Research Article

Concept Development of Compact Automatic Filling Machine (CAFM)

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Abstract
Activities of daily life are effective with increased involvement and excitement. Manufacturers, especially who are concerned about health-related products, offers and keep improving their products with extreme convenience function and innovative design to meet customer's requirements satisfaction. An average amount of water intake of people has increased in the recent years and thus, rising consumption of bottled water. This key factor drives the bottled water packaging market globally. A home water treatment unit is even though the popular choice for investing and saving money, people are highly concern on wastage, especially spilling water during the filling process. A Compact Automatic Filling Machine (CAFM) proposed in this research study, allows automatic bottling to fulfil the basic need of drinking water with concern to speed. In addition, the paper proposed a novel idea of filling instead of the general approach of filling one by one. The proposed innovative filling approach provides better and easy interfacing panel with multi-filling platform. It can be installed in various large-scale consumer service providers including canteen, school and Small and Medium-sized Enterprises (SMEs) to introduce refilling for selling bottles. Further, high-income earners and elders who require assistance can also use it as it requires minimum time and human-labour involvement. Refilling of bottles not only saves the cost of buying a new packaged drinking water but also reduces the number of disposable plastic water bottles consumption.

Keywords: Product development, Engineering design, Conceptual design, Needs, Bottling machine

1 Introduction

Creating and launching a new product to the competitive market while satisfying customer's requirement are laborious without analyzing, and understanding the factors that influence a customer's decision [1]–[2]. A characteristics of the customer varies in terms of age, gender, education, income, knowledge, and attitudes towards health-related issues (perception).

If the product or service is impressive, it can promotes with no requirement for advertisements. The initial phase recommended for a designer includes classifying appropriate needs and identifying target group. Currently, the health-related products have been introduced as the vital items for enhancing the quality of life. The users have been requiring product characteristics and safety measures as main concerns. Many factors that are related to product characteristics have been reported to have an effect on visual search performance. However, improving quality of life involves action not only by researching, but also by testing. The user expects or feels bias on the product recommended by the reliable resources. The concept of product design development (PDD) has been applied for assisting the manufacturers and designers to quickly achieve their targets as shown in Figure 1 [3]. The first stage of PDD is concept development (CD). This stage consists of many activities that involve creating, adding, testing, modifying, and refining physical characteristics of a new product

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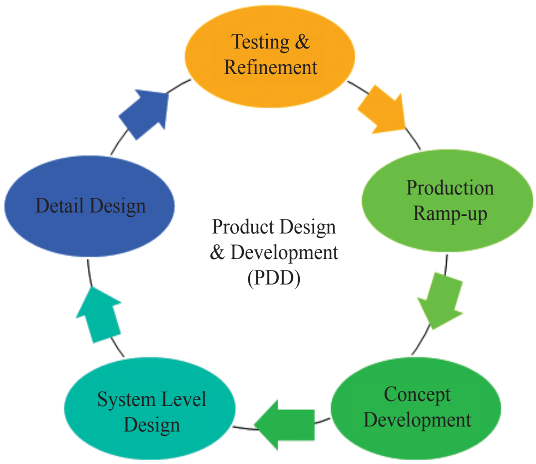


Figure 1: Product design and development diagram.

item to satisfy customer needs or support current and upcoming market trends. After obtaining the core product idea, the second stage of PDD called *system level design* is performed where the designers and engineers develop the product architecture in detail, and manufacturers determine which components should be made or purchased, and identify the necessary suppliers. The product architecture identifies the product in chunks or organizes the product features into groups of primary functional system and subsystem. Then, *detail design* stage starts to generate the virtual model from the classified groups obtained from the previous stage. When a prototype is required for functional test or checking physical characteristics, rapid prototyping/manufacturing technologies can be applied.

Nowadays, the people tend to consume more water to meet the daily requirements and get the health benefits, since the water is the most important substance for human body; it helps maintaining the balance of body fluids [4]. In 2010, 37.8% of Thai people drank bottled water. The average amount of water people drink has increased by 24.25% (reported in 2014) [4]. Since 2013, the quality of self-service drink water vending machine has been reduced; only 33% are passed the standard level researched by Thai health promotion foundation (ThaiHealth) [5]. Moreover, the rising consumption of bottled water is one of the key factors driving the bottled water packaging market globally; bottled water has led that growth, with consumption nearly doubling to 21 gallon water containers a year [6].

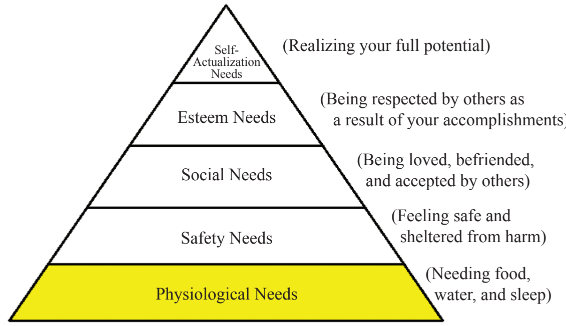


Figure 2: Maslow's Hierarchy of need.

2 Research Background

2.1 *Stimulus-response theory*

Customer buying decision is occurred initially from "stimulus" which refers to inspiration that causes a physiological response (e.g., feeling or action such as generating the need to buy the product). This stimulus can be divided into two types which are inside and outside stimulus [7], [8]. Basically, designers, manufacturers, and marketing researchers focus on outside stimulus since it can increase a customer motivation. The consequence of stimulation is transferred to customer's black box which refers to the unpredictable box that contains customer expressions and comments on a product.

At first, a designer does not know exactly how customers think of the filling machines. Therefore, it is the task of a designer to seek for customer's aspects, which can be influenced from many factors such as cultural, social, personal, and psychological factor, on a product [9]–[12]. The Maslow's Hierarchy of need can help to classify the needs into five levels [13].

The bottled water can be counted as one of the physiological needs (as shown in Figure 2 at the highlighted area) since this developed machine relates directly to the drinking water which can be filled into a container automatically. Next, the self-administered questionnaires about the customer's perceptions and the influences of filling machine were raised and distributed to the people who live in the Bangkok metropolitan region. Finally, the "responses" of customer were revealed and translated to be a design where four issues had been taken into considerations: product's quality, price, brand personality, and social trend.

