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Original

Cold chain adoption for fresh durian products by the simulation technique

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Abstract: The short shelf life of durian products is a problem that has led to missed opportunities for businesses in the supply chain to extend the selling period. Therefore, this research developed a Discrete-event simulation model using FlexSim software to apply the cold chain in fresh durian products in order to extend their shelf life. The focus of this simulation was on adding a pre-cooling process that could extend the shelf life of fresh durians by approximately 7 days or 35.80% of the product's life. However, it resulted in an increased operational cost of 9,700.6 baht or 3.43% of the total operating cost. Additionally, the study experimented with increasing the number of durian orchards in the supply chain to test potential future scenarios. The consistent results of the study indicated that the shelf life of fresh durians could be extended by approximately 7 days or about 35.87% of the product's life, but with an increased operational cost of 10,446.8 baht or 3.58% of the total operating cost. Therefore, members of the fresh durian supply chain should consider implementing the cold chain to enhance opportunities for selling fresh durians for a longer period.

Keywords: Cold chain, durian, simulation technique.

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1. Introduction

Durian is an economically significant fruit in Thailand. The country is a major producer and exporter, ranking first in the world. The principal consumer of Thai durian is China, accounting for approximately 70% of the total export market (Kasikorn Research Center, 2021). In 2022, Thailand exported fresh durian valued at 110,146.21 million baht or approximately 827,219 tons (Ministry of Commerce, 2023). The key durian cultivation areas in Thailand are located in the eastern region, specifically in Chanthaburi Province, which covers an area of 225,273 rai, followed by Chumphon Province in the southern region, which covers an area of 192,685 rai. Chanthaburi Province stands as the highest durian-producing province in Thailand, yielding approximately 339,292 tons per year (Trade Policy and Strategy Office, 2021).

Currently, a significant issue with fresh durians is the limited development of the supply chain, which has implications for the quality and shelf life of the product. Thus, the supply chain for fresh durians in Thailand requires further research and development to improve its effectiveness. Such improvement is crucial to extend the shelf life of fresh durians and enable longer durations for the export of Thailand's fresh durian products (Siriprasertchok & Panyagometh, 2020). It will contribute to boosting the capacity of fresh durian exports to farther-off nations like the US and raising the GDP of the nation. Past research studies have shown that many developed countries, including the United States, Japan, and Canada, prefer using the cold chain to extend the shelf life and maintain the quality of fresh fruit for longer durations. In the case of Thailand's fresh durian cold chain, however, there are still challenges in implementing the cold chain due to the high costs associated with it (Sahawiriya et al., 2022).

This case study on the cold chain for fresh durians was based in Chanthaburi Province and involved 24 farmers, one packing house, and one transport company. The daily export of fresh durians to China amounts to approximately 2 containers, 40 feet each. The primary processes include harvesting, quality inspection, packaging, and transporting fresh durians to the port for export. This research aims to study the outcomes of implementing the cold chain for fresh durians using the Simulation technique to describe the current operational system and predict the potential impact of adopting the cold chain in this specific case study

1.1. Objectives

To study the workflow for the supply chain in fresh durian products using a case study approach and the simulation technique

To apply the cold chain in fresh durian products using a case study approach and the simulation technique.

2. Literature review

2.1. Cold chain

The cold chain refers to the process of maintaining the most suitable product temperatures throughout the entire supply chain from harvesting, storage, packaging, transportation, and distribution, to maintain the freshness and quality of products for the longest possible duration. The factors of the cold chain include 1) pre-cooling systems, 2) cold rooms, and 3) temperature-controlled transportation (Office of the National Economic and Social Development Council, 2021). Past research has explored various applications of the cold chain for durian products. Sahawiriya et al. (2022) designed a distribution system for pre-cut and ready-to-eat fresh durian products using target-based programming with a focus on analyzing transportation costs and time. The Agricultural Development Policy and Planning Division (2021) developed guidelines for cold chain management of durian products, particularly concerning frozen durians. However, limited attention has been given to fresh durians. Additionally, Cheanta and Yiangkamolsing (2020) improved the efficiency of frozen durian production by applying Good Manufacturing Practices (GMP) principles, but there remains a lack of research on the fresh durian cold chain.

