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Microcontroller-based 'Drop-and-Tap' Vending Machine with Stored Value System Using Radio Frequency Identification (RFID) Scanner Technology

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Abstract: **Garbage disposal is now a worldwide concern. Huge volumes of waste generated every day are disposed by means that cause adverse environmental effects. According to the UN, between now and 2025, the world population will increase by 20% to reach 8 billion inhabitants (from 6.5 today). In Basilan Province, of the estimated 3,000 tons of garbage generated daily in 2020, approximately 300 tons per day is recycled or composted. The remaining is either hauled to dump sites or dumped illegally on private lots, or irresponsibly thrown into rivers, creeks, and oceans. In order to achieve the goal of reducing pollution, recycling techniques uses the trash to cash approach. The Vending Machine will be composed of three main parts: the vending machine (1), the control center (2), and the bottle acceptor unit (3). The proponents of the study have adapted the Prototyping Methodology as guide in the development of the Vending Machine. A version of the system is developed in system prototyping to quickly check the customer's requirements and the feasibility of some design decisions. The Reverse Vending Machine was able to satisfy the objectives of the study with respect to the scope and limitations provided. The tests done confirms that the device is accurate in reading RFID accounts, distinguishing plastic bottles from other materials, adding points, and dispensing products.**

Keywords: **drop and tap vending machine, stored value system, scanner technology.**

I. INTRODUCTION

Garbage disposal is now a worldwide concern. Huge volumes of waste generated every day are disposed by means that cause adverse environmental effects. According to the UN, between now and 2025, the world population will increase by 20% to reach 8 billion inhabitants (from 6.5 today). With this increase in population, the responsibilities towards waste management also increases. Management of waste is a big challenging problem in urban areas for most of the countries throughout the world and is seen in most of the developing countries than in the developed countries. An efficient management of waste is a requirement for maintaining a clean and green environment as there is increase in all kinds of wastes thrown by many places like industrial, agricultural, home waste, etc. Waste collection and recycling is done through various technologies. The current growth in nation with large residential area and a demand for modernization in the city creates a challenging task for waste management people.

In Basilan Province, of the estimated 3,000 tons of garbage generated daily in 2020, approximately 300 tons per day is recycled or composted. The remaining is either hauled to dump sites or dumped illegally on private lots, or irresponsibly thrown into rivers, creeks, and oceans. If not, garbage is openly burnt, adding to the heavily polluted air shed. Local government units are responsible for garbage collection within their area of jurisdiction. Most hire private collection firms. Collection services are often irregular due to traffic. In squatter areas, garbage may not be collected at all, leading to illegal dumping. Mismanagement of wastes has serious environmental effects, thus the passage of the Republic Act (RA) 9003 or the Ecological Solid Waste Management Act of 2000. The effective management of wastes considers the basic elements of minimization, segregation and proper identification of wastes. RA 9003 declares the policy of the state in adopting a systematic, comprehensive, and ecological solid waste management program that ensures the protection of public health and the environment. It mandates the proper segregation, collection, transport, storage, treatment, and disposal of solid wastes through the formulation and adoption of the best environmental practices. Segregation at source should always be the responsibility of the waste-producer. Segregation should take place as close as possible to where the waste is generated and should be maintained in storage areas, even during transport. In RA 9003, Article 2 Section 21 states that the Local Government Units (LGUs) should provide for the residents a designated area and containers in which to accumulate source- segregated recyclable materials to be collected by the municipality or private center. As a result, the LGUs came up with color-coding of containers to indicate different types of wastes but the residents practically do not follow this system because either they are merely lazy to segregate, or they do not understand the intention of segregating.

We are surrounded by tons of packaging invading our everyday life. We have become used to throwing away packaging as if it were thrash. The problem is we throw away too much and disregard the potential of waste. However, with a mind shift and the help of modern recycling techniques, trash becomes a valuable source that can be put back into the cycle of consumption. Since 1991, manufacturers and retailers become responsible for the recycling of packaging they produce and sell. One challenge to recover packaging is the collection after the usage. Manufacturers and retailers are obliged to charge deposits on packaging. The deposit-refund scheme is a reconfiguration of waste collection. It involves the participation of consumers, because they are economically influenced to bring back their packaging.

