ADVANCING SUSTAINABILITY: INTRODUCING REVERSE VENDING MACHINES TO UNIVERSITY CAMPUSES

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ABSTRACT

The urban areas of Bangladesh are currently facing a pressing issue of solid waste generation and management, with an alarming daily accumulation of approximately 25,000 tons, equivalent to 170 kg per person per year. This crisis significantly contributes to environmental problems, including climate change, environmental pollution, and deforestation. One promising solution for effective plastic waste disposal is the Reverse Vending Machine (RVM). An RVM is a device designed to accept barcoded plastic bottles and offer digital cash or redeemable coupons in return. This study focuses on investigating the challenges associated with implementing eco-friendly devices like RVMs in university dormitories and campuses. For our research, we selected four university campuses, Rajshahi University of Engineering and Technology (RUET) and Rajshahi University (RU) in Rajshahi, Khulna University of Engineering and Technology (KUET) and Khulna University (KU) in Khulna. Surprisingly, despite the presence of numerous recycling bins on these campuses, they currently do not engage in any recycling activities for the waste generated. A well-organized Solid Waste Management (SWM) system can yield multiple benefits, including reduced waste disposal costs and the creation of a more sustainable environment. The primary objective of this study was to initiate the installation of RVM machines at strategic locations within these campuses, Analyze the entire supply and waste chain of PET bottle, establish incentive system, and assess the rate of waste reduction achieved through the implementation of RVMs. By introducing RVMs on campus, RUET, RU, KUET and KU can transition into more sustainable campusses, while also encouraging recycling in a convenient, incentivized manner. This approach can serve as a model for adoption in other universities as well and eventually in the national SWM system.

Keywords: *Reverse Vending Machine, Recycling Plastic, Sustainability, Solid Waste Management*

1. INTRODUCTION

Solid waste management is a trending topic worldwide. In terms of waste, the entire world is predicted to produce 3.40 billion tons of waste yearly by 2050, a significant increase from the 2.01 billion tons that are produced currently. By 2050, it is anticipated that the overall amount of waste produced in low-income nations would have increased by more than three times (Kaza et al., 2018). Currently, over half of waste is deposited in an open manner. The trajectory of waste increase will have significant effects on the environment, human health, and economic growth, necessitating immediate action. Figure 1 shows the methods of waste collection methods in South Asia.

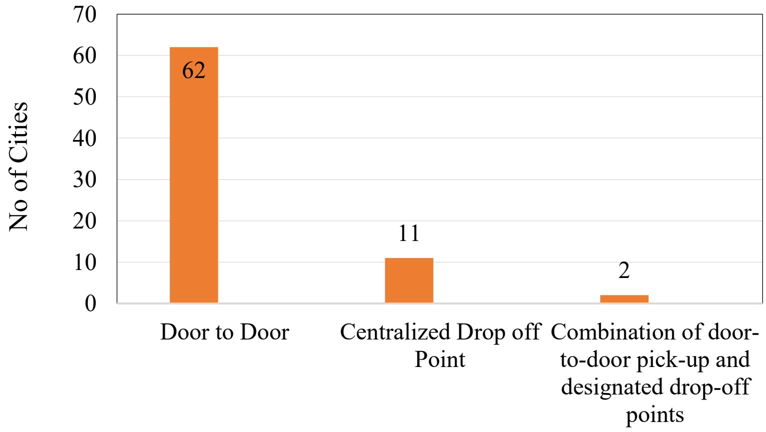

Figure 1: Waste Collection Methods in South Asia (Kaza et al.,2018)

Figure 2. shows the rate of waste collection and in that context, we can see Bangladesh is so Lagged behind. The proper waste collection chain is needed. Among all those wasted the collection of Polyethylene terephthalate (PET) is more necessary, because the PET a type of clear, strong, lightweight and 100% recyclable plastic. The separation from mixed waste is much more complex.

