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Applying Finite State Automata to Structural Design of an Automatic Ice Cream Machine

Novilia Lestari[1]*, Sri Wahyu[1], Melisa Sartika[1], Annisa Thurrabiah Khanza[1], Sadra Afifah[1], and Ade Candra Bayu[2]

[1]Mathematics Department, Padang State University, West Sumatera Province, Indonesa
[2]Department of Mathematics, Khalifa University, Abu Dhabi, United Arab Emirates

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Abstract: Technological advances encourage the implementation of automated machines to improve efficiency and process consistency, one of which is in automatic ice cream machines. These machines require a structured control system to manage the ordering flow and user interaction. This study aims to apply Automata theory, specifically Finite State Automata (FSA), to systematically model the working logic of an automatic ice cream machine. The system workflow is represented using Non-Deterministic Finite Automata (NFA) which includes the stages of cup size selection, flavor selection, topping selection, payment process, and order confirmation. This system allows the selection of 3 cup sizes: small, medium, and large, ensuring that each ordering process begins with an explicit cup size selection before the user proceeds to the next stage. Also, at the topping selection stage, the automata model is designed to be more flexible by providing transitions that allow users to choose no topping at all or to choose more than one topping. Model validation was carried out through simulations using JFLAP. The simulation results show that the model can accept valid input sequences and reject invalid inputs, so that the system flow runs consistently. Thus, FSA is proven effective as a formal framework in modeling and analyzing automatic ice cream machine systems.

Keywords: Automata, Finite State Automata, Ice Cream, Vending Machine

* Correspondence e-mail: novilialestari1000@gmail.com

1. Introduction

The rapid development of technology enables the improvement of human work effectiveness. New inventions in the field of technology assist humans in daily activities, making them more efficient. One of the most impactful technological inventions is the Vending Machine or automatic selling machine. A Vending Machine is a machine that can be used by business owners to carry out sales automatically without an operator (Salman et al.). Automatic machines are technologies aimed at transforming manual activities into automated ones to accelerate the production process and produce higher-quality goods (Kaunang, 2019). Automatic machines are often used in food and beverage sales so that the buying and selling process becomes more efficient, easy, and practical (Maulana et al., 2019). Automatic machines help increase time and cost efficiency in the sales process, and also simplify the process of selling a product (Ermawati et al., 2021). The application of automated technology has been used in the sales of various types of popular food items, including ice cream, coffee, and so on.

The high consumption rate and popularity of ice cream worldwide encourage ice cream business owners to continuously innovate in order to provide optimal service to consumers. The biggest challenge faced is how to minimize ice cream serving time so that consumers can obtain ice cream more practically without having to wait too long in queues or during the serving process (Maulana & Irawan, 2024). In addition, the wide variety of available ice cream flavors and toppings requires automatic ice cream machines to be able to produce ice cream according to consumer preferences (Kaunang, 2019). The use of automatic ice cream machines becomes a solution that can increase ordering efficiency, accelerate serving time, and reduce labor needs. However, in practice, unstructured automatic ice cream machines often cause problems, such as errors in the sequence of serving processes, inconsistency in flavor, and inefficient working time. To minimize errors in the automatic ice cream preparation process, a systematic approach is needed to model the machine's workflow logically and structurally. One approach that can be used to model processes in this automatic machine so that it can produce outputs according to predetermined inputs is the concept of Finite State Automata (Abdullah et al., 2022).

Finite State Automata (FSA) is a mathematical model of a system that can accept inputs and produce outputs, consisting of a number of states that can transition from one state to another according to the given input (Suharsih & Atqiya, 2019). FSA is a mathematical modeling system used for decision-making based on input in the form of a language recognized by the machine, producing outputs according to the rules defined in the machine (Salman et al.). When an input is received, the FSA reads the string sequentially, and each symbol/input triggers a transition to the next state. This process continues until all strings are read by the machine. If at the end of the reading process the machine is in the final state, then the string is accepted by the machine and produces the desired output (Kaunang & Waworundeng, 2019). FSA is highly effective and efficient in controlling the logical order of a process, especially in systems with structured workflows. With the ability to explicitly define and manage transition flows, FSA enables an automatic machine system to operate in a structured manner according to its designed workflow.

Several previous studies have been conducted and show the effectiveness of FSA in building automatic machines. Research conducted by Widodo et al (2022) explains that Finite State Automata is an alternative for analyzing the workflow of automatic ice cream machines by recognizing the input patterns provided. In addition, this study explains the concept of an automatic ice cream machine consisting of several flavors and toppings, as well as offering cash and non-cash payment methods. In this research, the authors develop the concept of the automatic ice cream machine automata proposed by Widodo et al. by expanding the complexity of the automata system. The development is carried out by adding a state for choosing ice cream cup sizes, as well as transition combinations that allow users to not choose toppings or to choose more than one topping.

