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Designing a system dynamics model for optimizing shrimp raw material supply in shrimp crackers production

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Abstract. Shrimp is a key raw material in shrimp crackers production. The competitive snack food industry leads to fluctuating demand for shrimp crackers, impacting the supply chain. Demand uncertainty often causes mismatches between the supply of shrimp raw materials and actual needs. Excess raw materials can lead to spoilage due to prolonged storage. The method used to design the raw material procurement model is a dynamic system with the consideration that the model is non-linear and dynamic. This study aims to develop a system dynamics model for shrimp raw material procurement to optimize stock management and reduce spoilage from excessive storage. The system dynamics model determined optimal procurement quantities, with an R value of 60 kg and a Q value of 360 kg, resulting in a reduced storage time of one day. The results of this research can contribute to planning the shrimp raw material supply system for shrimp cracker SMEs.

1 Introduction

Nowadays, industrial development is increasingly developing, as evidenced by the emergence of many companies operating in the industrial sector that manage various kinds of products. This means there will be a lot of competition [1]. Therefore, a company is required to have its own strategy to be able to compete, both in maintaining product quality, good marketing strategies, and good relationships with consumers.

Each company has different activities; for example, companies operating in the industrial sector will have a more complex level of activity than trading companies because industrial companies have production process activities. Broadly speaking, the definition of production activities is activities that create or add value to goods. So, the production process is a series of stages that must be passed in order to produce goods [2]. The production process can run smoothly if the need for raw materials for carrying out the process can be met. To meet these needs, a raw material control system is needed, which includes analysis of raw material needs and subsequent control of raw material inventory [3].

This research will be conducted on the household-scale shrimp cracker industry. In the shrimp cracker industry, the raw material inventory control system will control everything related to the raw material warehouse, both in terms of purchasing raw materials, receiving and storing them, and requesting and releasing them [4]. The shrimp cracker industry will place orders for shrimp raw materials after receiving information from the warehouse if the raw material supply has shown a minimum limit; however, due to the uncertain demand for shrimp crackers, companies often set orders for raw materials in excess of production needs, which makes the raw materials stored in the warehouse for too long, which makes the risk of damage to raw materials quite high.

Design a System Dynamic Model: Develop a system dynamic model for the raw material procurement system in the shrimp cracker industry in Sidoarjo. This model will simulate and analyze the inventory management process to identify potential improvements. Develop Scenarios to Mitigate Raw Material Damage: Create and evaluate scenarios to minimize the risk of damage to raw materials during storage. The study employs system dynamics simulation to address these objectives. Simulation techniques involve modeling and analyzing the behavior of a real system to make informed decisions without the need for extensive physical resources. By simulating the raw material control system, researchers can explore various scenarios and strategies to enhance inventory management. System dynamics is particularly suited for this research as it focuses on understanding how a system evolves over time and how it responds to external disturbances or internal changes [5], [6]. The research contribution is to provide a tool that can help policy makers carry out analysis and decide on appropriate stock management optimization strategy planning through a scenario in system dynamic modeling.

2 Research Method

2.1 System Dynamic Simulation Method

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This research will use the system dynamic simulation method [7] with the aim of minimizing raw material damage due to prolonged storage and optimizing procurement processes. The employment of system dynamics in this research was intended to describe and solve complex problems related to the raw material procurement system in the shrimp cracker industry in Sidoarjo.

System dynamics is a set of tools with a holistic approach used for simulating and forecasting an object [8], [9]. It possesses some advantages over other methods, one of which is that its models are able to offer predictions greater in reliability than statistical models. System dynamics provides ways to understand why an industry behaves in a certain way, detects early changes in the structure of the industry, and determines the factors that forecast such behavior in a significant, sensitive fashion [10]. System dynamics models allow for reasonable scenarios as inputs for a company's decisions and policies [11]. Several researches related to use system dynamics are done by [12], [13], [14], [15], [16], [17].

2.2 Data Collection

This research is quantitative research, and the research method is the survey method. Primary data was obtained through interviews with shrimp cracker business actors using a questionnaire. The data obtained includes the type of production input, the amount of shrimp raw materials needed, the production process, reorder point (R), and order quantity (Q). The interview data was then analyzed using Vensim PLE software.