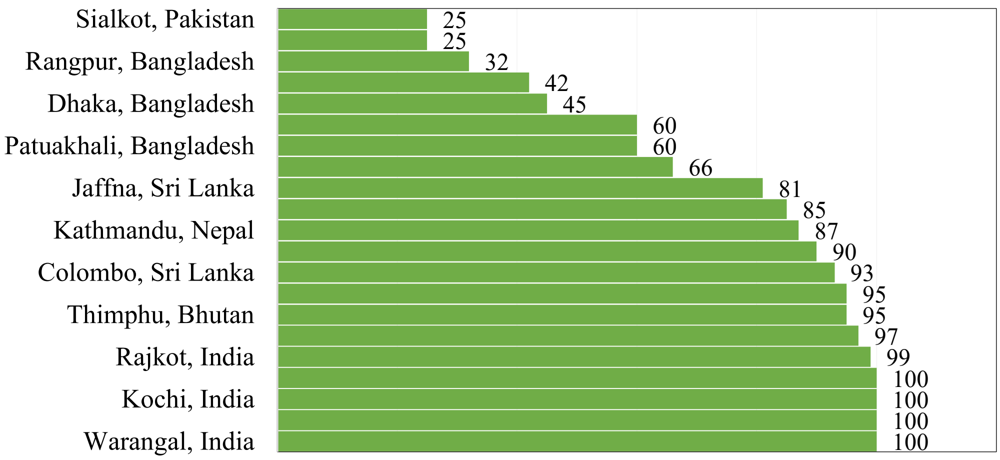

Figure 2: Waste Collection Rates of South Asian Cities (Percentage Coverage) (Kaza et al.,2018)

Before heading into solving the issue, let's have a glimpse on Plastic and plastic bottles. The invention of plastic bottles, known for being cost-effective and less risky than glass and metal containers, has driven the expansion of the beverage industry. Consequently, this growth has led to the generation of substantial amounts of plastic bottle waste. With the invention of the first polyethylene terephthalate

(PET) bottle in the late 1970s, plastic bottles became widely used. When the Ocean Conservancy organizes annual beach clean-ups in September across more than 100 countries, plastic bottles and bottle caps come in third and fourth place among the plastic waste items collected (Parker, L., 2019). The harmful outcome of improper waste disposal practices can significantly affect regular individuals through food chains. As an illustration, studies revealed that average fish consumer from Europe ingests 11,000 microplastic (plastic particles measuring less than 1 mm) annually. Entrepreneurs worldwide are repurposing bottles that would otherwise end up in the garbage to create printer ink cartridges, floors, fence posts, roofing tiles, carpets, and boats, to mention a few products. Bottles have even been used to build houses. (Parker, L., 2019).

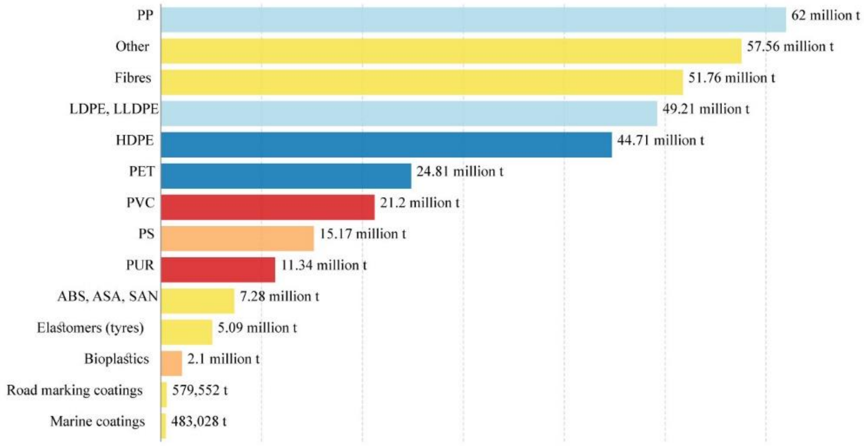

Figure 3: Global primary plastic production by polymer, 2000 to 2019 *(Global Primary Plastic Production by Polymer, 2000 to 2019, n.d.)*

recovery of plastic waste won't improve much until it is given greater value, achieved through an additional cost of the product says Mark Murray, executive director of Californians Against Waste. The most expensive part of waste management is frequently collecting and transporting rubbish, but there is a lot of technology available to boost productivity. Reducing production and consumption of plastic as well as improving waste management practices to stop leaks and contamination are just a few strategies to reduce plastic waste. In order to implement these changes, a wide range of societal stakeholders must get involved, including individuals, governments, corporations, community organizations, and manufacturers. *(Kaza et al.,2018).*

