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# System dynamics modeling in competitive cocoa agroindustry management: a case study of Socolatte in Pidie Jaya regency

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**ABSTRACT**

*The declining competitiveness of the regional cocoa agroindustry poses a major challenge to sustainably enhancing the added value of cocoa commodities. This study aims to design a competitive management model for the cocoa agroindustry in Pidie Jaya Regency, using Socolatte as a case study of a community-based processing industry. A system dynamics approach was used as the modeling method, based on systems thinking and incorporating feedback loops and time delays to understand complex behavioral dynamics within the agroindustry management system. Primary data were collected through in-depth interviews with key stakeholders across the cocoa value chain, including farmers, traders, processors, company leaders, and cooperatives. Secondary data were obtained from relevant institutions. The model was formulated and simulated using Vensim PLE software. The results identified ten key sub-models: cocoa bean transportation, harvesting on company/cooperative plantations, sales from supported smallholder farms, harvesting on independent smallholder farms, processing capacity management, factory labor, final processing stages, Socolatte inventory management, Socolatte market and order system, and Socolatte financial management. The novelty of this study lies in the holistic integration of various sub-systems within a community-based cocoa agroindustry into a single dynamic modeling framework, which has rarely been applied in a localized context such as Pidie Jaya. The model maps causal relationships across production, management, distribution, and financial aspects simultaneously, providing a strategic decision-making tool for agroindustry stakeholders. These findings offer strategic insights to improve system efficiency, enhance product value, and increase profitability for both smallholder cocoa farmers and local cocoa processing companies in Pidie Jaya Regency.*

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## INTRODUCTION

Cocoa (*Theobroma cacao*) originates from the tropical rainforests of the Americas and has long been cultivated as a food source by ancient civilizations such as the Maya and Aztec. In Indonesia, cocoa was introduced by the Spanish in Minahasa, North Sulawesi, and has since developed rapidly, especially in Sulawesi, which is now the main center of national production (Wahana Interfood 2021). Indonesian cocoa consists of two main types: fine cocoa (Criollo) and bulk cocoa (Forastero). The Forastero variety is the most widely cultivated due to its higher productivity and better adaptability to tropical climates, particularly by smallholder farmers in Sulawesi and Sumatra (ICCRI 2020; Indonesia Investments 2022).

Cocoa is one of the leading commodities in Indonesia's plantation sector. In 2022, the total area under cocoa cultivation reached approximately 1.42 million hectares, with a total production of 650,612 tons, more than 99% of which was managed by smallholder farmers (Ditjen Perkebunan 2023). Indonesia remains the third-largest cocoa producer in the world, after Pantai Gading and Ghana. However, national productivity remains relatively low at around 0.4 tons per hectare well below the ideal potential yield of 1 to 2 tons per hectare. Factors contributing to this low productivity include aging plantations, pest and disease infestations, and limited access to high-quality planting materials and technical training for farmers. In terms of exports, Indonesia exported approximately 14,451 tons of cocoa beans in 2023, with a total value of around IDR 750 billion. However, this figure has declined compared to previous years due to a decrease in both export volume and global market prices (BPS 2024; WITS World Bank 2023).

Aceh Province holds significant potential for the development of cocoa cultivation. According to data published by the Aceh Provincial Statistics Agency (BPS Aceh) in 2024, the total area of cocoa plantations in the province reached 101,230 hectares, with a total production of 40,724 tons (BPS Aceh 2024). Pidie Jaya Regency is one of the regions that has demonstrated a strong commitment to cocoa cultivation, with the local government designating cocoa as one of the priority crops, alongside rice and maize. Despite this commitment, cocoa development in Pidie Jaya faces several challenges in both upstream and downstream sectors. In the upstream sector, the main issue is low productivity, while in the downstream sector, the primary challenge lies in the high proportion of unfermented cocoa beans. In 2022, the area of cocoa plantations in Pidie Jaya Regency reached 15,186 hectares, with a production volume of 5,527.2 tons (Portal Aceh 2022). These figures indicate that Pidie Jaya is one of the key cocoa-producing regions in Aceh Province.

The length of the marketing channel does not necessarily influence price formation at the farm level, as the prevailing market structure is oligopsonistic. An oligopsony is a market condition where a few buyers dominate, with one or more acting as price leaders (Utami 2016). This oligopsonistic market structure has been observed in several regions, such as West Pasaman Regency (Danil et al. 2014), Central Sulawesi (Sisfahyuni et al. 2011), and Southeast Sulawesi (Ermiati et al. 2014), where prices are determined unilaterally by traders based on quality standards set by them. The price offered is then adjusted according to the quality of cocoa beans produced by farmers, where price reductions often occur due to moisture content exceeding 10% and inconsistent bean sizes. Such purchasing practices result in the absence of optimal pricing for farmers. The lack of a quality-based national cocoa trading system, along with inefficiencies in the cocoa supply chain, has hindered efforts to improve bean quality (Bunasor 2009). Currently, cocoa bean marketing remains conventional, where market actors transact independently through a market mechanism involving farmers, collectors, large traders, and exporters or cocoa agroindustries. This marketing pattern is reflected in studies conducted by Panlibuton et al (2006). In conventional marketing systems, price information typically originates from exporters and is then passed on to district-level collectors, village-level collectors, and ultimately to cocoa farmers (Dilana 2013). This marketing pattern needs improvement through the implementation of an integrated marketing system and price transparency aligned with quality, enabling farmers to achieve better margins.

Supply chains involve the flow of materials, processes, and costs from upstream to downstream with the objective of producing goods or services. This process is supported by information flow to ensure effectiveness and responsiveness in meeting consumer demand. The cocoa supply chain begins with the cultivation of cocoa by farmers, followed by harvesting, post-harvest processing, and the distribution of cocoa beans to intermediate processing industries (grinding industry), which

produce products such as cocoa powder, cocoa butter, and cocoa liquor. These intermediate products are then supplied to downstream industries that manufacture items such as confectionery, cakes, chocolate bars, ice cream, biscuits, as well as pharmaceutical and cosmetic products (Sriwana 2016; Saltini et al. 2013). Coordinating the flow of raw materials and information from upstream to downstream is crucial for traceability, which is now a market requirement to ensure food safety and security (Van Der Vorst 2006), and to enhance competitiveness. Integrated supply chain management from upstream to downstream is central to supply chain management concepts, aimed at meeting consumer needs responsively and improving cost efficiency throughout the supply chain (Chopra and Meindl 2013).