2.2 *Consumer's attitude and perception towards packaged drinking water and bottle refill machine*

Before starting to design an automatic filling machine, the researchers have tried to reveal the basic requirements and hidden needs from the questionnaires. Recently, tap water (i.e., water supplied to a tap or valve) has been played as the important and safe water resources for drinking, washing or cooking. The area of interest for distributing the questionnaires is Bangkok metropolitan region. The revealed requirements are applied further for creating the prototype of automatic filling machine. The questions are raised and focused on how the people (the target customers) think about their own tap water that it is safe and fit to drink, and if it is not, what they do for solving the problems. The results obtained from the questionnaires are presented in Tables 1 to 4. Types of bottle applied for filling water are listed in Table 2.

Question 1*: How do you manage and buy drinking water?*
Question 2*: Which types of the bottle are used for filling water?*
Question 3*: What are the reasons of spillage?*
Question 4*: Will you purchase the automatic filling machine with minimum human labour even if it is expensive?*

Table 1 presents the results of *Question 1* where the lifestyle of the people who live in the metropolitan areas were asked and revealed. The popular places for buying the bottled or drinking water and the way to manage or supply the drinking water have been studied and analyzed in this section. The answers were divided into 3 groups. For the first group, it was about *"buying a bottle or a gallon water container from the supermarkets"* which was approximately 34.55%. The second group was *"using a gallon water container delivery service for home"* which was about 9.75%. The third group was around 55.30% for *"using the strainer machine or water purification system"*.

From the results, the hidden issues can be translated that the people decide to use the strainer machine or water purification system because it can produce the drinking water by their own in the household, and this choice spends shorter time comparing to another groups. For the people who live in the limited areas (a room that has a vertical dimension as well as a horizontal one such as dormitory, condominium or apartment is expressed as short term or vacation period), they do not want to purchase the strainer machine or water purification system because of the living conditions.

The alternative purchasing bottled water or drinking water packaged in plastic or glass water bottles from the convenience stores or supermarkets is selected; however, this purchasing way increases the amount of plastic wastes. For home bottled water delivery service, this requires human labour for loading and unloading a large heavy gallon water container and the water is always spilled out. The appointment schedule for delivery is the main issue.

Table 1: How to manage and buy drinking water

How	Percentage of Response
Buying drinking water packaged in plastic or glass water bottles from the convenience stores or supermarkets	34.55%
Using a gallon water container delivery service for your home	9.75%
Using the strainer machine or water purification system	55.30%

Presented in Table 2 are the results from *Question 2* where the types of bottle being filled are shown. The size of bottle/container is presented as the volume (e.g., 300, 750, or 1000 mL). Most of the people prefer to consume and purchase the *"Packaged plastic bottle"* which could be varied into 4 main sizes; 750, 1000, 1500, and 6000 mL.

The indirect benefits obtained from this bottle type present as consuming fresh and new bottle, selling empty bottle for recycling or reusing purpose. The most interesting size which might be applied in the proposed approach is 1000 mL since it presents about 36.93% (the maximum amount) of the bottle types bought from the customers. Comparing to the refilled bottles, the users need to clean bottle before refilling, and the time spent for filling activity; even it is short, have the direct effect on fatigue and inconsistent messages of feelings and attitudes when many refilled bottles are applied. From these results, the researchers have tried to apply the obtained information to create the first prototype which can fill the water in different levels.

Table 2: Types of drinking bottle from the questionnaires

Type	Volume (mL)	Picture	Percentage of Response
Packaged Plastic Bottle (Commercial Type)	750		15.28%
	1000		36.93%
	1500		20.83%
	6000		2.75%
Empty Bottle (Refilled Type)	300		4.84%
	1000		2.75%
	1300		4.85%
	1700		10.42%
Others (Glass Type)	600		1.36%

Presented in the Table 3 are the results from *Question 3* where the reason of spillage, 57.97% of the spillage, came from the overflow problem since waiting to fill the water (a few minutes) might cause the fatigue and feelings of boredom/emptiness. The second reason presented on misalignment of bottle position (28.18%); especially the narrow-mouth bottle, it was quite difficult to adjust the center of the mouth to align with the head of filling valve. The third reason (12.23%) was about transporting bottle from the filling area immediately to the storage location without the bottle cap. These answers were analyzed and concluded that, recently, a home water treatment unit has been very popular choice for the urban families since they experienced some kind of contaminated materials that

Figure 3: Bottled water dispenser [14].

might become with the water flowing from the taps; the tap water fails. Using the water treatment unit can help them to reduce cost for purchasing the packaged drinking water. However, the price for a home water treatment unit is depended upon the mechanisms and processes required for purifying water. For public communities, the vending self-service refilled-water machines are available around the living places; however, those machines cannot be guaranteed as the optimum hygienic process and consumer safety.

Table 3: The reason of spillage

Cause	Percentage of Response
Overflow Spillage	57.97%
Bottle Filling Position	28.18%
Transport Spillage	12.23%

Whereas the people who stay in condominiums, apartments or dormitories prefer to purchase the convenient packaged drinking water even the prices are much more expensive since they feel comfortable drinking water from the popular providers who always maintain the highest standards of production and quality. Moreover, cleaning the used bottles is not required as in the refilling process. In order to integrate the benefits from both in-house water treatment filling unit and packaged drinking water, a bottled water dispenser (Figure 3) has been introduced as an affordable way to delight saving cost. This equipment requires delivery or self-pick-up of water in large bottle from vendor.

Table 4: Decision for buying the automatic filling machine

Decision	Percentage of Response
Yes	72.22%
No	27.78%

However, filling water to an empty bottle one by one causes fatigue from the redundant activity and water may be spilled all over surrounding areas. Times and efforts for waiting and maintaining the bottle in position are required for a whole filling process. In order to improve filling water activity without overfilling, spilling and misaligning bottle in place, the design and function of an automatic filling machine with fixed loading platform will be focused.