In that context incorporating Reverse vending machines (RVM) is a good hope. Reverse Vending Machine is a medium for incentivizing people who collect plastic bottle waste. Figure 4. shows a typical RVM below. Several countries have attempted to implement Reverse Vending Machines to manage plastic waste. Norway is now the global leader in the battle against plastic waste. According to *(Nurfikri & Martono, 2023),* Residents can return plastic for recycling at more than 12,000 reception stations and around 3700 reverse vending machines across the nation. *(Norway's Successful Plastic and Metal Recycling System, 2018).* Japan partnered with the company to provide Reverse Vending Machines *(Nurfikri & Martono, 2023)*. In India, reverse vending machines were first launched in 2016, however the absence of a thorough incentive structure has prevented them from being widely accepted. Consequently, those individuals who understand the significance of recycling are more likely to utilize these machines. On the other hand, Russia implemented Reverse Vending Machines in 2019, incorporating a unique approach by offering discounts for every beverage purchase through these machines. In Finland, a tax policy is in place for beverage manufacturers employing plastic bottles, with the government willing to reduce taxes for active participation in recycling. Due to a high level of public awareness, Finland doesn't rely on an incentive system. In Germany, the government collaborates with supermarkets that sell beverages to collect plastic bottles from their products *(Amantayeva et al., 2021).*

Meanwhile, in Bangladesh, there is a relatively low public awareness, with growing interest in using Reverse Vending Machines at urban level. But due to a high-level import cost for a single RVM, this dream is not getting the light of reality. Government of Peoples republic Bangladesh has taken some step towards Smart Bangladesh. In that context, Smart Rajshahi will be a pilot project among them. To meet this, our team from Rajshahi University of Engineering and Technology (RUET) and Khulna University (KU) is focusing on MADE IN BANGLADESH – RVMs and build our own prototype with a proper supply channel for Solid Waste Management (SWM).

Figure 4: Typical RVMs (*Stand Alone Machines - RVM Systems*, n.d.)

We will call it ProCritic-RVM in next discussions. We are also committed to creatin public education, strategically placing machines in easily accessible locations, and offering incentives such as discounts, bonuses, and card top-up balances.

2. METHODOLOGY

We are aiming to understand the feasibility of integration of RVMs into the waste management system particularly stating from university campuses of Bangladesh. We believe the university students are the most responsible persons representing the next generation. Initially we, shortlisted four universities in two major cities of Bangladesh; Rajshahi and Khulna City Corporation. Khulna University (KU), Khulna University of Engineering & Technology (KUET), Rajshahi University (RU) and Rajshahi University of Engineering and Technology (RUET). This paper studies the feasibility of incorporating RVMs and discuss further about the features and functions of RUET made RVM. For a successful implementation of the system, we have divided the study into two compartments. In the first half, we will conduct a feasibility analysis of the RVM depending on survey data Showing Functional Flow Block Diagram (FFBD) and Risk Analysis. Then in the second compartment we will elaborate our proposed ProCritic-RVM based on the feasibility analysis of previous half introducing features. Figure 4. shows the regular recycle path and shorter recycle path after implementing RVM into the system.

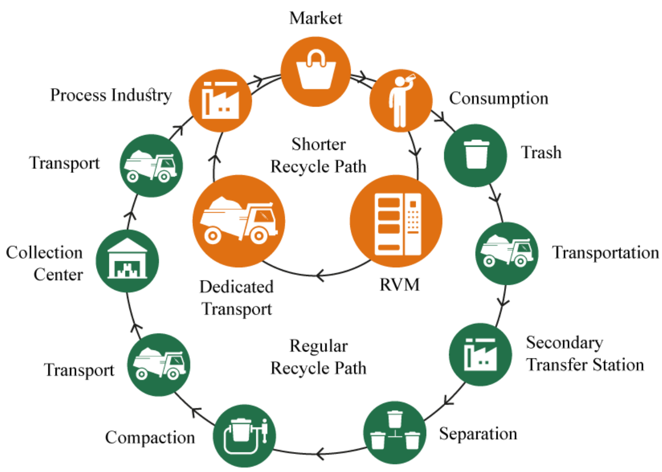

Figure 5: The Regular recycling path versus ProCritic-RVM based shorter recycle path