The Deposit – Refund Scheme

The deposit-refund scheme involves five actors: producer, retailer, consumer, operator and recycler. The producer pays the operator for its service which includes the deposit and the services charges to collect packaging. Then, the retailer pays the same deposit to the producer. The consumer pays this deposit to the retailer. A full refund is granted to the consumer if they bring back the packaging. Otherwise, the money of the deposit will go to back to the operator. Operators' role is to collect and sell packaging to a recycler. The recycler transforms used packaging into reusable materials to create new products. The relation between the five actors is further illustrated in the figure below:

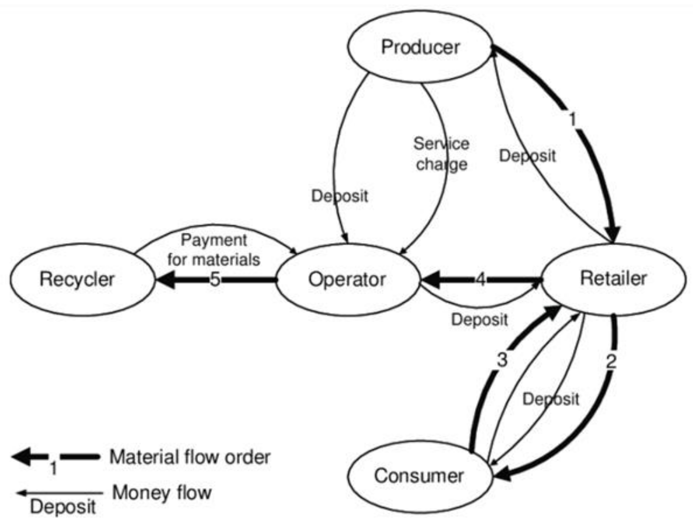

Figure 1. The simplified scheme of material and money flows of deposit-refund system

The aim of the system is to increase the level of recycling of packaging and transform trash into redeemable points. Recycling's goal is to reduce pollution. Since packaging is a main contributor to global pollution, it is important to limit its waste and avoid harmful consequences (Fishbein, 2007). Many surveys show benefits of recycling packaging to conserve energy, create jobs, lower the amount of waste, of greenhouse gases and of pollution rates (Dace & Pakere & Blumberger, 2013). Over time, the implementation of the deposit-refund scheme has increased the recycling of packaging, while the quantity of waste has decreased generating a positive environmental impact.

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In order to achieve the goal of reducing pollution, recycling techniques uses the trash to cash approach. Some examples include transforming plastic bottles/containers for water, milk and shampoo into new bottles, clothes and furniture. Plastic bottle caps are recycled into car batteries, clothes and carpets. Aluminum or steel tins and lids can be transformed back into their original material. Glass bottles are washed and used again. Additionally, Tetra Pak bricks recently became part of recyclable materials (Nkwachukwu & Chima & Ikenna, 2013).

Automation systems has many advantages over the manual systems because the use of automation systems increase efficiency, productivity and reduces the utilization of resources and operational cost. The automation systems play a vital role in the term "smart city" to make the routine life comfortable. Among all the existing application for the proper waste management can be a significant contribution in the society. Over the last few decades, a massive increase in the generation of municipal, industrial and medical solid waste has been seen. This increase has resulted in various environmental and health hazard issues specifically in developing countries like the Philippines. So, an efficient monitoring and management system for the produced solid waste is one of the primary needs especially in large urban cities like Isabela.

The researchers aim to construct a vending machine which converts plastic bottles and aluminum tin cans into credits that can be used to buy different merchandise within the vending machine. The purpose is to encourage proper waste disposal and waste segregation, and to start up a waste management system inside Basilan State College. The Vending Machine will be composed of three main parts: the vending machine (1), the control center (2), and the bottle acceptor unit (3). There are many other recyclable materials but the proposed system focuses on the plastic bottles and aluminum tin cans because they are used in everyday life and could be easily disposed of in collection points under the deposit-refund scheme.

Plastic bottles of drinks are of the pervasive plastic litter issues. Relative to drinking straws and grocery store plastic bags, plastic bottles are more space-consuming and they do not readily compact down. For every six plastic bottles bought, only one is recycled – five are thrown away to eventually end up in landfills, or the ocean. Plastic takes literally hundreds of years to decompose – poisoning the environment and the wildlife and other living organisms within. In the Philippines, Manila Bay used to be one of the most beautiful places specially to the sunset watchers. But now, it is considered one of the most polluted bays in the world due to the floating plastics aside from the sludge, human sewage, and industrial waste that regularly find their way to this body of water. Up to 100% of a PET package can be made from recycled PET, and the material can be recycled again and again to reduce the amount of waste going into landfills.