Vensim PLE is a modeling tool that allows users to conceptualize, document, simulate, analyze, and optimize system dynamic models. Vensim PLE provides a way to build simulation models from causal loop diagrams and stock and flow diagrams that is easy and flexible.

2.3 System Dynamic Model Development

Modeling of the system dynamic begins with articulating the problem [18]. This stage involves defining the model's objectives, boundaries, which encompass the timeframe and key variables, and setting reference modes.

Fig. 1 illustrates the process steps of system dynamic modeling. Several stages in the development of this model are describing the problem and identifying the variables that have an impact on a particular issue. The next stage of the system dynamic model that is carried out begins with system conceptualization through the preparation of a causal loop diagram. The purpose of preparing a causal loop diagram is to describe the relationship between elements in the raw material procurement system [9]. The model formulation stage is the next stage after the conceptual model is arranged in a structured manner. In the model formulation stage, a stock and flow diagram is created and a mathematical formulation is prepared in the diagram, so that it can be simulated [19]. In the stock and flow diagram, several submodels are formed which will represent the subsystems in the shrimp raw material procurement system.

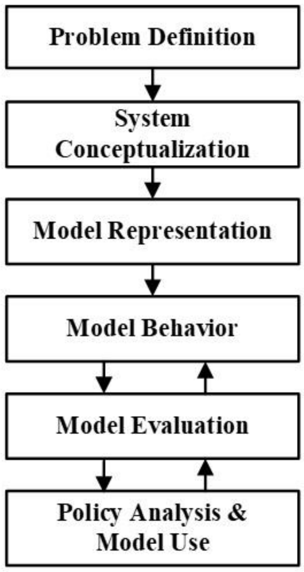

Fig. 1. Causal loop diagram.

To ensure whether the model created in the stock and flow diagram is running according to the researcher's perception, it is necessary to verify the model through a model check. After verifying the simulation model, it is necessary to carry out a validation stage [20]. At this stage, we see whether the model created is able to describe the real system correctly or not. In this research, model validation was carried out using statistical mean comparison tests in the equation or by comparison tests of amplitude variations (% error variance) in the equation [21]. In this research, the validation test carried out by researchers was based on the average comparison test, namely:

$$E = \left|\frac{\bar{S} - \bar{A}}{\bar{A}}\right| x\ 100\%$$

Criteria: The model is considered valid if the E value is ≤ 5%.

After the dynamic model of the shrimp raw material procurement system is verified and valid, it is continued with model simulation. The purpose of this simulation is to see the behavior of the shrimp raw material procurement system model that has been created by entering values into the simulation constants according to the conditions found in the real system. Next, project the procurement of shrimp raw materials to reduce the risk of damage to raw materials in the storage warehouse over the next month.

3 Results and Discussion

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3.1 System identification

In carrying out system identification, an understanding of the system and the observed system behavior is required. System identification includes the flow of procurement of shrimp raw materials, production processes, identification of variables in the system, and relationships between variables in the system.

Cracker making generally consists of three important stages, namely dough making, dough printing and drying. The first stage of fresh shrimp is cleaned by removing the skin and washed thoroughly. After that the shrimp is crushed with a grinding machine and mixed with tapioca flour and other spices and complementary ingredients. The dough that has been mixed, then stirred and kneaded until it becomes a smooth dough. The next stage is the process of printing dough, the process of printing cracker dough is intended to obtain a uniform shape and size. The last stage is the process of drying or drying. The drying process of raw crackers aims to produce materials with a certain moisture content. The moisture content contained in raw crackers will affect the quality and development capacity of crackers in the next frying process. A certain degree of dryness is needed raw crackers to produce maximum steam pressure in the frying process so that the cracker starch gel can expand. Drying crackers also aims at preservation, reduction of transportation costs and maintaining quality. The drying process can be done by drying in the sun or with an oven.

The production process is carried out after the raw materials are available, obtained from purchasing shrimp from suppliers, and the additional materials needed are also available. Variable identification is mainly obtained through interviews and observations, in addition to also being obtained through a literature review. After identifying the variables, identify the relationships between variables in the system, because in the shrimp cracker production system, there are several variables that are related and interact with each other.

3.2 System Conceptualization

System conceptualization in system dynamic simulation is carried out after the system identification stage. At the system conceptualization stage, a causal loop diagram and a stock and flow diagram are created.