2.1 SURVEY

Before heading into solving the problem, a good market survey is required. To achieve this objective, we developed the survey questionnaire using Google Forms, a widely used platform. The google form link was distributed among students at KU, KUET, RU, and RUET through email and various social media platforms. The survey included eight general questions covering individual identity, age, gender, the weekly consumption of beverage bottles, recycling habits, types of incentives preference, location preferences, and opinions on Reverse Vending Machines (RVMs). A total of 307, 310, 270, and 343 responses were collected from KU, KUET, RU, and RUET, respectively in 7 days. The minimal necessary sample size was calculated by taking into account criteria such as the population size, confidence interval, error margin, and standard deviation. With an error margin of 6% and a confidence interval of 96%, the population size was defined as the total number of residential and non-residential students and staff at the university. Table 1 illustrates the population figures for the selected universities. This calculation was based on the equation (1) provided by (Noordzij et al., 2010).

$$S_s = \frac{Z^2 p(p-1)}{c^2} \quad (1)$$

Where, S_s= Size of the sample, Z = The confidence level's Z-score is 2.33, and p is the decision probability, which is 50%. and c = Margin of error (5%)

$$Corrected\ S_s = \frac{S_s \times S_p}{S_p + S_s - 1} \quad (2)$$

Where, S_s= Size of the sample and S_p = Size of the population

Table 1: Size of the sample estimation for shortlisted campuses

Campus	Students	Staffs	Total Population	Ss	Corrected Ss
KU	9,710	1044	10754	235.25	230.24
KUET	5,682	877	6559	235.25	227.14
RU	38,291	4058	42349	235.25	233.96
RUET	6,484	867	7351	235.25	227.99

This turns out that the survey data we collected via Google forms, i.e., of 307, 310, 270, and 343 responses were sufficient for a decent analysis. From the survey data further analysis were conducted.

2.2 FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)

The Functional Flow Block Diagram (FFBD) is a graphical representation that depicts the functional relationships among system components in a structured manner (Eames et al., 2010). It employs blocks to represent major functions, and arrows to illustrate the flow of information or materials between these functions. This visual tool is commonly used in systems engineering to enhance understanding of complex processes and facilitate effective communication among project stakeholders. FFBDs are one of the classic business processes modelling methodologies, along with data flow diagrams, flow charts, Gantt charts, control flow diagrams, PERT diagrams and IDEF. In this scenario, the diagram will help us explaining the Application and Hardware activities of ProCritic RVM in brief.

2.3 RISK ANALYSIS

During the developmental and operational phases of a Reverse Vending Machine (RVM), diverse risks may emerge, presenting potential impediments to the machine or system's optimal functionality. To mitigate these risks, a paramount necessity is the implementation of a rigorous and comprehensive risk analysis. Within the framework of incorporating the RVM into the waste management system, a methodologically sound risk analysis approach was adopted. This approach entailed the systematic identification of potential risks, followed by the formulation of a robust mitigation and contingency measures. This systematic analysis is imperative for ensuring the uninterrupted and efficient operation of the integrated system. It serves as a proactive strategy to anticipate and address challenges, thereby enhancing the overall resilience of the RVM within the waste management infrastructure.

2.5 PROCRITIC RVM PROPOSAL

The ProCritic RVM Proposal is grounded in meticulous survey data and rigorous analysis, providing a comprehensive blueprint for the deployment of our Reverse Vending Machine (RVM). We are proposing our RVM based on the insights garnered from extensive surveys, capturing user preferences, technological expectations, and environmental considerations. Through a methodical analysis of this data, we have tailored the ProCritic RVM to align with public requirements, addressing identified pain points and optimizing user experience. The proposal outlines key features such as weatherproof design, anti-theft technology, ample storage capacity, built-in crusher for efficient size allocation, optical scanning and sorting capabilities, and a user-friendly interface. The incentive structure and robust supply chain further enhance the viability of our proposed RVM. This proposal reflects a strategic integration of empirical data and innovative solutions, positioning the ProCritic RVM as an advanced and user-centric contribution to sustainable waste management.