Factors influencing cocoa competitiveness, as identified by Panlibuton et al (2006), include the availability of raw materials, consistency of quality (such as moisture content, number of beans per 100 grams, and damaged beans), fat content, flavor, price, infrastructure and logistics, and government policies and regulations. According to Is, the weak competitiveness of Indonesian cocoa is attributed to the low use of superior seedlings, suboptimal post-harvest handling, inadequate quality of human resources, limited infrastructure, and a lack of supporting industries for the procurement of superior seedlings (Is 2008). Addressing these factors is essential for Indonesia to compete with leading global cocoa producers such as Pantai Gading and Ghana.

System dynamics is a methodology and mathematical modeling technique used to frame, understand, and analyze complex problems. It describes the feedback relationships among various variables within a system model. These feedback relationships are represented by arrows, where the direction indicates the affected (dependent) variable, and the sign reflects the nature of the influence. A system with a positive feedback loop tends to be divergent, indicating a continuous growth process that often results in an exponential growth pattern. Conversely, a negative feedback loop seeks to stabilize the system by achieving a specific goal. In such feedback systems, the output generated will influence the input again if the intended objective has not yet been reached. These systems are dynamic, evolve over time, and will reach a state of equilibrium once the goal is achieved (Rachmawati 2016). Considering the complexity and dynamic nature of the problem, this study aims to engineer a system dynamics model for managing a highly competitive cocoa agroindustry in Pidie Jaya Regency, with a specific focus on Socolatte Company as the case study.

## METHODS

This study adopts a System Dynamics approach for modeling, which is based on the perspective of information feedback and time delays to understand the complex behavioral dynamics of physical, biological, and social systems (Bell et al. 2003). A key assumption in this approach is that decision-making processes are structured as a set of circular and closed-loop causal relationships (Sterman 2000). A case study method is employed to gain an in-depth understanding of the phenomena and issues related to cocoa agroindustry management at Socolatte. The focus of this research is on the cocoa agroindustry supply chain, which exhibits specific characteristics, including the implementation of vertical integration and vertical coordination systems. Geographically, the supply chain actors involved in this study are located in Pidie Jaya Regency, Aceh Province.

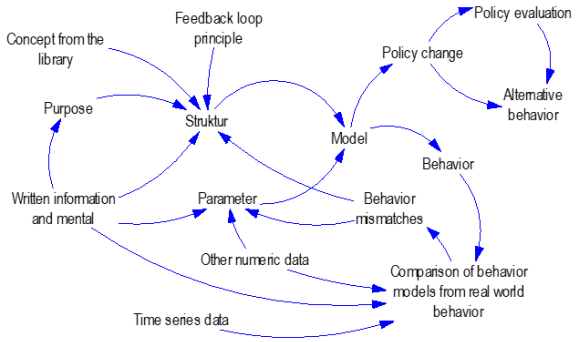



Figure 1 System dynamics model design (Tasrif 2016)

Respondents were selected based on the results of a supply chain mapping of the cocoa agroindustry in Pidie Jaya. The analyzed supply chain network includes cocoa processing industries, smallholder farmers, intermediary collectors, and the market. Based on this structure, respondents were purposively selected, consisting of individuals in key decision-making roles across various entities in the system. These respondents include Socolatte's top management, general manager, production manager, marketing manager, financial manager, plantation and factory managers, cocoa farmers, cocoa agroindustry managers, as well as cocoa traders and business operators.

The types of data used in the System Dynamics approach are classified into three main

categories: numerical data, textual data, and mental models. Numerical data were obtained from observations and performance records of the cocoa agroindustry. Textual data were collected through literature reviews of journals, books, and prior research reports. Mental models were developed based on in-depth interviews with key stakeholders in Socolatte's cocoa supply chain. All collected data were then synthesized into a model design using the System Dynamics methodology, as illustrated in Figure 1. The model development process began with the construction of causal loop diagrams to represent cause-and-effect relationships among variables within the system. This was followed by the formulation of flow diagrams or sub-models, consisting of levels and rates, to simulate the flow of materials, information, and finances within the agroindustry system. The next step was to develop a complete system model by structurally defining the relationships among variables to reflect a comprehensive representation of a competitive cocoa agroindustry management system. Once the system model was established, assumption testing was conducted to validate the model's consistency with real-world conditions.

As a delimitation of this study, the model development process is limited to structure verification and assumption validation. The simulation of policy scenarios intended to evaluate system behavior under various conditions and to generate alternative policy recommendations is not included in this article and will be presented in a follow-up publication. Throughout the modeling process, Vensim PLE software was used to support all stages, from initial model construction to structural verification.

## RESULTS AND DISCUSSION

### Management model of cocoa agroindustry at Socolatte company

Socolatte is a local company that processes cocoa into ready-to-consume chocolate. In its 10 years of operation in the industry, Socolatte has demonstrated the importance of supply chain implementation in business. This cooperative-structured company aims to absorb cocoa harvests and empower local cocoa farmers. In cocoa processing, attention to raw materials is crucial for ensuring operational consistency. Suppliers, who are local farmers in Pidie Jaya and members of the cooperative, are involved in the entire cocoa cultivation process, from land clearing, seed selection, fertilization, pesticide use, labor, harvesting, post-harvest handling, to fermentation. The cooperative plays a vital role in enhancing cocoa bean sales by farmers and improving knowledge about cocoa quality. Socolatte, as a cocoa processing industry turning beans into consumable chocolate, specifically orders cocoa beans from local farmers under the condition that the beans have undergone fermentation. Well-fermented cocoa beans command a higher market price compared to non-fermented beans. Under normal conditions, Socolatte purchases fermented cocoa beans at a price of IDR 40,000 per kilogram. However, in abnormal market conditions, the price can rise to between IDR 55,000 and IDR 70,000 per kilogram.