This study aims to create and develop a model of an automatic ice cream machine by implementing the Finite State Automata (FSA) concept. By using FSA, the working process of the ice cream machine can be controlled through several stages and operate sequentially. This automatic ice cream machine can create ice cream combinations with 3 cup size variants, namely small, medium, and large, 4 flavor options, peanut, chocolate, matcha, and strawberry and 4 topping variants, namely sprinkles, Oreo, cheese, and choco. This machine is also equipped with an automatic payment feature, both cash and non-cash, which can increase efficiency and minimize the number of staff needed to make and serve ice cream. The results of this study are expected to provide an overview of the model and workflow of an automatic ice cream-making machine, as well as serve as a reference for developing automation systems in other fields with structured workflows.

2. Methods

In this study, a formal model-based approach is used. This approach is applied through the creation of transitions between states when the user performs certain actions to describe the system as working logically and structurally (Kaunang, 2019). The steps of the research framework can be seen in Figure 1 below:

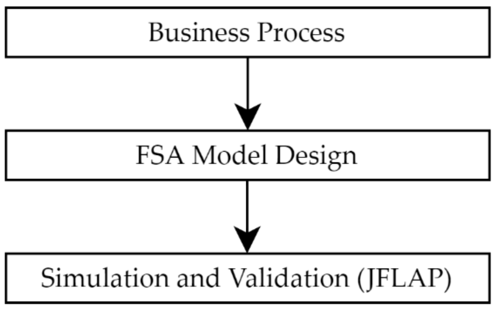

Figure 1. Research Framework

Figure 1 presents the research framework, which consists of several systematic stages. Each stage is designed to ensure that every process, from system design to system testing, is carried out according to the objectives. The stages in this study are explained as follows:

1. Business Process Analysis
   This step involves analyzing the level of consumer preference for ice cream, which helps the researchers understand the business flow of ice cream sales that becomes the basis for system design.
2. FSA Model Design
   After conducting the business process analysis, the next step is designing the system model of the vending machine using the concept of Non-Deterministic Finite State Automata. This stage results in an FSA diagram that illustrates the workflow of the vending machine.
3. Simulation and Validation (JFLAP)
   The proposed Finite State Automata (FSA) model is simulated and validated using the JFLAP application to verify the correctness of state definitions, transition functions, and overall system logic at the model level. The simulation is conducted by defining the initial state, final state, input symbols, and transition rules according to the designed Non-Deterministic Finite State

Automata (NFA). Various input sequences representing possible user interaction scenarios, including valid and invalid ordering flows, are applied to observe the behavior of the automaton. A valid sequence is characterized by its ability to reach the final state, while invalid sequences are rejected during the simulation process. This validation ensures that the automaton operates in accordance with its formal definition and is free from logical inconsistencies such as undefined transitions, unreachable states, dead states, or conflicting paths. Through simulation-based validation, the proposed FSA model is confirmed to provide a reliable and consistent formal representation of the operational workflow of an automatic ice cream machine without requiring physical or software implementation.

3. Results and Discussion

The application of the Finite State Automata concept in designing the structural workflow of an automatic ice cream machine is used to ensure that the machine's operating process runs systematically. This design takes into account several important stages, starting from selecting the ice cream cup, ice cream flavor, ice cream topping, additional toppings, up to the payment method. The results are presented through formal automata notation, transition tables, and input string testing using JFLAP, which illustrates the machine's behavior in responding to variations in user requests.

3.1. Automata Design of the Automatic Ice Cream Machine

The automata model designed in this study refers to the concept of Finite State Automata (FSA), specifically the Non-Deterministic Finite Automata (NFA) model. NFA is a type of Finite State Automata that may have no transition direction or multiple transition directions to different states with the same input (Pramadya et al., 2023). This model is used to read, recognize, and process inputs from users based on the transition flow between states that has been designed. The machine will process each input from the initial state to the final state sequentially and will only be accepted if the entire input path matches the valid transition routes in the automaton and ends in the final state.

The concept of the automata machine based on the NFA principle is formally defined in 5 tuples, namely:

$$M = (Q, \sum, \delta, S, F)$$

Where Q is the set of states, $\sum$ is the set of inputs, δ is the transition function, S is the initial state, and F is the set of final states. The complete configuration of this automatic machine is as follows.