3. RESULTS AND DISCUSSION

3.1 SURVEY

The survey findings, as depicted in Figure 3, reveal distinct preferences among students at Rajshahi University (RU), where a notable inclination toward in-app credits is observed. Conversely, at Khulna University (KU), students express a preference for Discounted tokens, ranking second in popularity. Notably, the primary choice for both Khulna University and Rajshahi University of Engineering and Technology (RUET) respondents is Donation. Although requests for Donation or tree plantation are comparatively lower, their prevalence is noteworthy.

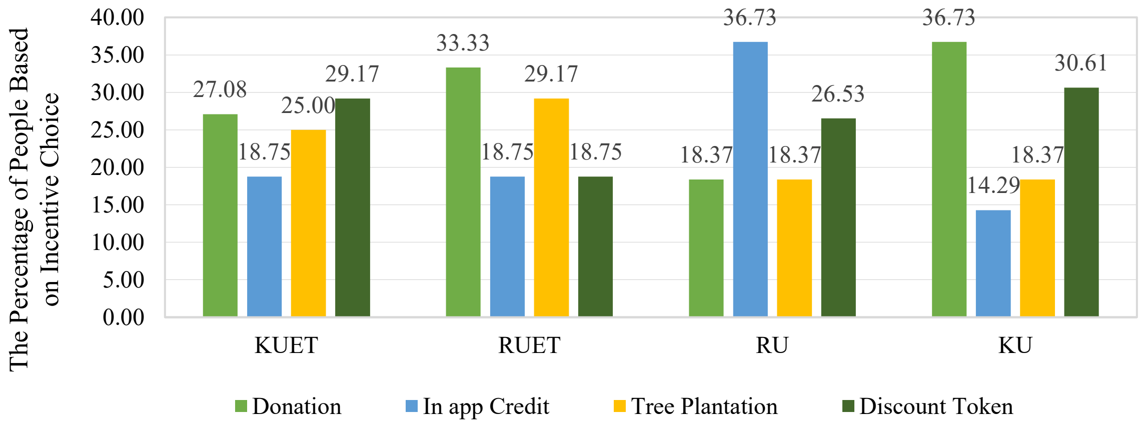

Figure 6: Incentive choice comparison in shortlisted campuses (random sampled 50)

Examining Figure 7, which represents a random sample of 50 people, it becomes evident that Rajshahi University generates approximately 323 bottles per week, underscoring the substantial volume of bottles produced. The survey specifically targeted individuals aged between 18-30, a demographic characterized by heightened consumption of beverage bottles at this life stage.

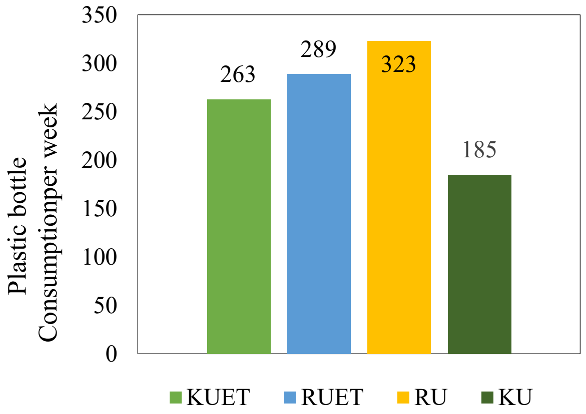

Figure 7: Plastic Bottle Consumption per Week in Shortlisted Campuses (Random Sampled 50)

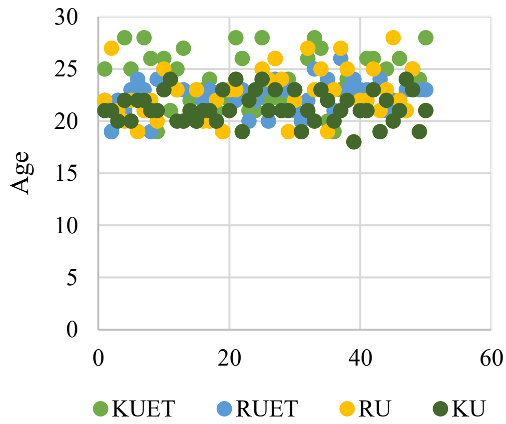

Figure 8: Age band of the people participated in the survey

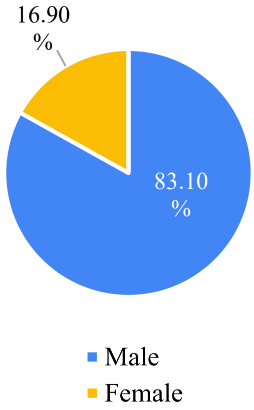

Figure 9: Plastic Bottle Consumption per Week in Shortlisted Campuses (Random Sampled 50)