2.2. Simulation

Simulation is the process of creating models that mimic the real-world scenarios of the systems being studied, allowing analysts to gain an overview of the systems and find ways to improve and address issues. Simulation techniques commonly used in logistics and supply chain research can be classified into three types including (1) discrete-event simulation (DES), often applied in operational management research more than policy management, (2) system dynamics (SD), suitable for policy management issues rather than operational management, and (3) agent-based modelling (ABM), which involves simulating scenarios using individual agents and focusing on the factors that impact system behavior in terms of decision-making behavior and agent characteristics (Owen et al., 2010; Siritan et al., 2013). Based on the aforementioned information, this research selected DES for simulating the fresh durian cold chain and applied it to compare the results before and after the adoption of the cold chain.

To the best of my knowledge, this research is the first study to focus on cold chain adoption in the fresh durian supply chain using discrete-event simulation. Adding to that, the main contribution of the study is to explore fresh durian flow and to investigate the performance impacts of cold chain adoption in the fresh durian supply chain.

3. Methodology

This research process began with studying the current operational conditions of the supply chain for fresh durian products through a case study. Subsequently, the cold chain was applied using a simulation technique called Discrete-event simulation (DES). Figure 1 illustrates the research process for this study using the simulation technique.

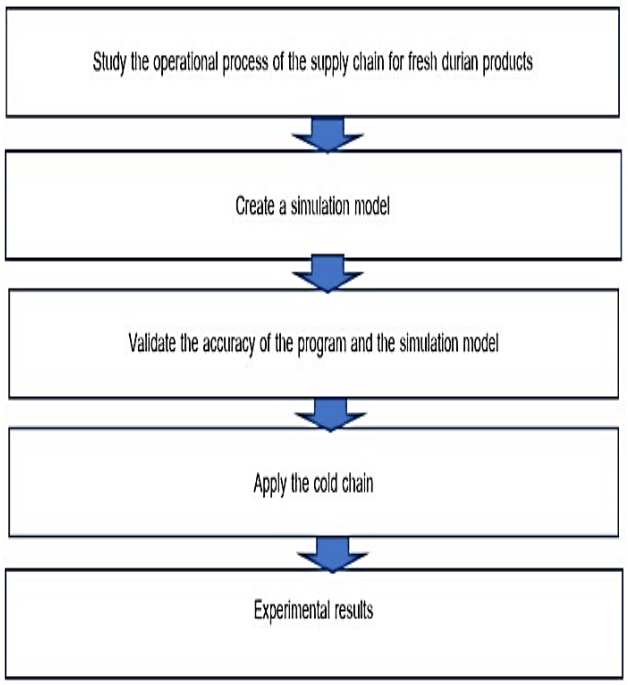

Figure 1. Research process steps.

3.1. Step 1: Study the operational process of the supply chain for fresh durian products

The current operational process of the supply chain for fresh durian products was examined by collecting data from records, observations, and interviews with relevant stakeholders, including farmers, packing houses, and transportation personnel. Table 1 explains the activities of farmers, while Table 2 explains the activities of packing houses, and Table 3 explains the activities of transportation personnel. In each activity, data on time and frequency were collected 30 times to determine the most suitable data distribution. Numeric values were used to represent the actual data collected, and Expert Fit software was employed with Automated Fitting (Figure 2) to find the most appropriate data distribution for each activity of farmers, packing houses, and transportation personnel, as shown in Tables 1, 2, and 3, respectively.

Table 1. Details of the operational processes of farmers.

Activity	Explanation	Statistical distributions (Minutes)
Harvesting durians	Farmers harvest durians from trees. For each tree, 2 people are required, resulting in a total of 4 people.	erlang (0.030364, 0.036330, 3.000000)
Moving durians to trailers	A single person is responsible for moving durians from the harvesting point to the trailer of a motorcycle.	lognormal 2(0.000000, 0.100480, 0.421665)
Moving durians to durian laydown areas	A single person rides the motorcycle to transport the durians to a durian laydown area.	beta (0.553789, 0.641852, 1.053878, 1.281907)
Quality inspection	A single person is involved in inspecting the quality of durians, ensuring they are suitable for delivery to the packing house.	weibull (0.046924, 0.058282, 2.000000)
Loading durians onto trucks	Farmers load the durians onto a pickup truck using people from the harvesting team.	weibull (0.051430, 0.023370, 2.000000)
Transporting durians to packing houses	Two people from the harvesting team drive the truck to the packing house.	triangular (35, 45, 40)