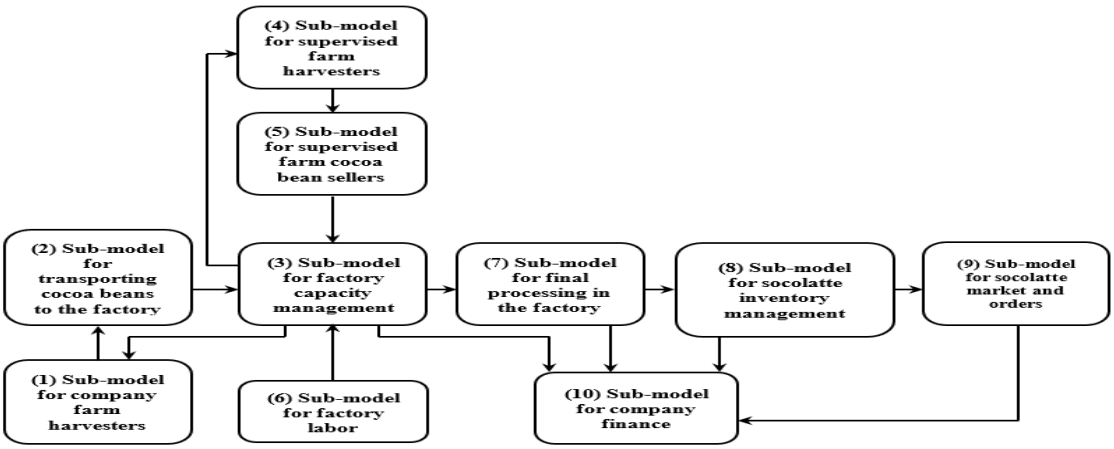



Figure 2 Interconnections between sub-model diagrams

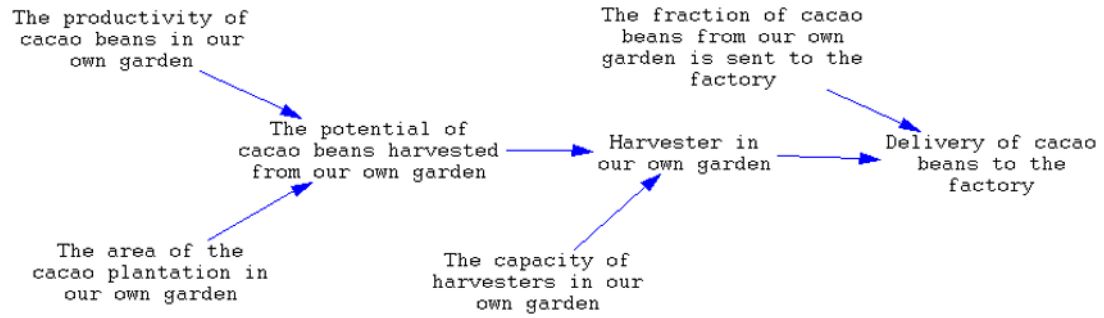



Figure 3 Sub-model diagram for transporting cocoa beans to the factory

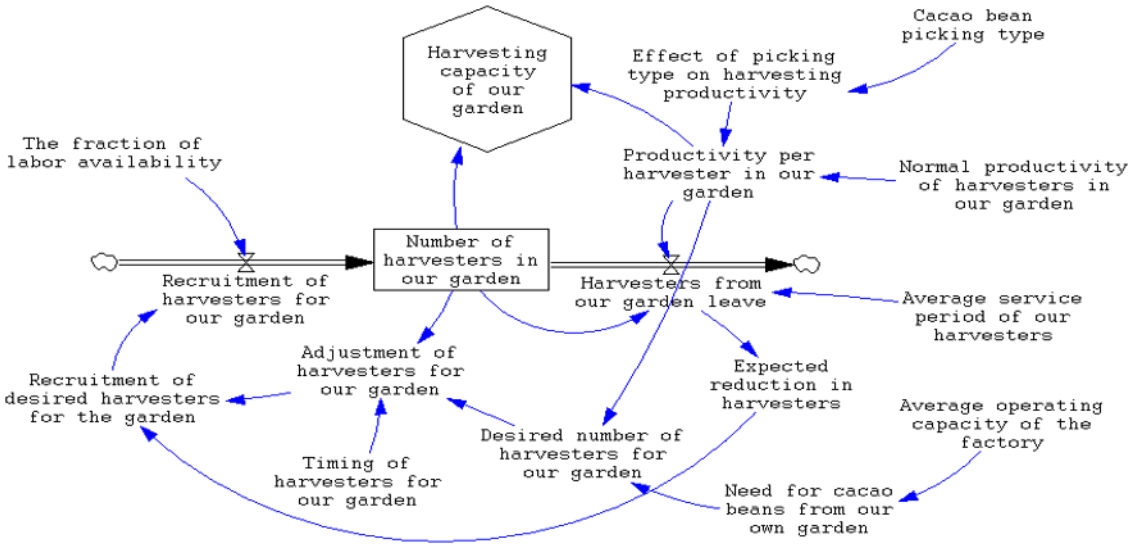



Figure 4 Sub-model diagram for company/cooperative farm harvesters

The interactions between variables and causality within the management structure of Socolatte's agroindustry need to be developed from a causal loop diagram into a sub-model diagram. In this sub-model diagram, the physical and decision-making structures that shape the behavioral dynamics of Socolatte's agroindustry management are identified and developed. The physical structure is represented through material and financial flows, while the decision-making structure is represented by the flow of information that governs decisions related to material and financial flows. Figure 2 illustrates the interconnections among sub-models in the flow diagram of cocoa agroindustry management for Socolatte.

