are described by using class diagram and simulation is deployed by using Java programming with Any Logic Software. The research framework is shown in figure 1.

Data collection to design interaction models between ABM and QIH-based actors was carried out in the Cirebon District of Indonesia. Data was collected by visiting several agricultural agencies in Cirebon District and shallot processing industry players and shallot farmers. The survey was conducted by interview to determine the attributes of each actor in the downstream shallot supply chain. The survey results also determined the role of each actor that will be used for quantitative processes in ABM.
Field conditions of the shallot supply chain
Interaction between QIH agent shallot supply chain
The results of the interaction in the form of a quantitative map of the ABM-based downstream
Map of current interactions between downstream supply chain agent
Map of interactions between proposed shallot agent

Figure 1. Framework for mapping the downstream supply chain of shallots based on QIH ABM.

The identification of QIH agents is carried out by conducting field visits to find out the actors currently involved in the shallot downstream in general. Furthermore, the form of interaction of each agent is carried out using state chart diagrams. After the agent representation and the form of interaction are designed, an analysis of the current form of interaction between agents is then carried out with a case study in the Cirebon district and the form of opportunities for future interaction models if downstream shallots are carried out with more variety of product derivatives. In the final stage analysis and evaluation of mapping scenarios of interaction models between supply chain agents in the future with greater product variation were conducted and compared with current conditions.

3. Results and discussion

3.1. Current identification of downstream supply chain agents
Based on the identification of field conditions in the Cirebon Regency, Indonesian shallots downstream products are generally still in the form of a simply-processed household scale. The actors involved from upstream to downstream in the shallot supply chain are farmers, intermediary traders, and processing industries, which are generally still on a household scale [8]. Farmers have a role as suppliers of raw shallot to intermediary traders which generally consist of cooperative partners, collecting traders, and sending traders) [9]. Traders are divided into wholesalers, market wholesalers, and retailers to be subsequently sold to home industries or in the form of commodities in traditional and modern markets. Before sending raw shallot to intermediary traders, farmers generally save them in government warehouses or farmers' cooperatives. The processing industry generally processes on a household scale in the form of simple preparations. The involvement of government and academics in a shallot downstream supply chain innovation system will help downstream in the shallot supply chain [10].

3.2. State chart model on QIH based agent interaction
State chart is an essential tool to model the interaction between agents commonly used in ABM design. With it, we can describe and model the interaction clearly and make connection between actors/class attribute in an ABM simulation.

3.2.1. Interaction between farmers and cooperative partners. The form of interaction between farmers and partner cooperatives is that farmers have stock of shallot and make sales to partner cooperatives. Partner cooperatives can buy, store for warehousing or sell to subsequent actors in the supply chain. The form of interaction in the form of state-chart diagrams is in figure 2.
Table 1. Current downstream shallot supply chains.

| Agents                        | Roles                                                                 |
|-------------------------------|----------------------------------------------------------------------|
| **Society/people agents**     |                                                                      |
| Farmers                       | Planting, harvesting, post-harvest, warehousing process, sales process |
| **Private Sector Actors**     |                                                                      |
| Partner Cooperation           | Buying to farmers, selling to wholesalers/industries, storage, shipping |
| Collectors                    | Buy and collect shallot from farmers, sales to wholesalers, traditional markets, modern markets and home industries, storage, shipping |
| Shippers                      | Delivering shallot commodities from one actor to another             |
| Wholesaler                    | Wholesaler market large quantities of shallot commodities to other small traders and processing industries |
| Wholesaler in traditional market | Large market traders market the number of shallots to small traders |
| Retailer                      | Retailers buy shallots from large traders or from shippers, collectors, cooperatives and partners as well as from farmers to sell to consumers |
| SME scale processing industry | SME scale processing industries are shallot commodity processors who buy from large traders and sell their processed products to small traders |
| **Government actors**         |                                                                      |
| Government                    | The government determines policies for trading activities            |
| **Universities actors**       |                                                                      |
| Universities                  | Conduct research to improve the performance of the shallot supply chain |

3.2.2. Interaction between farmers, cooperative partners, and collecting traders. The interaction between farmers, cooperative partners and collectors is in the form of shallot purchases and shallot commodity transportation which is depicted on the state chart for trading purposes in figure 3 and then figure 4 send the product to the trader, and trader transport it to the next actor in the Shallot supply chain.

**Figure 2.** State chart farmers’ interaction with cooperatives.

**Figure 3.** State chart of interactions of farmers, cooperatives and collecting trader.

**Figure 4.** State chart of interactions farmers, partner cooperatives, and collecting traders with sending traders.

**Figure 5.** Interaction of large traders with SME / industry and traditional markets.
3.2.3. Interaction between farmers, partner cooperatives, and collecting traders with sending traders. Shippers have the role of sending shallots from suppliers which in this case are farmers, cooperatives and collectors to large traders or large markets as well as large-scale processing industries and SMEs [7]. Further processing and resale will be made to retailers as well as to the processing industry which requires considerable amount of raw materials. The form of interaction in the form of state-chart diagrams is in figure 4.