Causal Loop Diagram

The causal loop diagram is arranged based on the variables that have been identified, which describes the relationship between variables in the shrimp cracker business (Figure 2). Some of the relationships between these variables are positive, and some are negative [22]. The main variable in the production of shrimp crackers is the shrimp raw material variable.

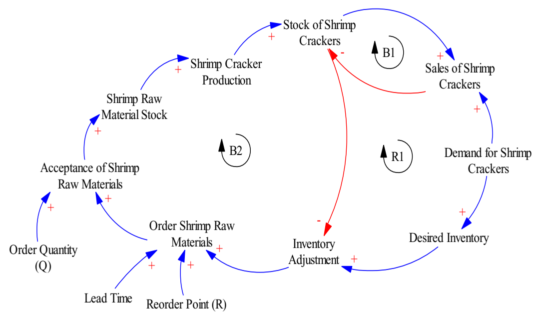

Fig. 2. Causal loop diagram.

Fig. 3 depicts the behavior of all stages in the shrimp cracker business in Sidoarjo. Positive sign (+) indicates variables changing in the same direction, while a negative sign (-) indicates variables changing in opposite directions. For instance, stock of shrimp raw materials has a positive effect on shrimp production. In the causal loop diagram, it has one reinforcing loop (R) and two balancing loops (B).

3.2.1 Stock and Flow Diagram

Next, based on the causal loop diagram, a stock and flow diagram is drawn up. The stock and flow diagram is a simulation of the shrimp cracker production business and contains the values and mathematical equations of each variable. Stock and flow diagrams are used for conductors in the simulation stage [23], [24]. Based on the model constructed by the causal loop diagram, the model in this research is divided into two submodels, namely (1) shrimp procurement submodel and (2) shrimp cracker production submodel. The purpose of dividing this submodel is to make it easier to carry out simulations. The following are two sub-models that are indicators of the raw material control system in the shrimp cracker industry:

3.2.2 Shrimp Procurement Submodel

In this submodel, the stock of raw materials will be controlled by the variable R (reorder point) [25] as an indicator of when to reorder raw materials from suppliers. Orders for raw materials will be made when the stock of raw materials is less than the reorder point value determined by the company. After an order is placed, the raw materials are sent by the supplier during the delivery lead time of six hours from the supplier to receipt of the raw materials.

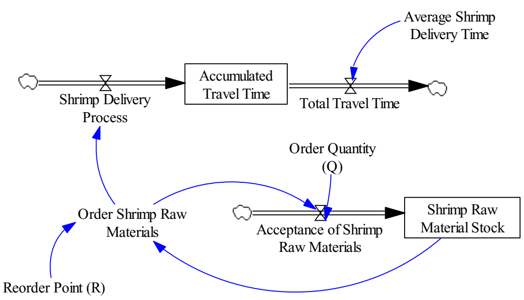

Fig. 3. Stock and flow diagram of the shrimp procurement submodel.

3.2.3 Shrimp Cracker Production Submodel

The processing of raw materials into shrimp cracker products that are ready to be marketed is done manually. In this production submodel, the production process is carried out for five hours, with a maximum production capacity of 30 kg of shrimp crackers per day. Due to the changing demand for shrimp crackers, to determine the amount of production, modeling was carried out with a normal random function on the shrimp cracker sales variable. If demand on that day exceeds production capacity, then the amount of production will only be in accordance with the company's production capacity, and if the amount of demand is below production capacity, then the amount of production will be adjusted to the amount of demand.

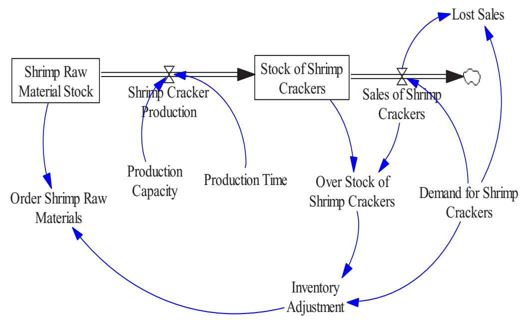

Fig. 4. Stock and flow diagram of the shrimp cracker production submodel.