3 Conceptual and System Level Design

The specifications of the developed filling machine have been emphasized on the functions of an easy access platform. The architecture of product (from system-level design stage) is applied for creating the detail design where the specific characteristics of acceptable/unacceptable containers being placed into the rotary platform, and the geometric shapes of the machine's components are assigned and created as the prototype for unit testing. The purpose of unit testing is to check that an individual part is working properly as expected. The obtained results have led to the fundamental concepts for designing the specifications of the first machine which is called *Compact Automatic Filling Machine (CAFM)* as shown in Figure 4.

3.1 *Conceptual design*

Machine embodies the following themes:

Design: The developed machine should be easily assembled by a customer at home where the concept of bottled water dispenser and automatic filling machine in industry will be applied. Actually, there is no standard for bottles, but there are common bottle sizes. Drinking water is available in many bottle sizes: 250, 500, 600, 750, 1000, and 1500 mL. The most popular bottle size for the family is 1500 mL. Therefore, size, shape and dimensions of 1500 mL bottle are applied to design the rotary platform for the first model of automatic filling machine. This concept and functions of this first prototype were used as the guidelines for the next model that the model no.2-compact automatic filling machine (CAFM).

Once the customers start using the proposed machine, they can load/unload a bottle or tank of the water easily. Command buttons (appearing in a user interface) can allow a customer to trigger an action quickly on LED buttons. The rotary platform provides 4 slots with 1500 mL bottle size, for this initial developed version. For an opaque bottle, the light does not pass directly through the materials, it cannot be applied in this machine since the sensor cannot detect the water inside the bottle.

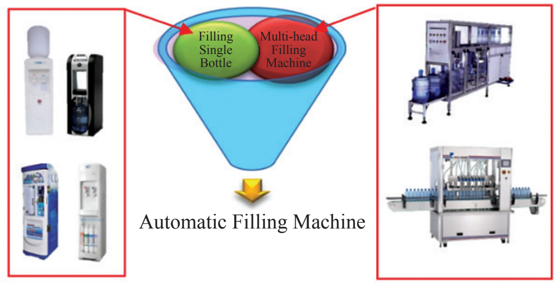


Figure 4: Compact Automatic Filling Machine (CAFM).

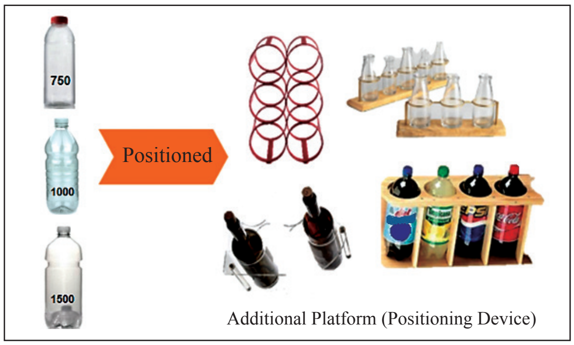


Figure 5: Additional platform for position cylinder bottle.

Function: Customers can understand and interact with the content within a few minutes. On each filling activity, the platform of CAFM provides the rotation of 90°-counter clockwise with a valve attached on the top section. Platform (positioning device) should support shape of cylinder bottle (Figure 5). The total number of bottles that can be filled is four. Level sensor is applied for checking the level of the water inside the tank and the water filled from the valve.

Protection: Hard-sided stainless steel housing is formed and applied for protecting the body of the machine from external impaction while repositioning or using. Inside the housing, the room is designed to be perfectly fitted to the rotary platform, and four flexible rubber rings are inserted around four circular slots for supporting and fixing the bottles in location.

3.2 *System level design*

The main components of the CAFM can be classified into 3 groups; *"keyboard"*, *"power supply"* and *"controlling system"*. The area of most concern is filling activity where the water can be filled and stopped at the right time and a bottle is placed correctly; the components of *"keyboard"*, and *"controlling system"* groups are focused and taken into considerations. The descriptions of all components are presented in Tables 5–7.

Table 5: Components of keyboard

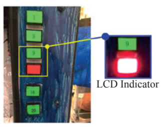
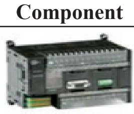
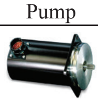
Keyboard	
Picture	**Description**
 LED Indicator	**LED indicator** It is used to alert the user when water level is below minimum level.

Table 6: Power supply

Power supply	
Picture	**Description**
 Power supply	**Power supply** It is used to control the amount of power input for the system.

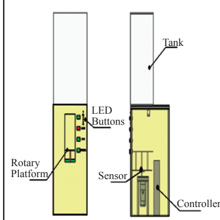
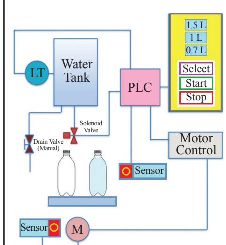
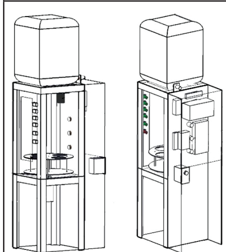
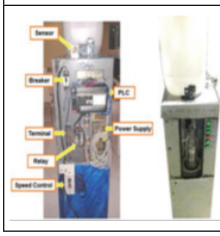
Table 7: Components of controlling system

Controlling system	
Component	**Description**
 Programmable Logic Controller (PLC)	**Programmable Logic Controller** It is used to control the automatic system with intelligence by controlling appropriate sensor, valve, pump and motor.
 Capacitive sensor	**Capacitive sensor** It is used to detect the level of the water.
 Solenoid valve	**Solenoid valve** It is used to control the water Flowrate of water.
 Pump	**Pump** It is used to provide constant flow rate output
 AC Motor	**AC motor** It is used to rotate the platform where an empty bottle can be positioned and aligned.

4 Detail Design

Presented in Table 8 is the detailed design of the proposed approach where 4 main steps are required.

Table 8: Details design of the automatic filling machine

Illustration	Description
	**Main requirements**: Designing of an automatic filling machine that consist of, 1. Filling system: Automatic mode with different volume levels. 2. Changing position of a bottle: Automatic mode 3. Providing the storage tank on the top of the machine: Based on available dimensions of bottles in the market.
	**Functional design**: Design the automatic system that works with controlling application that consists of, 1. Water Tank 2. Keyboard with LED indicator 3. Solenoid Valve 4. AC pump 5. Capacitive sensor 6. Motor 7. Motor control 8. Rotary table
	**Drafted Final design**: Design the overall layouts of the automatic filling machine where the 8 main components (from the "Functional design") are positioned in the appropriate location inside the drafted final model.
	**Final design**: Construct the final prototype of the automatic filling machine and test.