**Sub-model for transporting cocoa beans to the factory**

This sub-model illustrates the process of transporting cocoa beans from the company's plantations to the factory. The quantity of cocoa beans harvested depends on the yield potential of the beans in the plantation and the harvesting capacity at the plantation. Once harvested, the cocoa beans are transported to the factory. This sub-model includes parameters for the fraction of cocoa beans sent to the factory, which are used to predict any shrinkage or loss of cocoa beans during transit from the plantation to the factory. However, for the purposes of this study, it is assumed that there is no shrinkage or loss of cocoa beans during transportation. Further details can be found in Figure 3.

**Sub-model for company farm harvesters**

The harvesting capacity at the plantation is determined by the productivity of the harvesters and the number of harvesters working (see Figure 4). The availability of harvesters in the vicinity of the plantation is a major limiting factor in determining the number of harvesters. Additionally, since cocoa harvesters are daily workers, their working hours are shorter compared to permanent employees. As a result, there is a dynamic change in the number of harvesters at the plantation, and plantation managers need to adjust the number of harvesters according to the demand for cocoa beans that need to be harvested. The productivity of harvesters is also influenced by the harvesting standards set by the factory management. As the quality standards for

harvesting set by the management increase, the productivity of the harvesters tends to decrease. This is because harvesting high-quality cocoa beans requires more time compared to harvesting lower-quality beans. Therefore, the accuracy in selecting high-quality cocoa beans is a key factor affecting harvester productivity.

**Sub-model for supervised farm cocoa bean sellers**

In the supply chain of the Socolatte industry under investigation, in addition to sourcing cocoa beans from its own plantations, the company or cooperative also establishes partnerships to obtain supplies from affiliated cocoa farms. The sub-model for the sale of cocoa beans from affiliated farms is similar to the sub-model for transporting cocoa beans to the factory. The process of selling cocoa beans from affiliated farms is determined by the productivity of the cocoa beans and the productive area of the affiliated farms.

The primary distinction between the sub-model for selling cocoa beans from affiliated farms and the sub-model for transporting cocoa beans to the factory is that the former involves a sales transaction, while the latter does not, as the company's own plantations are considered internal (see Figure 5). Similar to the sub-model for transporting cocoa beans to the factory, the sub-model for selling cocoa beans from affiliated farms includes parameters for the fraction of cocoa beans sent to the factory to predict spoilage or loss of beans. However, this study assumes that there is no spoilage or loss of cocoa beans from the affiliated farms.