3.2.4. Interaction between big traders and with traditional markets, retailers and onion SMEs. This form of interaction is the supply of large traders [12] to SMEs as well as the processing industry and traditional traders to be sold to small consumers. The form of interaction in the form of state-chart diagrams is in figure 5.

3.2.5. The definition of the attributes and processes of each agent is based on class diagrams. The first agent in this mapping is farmers. Farmers have the role of planting, storing in warehouses (both government and private) and selling shallots to the next actor, in this case an intermediary trader. The form of the Farmer's agent design in this mapping is as follows in figure 6.

With the formulation of each function is as follows:
- **Planting** = Random (duration of planting, number of planting);
- **Harvesting** = Random (duration of harvest, number of harvest);
- **Post-harvest process** = Random (duration post-harvest);
- **Warehousing process** = Random (Warehousing duration, Amount warehoused);
- **Selling process** = send (selling price, selling amount)

**Figure 6.** Farmer agent design.

Attributes to the farmer's agent in the case of the downstream supply chain mapping based on agent modelling consist of planting time, harvest time, post-harvest time, storage time, number of seedlings planted, number of harvests, amount of warehousing and selling price. The focus of this research is to look at the performance and performance of the onion downstream supply chain so that the long attribute of the process in farmers is made as a "delay" in the object-oriented programming thread process (not decomposed into a more detailed process). The duration of planting is dynamic, with a value of 50-90 days. The harvest time is assumed to be one day per hectare, with the value of the number of harvests and warehousing per hectare of 10 000-12 000 kg per hectare. The length of the shallot warehousing depends on the requests that come with the next actor. The amount needed for planting shallot seedlings is around 800-1500 kg per hectare. The selling price follows the market mechanism with the lowest price of Rp18,000 and the highest price of Rp55,000 per kg.

The second agent is a cooperative partner. Farmer partner cooperatives have the task as a combination of farmer groups, collectors and distributors of farmers' crops to the industry or large traders. The design forms of cooperative partner agents are represented in figure 7.
The function is formulated in object-oriented programming as follows:

- **Purchases to farmers** = send (stock, purchase amount to farmers)
- **Sales to wholesalers** = send (Shipping amount, Shipping fee)
- **Sales to home industry** = send (number of Shipment, Shipping fee)
- **Storage** = inv (Warehousing fee, Inv. Amount)

**Figure 7.** Design of cooperative partner agents.

Partner cooperative agents have the attributes of the number of shallots stock, the number of purchases to farmers, and the selling price to wholesalers and the processing industry. The process of this agent is buying to farmers, selling to wholesalers, selling to home industries and storing processes for the stock, and sending shallots that have been sold to the next sphere in the downstream supply chain of shallots.

The third agent is a collector. Collecting traders have the role of buying shallots from farmers to be distributed to larger traders, small and medium industries, or to modern and traditional markets. The design form of the collecting trader agent is depicted in figure 8.

- **Purchases to farmers** = buy (total purchase to farmers)
- **Sales to large traders** = send (number of Stock Merchants, Collectors, number of Shipment)
- **Sales to home industry** = send (shipping costs, shipping amount)
- **Storage** = INV (Warehousing fee, Warehousing amount)
- **Shipping** = send
- **Sales to traditional markets** = send (shipping amount, shipping fee)
- **Sales to modern markets** = send (shipping costs, selling prices)

**Figure 8.** Design of collecting trader agents.

Collectors have the attributes of the amount of stock available to them, the number of purchases to farmers, selling prices, warehousing costs, the number of shipments, and shipping costs to the next sphere in the supply chain. Furthermore, the attributes defined in the class processes of collecting traders have seven processes, namely buying to farmers, selling to wholesalers, selling to home industries, storage, shipping, selling to traditional markets, and selling to modern markets.

Based on field observations in Cirebon district, the selling price at the level of collectors/cooperatives is more the price of farmers plus an average profit of Rp2.000 from the purchase price to farmers. The average storage capacity is 15.000 kg of shallots. Purchases to farmers are assumed to meet demands coming from large traders as well as home industries or retail traders and to fulfil / maintain stock at 30% of warehouse capacity. Shallots are delivered to the next actor/sphere with a shipping fee of Rp15.000 per km with a fleet of 2.000-5.000 kg.

The next agent is the sending trader. Delivering from farmers to cooperative partner warehouses, to collecting traders, large traders, modern market traders, traditional markets, and small-scale processing industries. The form of sending merchant design is shown in figure 9.
The formulation of the shipping merchant function in the object programming language is

\[
\text{Retrieval} = \text{send} (\text{price}, \text{cost}, \text{distance}, \text{type of fleet}, \text{amount, cooperative})
\]

\[
\text{Shipping} = \text{send} (\text{shipping cost}, \text{distance, fleet}, \text{shipping amount, shipping duration})
\]

\[
\text{Loading} = \text{load} (\text{loading time, Cooperative price, Collector price, quantity})
\]

**Figure 9.** The design class of the sending merchant's design.

The sending trader has the attributes of the purchase price from the farmer, shipping costs, distance, type and capacity of fleet, number of shipments, the price of the cooperative, the price of the collecting trader, and the shipping time. There are three processes for sending traders, namely taking goods from farmers, shipping, and loading when they arrive at the next actor in the supply chain.