Step 1: All main requirements and automatic conditions, such as filling system with different level or changing bottle system, are considered and added to the functional design characteristic.

Step 2: After listing all requirements, the internal system which can support all components and functions

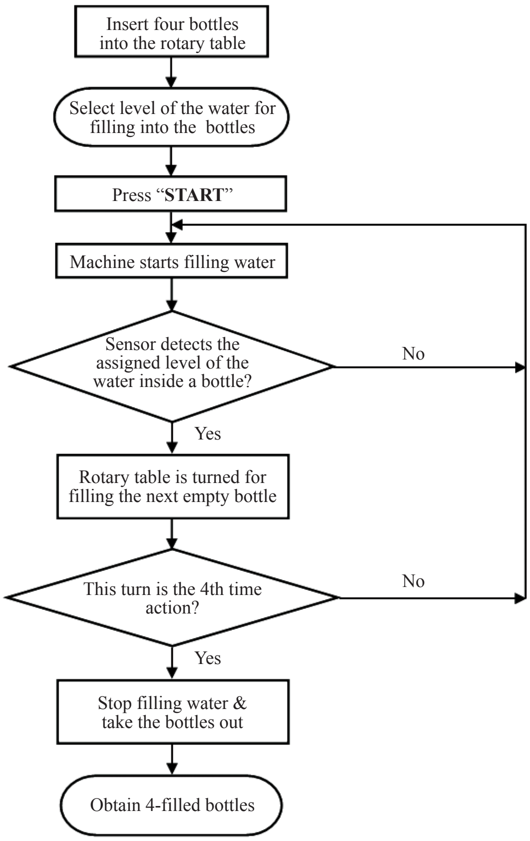


Figure 6: The overall steps required for applying the Compact Automatic Filling Machine (CAFM).

are designed. The system includes water tank positioning level, keyboard with LED indicator, solenoid valve, AC pump, motor, motor control, and rotary table.

Step 3: After designing the internal system, the external design of the machine is generated.

Step 4: The final draft design is constructed (the first prototype).

Illustrated in Figure 6 are the overall steps required for applying the automatic filling machine.

5 Results and Discussion

The plastic tank is applied to storage water for filling into the bottle where the level of the water can be checked quickly by a capacitive sensor. The user can adjust the amount of the water filled into the bottle easily by pressing the button. The rotary table can support the automatic filling activity where 4 empty bottles can be filled in sequence without human labour required. AC motor receives the commands from the ladder diagram of PLC application. This rotary table works with *4 capacitive sensors; 3 sensors* for measuring level of water inside the bottle, and *1 sensor* for measuring the level of the water inside the tank. The timer is not applied in this machine for controlling the volume of the water inside the containers. First prototype is shown in Figure 7.

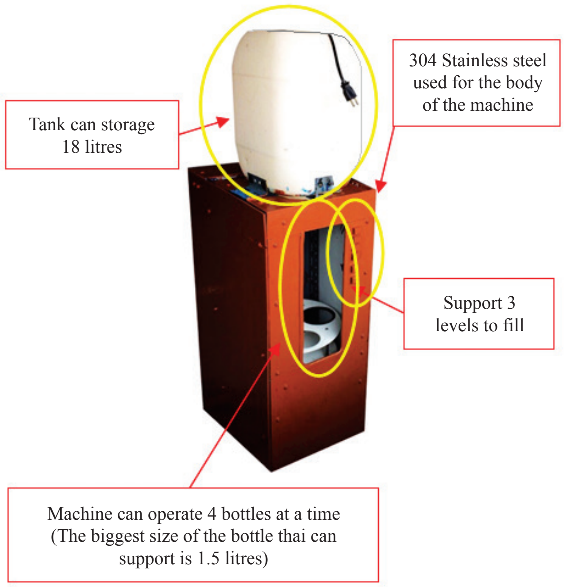


Figure 7: The first prototype.

When the unstable flow of the water from the tank (failure of valve employed in reciprocating pump) is transferred to the narrow-mouth bottle, this causes the built-in turbulence of the water inside the bottle where the water splashes from the bottles while the machine is still running.

The material used for creating the body of the machine is 304-stainless steel. The weight of the entire body of this machine is quite high; manpower is required for positioning the machine in place. These may have a direct impact on the performance of the machine where the relationship between the optimal time spent on filling water from the storage tank to the desired level of the empty bottle and the real-time filling volume are very difficult to define and analyze. Using the capacitive sensors can help the machine to automatically close or stop functioning by itself when the failure is occurred.

However, during filling process, the small vibration due to water turbulence inside the bottle may cause an error response since the level-sensor detection cannot perform correctly. Another technique for controlling the status of the valve in filling process should be considered.

The working processes with pictures for operating the first model of the proposed machine are shown in Table 9.

Table 9: Working processes

Picture	Description
	**Step 1**: Load the first bottle into the platform of the rotary table.
	**Step 2**: Press "***Turn***" button to rotate the platform in clockwise direction for positioning the new empty bottle. (Keep doing this activity until 4 empty bottles are located)
	**Step 3**: Check the number of empty bottle whether or not all 4 slots on the platform are filled, then press "***Turn***" button again to select the level of the water (*700 mL, 1000 mL, and 1500 mL*)
	**Step 4**: Press "***Start***" button to operate the machine
	**Step 5**: The machine is now filling the water to the empty bottle.
	**Step 6**: Sensors detect the level of the water inside the first bottle, the valve stop filling the water to the full bottle, and then the next platform is turn to the next slot. (*Keep doing this activities until obtaining 4-full bottles*)
	**Step 7**: Machine stops filling the water and then the "***Turn***" button shows the tight again for indicating the "***Finish***" stage. Remove *4- full bottles* out of platform.