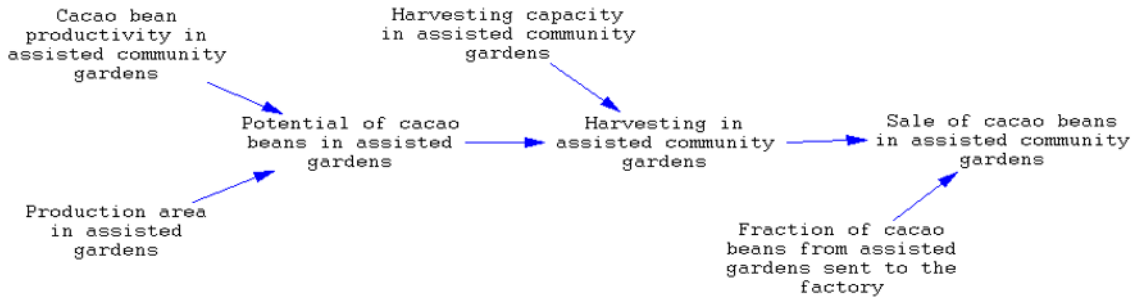



Figure 5 Sub-model diagram for supervised farm cocoa bean sellers

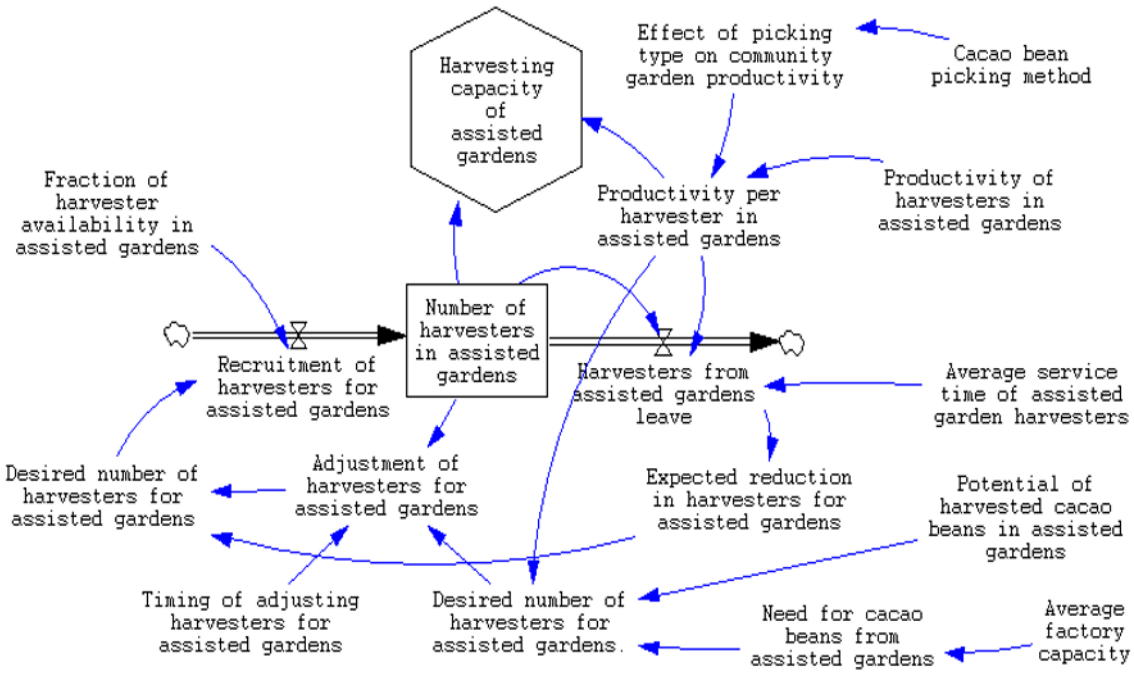



Figure 6 Sub-model diagram for supervised farm harvesters

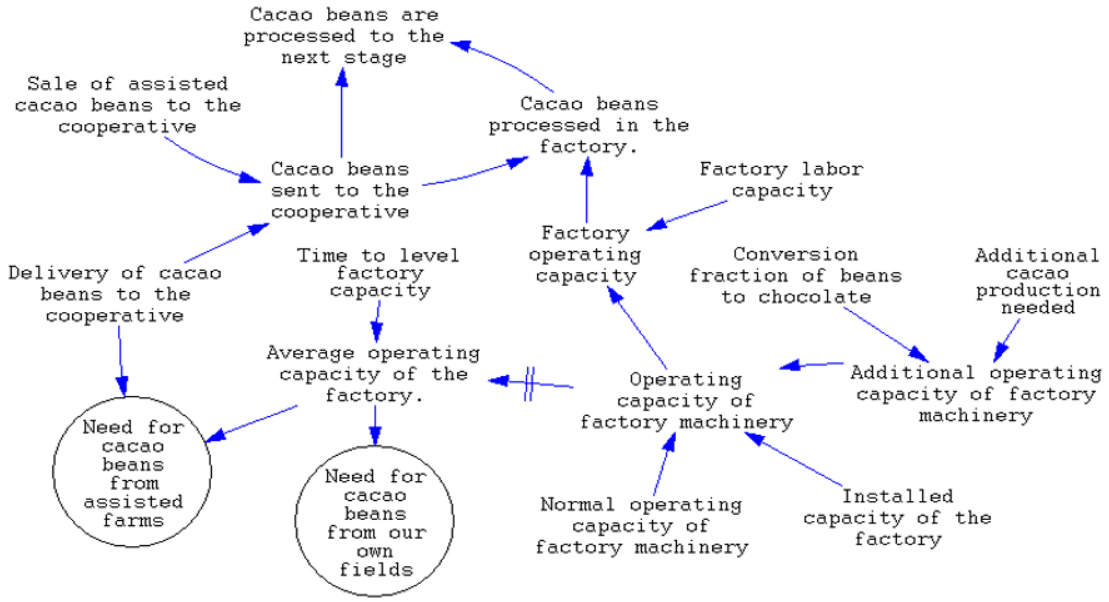



Figure 7 Sub-model diagram for factory capacity management

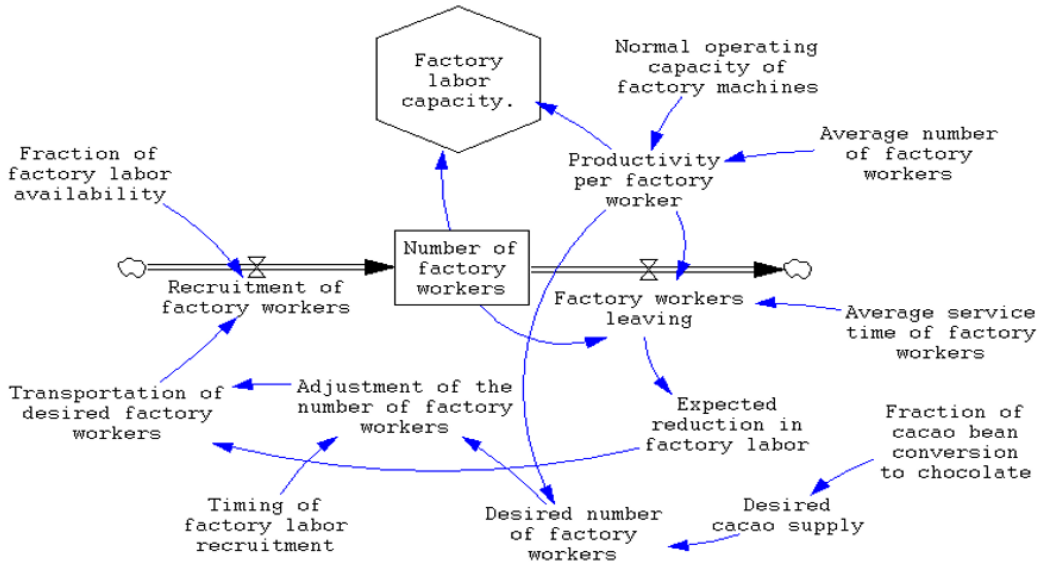



Figure 8 Sub-model diagram for factory labor

**Sub-model for supervised farm harvesters**

The sub-model for harvesters in affiliated farms is a replication of the sub-model for harvesters in company-owned plantations (see Figure 6). The difference lies in determining the number of harvesters needed for affiliated farms, which depends on the minimum potential of cocoa beans that can be harvested and the demand for cocoa beans from the affiliated farms.

Similarly to the sub-model for company-owned plantations, the availability of harvesters and the productivity of harvesters in affiliated farms determine the harvesting capacity of these farms. Additionally, the productivity of harvesters in affiliated farms is also influenced by the type of cocoa bean harvesting standards set by the company's management.

**Sub-model for factory capacity management**

Cocoa beans delivered from both company-owned and affiliated farms are processed at the processing plant. The plant management prioritizes the processing of cocoa beans as a primary allocation. Therefore, cocoa beans are allocated for processing until the plant's capacity is met. Given this situation, if the supply of cocoa beans exceeds the processing capacity, the plant management will decide to process the surplus cocoa beans into different cocoa products. The quantity of cocoa beans processed into chocolate is determined by the minimum value between the amount of cocoa beans

delivered to the plant and the plant's capacity. The plant's labor capacity is determined by the minimum value between the available workforce and the operational capacity of the plant machinery. The operational capacity of the machinery itself is the minimum value between the installed capacity of the plant and the sum of the normal operational capacity of the machinery plus any additional capacity.