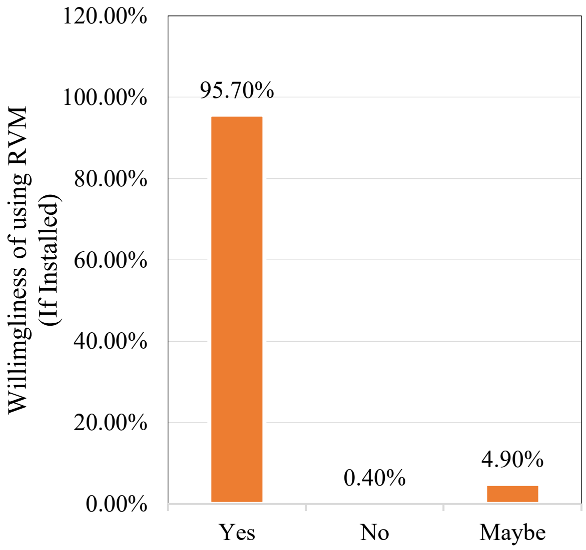

Figure 10: Plastic Bottle Consumption per Week in Shortlisted Campuses (Random Sampled 50)

3.2 FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)

The Functional Flow Block Diagram (FFBD) constitutes a hierarchical and temporally sequenced flow depiction illustrating the systematic progression of a system's functional activities. Originating in the 1950s through the efforts of TRW Incorporated, a defense-oriented enterprise, the modern FFBD provides a structured representation of tasks derived from functional decomposition, presenting them in a coherent, chronological order (Eames et al., 2010). In this study, we employed the FFBD methodology to elucidate the comprehensive operational framework of the ProCritic Reverse Vending Machine (RVM). The top level delineated fundamental procedural steps, while the subsequent Second level (A, B, C, and D) explicated intricate sub-steps, encompassing processes such as plastic sorting, conditional acceptance of bottles, user identification, and incentive selection. This approach facilitates a detailed and systematic comprehension of the ProCritic RVM's operational intricacies.