6 Testing and Analysing on the First Prototype

Three main issues; *flow rate*, *error test on "Start/Stop" mode*, *and Failure Rate*, are considered and analysed for checking the conditions of this first prototype.

6.1 *Flow rate test*

The flow rate test had been conducted to determine the time spent on filling process of 700, 1000, and 1500 mL fill volumes by using 3 filling systems: *purification system*, *bottled water dispenser*, *and the proposed machine*. The testing results are shown in Table 10.

Table 10: The results of flow rate test

Volume	Purification System 	Bottled Water Dispenser 	Automatic Filling Machine 
700 mL	28 s	17 s	**10 s**
1000 mL	41 s	24 s	**14 s**
1500 mL	62 s	35 s	**21 s**

6.2 *Error test on "Start/Stop" mode*

The water flow rate on "Start/Stop" mode was considered in this section. The errors were indirectly proportional to the quantity of volume. This conclusion could refer to the previous failure rate mathematical model. The pump played as the major role in the flow failure rate, since the flow rate was very inconsistence during the start and stop modes of each filling. To analyze the Start/Stop error of each volume size, filling water from one bottle to another about 10 times were observed.

Notice that, before starting 1500 mL filling process, 4 small trays were positioned underneath the 1500 mL bottles (4 bottles) on the rotary platform for supporting the "overflow" situation that made the amount of water might exceed the capacity of the bottle. The results (the amount of water inside the bottle after filling process) are shown in Table 11.

For 700 and 1500 mL filling processes, the majority problem found was shown through "overflow" events.

The researchers had made a list of the most common parts that caused the valve to not stop filling with water, and recorded the obtained list as the historical data for the next improvement. Whereas, for 1000 mL filling process, the main problem was that the water could not meet the desired amount at the end of the process.

Table 11: The results of filling test

Volume (mL)	System				Error (%)
	Expected Vol.		Actual Vol.		
	Result	Mean	Result	Mean	
700	700	700	703	724.1	3.443
	700		700		
	700		688		
	700		684		
	700		712		
	700		722		
	700		765		
	700		754		
	700		741		
	700		772		
1000	1000	1000	1007	976.7	2.33
	1000		971		
	1000		975		
	1000		932		
	1000		997		
	1000		941		
	1000		950		
	1000		985		
	1000		1008		
	1000		1001		
1500	1500	1500	1509	1533.7	2.247
	1500		1497		
	1500		1495		
	1500		1555		
	1500		1579		
	1500		1563		
	1500		1553		
	1500		1561		
	1500		1491		
	1500		1534		

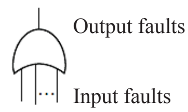
6.3 *Failure rate*

Illustrated in Figure 8 is the *FTA* that was constructed to define the reliability in the simplest way for the viewer to understand with crucial information on it, such as the reliability on every end events. In general, *FTA* converts the complicated system into a simple logical diagram.

The method helps the user understand what the programmer wants to show in simple form, in this case the reliability. It presents the model visually on what and how the equipment fails, the events are linked by gates, AND and OR gates which identify how each or both failure cause the top event to fail.

Each gates have their own formula to calculate the reliability. The probabilities of the occurrence of the output fault events of logic gates (OR and AND) are given [15] as shown in Equations (1) and (2) below

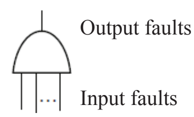
OR gate



$$P\ (E_0) = 1 - \prod_{i=1}^{n} \{1 - P(E_i)\} \tag{1}$$

where:
$P(E_0)$ is the probability of occurrence of the OR gate output fault event, E_0
n is the number of independent input fault events
$P(E_i)$ is the probability of occurrence of input fault event E_i for $i = 1, 2, 3, \ldots, n$.

AND gate



$$P\ (Y_0) = \prod_{i=1}^{n} P(Y_i) \tag{2}$$

where
$P(Y_0)$ is the probability of occurrence of the AND gate output fault event, Y_0
$P(Y_i)$ is the probability of occurrence of input fault event Y_i for $I = 1, 2, 3, \ldots, n$.

Recently, this machine had been introduced as a new design for filling water to the bottle automatically; there were no historical records or data of the failure events. The mathematical models and parameter considerations were mostly based on three major failure events and how they linked to the machine's components by applying AND/OR gates.

The reliability of this first system had been considered and identified for an 8-hour mission per day. FTA was created by hands-on practical activities. Each session involved non-stopping machine usage at its full capacity. For the failure of the top event ("Failure of the proposed machine"), OR gate was applied for representing the sensitive case; if any one of the three major functions: Volume selection (mentioned in Exterior failure), Constant water flow rate (mentioned in Flow failure), and Water level detection (mentioned in Spillage failure) is performed incorrectly, the machine fails. This filling machine was expected to work with full capacity of 100%, and the experiments had been conducted for 2 months to check about filling and positioning functions.

Three cases of the subsystem analysis were presented in the next paragraph. For each consideration, it starts with a "top level" event which represents as a failure. The researchers keep trying to figure out what lower-level faults or failures could cause a problem. The activities have been run repeatedly until the root causes are identified. The undesired consequence is considered as the root of a tree of logic.

Case I: Poor planning & control

For poor planning & control , selecting the amount of water for filling is considered as the main issue. Three scales of filling volume are 700, 1000, and 1500 mL. Each of these quantities is considered when the "Volume Button" is pressed, and LED light representing the signal that passes through the controller is energized. Then the filling head delivers the desired amount of liquid into the empty bottle one by one. If the error is found during this selection or filling activity, the valve will not open for releasing water even though the pump is energized.

For the filling conditions, "Inserting 700 mL bottle" has only 1 choice for sending volume signal which is 700 mL; whereas "Inserting 1000 mL" has 2 choices of commands which are filling 1000 mL and 700 mL of water. For 1500 mL filling process, it has 3 choices for sending signal of 1500 mL, 1000 mL or 700 mL operations. Both events, "Insert bottle 1000 mL" and "Insert Bottle 1500 mL", have OR gate to calculate the reliability of the filling system.

The obtained analysis can help the designer to redesign and improve some components of the first prototype to be more robust. Moreover, forecasting the filling situation by using these recorded data may prevent the future failure event.

