A framework for designing symbiotic simulation decision support systems for horticultural supply chains involving smallholder farmers

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Abstract. Horticulture is one of the important components of Indonesia’s economy that come from the agricultural sector. However, many challenges are encountered in the development of horticultural supply chains (HSCs) in Indonesia. One of them is the lack of production planning that suits the market demand. This results in inefficiency, high food losses and price fluctuation. HSCs systems are complex, especially in developing countries like Indonesia in which many smallholders are involved. Concerning this situation, ICT-based approaches have been widely proposed to integrate planning along supply chains. One of the approaches is a symbiotic simulation that enables a close association between the real system and simulation system. Symbiotic simulation is designed to support decision-makers to plan their activities using the real/near real-time data generated by the real systems as the inputs. However, how this system model can be used in HSC systems involving many smallholders is still a question. This paper proposes a framework to design decision support symbiotic simulations for HSC systems involving smallholders. The framework is designed based on the literature study on symbiotic simulation and agricultural supply chains in developing countries. In this framework, four activities in the HSCs are considered: 1) production; 2) post-production; 3) logistics, and 4) market. This framework can be used by farmer organisations or agricultural companies that have partnerships with smallholders to plan their activities along their supply chains.

1. Introduction
Horticulture is one of the important components of Indonesia’s economy that come from the agricultural sector. Even though the contribution of the horticultural sub-sector to Indonesian GDP is only about 1.6% [1], the GDP from horticulture increases by 4.17%[2] (the highest in the agricultural sector) during the Covid-19 pandemic in 2020. Concerning employment, the number of labour in the horticultural sub-sector in Indonesia reaches 3.16 million in 2020[3]. In addition, the horticultural sub-sector also contributes to the Indonesian economy through export. In 2020, the export value of horticultural products grew by 38.99% compared to 2019[3].
Indonesian horticultural supply chains, however, still faces many challenges. One of the main challenges is the lack of production planning that suits the market demand. It leads to high post-harvest losses, inefficient resource management, and price fluctuation. The long supply chain with a lot of smallholder farmers involved is believed the main factor causing it [4], [5]. These smallholder farmers are characterized by a lack of access to knowledge and information of the market [6].

The ICT-based approach in which data and information can be widely distributed efficiently is believed to deal with this situation. Many ICT-based approaches to support production planning have been widely developed. One of them is the symbiotic simulation system that enables a close association between physical (real system) and simulation system [7]–[9]. The symbiotic simulation system can be used as decision support system to make plans at the operational level using (near)real-time data (discussed in more detail in Section 2.2).

Symbiotic simulation system has been developed in various domains. In the business domain, it has been developed to support the manufacturing process [10], [11] and business management [12] to be more efficient. In the service sector, symbiotic simulation has been developed to make resource plans to increase the service level [13]. In the transportation sector, it has been developed for smart navigation [14], hindering collision [15] and response to disruption [16]. With respect to supply chain systems, the symbiotic simulation has been developed for inventory management [17].

Building upon previous works, this paper focuses on symbiotic simulation for horticultural supply chains to match the production plan with the market demand. More specifically, this paper has the aim to design a framework for symbiotic simulation implementation in horticultural supply chains in Indonesia in which many smallholder farmers are involved.

1.1. Horticultural supply chains in Indonesia: structure, governance and challenges

The horticultural supply chain in Indonesia, in general, consists of farmers, local traders (small and big local traders), and markets [6]. In addition, farmers can organise themselves to establish a farmer organisation (e.g. formal farmer group, cooperative) to market their crops [18]. In general, the structure of horticultural supply chains in Indonesia is provided in Figure 1.

![Figure 1. Horticultural supply chain System in Indonesia (adapted from [6]).](image-url)
Most farmers in Indonesia, as in other developing countries, are smallholder farmers who lack access to capital, knowledge, information and markets [6], [18], [19]. To this end, farmer organisations can be used as a means to improve their market access, in addition to capital, knowledge and information [18], [20], [21]. Therefore, the framework of symbiotic simulation this paper proposed focuses on the supply chains of farmer organisations (FOs).

In general, markets for horticultural products can be distinguished into traditional and modern markets. In the traditional markets, there is less restriction regarding the quality of product, volume of supply and the supply schedule [22]. However, there is a risk of price fluctuation. In addition, the price from traditional markets, on average, is lower than the price from modern markets [22], [23]. In contrast, the quality of products, the volume of supply and the supply schedule are the main requirements of the modern markets (e.g. supermarkets, industries, e-commerce companies, restaurants). However, they offer more stable and higher prices (on average) than the traditional markets [22], [23].