Accurate engineering and other technical data are virtually absent for existing disposal facilities and practices, and an assessment can only be prepared from brief site observations and verbal site reports. Nevertheless, Metro Manila must act immediately to improve waste disposal practices and establish sanitary landfill facilities. Until proper waste disposal is achieved, waste dumping will continue to cause serious public health, environmental, and social problems. The easiest and least expensive way to help hasten the deemed city-wide waste disposal process is to start in an establishment-, institution-, or company-based segregation.

The proposed system can increase the level of recycling of packaging and transform trash to redeemable points using the vending machine. The advantage of collection points, that take the shape of a vending machine, is to reduce the transport of waste. Instead of having garbage trucks collecting waste in front of each citizen's door, they mostly collect waste at central hubs. Since the consumer is economically and perhaps environmentally motivated to bring its waste in these hubs, garbage trucks reduce their ride frequency. Conveniently, these hubs are usually within retailers. This allows the consumer to buy and throw at the same spot.

Additionally, these collection points sort, shreds and store automatically different types of packaging. When the waste is brought by operators from collection points to the recycler, it is already in a convenient shape and size. Sorting is crucial for recycling. For example, mixing different types of plastic can lead to a new plastic with poor proprieties. Fortunately, research is done to solve the issue and evaluate the processability and compatibility of different plastic (Hon & Buhion, 2014). Nevertheless, it is useful to sort in the first place and avoid resorting to an additional resourceful step in recycling. Another advantage of the reverse-vending machine is its technology to store waste. One way to store is to shred packaging to reduce its volume. The machine has integrated shredders which can cut paper, plastic and metals. The reduced volume is necessary to store a large amount of packaging and transport it efficiently.

There are limitations to the vending machine. For example, it does not recognize every type of packaging. It is yet not possible to differentiate types of plastic. It is even harder for a machine to separate wraps of plastic that covers the entire packaging. This is problematic since the mixing of plastic leads to additional steps in the process of recycling. Another limitation is that

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plastic is made off many colors. When colors are mixed, the recycler loses the ability to decide of the color (Lavee, 2010). This is limiting the process of creation. On top of that, recycling shows limitations too. For instance, glass bottles can be washed and used again up to 50 times (Numata, 2009). Plastic bottles can be shredded and molded into new bottles up to 20 times. Nevertheless, for a sustainable transition it is more environmental-friendly to reuse a bottle, even once, than throwing it right away. It is important to acknowledge the limitations of the vending machine and recycling when we evaluate the possible expansion of the range of accepted packaging. To find potentially accepted packaging, first we need to understand the vending machine's design.

II. METHODOLOGY

The figure shows the flow of operation in the Reverse Vending machine. The process starts from the detection of an RFID card indicating that a user is trying to access the machine. Upon verification of the user, the machine will show messages through an LCD screen asking for the desired course. If the user wants to deposit bottles, the machine will be ready to take in inputs. The plastic bottles will be verified using the photo-electric sensor and capacitive sensor. If the input is rejected, the machine discards the input and continues to ask for plastic bottles until the accepting phase is terminated. After the deposition of plastic bottles, the corresponding value of the inputted plastic bottles will be added to the total value stored in the RFID card and the sum will be displayed via the LCD screen. The machine will then ask if the user would like to make purchase. If the user decides to purchase, the machine will be ready to take orders. Upon totaling the value of the ordered goods, the machine checks if the account has enough credits to pay for the order. If not, the machine will cancel the order and then again be ready to accept additional plastic bottles. If the account has enough credits, the machine will deduct the cost from the total credits stored and would output the ordered goods. The machine would then again ask if the user would like to make purchase. If not, the machine terminates operation. The user also has the option to check the number of points available in the card.