Case II: Water connot be filled

The key reference of this analysis is the time spent on filling water into the bottle with different sizes. To identify the filling time of each volume size, filling water from one bottle to another about 30 times are observed where the known bottle size is filled by filling head of the developed machine. The average filling duration is applied as the reference value for checking flow failure. Moreover, the operational state of Pump and Valve are considered as these following conditions:

- *Pump*: Water should be released from the filling head with the constant flow rate (i.e., if it fails, the flow rate will fluctuate and cause volume error), and the time spent on filling activity is around the reference value. However, when the time is varied or differentiate from the reference one, the pump indicates a malfunction (i.e., the state of something that functions wrongly or does not function at all).
- *Valve*: The valve is controlled by sensor detection and PLC to open and close. For closing operation, there is no water coming from the water supply pipe; user could not find any leaks. Whereas the opening valve lets the water release out fluently to the container.

In this case, AND gate is applied for finding the reliability of Pump and Valve. The error (i.e., the deviation between the expected and the actual results of each volume quantity is compared) is recorded by consecutive filling for 10 times to find the average value. From the spreadsheet, it shows that 700 mL filling process has the most error comparing to the 1000 and 1500 mL ones.

Case III: Overflow spillage

Two events; Motor and Sensor, are analysed by AND gate. Motor should provide a constant rotational speed for the rotary platform; otherwise, the water spills may occur during filling. For the sensor, it is used to detect and check the level of the water inside the bottle. If the water has not been reached the set point yet, the valve keeps releasing the water continuously. If the sensor cannot perform well, the water will be filled excessively. The rotation speed is counted as one of the main issues in the spillage failure analysis; if it is run too fast, the sensor cannot detect the object's position. This malfunction leads to the creation of open-and-close failure of the valve.

After constructing the FTA diagram, the mathematical models were applied to calculate the reliability for each item of the subsystem. For this case, Corrective Maintenance (CM) was performed as the maintenance that involves the failure events where Mean Time To Repair (MTTR), Mean Time To Failure (MTTF) and Mean Time Between Failures (MTBF)

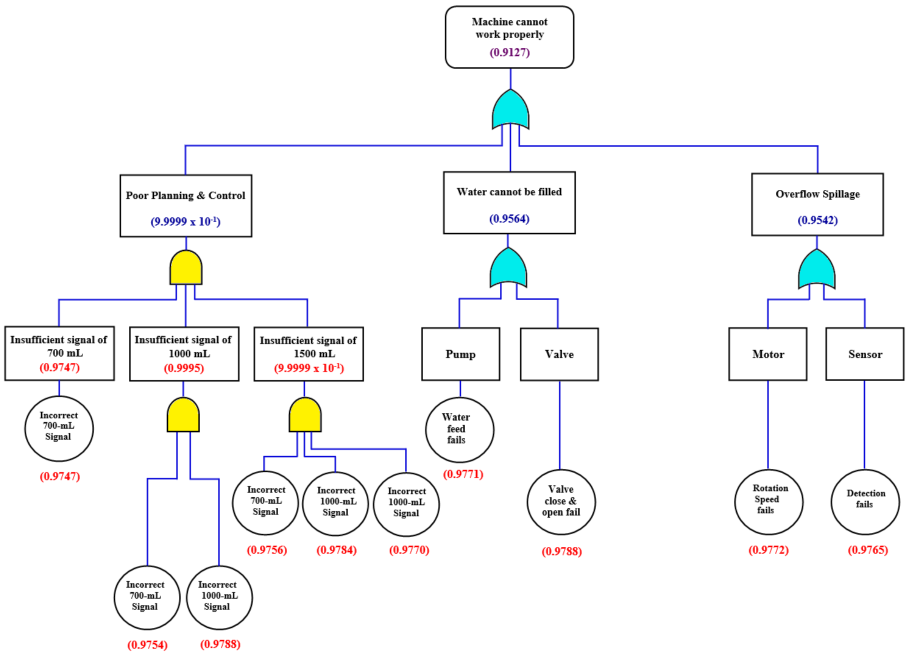


Figure 8: Fault tree with specific and calculated fault event occurrence probability values.

were considered as the important factors for analysing and identifying failure of the machine. The calculation results of *"Poor planning & control "*, *"Water connot filled "*, and *"Overflow spillage"* were presented in Tables 12 and 13. The failure rates of 3 failure types (from 3 subsystems) were summarized in Table 14. The FTA with specified and calculated fault event occurrence probability values were shown in Figure 8.

Table 12: The calculation result of "Poor controlling and Control" and "Probability of occurrence of events"

Poor Controlling and Control					
Size of Bottle	**Incorrect 700 mL Signal**				
	MTBF (Hour)	**MTTF (Hour)**	**MTTR (Hour)**	**Failure Rate (Failure/Hour)**	**Reliability**
Bottle 700 mL	500	391	109	0.002558	0.9747
Bottle 1000 mL	-	-	-	-	
Bottle 1500 mL	-	-	-	-	
				0.002558	
Size of Bottle	**Incorrect 1000 mL Signal**				
	MTBF (Hour)	**MTTF (Hour)**	**MTTR (Hour)**	**Failure Rate (Failure/Hour)**	**Reliability**
Bottle 700 mL	500	401	99	0.002494	0.9754
Bottle 1000 mL	500	466	34	0.002146	0.9788
Bottle 1500 mL	-	-	-	-	
				0.00464	
Size of Bottle	**Incorrect 1500 mL Signal**				
	MTBF (Hour)	**MTTF (Hour)**	**MTTR (Hour)**	**Failure Rate (Failure/Hour)**	**Reliability**
Bottle 700 mL	500	405	95	0.002469	0.9756
Bottle 1000 mL	500	459	41	0.002179	0.9784
Bottle 1500 mL	500	429	71	0.002331	0.9770
				0.006979	

Table 13: MTBF, MTTF, MTTR, Failure rate and reliability of 4 items: pump, valve, motor , and sensor

Item		MTBF (Hour)	MTTF (Hour)	MTTR (Hour)	Failure Rate (Failure/Hour)	Reliability
Water connot be filled	Pump	500	432	68	0.002315	0.9771
	Valve	500	467	33	0.002141	0.9788
Overflow Spillage	Motor	500	433	67	0.002309	0.9772
	Sensor	500	421	78	0.002375	0.9765

Table 14: Summary of reliability of 3 events

Types	Failure Rate (Failure/Hour)
Poor Planning and Control	9.9999×10^{-1}
Water cannot be filled	0.9564
Overflow Spillage	0.9542

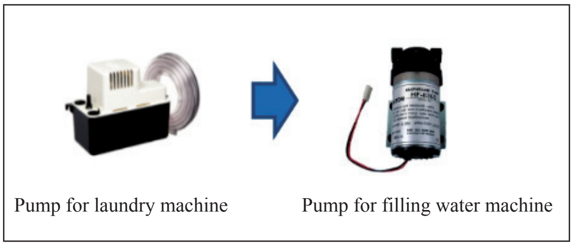


Figure 9: The change of water resource.