Most FOs in Indonesia focus on modern markets to increase the farmer members income [6]. To fulfill modern markets demand, the FOs established internal governance to manage the supply from farmer members [24], [25]. In general, farmer members have a role in production, while the FOs perform post-harvest (sorting, grading, packaging), logistics, and market activities for products supplied by the members [24]. In addition, there is usually a price agreement between the FOs and their farmer members [22], [23].

In many cases, FOs face difficulty to match the demand from markets and the supply from farmer members. The different nature of the market and production of horticultural products (discussed in more detail in Section 3.1) is one of the main factors causing it [6]. With respect to this situation, the symbiotic simulation system is believed can be used as a tool to address these challenges.

1.2. Symbiotic simulation system
Symbiotic simulation is a technology emphasising a close association between a simulation system and a physical system (a real system) [7]–[9]. The simulation system and physical system are interdependent and can be beneficial to each other. The simulation system acquires real-time or near real-time data from the physical system to be used as inputs to do simulation and, in certain cases, to improve the simulation model. Meanwhile, the physical system can use the results of the simulation, i.e. the best scenario, to support decision making at operational level [7]–[9].

One of the main benefits of a symbiotic simulation system is the (near)real-time interaction between the simulation and physical system that enable continuous improvement for these two systems [17], [26] or at least for one system [27]. This (near)real-time interaction between these two systems does not exist in the traditional (offline) simulation.

Even though there is a close association between the simulation and physical system, there is no restriction that a symbiotic simulation has control feedback [27]. Therefore, the symbiotic simulation is distinguished into two types: 1) closed-loop; and 2) open-loop [27]. In the closed-loop system, there is control feedback from the simulation to the physical system. The output of the simulation is used as an input for decisions in the physical system. Meanwhile, in the open-loop system, the output of simulation does not affect the physical system [7], [8], [27]. The open-loop system is used to predict the behaviour of the physical system, to validate the simulation model, and to detect anomalies both in the simulation and physical system [7], [8], [27].

This paper focuses on the closed-loop symbiotic simulation system. The closed-loop system can be further distinguished into: 1) symbiotic simulation control system (SSCS); and 2) symbiotic simulation decision support system (SSDSS) [7], [8], [27]. The difference between these two systems relies on the control mechanism from the simulation system to the physical system. In the SSCS, the simulation system automatically controls the physical system using machines without human intervention. Meanwhile, in the SSDS, the simulation system indirectly controls the physical system by producing the best scenario as an input for decision-makers (humans) [7], [8], [27].
Concerning the horticultural supply chain system that requires human intervention, this paper focuses on the SSDS. The SSDS is depicted in Figure 2.

![Figure 2. Symbiotic simulation decision support system (SSDS) (adapted from [7], [27]).](image)

In the SSDS, the data from the physical system is measured and collected as inputs for the simulation system. The measurement and collection of data can be done automatically (online) using sensors or manually by humans (offline) [7]. Then, the simulation system produces the best scenario to be used by the decision makers to improve the physical system. The process is cyclic with continuous feedback [7], [27].

2. A proposed framework for implementing symbiotic simulation systems in horticultural supply chain in Indonesia

This section discussed the proposed framework of symbiotic simulation systems for the horticultural supply chains in Indonesia that is designed based on the principle of horticultural supply chains and symbiotic simulation (Section 2). First, the system of the horticultural supply chain in Indonesia, especially FOs chain system, is described in Section 3.1. Then, the proposed framework is provided in Section 3.2.

2.1. System description

The horticultural supply chain system of FOs consists of farmer members, the FOs, and markets. Farmer members have a role in crop production. For the large FOs, farmers are usually organised into groups (groups of farmers). The FOs take roles in the market, logistics, and post-harvest activities including its operational plans. The plans are required to fulfil market demand that usually come from multiple markets.

Most often, FOs face challenges in making their operational plans that are mostly caused by the different nature of the market and production. With respect to markets, it is characterised by daily demand (as daily product), product-based (e.g. salad, food package), and multiple markets with different requirements (e.g. modern and traditional markets, end consumers). On the other side, the production is characterised by commodity-based, time delay in production (in average 2-4 months), scattered locations owned by farmer members, multi-actors involved (smallholder farmers), variability in yield and quality of produce, and the existence of uncontrollable variables (e.g. weather). The system of the horticultural supply chain of FOs is depicted in Figure 3.
The symbiotic simulation framework proposed in this paper focuses on SSDS, as discussed in Section the SSDS framework is designed based on the system depicted in Figure 3. It is assumed that the FOs are growing FOs with a lot of smallholder farmers involved. These smallholder farmers are organised into groups of farmers (GoF). Every GoF has coordinators (can be more than one). Meanwhile, with respect to the market aspect, FOs supply products to multiple markets.