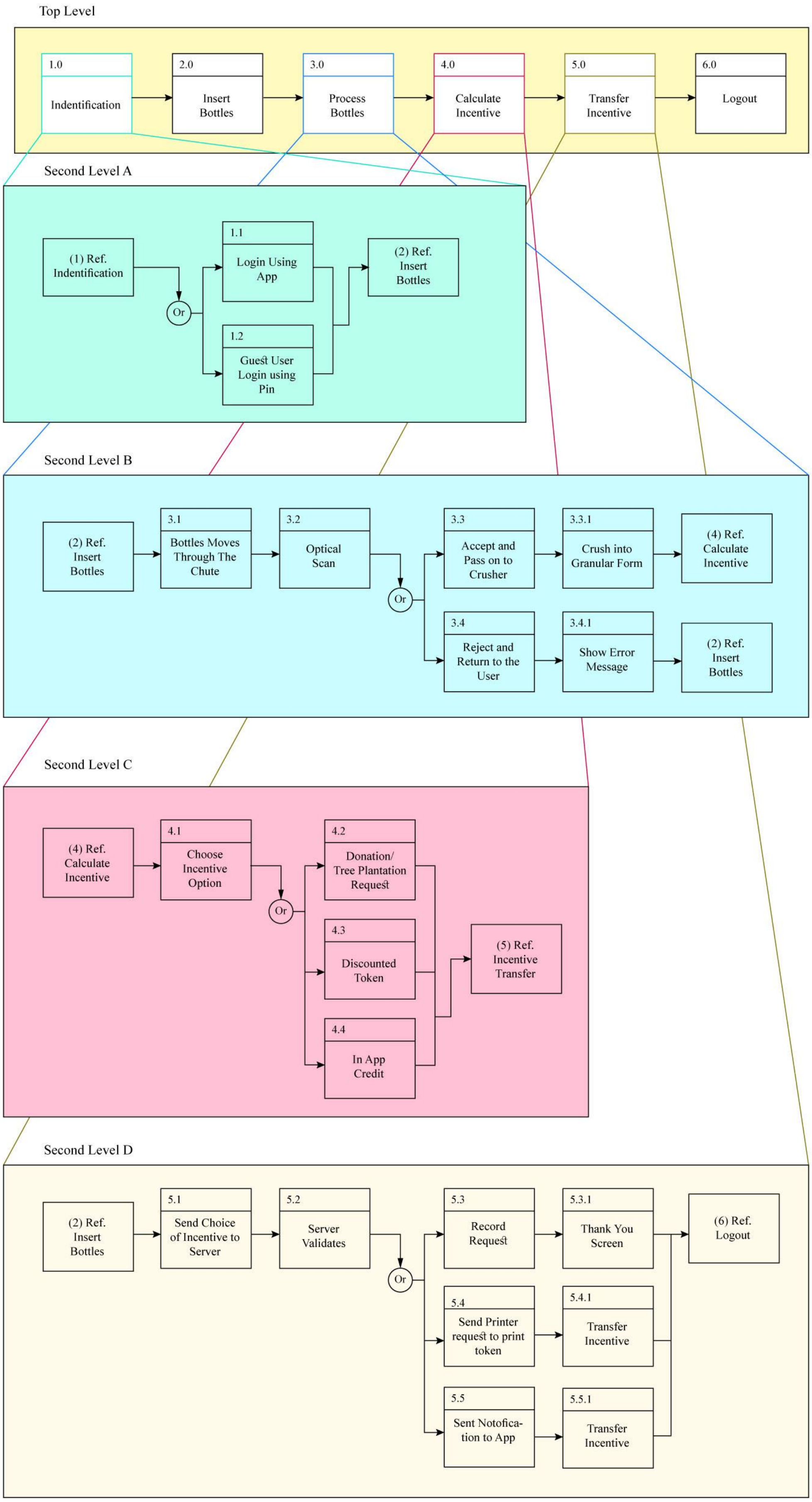

Figure 11: Functional Flow Block Diagram (FFBD)

3.4 RISK ANALYSIS

Effective risk management involves proactively identifying potential risks, conducting comprehensive assessments of their impact and likelihood, and developing adaptive plans that can be adjusted as circumstances evolve. Clear communication about identified risks and their mitigation strategies are crucial for maintaining transparency and stakeholder awareness. Implementation of well-thought-out risk mitigation strategies demonstrates a commitment to minimizing potential negative outcomes, while continuous monitoring ensures that risk management remains a dynamic and responsive process.

Table 2. Risk Analysis and Mitigation Techniques

Risk	Mitigation
Poor cleanliness near an RVM	Weekly Cleansing of Machines
The unwillingness of people to go to an RVM	Promotion of RVM via print media or social media platform
The unwillingness of users to download the mobile app	Offer Guest mode for non app user
Safety issue of the machine	Make the machine attached to ground with bolts with proper safety
Prototype-making may take too long	Collaborate with industries and R&D institutes
Competitors	Develop more reliable Machines and increase incentives
All aged People using RVM	Make the Machine User Friendly
Technical Issues with the Mobile App	Regularly update and test the mobile app for compatibility
Negative Publicity from Competitors	Monitor industry trends and address competitor concerns
User participation increment	Develop user-friendly manuals on the RVM in easy language
Weather-Related Challenges	Design RVM installations to withstand various weather conditions
Supply Chain Disruptions	Diversify suppliers and maintain open communication
Waste Sorting Challenges	Incorporate advanced sorting technologies in RVMs
User Feedback Management	Implement a user feedback system for opinions and suggestions
Stakeholder Collaboration:	Foster collaboration with local businesses, waste management authorities, and environmental organizations

3.5 PROCRITIC-RVM

Figure 12. depicts a three-dimensional representation of the ProCritic Proposed Reverse Vending Machine (RVM), taking into consideration the feasibility and comprehensive studies detailed in the preceding chapter. The design of this RVM aligns with public requirements, addressing potential risks. Noteworthy features include weatherproof construction, antitheft technology, substantial storage capacity, an inbuilt crusher for optimal size allocation, optical scanning and sorting capabilities, and user-friendly functions. Moreover, the RVM provides various incentives and is supported by a robust supply chain, ensuring an efficient and high-quality PET collection system.