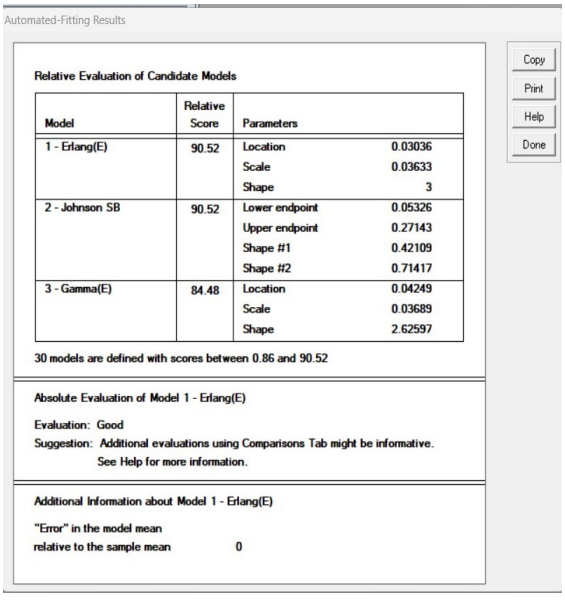

Figure 2. Example of data distribution analysis.

Table 2. Details of the operational process of the packing house.

Activity	Explanation	Statistical distributions (Minutes)
Unloading durians from trucks	People accompanying the truck will unload the durians from the truck; 2 people are required for each truck.	erlang (0.005142, 0.008324, 4.000000)
Quality inspection	Quality inspection of durians for export using a pickup truck requires 1 person, and there are a total of 3 people in the packing house.	Johnsonbounded (0.014150, 0.176776, 0.558176, 2.873754)
Applying ethephon to the stems (Agricultural Development Policy and Planning Division, 2021)	A person from the pickup truck will apply Ethephon to the stems of every durian. In the packaging and processing facility, there are a total of 3 people.	gamma (0.000000, 0.002073, 9.192438)
Weighing	The durians are weighed after unloading from the truck; 1 person is required for each basket. In 1 basket, there are 16 durians, and there are a total of 3 people in the packing house.	gamma (0.000000, 0.002073, 9.192438)
Moving durians to a durian laydown area	For each basket, 1 person is required, and there are a total of 3 people in the packing house.	beta (0.113472, 0.320094, 1.305915, 2.104229)
Dipping durians	Two people are required for dipping the durians, which usually begins at around 16:00 each day.	loglaplace (0.006851, 0.018149, 2.758691)
Lifting durians	To lift the durians and place them in baskets, 2 people are required. Each basket contains 16 durians.	loglaplace (0.005714, 0.016786, 3.057496)
Moving durians to a durian laydown area	Each basket requires 2 persons, and there are a total of 4 people.	beta (0.000165, 0.176181, 6.558666, 10.468230)
Placing durians on a drying platform	People assist with moving durians to the drying platform by lifting them out of the baskets and placing them to dry.	beta (0.013552, 0.067067, 2.563239, 7.603884)
Drying durians	The durians are dried for a specific time.	triangular (720, 840, 780)
Packing durians into baskets	Durians are packed into baskets, with 1 person per basket, and there are a total of 3 people.	beta (0.596118, 1.969835, 4.005537, 2.139787)
Attaching labels to the stems	Labels are attached to the stems of every durian, requiring 1 person.	Weibull (0.000000, 0.242495, 6.729324)
Placing durians into cartons	Durians are placed into cartons, with 1 person per carton, and there are a total of 3 people.	beta (0.403770, 2.070229, 1.435171, 2.939042)
Wrapping durian boxes	The durian boxes are wrapped, with 1 person required.	loglaplace (0.202788, 0.078708, 2.952462)

Table 3. Details of the transporter workflow.

Activity	Explanation	Statistical distribution (Minutes)
Loading durian boxes onto the truck	Durian boxes are loaded onto a 40-foot refrigerated container truck, which requires 6 people.	triangular (75, 90, 105)
Transporting durians to the port	Two people are needed per truck. The truck transports the durians to the port for export via ship.	triangular (180, 240, 200)

This research was approved by the Research Integrity Department Ethical Board of the Prince of Songkla University (No. PSU-HREC 64-043-1-1). The researcher was given permission to collect data with consent waiver. The researcher confirms that this research was conducted in line with the Declaration of Helsinki principles.