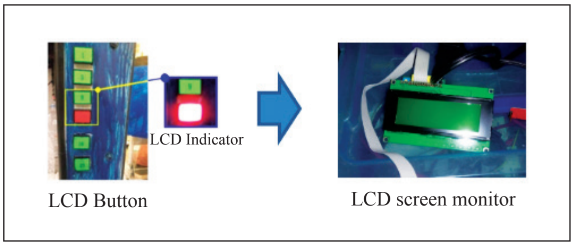


Figure 10: The change of user interface.

7 The Second Design

The purposes to make the second prototype are eliminating the errors from the first prototype, and improving the efficiency and functions. There are five main components developed.

- Water feeding device
- User Interface
- Protection – Body
- Water resources
- Controller

7.1 *Water resources*

From the first prototype, the water flow was expected to be high enough for filling the water into the empty bottle with a short period of time; the pump for laundry machine was applied for demonstrating the proposed technique. However, it presented some errors during feeding water, the turbulent flow was the main issue and this pump produced loud noise during the operation. The current location of the pump was fixed and was difficult to read just because of the geometric shape of the pump. Replacing this pump to be the specific type which is suitable for filling machine is introduced. Using the alternative pump can help the system to stop filling on time as shown in Figure 9.

7.2 *User interface*

After obtaining some comments from the users (for the first prototype), some users said that the machine was too hard to use and they would not enjoy working with complicated equipment. Using digital LCD screen with quick and easy access to all functions should be constructed for the second model (Figure 10).

7.3 *Protection of the machine's body*

From the first prototype, the stainless steel was applied as the protection of the body (i.e., machine frame and housing); however, it caused the machine too much weight. Moving this prototype from one place to another requires around 2–3 men for carrying it. Therefore, the stainless steel was changed to be the acrylic plate (Figure 11). The weight of the second model is lower than the first one and only 1 man is required to carry it.

7.4 *Water resources*

Since the first prototype was designed to support only the tank. It would be better to provide the alternative

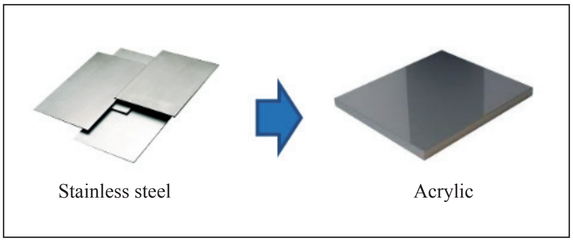


Figure 11: The change of machine frame and housing.

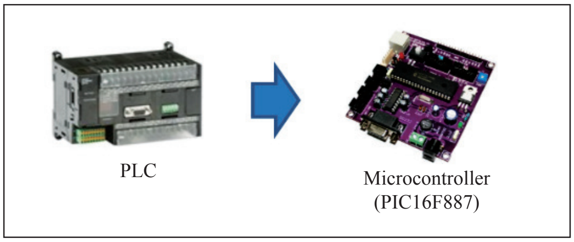


Figure 13: The change of controller.

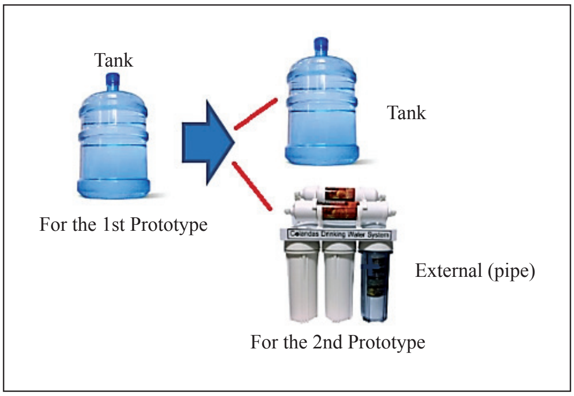


Figure 12: Adding water resources.

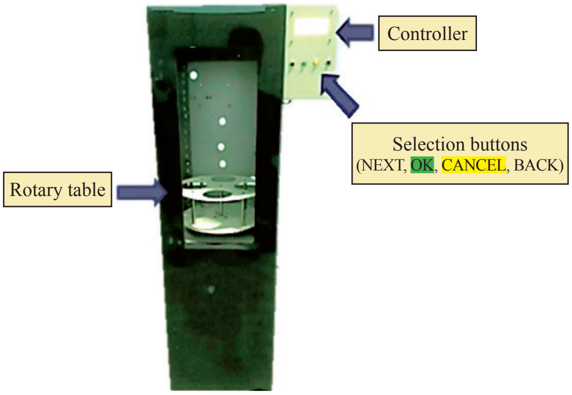


Figure 14: The new components of the second prototype.

channels for supporting many different water resource platforms. The pipeline from external filtration system was added as shown in Figure 12. Two choices of the water resources can help the users when the water inside the tank is not enough, they can apply the alternative channel for filling water continuously.

7.5 *Controller*

From the first prototype, PLC was selected to control all function of filling machine; however, the price is very expensive and it is quite heavy for attaching inside the main frame. Applying the microcontroller (PIC16F887) can reduce some machining cost and it is easily to be placed in the limited area as shown Figure 13.