Figures 13 and 14 showcase an illustration of the token printing facility, accompanied by a guest user pin input system. The design notably incorporates two separate chutes designated for the segregation of white and colored bottles.

Figure 12: ProCritic RVM 3D Representation

Additionally, an illumination feature is integrated into the hood to facilitate night operation. The structural design is engineered to withstand both rainwater and sunlight, ensuring durability and operational resilience in varying environmental conditions.

Figure 13: ProCritic RVM with separate input holes for coloured and white bottles

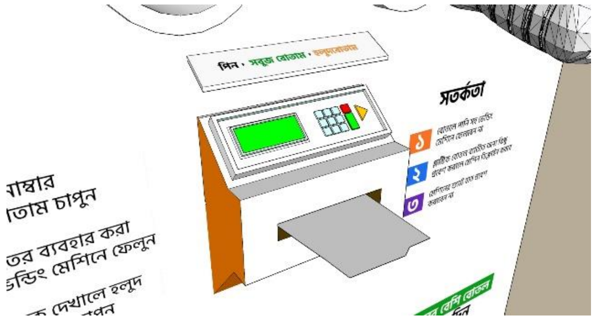

Figure 14: ProCritic RVM Token Printing Facilities

4. CONCLUSION

In conclusion, the feasibility study conducted on the integration of Reverse Vending Machines (RVMs) into the University campuses in Bangladesh i.e., representing all developing countries has revealed promising insights and recommendations. The survey results emphasize the potential user's positive inclination towards utilizing RVMs, contingent upon strategic considerations. Education campaigns through extensive advertising, mobile applications, and informative billboards are pivotal to fostering public engagement. Optimal placement of RVMs near residential halls and internal shops in campus is crucial for maximizing public involvement. Aligning with identified customer and functional requirements, as reflected in the Functional Flow Block Diagram (FFBD), and the risk analysis, holds the potential to enhance the current waste management system and contribute to the circular economy of the country. This, in turn, supports national targets of waste reduction and increased public awareness about recycling practices, thereby motivating positive lifestyle changes.

Moving forward, the prototype development for RVMs in RUET by Team ProCritic will serve as a crucial step in advancing sustainability. Successful experiments in Rajshahi and Khulna should prompt the extension of surveys to other busy cities like Dhaka and Chittagong for a comprehensive understanding of localized needs. Benchmarking against global experiences and in-depth cost analyses for mass manufacturing should be pursued as the next steps.

Point-wise outcome aligning with the objectives we have set before -

1. Positive User Inclination: Survey results show users are positively inclined towards RVMs, subject to strategic considerations.
2. Educational Campaigns: Comprehensive campaigns via advertising, mobile apps, and billboards are pivotal for fostering public engagement.
3. Optimal Placement: Strategic placement of RVMs near residential halls and internal shops maximizes public involvement.
4. Alignment with Requirements: Adherence to customer and functional requirements, as seen in the FFBD and risk analysis, enhances the waste management system.
5. Contribution to Circular Economy: RVM integration supports the circular economy, aiding national waste reduction goals and raising recycling awareness.
6. Prototype Development: The RUET Team ProCritic's RVM prototype is a crucial step in advancing sustainability.
7. Expansion to Other Cities: Successful experiments in Rajshahi and Khulna prompt surveys in other busy cities for a comprehensive understanding of localized needs.

Acknowledging the study's limitations, including the focus on four varsities only on a singular waste type (plastic), and the exclusion of the entire waste supply chain, future research endeavours should broaden the scope by incorporating Aluminium cans, glass etc too. Integration of Industry 4.0 technologies with the proposed RVMs presents an avenue for exploration to further enhance efficiency and sustainability. In summary, the study provides a foundational framework for the implementation of RVMs in Bangladesh, underscoring the need for continuous research, stakeholder collaboration, and adaptation to evolving technological landscapes in solid waste management.

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