Over a certain period (delay), the operational capacity of the machinery dictates the calculation of the cocoa beans required from both the company-owned farms and the affiliated farms (Figure 7). The company/cooperative management decides to prioritize meeting the cocoa bean requirements from the company's own farms. In the event of a shortfall in cocoa bean supply to meet the processing plant's capacity, cocoa beans will be purchased from affiliated farms. However, to maintain commitment to the affiliated farm partners, the company will continue purchasing from them regardless of short-term needs.

**Sub-model for factory labor**

One of the key determinants of the operational capacity of the Socolatte cocoa processing plant is the workforce capacity. The majority of workers at the Socolatte cocoa processing plant are temporary employees who work from morning until night. This scheduling is implemented to meet production targets and maximize plant capacity (see Figure 8). The use of piece-rate labor in Socolatte's production process results in a labor sub-model structure similar to the harvesting sub-models for company-owned and partner farms. However, there are key differences: the productivity of plant workers is determined by the operational capacity of the machinery under normal conditions. Additionally, the average number of plant workers is determined by processing capacity and the volume of cocoa beans desired for processing.

**Sub-model for final processing in the factory**

Socolatte's products that meet company standards must undergo a final processing stage at the factory before being dispatched to distribution centers. This final stage includes quality control, mixing, and packaging. Prior to this final stage, the factory management sends samples from each product category to a laboratory for testing. The results from the quality matching process, which compares the quality of the produced cocoa with market requirements, are used to ensure that the final products meet the market's quality standards. This process involves a verification delay for the samples, typically taking 1 to 2 business days. Further details of this final processing stage are illustrated in Figure 9.