3.2. Step 2: Creating the simulation model

After conducting the necessary research and gathering the essential data required to create a computer simulation model for cold chain adoption in fresh durian products, this research aimed to develop the model to demonstrate the current operations. The simulation was carried out using FlexSim software, which falls under the category of Discrete-event simulation. The model includes 24 farmers, 1 packing house, and 1 transportation personnel, representing a single farm, as shown in Figure 3. Figure 3 presents a sample of the simulation model depicting the workflow of one durian orchard, including 24 farmers, one packaging and processing facility, and one transporter.

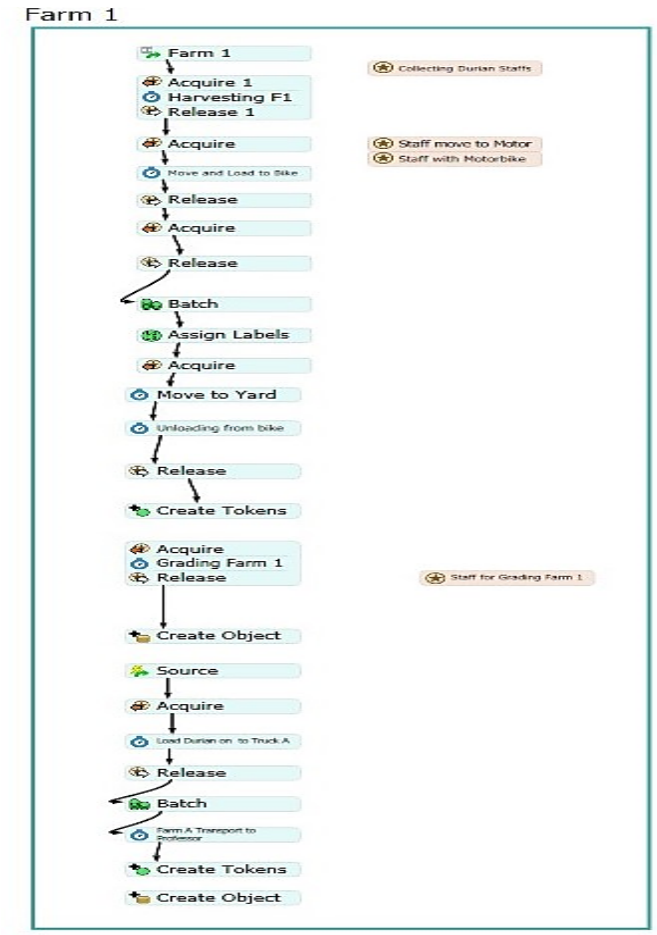

Figure 3. Example of a farmer's work process model.

3.3. Step 3: Verification and validation of the program and scenario model

In this research, the verification process was conducted to test the correctness of the simulation model by analyzing the operation of the fresh durian supply chain system in the model. Verification showed that the model had no error notifications and accurately represented the real-world behaviors in the system.

The validation process aimed to compare the results of the scenario model with the actual performance of the system to determine whether the model could effectively represent the current operations. The independent t-test was used to analyze the quantities of durians exported per day (in boxes) and the total duration of the process, from farmers to transportation personnel until the durians reached the port (in minutes). The scenario model was tested through 20 repeated runs run length of 3,060 minutes, and the obtained p-values were 0.191 for the quantity of exported durians (Table 4) and 0.594 for the process duration (Table 5). These p-values were greater than the significance level of 0.05, indicating that the scenario model could adequately represent the fresh durian supply chain system in this case study.

Table 4. Comparison of average quantity of durians (boxes) between the actual system and the simulation.

Sample group	N	$\bar{x}$	SD	t	Sig
Actual system	2	1,918.50	4.950	-1.355*	0.191
Simulation	20	1,913.15	5.344		

Note: *Statistically significant at the .05 level.

Table 5. Comparison of average duration of the process, from farmers to transportation personnel until durians reach the port (minutes), between the actual system and the simulation.

Sample group	N	$\bar{x}$	SD	t	Sig
Actual system	2	2,552.50	45.962	-.542*	0.594
Simulation	20	2,545.26	15.194		

Note: *Statistically significant at the .05 level.