$Q = \{Q_0, Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7, Q_8, Q_9, Q_{10}, Q_{11}, Q_{12}, Q_{13}, Q_{14}, Q_{15}\}$

$\sum = \{A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P\}$

$S = \{Q_0\}$

$F = \{Q_0, Q_{12}\}$

This automata configuration serves as the foundation for designing the logical workflow of the ice cream ordering process carried out automatically by the machine.

Table 1. Set of States

State	Description
Q_0	Initial state, the buyer starts the ice cream purchase
Q_1	Peanut flavor
Q_2	Chocolate flavor
Q_3	Matcha flavor
Q_4	Strawberry flavor
Q_5	Sprinkles topping
Q_6	Oreo topping
Q_7	Cheese topping
Q_8	Choco topping
Q_9	Cash payment
Q_{10}	E-money payment
Q_{11}	Receipt output or transaction cancellation
Q_{12}	Ice cream dispensed (final state)
Q_{13}	Medium cup
Q_{14}	Large cup
Q_{15}	Small cup

Table 1 shows that there are 16 states in the automatic ice cream machine, with the initial state being Q_0 and the final state being Q_{12}, which represents the ice cream output state. In addition, the symbols/inputs used in the FSA design can be seen in Table 2 below.

Table 2. Set of Inputs

Input	**Description**
A	Selecting peanut flavor
B	Selecting chocolate flavor
C	Selecting matcha flavor
D	Selecting strawberry flavor
E	Selecting sprinkles topping
F	Selecting Oreo topping
G	Selecting cheese topping
H	Selecting choco topping
I	Selecting cash payment method
J	Selecting non-cash (e-money) payment method
K	Further confirmation for transaction cancellation/printing payment receipt if purchase is approved
L	Transaction cancellation
M	Ice cream is prepared and dispensed from the automatic machine
N	Selecting small cup

O	Selecting medium cup
P	Selecting large cup

Table 2 contains 16 symbols that represent the flow of the Finite State Automaton (FSA) based on the set of inputs used in the machine's operation. The process begins with selecting the cup size, which consists of three different options indicated by symbols N, O, and P. Next, the user selects a flavor from four input choices, namely A to D, followed by topping selection with four variations, E to H. The next stage involves choosing a payment method, which provides two options, I and J. The transaction process ends with two possible final inputs: L for canceling the transaction or M, which indicates the completion of the transaction, where the ice cream is processed and dispensed from the machine.

To formally describe the machine's behavior, a transition table is designed to illustrate all possible state transitions based on the inputs received by the machine. Each input represents a stage in the ice cream ordering process, which consists of selecting the cup size, ice cream flavor, topping, and payment method. The transition design is arranged systematically to ensure that every input path can be verified for correctness through state transitions. The transitions that illustrate all possible state movements can be seen in Table 3 below.

Table 3. Ice Cream Maker Machine Transition Function

δ	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Q_0	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	Q_{15}	Q_{13}	Q_{14}
Q_1	∅	∅	∅	∅	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_2	∅	∅	∅	∅	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_3	∅	∅	∅	∅	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_4	∅	∅	∅	∅	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_5	∅	∅	∅	∅	∅	Q_6	Q_7	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_6	∅	∅	∅	∅	Q_5	∅	Q_7	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_7	∅	∅	∅	∅	Q_5	Q_6	∅	Q_8	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_8	∅	∅	∅	∅	Q_5	Q_6	Q_7	∅	Q_9	Q_{10}	∅	∅	∅	∅	∅	∅
Q_9	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	Q_{11}	∅	∅	∅	∅	∅
Q_{10}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	Q_{11}	∅	∅	∅	∅	∅
Q_{11}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	Q_0	Q_{12}	∅	∅	∅
Q_{12}	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
Q_{13}	Q_1	Q_2	Q_3	Q_4	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
Q_{14}	Q_1	Q_2	Q_3	Q_4	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
Q_{15}	Q_1	Q_2	Q_3	Q_4	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅

Table 3 presents all possible transitions from one state to another based on the selected inputs. State Q_0, as the initial state, can only accept inputs N (selecting a small cup), O (selecting a medium cup), and P (selcting a large cup), which represent the choice of ice cream cup size. This indicates that every ice cream ordering process always begins with the selection of a cup size. Furthermore, states Q_{13}, Q_{14}, and Q_{15} can only accept inputs A, B, C, and D as ice cream flavor choices. Here, there is a possible transition where the user does not choose a topping and can directly choose the payment method. Meanwhile, states Q_1, Q_2, Q_3, and $Q4$, which represent ice cream flavor states, can accept inputs E, F, G, and H as topping choices, as well as inputs representing the type of payment method. Meanwhile, states Q_5, Q_6, Q_7, or $Q8$ can accept inputs of three other topping choices, allowing buyers to choose more than one type of topping, as well as inputs I and J as cash or non-cash payment methods.