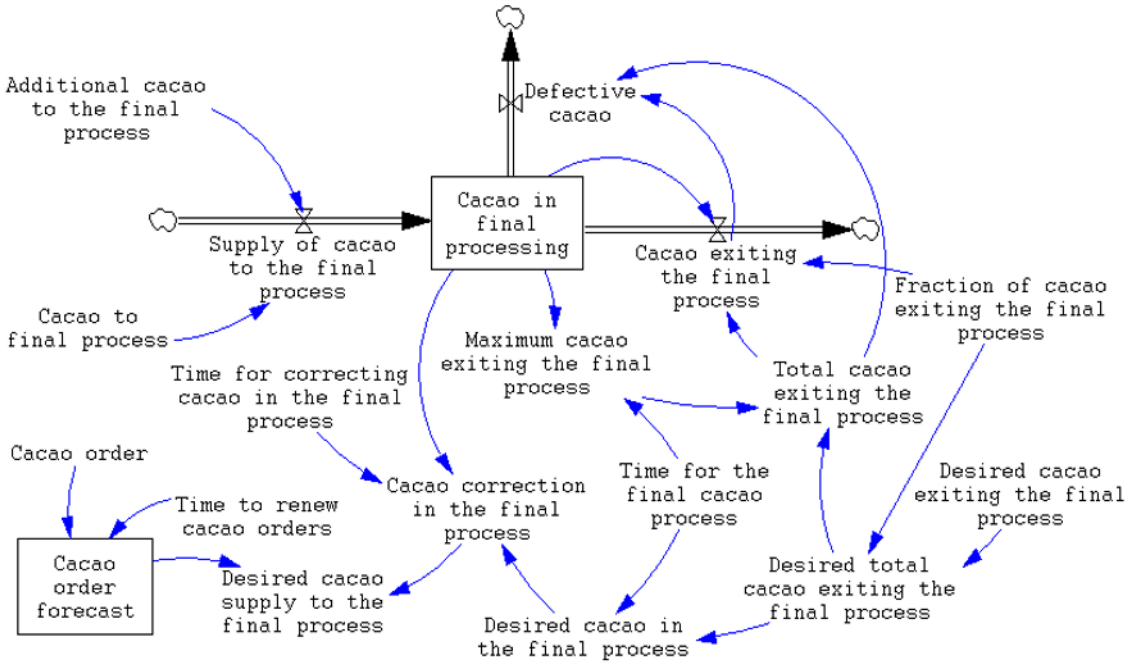



Figure 9 Sub-model diagram for final processing in the factory

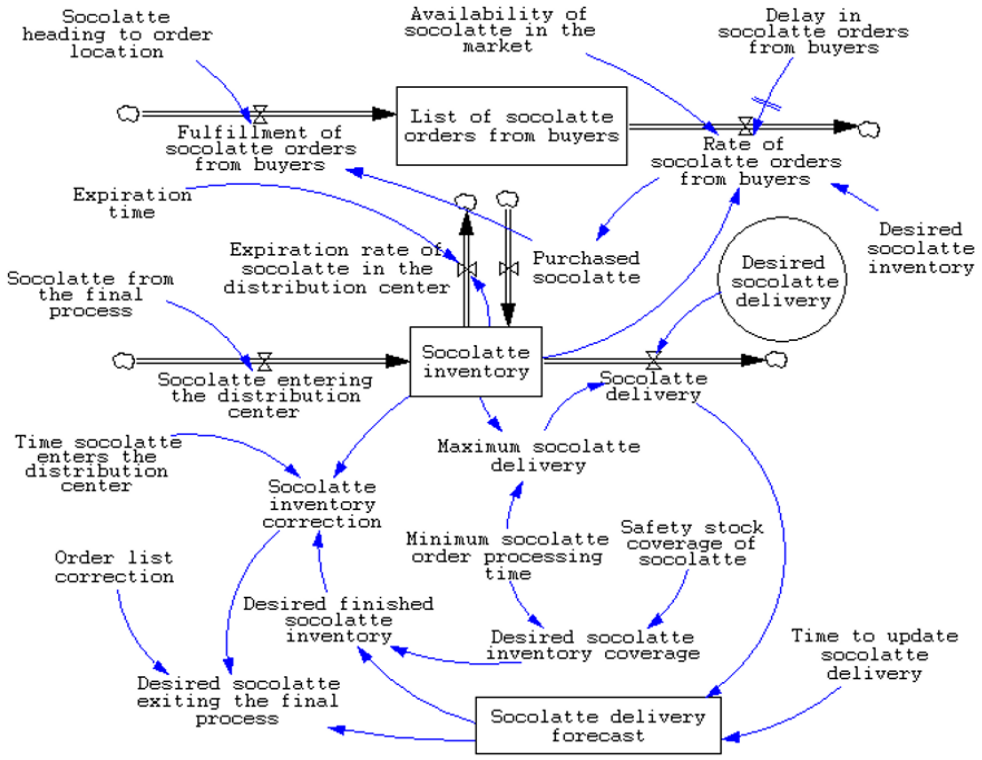



Figure 10 Sub-model diagram for Socolatte inventory management

**Sub-model for socolatte inventory management**

After passing the final processing stage at the factory, the Socolatte chocolate products that meet quality standards are dispatched to distribution centers. These centers perform three primary logistics functions: (1) receiving logistics, (2) chocolate supply management, and (3) marketing and distribution of Socolatte products. The processed cocoa products resulting from the final stage are ready-for-sale chocolate. The distribution center management sets a safety stock target of 30 days to avoid stockouts or delivery failures that could potentially lead to market losses.

The Socolatte inventory management sub-model considers the expiration dates of stored products. Socolatte products that have been packaged and stored at room temperature have a shelf life of 1.3 years (455 days). The distribution center serves as the separation point between the push and pull systems within the cocoa processing industry's supply chain. The push system includes a series of activities involving cocoa quality management, factory production capacity management, and cocoa cultivation processes in company/cooperative plantations and partner farms. Conversely, the pull system encompasses inventory management activities at the distribution center and the final processing stage at the factory. Based on Figure 10, the pull system within Socolatte's supply chain is reflected in the distribution determined by management's decision rules, calculated as the minimum value of the maximum desired shipment quantity of Socolatte. The desired cocoa shipment quantity is determined by dividing the number of orders received by the target delivery time. Thus, Socolatte's product shipments will adaptively respond to the dynamics of changes in consumer orders.

**Sub-model for socolatte market and orders**

Generally, the market that provides orders is considered an external factor influencing the company. In this study, a sub-model for the market and orders of Socolatte was developed to understand the extent to which the physical and business decision structures are responsive to market influences. This sub-model aims to illustrate how the market provides feedback on the orders received by the company. Consequently, this analysis will reveal the structural causes of the dynamics occurring in the Socolatte supply chain interactions in response to market feedback.

The performance of Socolatte in fulfilling each order will be perceived by buyers, impacting the company's market attractiveness. If the market perceives that Socolatte is able to fulfill orders effectively, the company's market appeal will

remain strong. Conversely, if the company is seen as unable to meet orders fully, its attractiveness will decrease, leading to a reduction in market share. This challenging situation will result in a reduction in the number of orders, as the market may redirect some orders to other cocoa processing companies (Figure 11). Through the Socolatte market and orders sub-model, an understanding of the physical structure, decision structure, and feedback mechanisms that drive the dynamics of market share performance indicators will be achieved.

**Sub-model for company finance**

Supply chain management performance is influenced by the financial perspective of the company. In the financial sub-model of Socolatte, this performance is measured using two primary metrics: profit and value added. Additionally, the company accounts for expenditures related to costs incurred in the management of the Socolatte supply chain, which encompasses all activities from upstream (cocoa plantations) to downstream (distribution of Socolatte chocolate products).

Socolatte's revenue primarily comes from the sale of chocolate products. Additionally, Socolatte operates a subsidiary café offering a range of food and beverages made with Socolatte chocolate. Orders can be placed either online or by visiting the Socolatte café located in Pidie Jaya. The company's products have expanded to Java, with shipments to Batam and Jakarta. A significant portion of the products is also purchased by local residents as souvenirs to be shared with family or colleagues outside Aceh. In Aceh, Socolatte products are available in souvenir shops and several coffee shops in Banda Aceh that feature Socolatte chocolate drinks on their menu.

In the financial sub-model of the company, the structure of expenditure management across Socolatte's supply chain, from cocoa plantations to product distribution, is detailed as follows. In the cocoa plantation sector, the costs incurred include the production costs of cocoa beans, which cover garden maintenance, supervision, harvesting, pod stripping, fermentation, and storage of cocoa beans from the company-owned plantations. Additionally, there are costs associated with purchasing cocoa beans from partner farms. In the factory sector, expenses are concentrated on the processing costs of cocoa beans into finished chocolate, encompassing all related production costs. At the distribution center, expenditures include product expiration costs, inventory costs, and sales costs. Expiration costs refer to products that are not sold before their expiration date, while inventory costs are related to storing products to meet market demand, and sales costs encompass the expenses for product distribution and marketing. This cost structure, as depicted in Figure 12, provides a comprehensive overview of the expenditures associated with supply chain management at Socolatte.