In this framework, first, the involved actors are defined (farmers, GoF, FOs and markets). However, the framework is confined to FO and its members. Meanwhile, markets are external actors affecting the system of the FO through the nature of their demand. Then, four activities of horticultural supply chains are considered: 1) production, 2) post-harvest, 3) logistic, and 4) market. The framework also indicated which actors do which activities. The proposed framework for implementing SSDS in the horticultural supply chain of FOs in Indonesia is provided in Figure 4.
From Figure 4, it can be seen that farmer members (GoF) are responsible for the production activities. Meanwhile, the post-harvest, logistics, and market are performed by the FO. Concerning operational plans, the FO is responsible for market, logistics, post-harvest and production plans. The FO together with the GoF coordinators determines the operational plans based on market demand. These plans include the production plan. The production plan, then, is informed to farmer members (through GoF) to be implemented. Meanwhile, the plan of post-harvest, logistics, and markets are implemented by the FO.
With respect to data as inputs for the simulation system, four databases are defined based on four defined activities: the database of the market, logistics, post-harvest, and production. The data of the market, e.g. kinds of products (including its bill of material), quantity, quality, supply schedule, price, are collected and recorded by the FO. The FO is also responsible for collecting and recording the data of logistics (e.g. vehicles, routes, time, costs) and post-harvest (e.g. tools, machines, worker, cost). Meanwhile, for the data of production, e.g. plots (size, location), production inputs, pests and diseases, harvesting (yield, quality) are the responsibility of GoF through the coordinators. It is because smallholder farmers will face difficulty if they have to be responsible to collect and record the data individually. Most data are collected offline. The data that can be collected online are weather data, e.g. temperature, rainfall, humidity that can be captured by the sensor installed in certain plots.

In the simulation system, the data of the market, logistics, post-harvest and production (near real-time data) are analysed using several data analytic methods, e.g. correlation, cluster analysis, to examine the relationship between variables [29]. Then, the scenario manager is used to build several possible scenarios by combining the data with several criteria. From this process, two datasets are distinguished: 1) input dataset; and 2) output dataset. Each scenario is represented with different input and output datasets. The two datasets are used in machine learning to obtain the patterns of the given datasets. After that, the simulation model is constructed based on the obtained patterns from machine learning. In other words, the simulation model adapts the physical system condition with the help of machine learning. The simulation model then provides data output which will be further processed with the optimization model. The best scenario, then, is produced from this process. The best scenario is the input for the FO and GoF coordinators (as the decision-makers) to determine the operational plan to be matched with market demand. In this framework, the activities in physical and simulation systems are done iteratively with continuous feedback between these two systems.

3. Conclusions
This paper provides a framework for implementing symbiotic simulation, more specifically SSDS, in horticultural supply chains in Indonesia. The proposed framework has the aim to match the production with the market demand. This framework enables the involvement of smallholder farmers in the system through GoFs and the FO. In this framework, four activities in the horticultural supply chains are considered: 1) production; 2) post-production; 3) logistics, and 4) market. This framework can be used by FOs or agricultural companies that have partnerships with smallholders to plan their activities along their supply chains.

References
[1] Statistics Indonesia, “Distribusi PDB Triwulanan Seri 2010 Atas Dasar Harga Berlaku,” 2021.
[2] Statistics Indonesia, “Laju Pertumbuhan PDB Seri 2010,” 2021.
[3] Direktorat Jendral Hortikultura Kementerian Pertanian, “Laporan Tahunan 2020,” 2021.
[4] T. Perdana and Kusnandar, “The Triple Helix Model for Fruits and Vegetables Supply Chain Management Development Involving Small Farmers in Order to Fulfill the Global Market Demand: A Case Study in ‘Value Chain Center (VCC) Universitas Padjadjaran,’” Procedia Soc. Behav. Sci., vol. 52, pp. 80–89, 2012.
[5] Y. Handayati, T. M. Simatupang, and T. Perdana, “Value Co-creation in Agri-chains Network: An Agent-Based Simulation,” Procedia Manuf., vol. 4, no. Less, pp. 419–428, 2015.
[6] K. Kusnandar, “Empowering stakeholders to organise their agricultural production and supply chains for a sustainable and inclusive future in Indonesia,” Delft University of Technology, the Netherlands, 2021.
[7] B. S. Onggo, N. Mustafee, A. Smart, A. A. Juan, and O. Molloy, “Symbiotic simulation system: hybrid systems model meets big data analytics,” in 2018 Winter Simulation Conference (WSC), 2018, pp. 1358–1369.
[8] B. Tjahjono and X. Jiang, “Linking symbiotic simulation to enterprise systems: framework and applications,” in 2015 Winter Simulation Conference (WSC), 2015, pp. 823–834.
[9] H. Aydt, S. J. Turner, W. Cai, and M. Y. H. Low, “Research issues in symbiotic simulation,” in *Proceedings of the 2009 winter simulation conference (WSC)*, 2009, pp. 1213–1222.