3.3 Model Verification and Validation

Model verification is the stage of proving that the computer model that has been prepared in the previous stage is capable of carrying out simulations of the abstract model being studied [26]. Model verification is a testing stage to determine to what extent the computer program that has been created shows the correct behavior and response. Verification is carried out by looking at the units used and whether the formulation is as desired or not. Verification is carried out by checking the formulation and checking the units of variables in the model. If there are no errors in the model, then the model has been verified. Based on the results of the simulation carried out, the model is running correctly without errors in the formulas or in the unit. Thus, the simulation that has been built can be used to carry out improvement scenarios.

Validation in system dynamic modeling can be done in several ways, including direct structure tests without running the model, structure-oriented behavior tests by operating the model, and comparing model behavior with the system. real (quantitative behavior pattern comparison). Model validation is carried out in accordance with the modeling objective, namely comparing the dynamic behavior of the model with real system conditions. If the model is considered valid, then this model can be used as a representative of the real system. Validation in this modeling is carried out with a behavior validity test, where the actual values in the real system are compared with the simulation output values.

In this research, the variables tested were orders for shrimp raw materials and the production of shrimp crackers. The Barlas model is used to test the validity of the model. This model is considered valid when the percent error of the mean (E1) is less than 5% and the percent error of the variance (E2) is less than 30% [21]. The validation results for ordering shrimp raw materials and producing shrimp crackers are presented in Table 1.

Table 1. Validation results using E.

Parameter	Order Shrimp Raw Materials	Shrimp Cracker Production
E_1	1.856%	1.957%
E_2	12.524%	13.758%
Information	Valid	Valid

3.4 System Dynamic Scenario for the Procurement of Shrimp Raw Materials

The scenario in this research is a description of a condition that is created as a basis for consideration by researchers in making decisions and preparing the steps to be taken according to real conditions. According to [23], in system dynamic simulation, there are two scenario options, namely parameter scenarios and structure scenarios. Parameter scenarios are carried out by changing the parameter values in a variable in the model that has been created to obtain the best results. In this scenario, the existing model structure is then changed to a new model structure so that system performance increases. For this reason, sufficient knowledge about the system is required so that the new structure can improve system performance.

The scenarios proposed in this research are parameter scenarios, namely by changing the parameter values R (reorder point) and Q (order quantity), consisting of scenarios without improvements and scenarios with improvements. The scenario without improvement is a scenario in real conditions in accordance with the existing shrimp cracker production process. An improved scenario is one that combines the R value (reorder point) and the Q value (order quantity), which is best for the effectiveness of storing raw material stock during the one-month production period, so that in the production process there is no shortage of raw material stock [27]. To determine the correct combination value of R and Q in this research, use Vensim software by sorting the R and Q values from the lowest in multiples of 30 kg, which is the average production amount in the shrimp cracker industry. From the results of this initial scenario, the most effective scenario will be chosen, which can be applied as a suggestion to the shrimp cracker industry in Sidoarjo. The scenario design is shown in Table 2.

Table 2. The scenario design.

Scenario	*R (Reorder Point)*	*Q (Order Quantity)*
Scenario 1 (initial)	30 kg	480 kg
Scenario 2	30 kg	180 kg
Scenario 3	60 kg	300 kg
Scenario 4	60	1

3.4.1 No Improvement Scenario

This scenario is a real one in the shrimp cracker industry. In this scenario, the company sets the R value at 30 kg and the Q value at 480 kg. So when the stock of raw materials is < 30 kg, the company will order 480 kg of raw materials from the supplier, with a delivery lead time of six hours from the supplier to receipt of the raw materials. In this scenario, orders for raw materials are made every 3 days, and then the ordering department will place orders for raw materials from suppliers. With a Q value of 480 kg per order of raw materials, the average stock of raw materials for one month is 15.05 kg.

3.4.2 Scenario with Improvements

This scenario is a trial scenario, where there are 3 scenarios using a combination of R and Q values. In scenario 2, the company sets the R value at 30 kg and the Q value at 180 kg. So when the stock of raw materials is < 30 kg, the company will order 180 kg of raw materials from the supplier, with a delivery lead time from the supplier to receipt of the raw materials of six hours. With a Q value of 180 kg per raw material order, the average stock of raw materials for one month is 5.64 kg. Next, in scenario 3, the company sets the R value at 60 kg and the Q value at 300 kg. So when the stock of raw materials is < 60 kg, the company will order 300 kg of raw materials from the supplier, with a delivery lead time from the supplier to receipt of the raw materials of six hours. With a Q value of 300 kg per raw material order, the average stock of raw materials for one month is 9.82 kg. In scenario 4, the company sets the R value at 60 kg and the Q value at 360 kg. So when the stock of raw materials is < 60 kg, the company will order 360 kg of raw materials from the supplier, with a delivery lead time from the supplier to receipt of the raw materials of six hours. With a Q value of 360 kg per raw material order, the average stock of raw materials for one month is 9.65 kg. The comparison results for the four scenarios are shown in Figure 5.