3.4. Step 4: Applied cold chain adoption

The cold chain process consists of several stages, including pre-cooling, refrigerated storage, and refrigerated transport (Sharma & Pai, 2015). Currently, the cold chain process for fresh durian products involves maintaining the temperature at approximately 15 °C during storage and transportation using refrigerated containers. In this research, an additional step of pre-cooling was implemented right after the wrapping process of the durian boxes at the packing house. This step was added because fresh durian can undergo pre-cooling within 48 hours after harvesting (Romphophak et al., 1997). After pre-cooling, the durian boxes were loaded into refrigerated containers, maintaining the temperature at 15 °C, for transportation to the port.

The pre-cooling process was conducted using forced air cooling as it was suitable for fresh durian (Paull & Ketsa, 2014). This step required 2-4 hours to reduce the temperature of fresh durian to approximately 15 °C, consuming 35 kWh of electricity per pre-cooling session. Each pre-cooling session could handle 3 tons of durian (United States Agency International Development, 2009). Therefore, the simulation model used 14 units of the pre-cooling equipment, considering the daily export quantity of fresh durian in the case study, which was approximately 40 tons.

4. Results

After applying the cold chain in the simulation model by incorporating the pre-cooling process, the simulation model was run 20 times. The experimental results are shown in Table 6.

Based on interviews with packaging operators, it was found that the current shelf life of fresh durian is approximately 14 days from the harvest date. However, research by Siriphanich and Romphophak, (2011) showed that fresh durian can have a longer shelf life of up to 21 days under cold chain management at 15 °C. Therefore, the shelf life of fresh durian in the simulation was calculated by subtracting the average time duration of the cold chain operation from the durian's shelf life. However, the operational costs were calculated based on labor, fuel, electricity, packaging, and transportation costs for the transportation service provider.

Table 6. Results from adoption of the cold chain.

Results	Current scenario in simulation	Cold chain adoption in simulation
Quantity of durian (Boxes)	1,913.15	1,914
Processing time (Minutes)	2,545.26	2,804.29
Shelf life of fresh durian (Days)	12.23	19.05
Operational costs (Baht)	272,827.8	282,528.4

From Table 6, it can be observed that the implementation of the cold chain resulted in increased operational time and operational costs. The operational time increased from the original 2,545.26 minutes to 2,804.29 minutes, and the operational costs increased from 272,827.8 Baht to 282,528.4 Baht due to the electricity costs for the pre-cooling process. Nevertheless, the shelf life of fresh durian increased from 12.23 days to 19.05 days after applying the cold chain.

To ensure that the research outcomes could reflect potential future events, this study conducted scenario testing for a situation where the number of durian orchards in the supply chain increased**.** The experiment increased the number of orchards from 24 to 25, and the results are shown in Table 7. It can be observed that the trend of the results remains consistent, indicating that cold chain adoption is still suitable in scenarios where the number of durian orchards in the supply chain increases, which may occur in the future.

Table 7. Results from applying the cold chain in a scenario with increased orchards.

Results	Current scenario in the simulation	Applied cold chain in the simulation
Durian quantity (Boxes)	1,993	1,993
Processing time (Minutes)	2,553.37	2,784.95
Shelf life of fresh durian (days)	12.23	19.07
Operation cost (Baht)	281,405.5	291,852.3

To summarize, the simulation results indicate that implementing a cold chain can enhance the fresh durian supply chain's performance by extending its shelf life. This can have a significant positive impact on Thailand's economy by enabling it to export fresh durian to other countries.

5. Discussion

From the study on the application of cold chain adoption in the fresh durian products supply chain using simulation technique, the research results indicate that members in the fresh durian supply chain should adopt cold chain to extend the shelf life of fresh durians by approximately 7 days. This will provide more opportunities for supply chain operators to increase sales of fresh durian, including the possibility of exporting to distant countries. These findings are consistent with the research conducted by Kanchanasuwan (2018) who designed a cold chain for fresh mango and extended the shelf life from approximately 7 days to 22 days.

6. Conclusion and recommendation

This research demonstrates that cold chain adoption is beneficial for entrepreneurs in the fresh durian supply chain. Entrepreneurs should consider implementing the cold chain to prolong the shelf life of products, enabling them to export fresh durian to distant countries or extend the selling period to increase profitability.

Conflict of interest

The author has no conflict of interest to declare.

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