[10] E. L. S. Teixeira, B. Tjahjono, S. C. A. Alfarò, and R. Wilding, “Extending the decision-making capabilities in remanufacturing service contracts by using symbiotic simulation,” *Comput. Ind.*, vol. 111, pp. 26–40, 2019.

[11] H. Aydt, W. Cai, S. J. Turner, and B. P. Gan, “Symbiotic simulation for optimisation of tool operations in semiconductor manufacturing,” in *Proceedings of the 2011 Winter Simulation Conference (WSC)*, 2011, pp. 2088–2099.

[12] M. Y. H. Low et al., “Symbiotic simulation for business process re-engineering in high-tech manufacturing and service networks,” in *2007 Winter Simulation Conference*, 2007, pp. 568–576.

[13] D. Oakley, B. S. Onggo, and D. Worthington, “Symbiotic simulation for the operational management of inpatient beds: model development and validation using A-method,” *Health Care Manag. Sci.*, vol. 23, no. 1, pp. 153–169, 2020.

[14] H. Aydt, M. Lees, and A. Knoll, “Symbiotic simulation for future electromobility transportation systems,” in *Proceedings of the 2012 Winter Simulation Conference (WSC)*, 2012, pp. 1–12.

[15] J. Holt, S. Biaz, L. Yilmaz, and C. A. Aji, “A symbiotic simulation architecture for evaluating UAVs collision avoidance techniques,” *J. Simul.*, vol. 8, no. 1, pp. 64–75, 2014.

[16] L. Rhodes-Leader, B. S. S. Onggo, D. J. Worthington, and B. L. Nelson, “Airline disruption recovery using symbiotic simulation and multi-fidelity modelling,” 2018.

[17] Z. Fanchao, S. J. Turner, and H. Aydt, “Symbiotic simulation control in supply chain of lubricant additive industry,” in *2009 13th IEEE/ACM International Symposium on Distributed Simulation and Real Time Applications*, 2009, pp. 165–172.

[18] G. Kariuki and F. Place, “Initiatives for Rural Development Through Collective Action: the Case of Household Participation in Group Activities in the Highlands of Central Kenya,” *CAPRi Work. Pap.*, pp. 1–45, 2005.

[19] J. H. Trienekens, “Agricultural value chains in developing countries a framework for analysis,” *Int. food Agribus. Manag. Rev.*, vol. 14, no. 2, pp. 51–82, 2011.

[20] T. T. T. Ha, S. R. Bush, and H. van Dijk, “The cluster panacea?: Questioning the role of cooperative shrimp aquaculture in Vietnam,” *Aquaculture*, vol. 388, pp. 89–98, 2013.

[21] J. Thorpe, “Procedural Justice in Value Chains Through Public-private Partnerships,” *World Dev.*, vol. 103, pp. 162–175, 2018.

[22] Natawidjaja et al., “Horticultural producers and supermarket development in Indonesia,” World Bank Report No.38543-ID, 2007.

[23] R. Natawidjaja, E. Rasmikayati, Kusnandar, D. Purwanto, T. Reardon, and H. Zhi, *Restructuring of agrifood Chains in Indonesia: The case of potato farmers in West Java (B)*. London: Regoverning Markets Agrifood Sector Studies, IIED, 2007.

[24] M. Arsyad, S. Rahmadanih, A. Hasnah, and A. Darwis, “Role of joined farmer groups in enhancing production and farmers income,” in *IOP Conf. Ser. Earth Environ. Sci.*, 2018, vol. 157, no. 1.

[25] A. Kharisma and T. Perdana, “Linear programming model for vegetable crop rotation planning: a case study,” *Int. J. Agric. Resour. Gov. Ecol.*, vol. 15, no. 4, pp. 358–371, 2019.

[26] S. N. Hetu, S. Gupta, V.-A. Vu, and G. Tan, “A simulation framework for crisis management: Design and use,” *Simul. Model. Pract. Theory*, vol. 85, pp. 15–32, 2018.

[27] H. Aydt, S. J. Turner, W. Cai, and M. Y. H. Low, “Symbiotic simulation systems: An extended definition motivated by symbiosis in biology,” in *2008 22nd Workshop on Principles of Advanced and Distributed Simulation*, 2008, pp. 109–116.

[28] Kusumiyati, Hadiwijaya Y, Putri I E and Munawar A A 2021 Multi-product calibration model for soluble solids and water content quantification in Cucurbitaceae family, using visible/near-infrared spectroscopy *Heliyon* 7 e07677