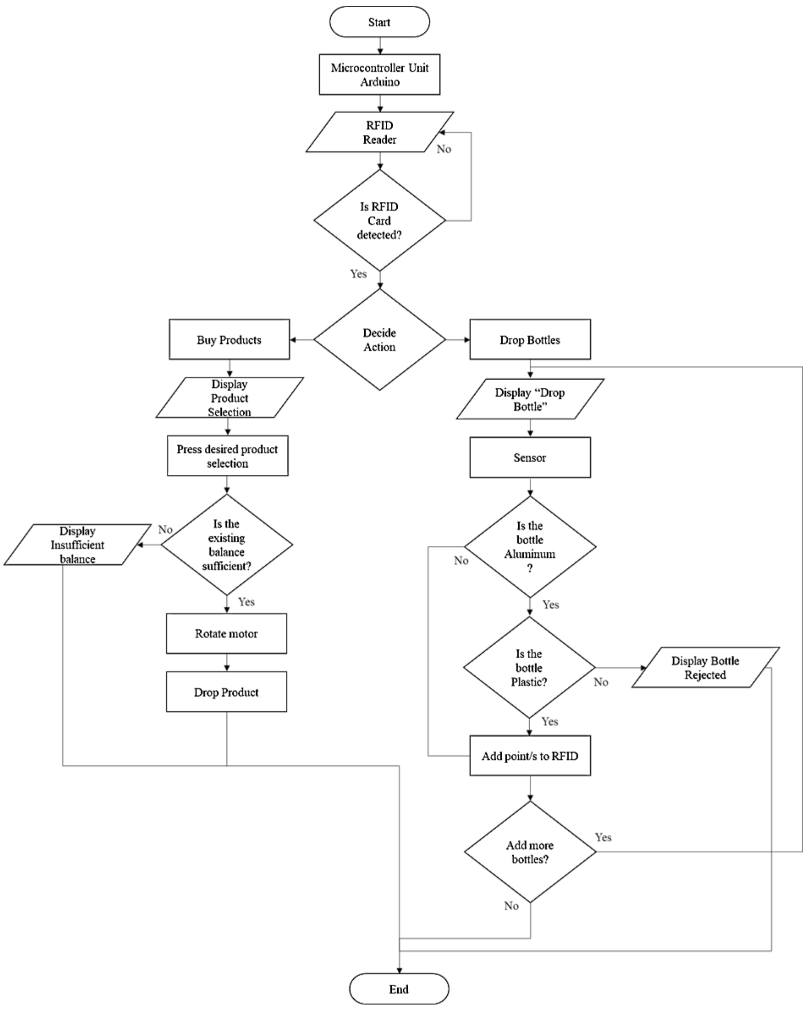

Figure 2. Flowchart diagram

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The Vending Machine will be composed of three main parts: the vending machine (1), the control center (2), and the bottle acceptor unit (3). The vending machine will have a display area (4) which will also serve as storage for the items to be sold. Products purchased will be obtained through the vending machine dispenser (5). All processes will be controlled and ordered by the control center. The control center will be containing the microcontroller unit (6) and the RFID reader (7) will be connected to it. Through a plastic bottle inlet (8), the bottle acceptor unit accepts plastic bottles and aluminum cans. Rejected plastic bottles will be returned via the bottle acceptor dispensing area (9). Inside the bottle acceptor unit, the photoelectric sensor and capacitive sensor (10) will be located near the inlet. The conveyor belt will move depending on the sensor. If the bottle inserted is rejected, the conveyor belt (11) moves down and dumps the bottle on the bottle acceptor dispenser (12). If the bottle is accepted, the conveyor belt moves up and dumps the bottle to the storage (13). An ultrasonic proximity sensor (14) will be used to detect if the storage bin is already full.

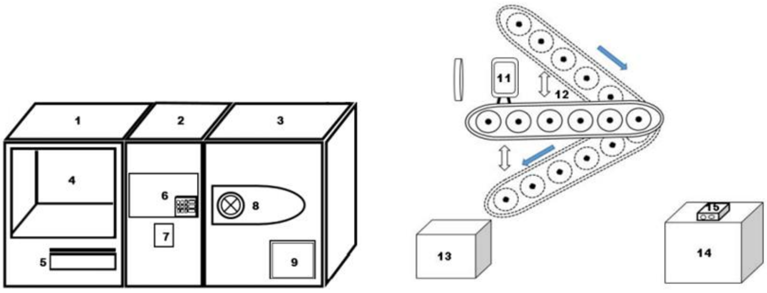

Figure 3. Project Prototype

The proponents of the study have adapted the Prototyping Methodology as guide in the development of the Vending Machine. A version of the system is developed in system prototyping to quickly check the customer's requirements and the feasibility of some design decisions.