The next agent is a wholesaler. Large traders buy from partner cooperatives, collectors, and sending traders to industries, modern markets, and traditional markets. Agents of large traders’ market large quantities of shallot commodities to industries. The design of the sending merchant class is shown in figure 10.

**Figure 10.** Design of sending merchant class.

The next agent is a large market trader who has a role to market the amount of shallot to small traders. The function of a large-scale market trader is more or less the same as that of a large-scale trader but has a supply chain flow that goes directly to small-scale traders in traditional markets. The design of a large market trader class as shown in figure 11.

**Figure 11.** The design of a large market trader class.
The next agent is a retailer with the role of buying shallots from large traders or from sending traders, collectors, cooperatives and partners as well as from farmers to be sold to consumers. The function process for these agents is selling to small scale consumers and buying to other big traders. Figure 12 is the retailer’s class design.

```
Retailer
- Oder price : int
- order quantity : int
- Sales price : int
- Number of sales : int
+ Purchase() : int
+ Sales() : int
```

**Figure 12.** Design of a class of retailers.

The next agent is the SME scale processing industry. A common form of processing industry in Indonesia. The processes contained in this agent are as follows: buying shallot from large traders, producing certain types of onion derivative products, selling processed products, and storing raw materials. Figure 13 is a class design of SME scale processing industry agents.

```
SME scale processing industry agents
- Raw material amount : int
- Production amount : int
- Inventory amount : int
- Purchase price : int
- Price of selling product : int
+ Buy onion() : void
+ Production of shallot product() : void
+ Selling processing product() : void
+ Storage() : void
```

**Figure 13.** Design class of SME scale processing industry agents.

The next actor is one part of the quadruple helix which has the role of determining policies for trade activities and the downstream agro-industry supply chain of shallots. Supply chain management approach is applied can efficiently integration and synergies among the suppliers, entrepreneurs, warehouses and other actors, so that products can be distributed with the right quality, place and time to reduce costs and satisfy customers [13] In this agent the process carried out is the establishment of rules to regulate the flow of data traffic in agent-based simulations [14]. The attributes used for setting this rule are the number of shallots circulating in the market, setting the highest price, setting the lowest price.

3.2.6. Simulation of shallots downstream mapping. A form of interaction simulation between cooperatives, wholesalers and sending traders for the research area in Cirebon Regency. The agent-based image mapping implemented in Any Logic software is as follows. The yellow buildings are cooperatives, vehicles are sending traders, and green are big traders (in figure 14). We collected data from survey in Cirebon district and make a random generator number from computer according to the survey. The random value from generator random number is used as input in this simulation.
14. Maps the interaction simulation of each QIH actor.

3.2.7. Measurement parameters of simulation results. Measurement of quantitative parameters in this simulation uses a template from the Any Logic supply chain that runs on the Any Logic cloud database server [15]. Display the results of the simulation run is as follows.

![Simulation Diagram]

$s$ is the estimated number of orders that an actor must order in the onion supply chain with the rule of inventory amount + backlog production + estimates that will be transported from order S, then an actor will order as much as $s$. The measurement results of the interactions between the 3 main actors namely suppliers, wholesalers and processing are in figure 15.

![Figure 15](image)

**Figure 15.** Measurement of supply chain costs from the interactions of each QIH actor.

3.2.8. Implications and discussion of the current mapping of shallots downstream conditions. Based on the ABM and QIH-based mapping results, it can be seen that the shape of the shallot supply chain downstream is very long and has a shortage problem that allows the price of shallots at the trade and industry level to be high [16]. In addition, the process which is relatively simple in the form of fried shallots shows added value in the downstream supply chain which is still quite small. The next design should lead to the potential of potential shallot derivative products including innovation support and interaction of each of the QIH actors in supporting the downstreaming of shallot products that have high diversity. It is clear that future development opportunities are very prospective in the development
of other shallot product derivative supply chains and industries that have greater added value than the current supply chain scale.

4. Conclusions and Recommendations
This research produces a form of shallots agro-industry downstream supply chain mapping that illustrates the current conditions and the agents that interact in them based on agent-based modeling and QIH. This form of interaction consists of 4 actors’ classifications, namely farmers, private sector (partner cooperation, collectors, shippers, wholesaler, retailer, and SME scale processing industry), government, and universities interacting to form a downstream supply chain. This modeling can be the basis for further research in the form of value chains, strategies, and institutional design. However, it still has shortcomings, namely the uncertainty of the supply chain system for downstream derivative products, so it is necessary to design an institutional downstream in the form of an innovation system with expert judgment for analysis quantitative towards institutional conceptual models and competitiveness. This results in the formulation of recommendations that contribute to actors of shallots in the downstream supply chain. Finally, it can guarantee the realization of a good shallot downstream product industry.

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