3.2. JFLAP Application

The design of the FSA using the Non-Deterministic Finite Automata (NFA) approach and its testing process was carried out using the JFLAP application. Java Formal Languages and Automata Package (JFLAP) is a software tool designed to support the learning and simulation of concepts in automata theory and formal languages (Widodo et al., 2022). Through this application, users can model automata, evaluate input strings, and visualize transition paths interactively.

In the context of the automatic ice cream machine system, JFLAP is used to design the automata that represent the entire sequence of processes from start to finish (beginning from the selection of cup size, ice cream flavor, topping variations, to the payment method and transaction confirmation). With JFLAP, each state in the ice cream-making process can be modeled in a structured manner, while the transitions between states illustrate the actions or choices made by the user. In addition, this application is also very helpful in the system logic verification process, as users can directly observe how specific inputs are processed by the designed automaton. The automata diagram of the automatic ice cream machine system can be seen in Figure 1 below.

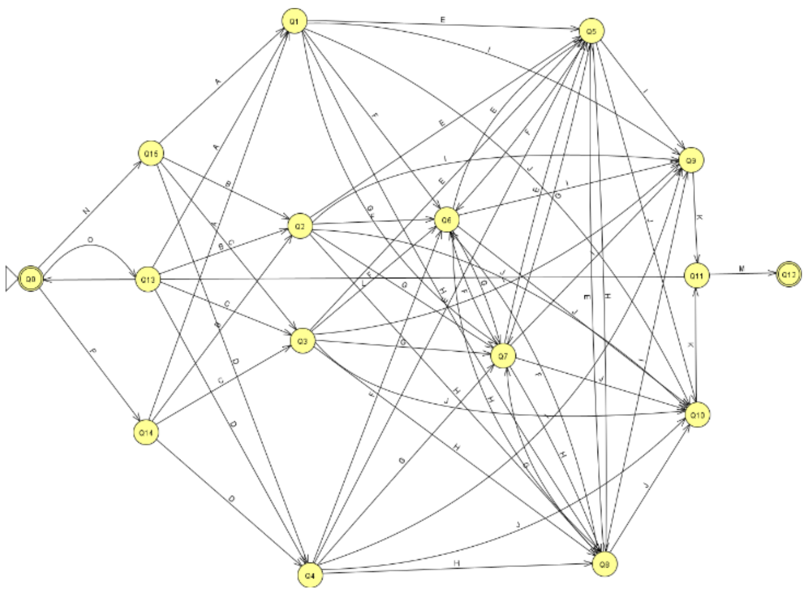

Figure 2. Automata Diagram of the Ice Cream Machine Using JFLAP

In Figure 2, the state transition diagram of the automatic ice cream machine is shown, which represents the process flow in detail. The process begins at the initial state, followed by the selection of the desired ice cream cup size, then transitions to the flavor selection state and continues to the three types of topping selections, namely not using any topping, using one topping, and selecting more than one topping. The system then branches into two payment states (cash/non-cash) before reaching the final confirmation state. In this confirmation state, if the transaction is approved, the system will print the purchase receipt and then transition to the final state with the output of the ice cream; conversely, if the transaction is canceled, the system will return to the initial state.

3.3. Validation of Machine Input and Output Paths

To verify that the automata operates as expected, a validation process is carried out by testing various input scenarios that represent real user requests. This testing aims to evaluate the transition paths from the initial state to the final state and to ensure that the system is able to accept or reject inputs according to the automata structure that has been designed. The validation is performed using the JFLAP software, which allows visualization of the input paths within the automata.

The following table shows the test results for inputs that represent variations of user choices when ordering ice cream.

Table 4. Input String Test Results

No	Order	Initial State	String Input	Final State	Result
1	Small cup, peanut flavor, sprinkles topping, cash payment, receipt issued, ice cream dispensed	Q_0	NAEIKM	Q_{12}	Accepted
2	Small cup, peanut flavor, sprinkles topping, oreo topping, cash payment, receipt issued, ice cream dispensed	Q_0	NAEFIKM	Q_{12}	Accepted
3	Small cup, chocolate flavor, e-money payment, receipt issued, ice cream dispensed	Q_0	NBJKM	Q_{12}	Accepted
4	peanut flavor, cash payment, ice cream dispensed	Q_0	AIMO	Q_{13}	Rejected
5	matcha flavor, cheese topping, receipt issued, ice cream dispensed	Q_0	CGMP	Q_{14}	Rejected
6	Medium cup, matcha flavor, cheese sauce topping, e-money payment, receipt issued, ice cream dispensed	Q_0	OCGJKM	Q_{12}	Accepted
7	Large cup, strawberry flavor, e-money payment, receipt issued	Q_0	PDJK	Q_{11}	Rejected

Table 4 shows 7 input string test cases in the ice cream ordering process, consisting of the initial state, input string, and the final state used. In this test, the results of the input strings include both rejected and accepted outcomes. The following are the results of the FSA testing using the JFLAP application based on the orders listed in Table 4.