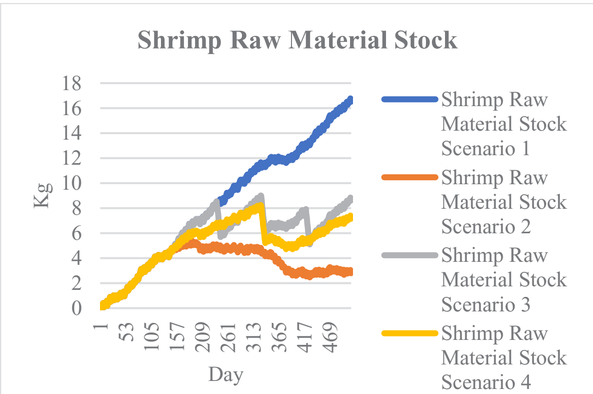

Fig. 5. Comparison of shrimp raw material stock scenarios.

After creating several scenarios, the results of each scenario were then recorded with the following data:

Table 3. Scenario results data.

Scenario	R	Q	Average storage time of shrimp	Average shrimp stock	Shrimp needs / production
Initial (1)	30 kg	480 kg	3 day	15.05 kg	Fulfilled
2	30 kg	180 kg	2 day	5.64 kg	Not fulfilled
3	60 kg	300 kg	2 day	9.82 kg	Fulfilled
4	60 kg	360 kg	1 day	9.65 kg	Fulfilled

From the data above in the second scenario, the combined value of Q and R does not meet the production requirements because in the simulation there is a shortage of raw material stock, which results in the production process stopping on that day because they have to wait for the raw material delivery process from the supplier. Meanwhile, for the initial, third, and fourth scenarios, the combined values of Q and R meet the production requirements because, in the simulation, there is no shortage of raw material stock within one month of the production period. However, the storage time for raw materials in the third scenario is better than the initial scenario because it only takes two days to use up the stock of raw materials, which means the risk of damage to raw materials due to being stored for too long can be minimized in the third scenario. Based on the scenario results data, scenario four is better than scenario three because it only takes one day to use up raw material stocks.

4 Conclusion

The study addresses the issue of fluctuating shrimp supply in the household-scale shrimp cracker industry in Sidoarjo, which often leads to losses due to the limited storage life of shrimp. The research designs a system dynamic simulation model to control inventory levels and optimize the reordering process.

The model utilizes the reorder point variable (R) to determine when to reorder raw materials. Orders are placed when the raw material stock falls below this predetermined threshold. The raw material delivery includes a lead time of six hours, and the order quantity (Q) is based on the production capacity and production time variables. By controlling these variables, the model aims to mitigate the risk of raw material damage and ensure continuous production.

Simulation results indicate that the optimal combination of reorder point (R) and order quantity (Q) is 60 kg and 360 kg, respectively. This combination effectively meets the production needs for one month and allows for efficient use of raw materials. With this combination, raw material stocks are depleted in one day of production, minimizing the risk of spoilage and ensuring that production runs smoothly.

It is recommended to implement the R value of 60 kg and Q value of 360 kg in the shrimp cracker industry to maintain optimal inventory levels and reduce the risk of raw material spoilage. This combination ensures that production needs are met without shortages and that raw materials are used efficiently.

Future research could explore the impact of varying lead times, production capacities, and order quantities on inventory management and supply chain efficiency. Further studies could provide additional insights into optimizing inventory levels and improving overall operational efficiency. This research provides a valuable model for managing inventory levels in the household-scale shrimp cracker industry. By utilizing system dynamic simulation, the study identifies an optimal combination of reorder point and order quantity that meets production needs and minimizes the risk of raw material spoilage. The proposed model offers practical solutions for improving inventory management and reducing losses in the shrimp cracker industry.

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