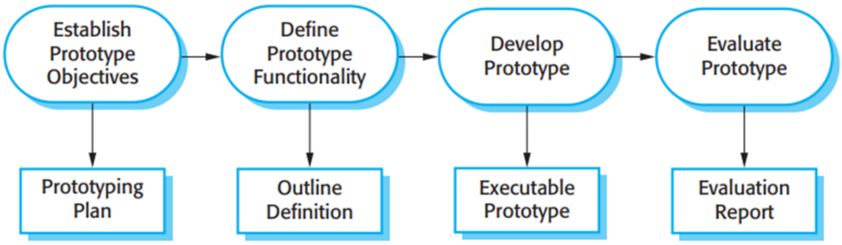

Figure 4. The process of prototype development

A prototype is an initial version of a software system that is used to demonstrate concepts, try out design options, and find out more about the problem and its possible solutions. The proponents of the study utilize the Prototyping Method to help in the elicitation and validation of system requirements and to explore particular software solutions to support user interface design. The objective of prototyping was made explicit from the start of the process which are to validate functional system requirements and to develop a system to demonstrate the feasibility.

Nonfunctional Requirements

This section describes the nonfunctional requirement of the Vending Machine.

Technical Requirements

Hardware Requirements:

- Laptop

  Processor: Intel Core i3 or higher

  RAM: 4 GB or higher

  Hard Disk Drive: 500 GB or greater

  Network: Static IP

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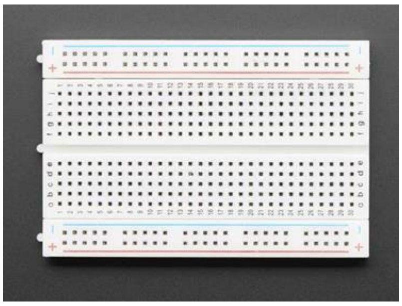
- Arduino mega

- Breadboard



- Dupont Wires

- Lm2596 dc-dc buck converter

- Servo

- Motor

Capacitive proximity sensor

- Ultra sonic sensor

RFID module

- Inductive proximity sensor

Micro SD card module

The design project is constructed by the fulfillment of certain criteria:

1. Reliability

The machine must be able to function with minimum supervision. It must be able to operate within the proposed operating hours without fail. All the components used must work properly and according to the designated task. To ensure a continuous operation of the machine, the machine will be having two power sources: commercial and solar. The solar panels with battery is deemed the ideal and preferred power source; however, in this prototype, it will be the back-up power provider only during commercial power outages. (Outside the research project's limitations, the auto-switch design can be reversed to make the renewable solar as the default power source while the commercial power source shall automatically activate only when there is no light source or when the stored power is low.)

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2. Accuracy

The machine must be able to differentiate plastic bottles from other types of materials and therefore reject the material if it is not plastic bottle. The E3ZM-B photoelectric sensor will be used as it is designed specifically for plastic bottle sensing. The adding and subtracting of points must also be accurate. Points must be added every time a deposited plastic bottle is accepted, and exact number of points must be deducted every time a purchase is made.

3. Efficiency

With the presence of a renewable energy source, the machine can be cost and energy effective as the solar panel is deemed to reduce consumable energy consumption. The charging and discharging time of the battery will be computed to determine if the solar panel will help save energy and money. The machine will be constructed using devices with low power requirements to maximize energy efficiency.

4. Response Time

The machine must be able to complete operation quickly. Transaction time must be optimum for the user. The machine must exhibit fast collection of data and execution of commands. 5. Functionality The machine must be able to function and complete process of operation without fail starting with the detection of the RFID Card up to the storage of accepted plastic bottles or dispensing of purchased items.

III. PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

Table 1 shows a 100% accuracy on RFID Card recognition. This implies that the RFID card recognition mechanism is accurate and reliable. In all trials, the mechanism recognized and matched the RFID account number. This aspect is important because if an RFID is not recognized properly, the user's intended transaction with the machine will not be possible.