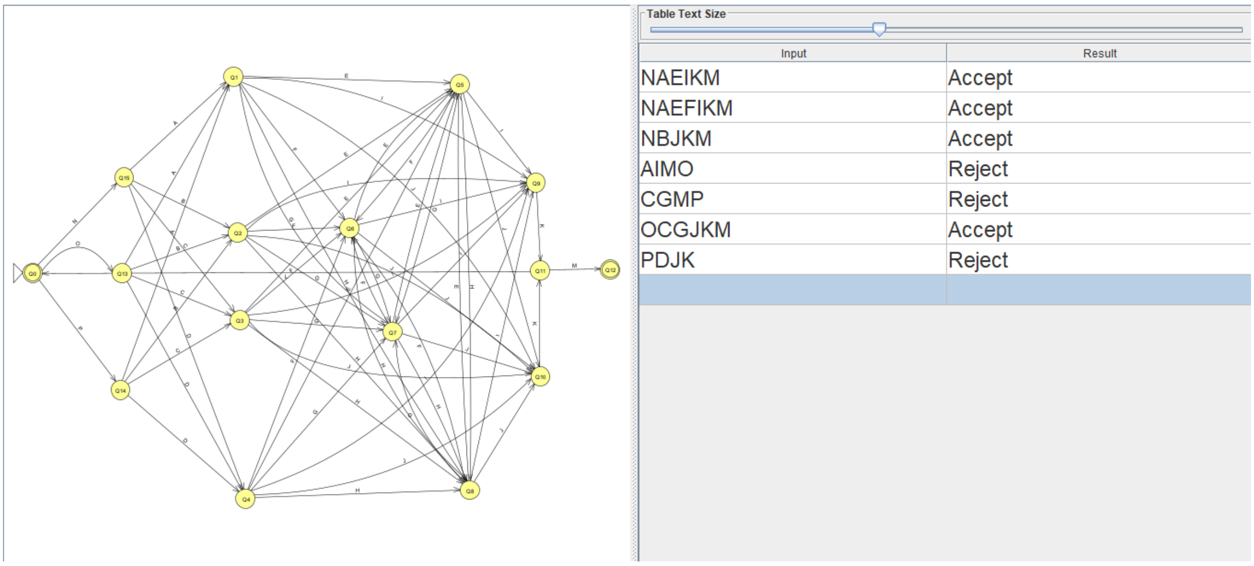

Figure 2. Testing of Ice Cream Making Machine Using JFLAP

Figure 2 shows the FSA verification process using the JFLAP application, where the order inputs from Table 4 are entered into the system. The application then automatically performs the verification by producing an output in the form of either an accepted or rejected status.

Input	Result
NAEIKM	Accept
NAEFIKM	Accept
NBJKM	Accept
AIMO	Reject
CGMP	Reject
OCGJKM	Accept
PDJK	Reject

Figure 3. Ice Cream Making Machine Test Results Using JFLAP

Figure 3 illustrates the simulation results of the input paths representing the order scenarios based on Table 4. Based on these results, the designed automata system successfully processes the input string until it reaches the final state, which is indicated by an accepted status.

4. Conclusion

Based on the research results, it can be concluded that Finite State Automata (FSA) was successfully applied in designing the working logic of an automatic ice cream machine. Model development was carried out by adding a state for selecting the size of an ice cream cup consisting of three choices, as well as designing transitions that allow users to choose no topping, choose only one topping, or choose more than one topping, so that the model that initially only included four flavor choices and four topping choices became more flexible and closer to real-world ordering conditions. Testing using JFLAP showed that the FSA design was able to accept valid input sequences and reject invalid input sequences, so that the ordering flow ran in a structured and consistent manner. However, this research is still limited to the simulation stage and has not been tested directly on an actual automatic ice cream machine. Therefore, further research is recommended to implement this model on a real machine and develop additional features, such as accepting various cash denominations and ice cream flavor combinations, so that the system becomes more complete and in accordance with user needs.

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