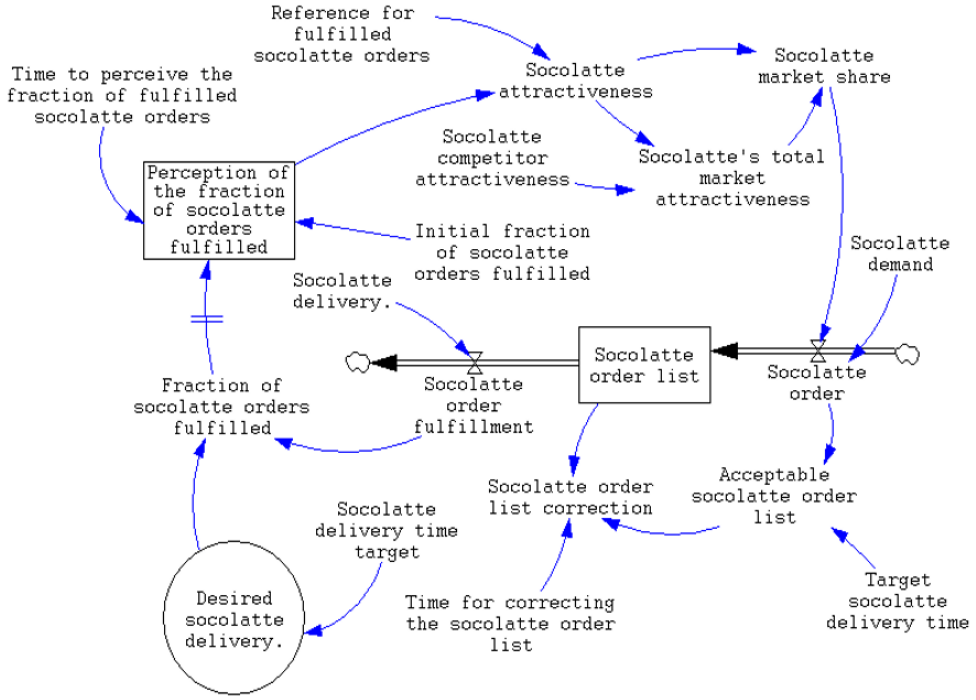



Figure 11 Sub-model diagram for Socolatte market and orders

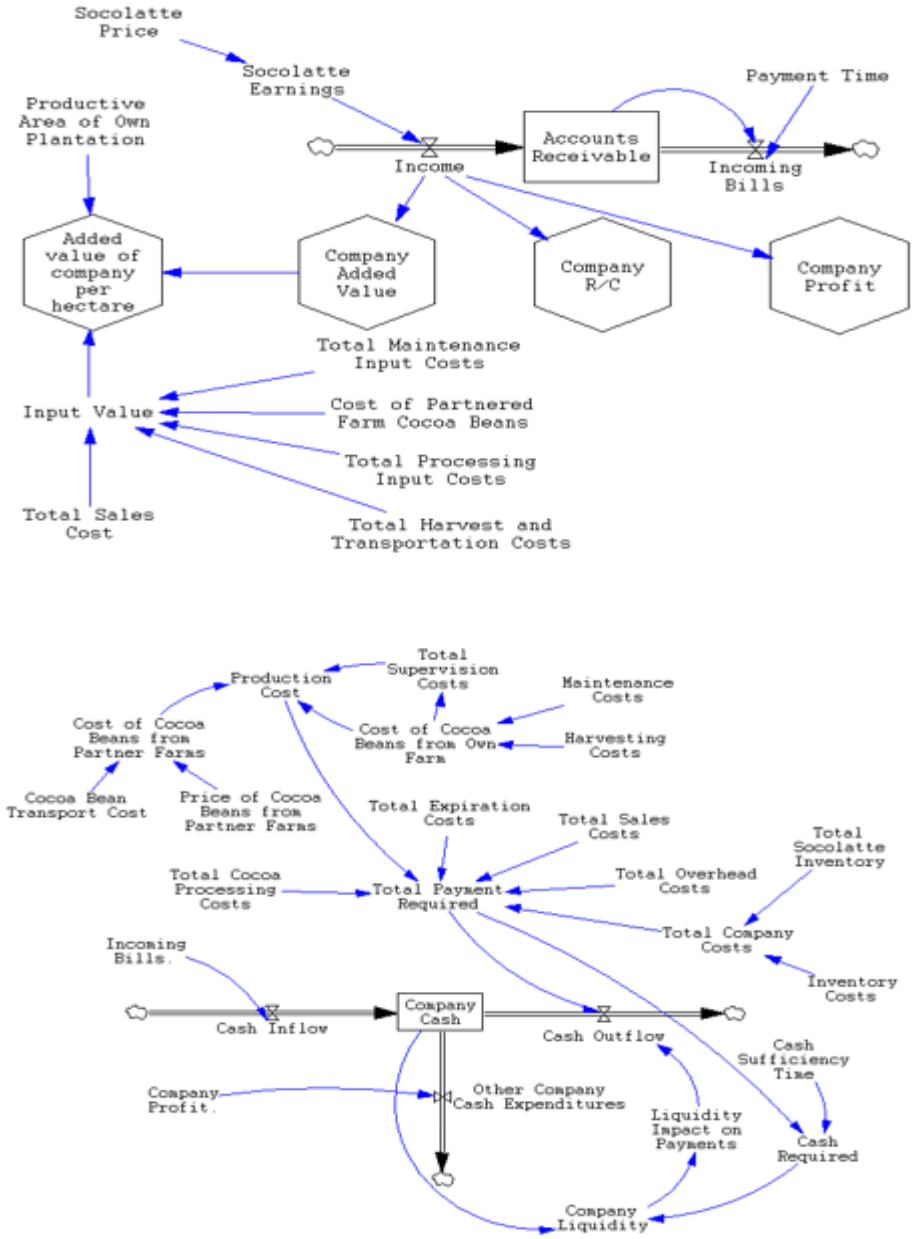



Figure 12 Sub-model diagram for Socolatte company finances

## CONCLUSION

This research successfully identifies ten key sub-models within the cocoa agroindustry management system: (1) transporting cocoa beans to the factory, (2) company farm harvesters, (3) supervised farm cocoa bean sellers, (4) supervised farm harvesters, (5) factory capacity management, (6) factory labor, (7) final processing in the factory, (8) Socolatte inventory management, (9) Socolatte market and order system, and (10) company financial management. The existence and interaction of these ten sub-models provide comprehensive insights into the structure and behavior of the cocoa supply chain system in Pidie Jaya Regency. By understanding how each sub-model functions and interrelates, management can identify critical leverage points that influence competitiveness. This enables the company to implement more targeted strategies for resource optimization, improve operational efficiency, and respond more effectively to market demands, ultimately enhancing local competitiveness.

The novelty of this research lies in the holistic integration of internal and external supply chain elements, specifically combining vertical integration and vertical coordination into a unified system dynamics model. Such integration has not been widely applied in community-based

agroindustries at the regional level, especially in the context of the cocoa sector. The resulting model serves as a strategic framework for stakeholders to simulate various scenarios and design data-driven interventions aimed at improving overall system performance in a sustainable manner.

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