TABLE 1. RFID CARD RECOGNITION TEST RESULTS

RFID Card Recognition				
RFID Card	RFID Card Account Number	Account Number Recognized by Machine	Recognized or Unrecognized	Match or Mismatch
Card 1	3402a05b	3402a05b	Recognized	Match
Card 2	a416985b	a416985b	Recognized	Match
Card 3	748ba45b	748ba45b	Recognized	Match
Card 4	34689b5b	34689b5b	Recognized	Match

TABLE 2. INPUT SENSING AND POINTS ADDING TEST RESULTS

Input Sensing and Points Adding										
Type of Input	Results									
	Accepted(✓) or Rejected(✗)					Number of Added points				
	Trial1	Trial2	Trial3	Trial4	Trial5	Trial1	Trial2	Trial3	Trial4	Trial5
1. Plastic Bottle	✓	✓	✓	✓	✓	10	10	10	10	10
a. Knight's Café Water Bottle	✓	✓	✓	✓	✓	10	10	10	10	10
b. Smart C Bottle	✓	✓	✓	✓	✓	10	10	10	10	10
c. C2 Bottle	✓	✓	✓	✓	✓	10	10	10	10	10
d. Blu Bottle	✓	✓	✓	✓	✓	10	10	10	10	10
2. Crumpled Paper	✗	✗	✗	✗	✗	0	0	0	0	0

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Table 2 shows a 100% accuracy in input sensing and points adding. This implies that the input sensing and points adding mechanism is accurate and reliable. In all trials, the machine added points to the account when bottles were detected and rejected when materials other than bottles were inserted.

TABLE 3. ITEM PURCHASING AND DISPENSING TEST RESULTS

Item Purchasing and Dispensing				
Item	Cost per Item	Points Before Purchase	Points After Purchase	Number of Items Dispensed
Item 1	10	250	240	1
Item 2	20	20	0	1
Item 3	30	490	460	1
Item 4	40	300	260	1

Table 3 shows a 100% accuracy in item purchasing and dispensing. This implies that the item purchasing, and dispensing mechanism is accurate and reliable. In all trials, the machine dispensed the intended item and the points in the card is deducted by the equivalent cost of the item purchased. This ensures that the user's purchasing intention is met and the item payment in terms of points is properly computed. Standard vending machines must have 100% reliability in this aspect.

TABLE 4. RESPONSE TIME TEST RESULTS

Trials	Time		
	Bottle Acceptance Process	Product Dispensing Process	Total Operating Time
Trial 1	12.46 sec	16.23 sec	44.18 sec
Trial 2	12.64 sec	18.23 sec	48.54 sec
Trial 3	13.54 sec	16.83 sec	54.04 sec
Trial 4	13.24 sec	17.84 sec	40.03 sec
Trial 5	13.11 sec	18.52 sec	40.09 sec
Ave. Time	12.99 sec	17.53 sec	45.38 sec

In comparison with standard vending machines, the machine demonstrates relatively the same response time. Considering a single transaction, the machine can operate in less than a minute. The machine was able to satisfy the response time set by the design criteria as shown in Table 4.

TABLE 5. BATTERY CHARGE & DISCHARGE TIME TEST RESULTS

Trials	Time	
	Charging Time	Discharge Time
Trial 1	6 hrs. 28 mins.	16 hours
Trial 2	8 hrs. 44 mins.	30 hours
Trial 3	8 hrs. 24 mins.	21 hours
Trial 4	7 hrs. 02 mins.	27 hours
Trial 5	6 hrs. 54 mins.	15 hours
Ave. Time	7.507 hours	21.8 hours

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Table 5 shows the charging and discharging time of the machine. The discharging time is affected by the frequency of machine usage. On average, the charging time does not exceed one day, and it provides a backup power sufficient for a whole day operation. The data gathered does not match the computed theoretical charging and discharging times due to uncontrollable variables such as the number of times the machine was used during testing period. Some of the devices' power consumption depends when it is on idle or currently in use.

IV. CONCLUSION

The Reverse Vending Machine was able to satisfy the objectives of the study with respect to the scope and limitations provided. The tests done confirms that the device is accurate in reading RFID accounts, distinguishing plastic bottles from other materials, adding points, and dispensing products. The machine has a response time relative to existing vending machine thus the one-minute response time limitation was met. With the addition of solar panel and battery, the device exhibits efficiency as it provides alternative power source. The machine is reliable for it can perform stand-alone operation and requires minimum supervision

V. RECOMMENDATIONS

- Design prototype that makes use of solar power as default power source for better marketability to big end- users like LGUs in the province.
- Design can be further improved with inputs from business consultants on the viability of the machine.

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