The first prototype, the sensor was used to detect the water level and to stop filling water. It presented the problem about the water spillage and the filled amount cannot reach the desired position. For increasing the filling accuracy, the second prototype is designed to apply the timer for stopping the filling system. Therefore, the calculation of time for filling water is determined from the flow rate which is given from the pump.

The pump applied in this research provides the flow rate, $Q = 1.6$ L/min, and the unit is changed to be 0.0267 L/s. The time spent for filling water of 1 L is around 37.5 seconds. Finally, this 37.5 seconds value was assigned into the microcontroller to command the solenoid valve to stop filling water by using time constraint. After changing some components of the filling machine, the algorithm used for filling the water has been modified for supporting two types of water sources; tank, and external (the purification system).

8 The 2nd Design of the Automatic Filling Machine

The components of the second prototype are shown in Figures 14 and 15. Illustrated in Figure 16 are the virtual models of the first and the second prototypes. The compact-controller box was attached at the proper area around the right side of the second prototype for easily selecting the machine's conditions.

The working process can be divided into 6 steps as shown in Table 15. The mean error was determined (the average of all errors in a set) as shown

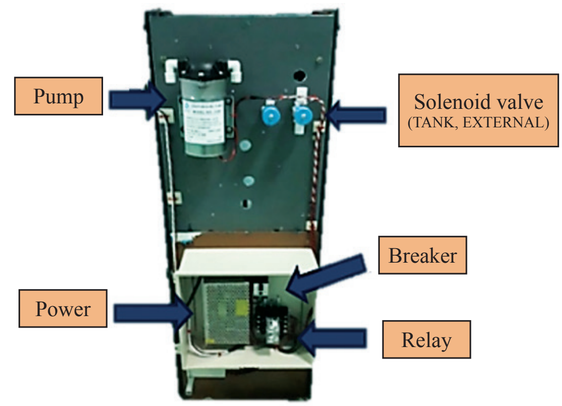
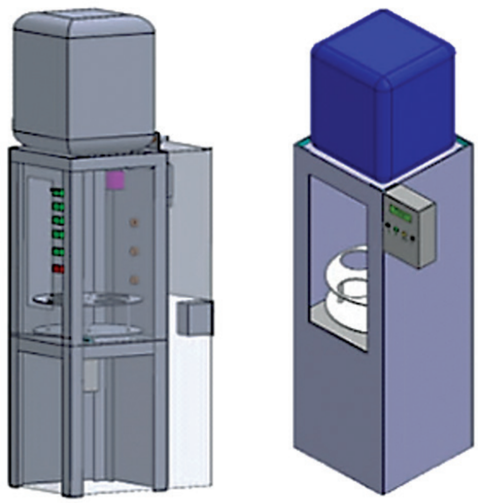


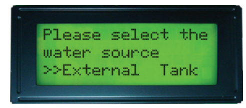
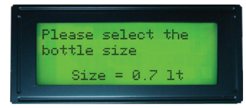
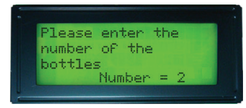
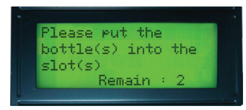
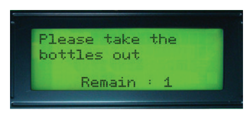
Figure 15: Back view of the machine.



1st Design 2nd Design

Figure 16: 3D virtual models of the first and the second prototypes.

Table 15: Steps required for the second prototype

Description	Screenshots
First step: Select the sources (***"External" or "Tank"***)	
Second step: Select the level of water (***"700mL, 1000mL, 1500mL"***)	
Third step: Select the number of bottles (***No. = 1,2,3 or 4***)	
Forth step: Press "Green" button to rotate the platform in clockwise direction for positioning the new empty bottle.	
(***Keep doing this until the "Remain :1" is shown***) *1 represents the last bottle*	
Fifth step: The machine is now filling the water to the empty bottles.	
Sixth step: Press "Green" button to rotate the platform in clockwise direction for taking the full bottle out of the machine. ***"one by one" until the "Remain :1" is shown 1 represents the last bottle.***	

in Table 16. The results of 700, 1000, and 1500 mL filling processes of the second prototype presented less error comparing to the first prototype. The proposed compact automatic filling machine (CAFM) can provide the benefits to reduce and eliminate the redundant works for waiting and filling the water into the bottle (one by one). Doing this filling activity can save the money for purchasing new bottle water (i.e., the drinking water packaged in plastic bottles) several times per week from the supermarket. This machine can be applied in a school, a canteen or a factory where the refilled bottle can be used.

This second machine can support the water filtration system where the pipeline can be attached directly and quickly to the water storage via the "External mode" and the user can select the sources of the water being used by easily pressing the switch on the control box. The key parts of the developed filling machine are the controlling system, and the sensors. The correct actions of the machine can be fully accomplished by well controlling the amount of water during filling activity where the inputs of the overall functions are from the sensors. For the slots of rotary platform, an adjustable rubber holder will be attached

Table 16: Errors from the second prototype

Volume (mL)	System				Error (%)
	Expected Vol.		Actual Vol.		
	Result	Mean	Result	Mean	
700	700 700 700 700 700 700 700 700 700 700	700	695 697 700 693 702 700 703 701 700 697	698.8	0.17
1000	1000 1000 1000 1000 1000 1000 1000 1000 1000 1000	1000	995 992 1000 1002 997 992 1000 1003 1007 1001	998.9	0.11
1500	1500 1500 1500 1500 1500 1500 1500 1500 1500 1500	1500	1507 1499 1497 1500 1497 1501 1495 1505 1499 1502	1500.2	0.013

inside each slot for supporting different bottle sizes and fixing the bottle in place.

Reference

[1] S. Levy and H. Hino, "Emotional brand attachment: A factor in customer-bank relationships," *International Journal of Bank Marketing*, vol. 34, pp. 136–150, 2016.

[2] H. Y. Chen and K. L. Huang, "Construction of perfume bottle visual design model based on multiple affective responses," in *Proceedings of the IEEE International Conference on Advanced Materials for Science and Engineering: Innovation, Science and Engineering, IEEE-ICAMSE 2016*, 2016, pp. 169–172.

[3] K. T. Ulrich and S. D. Eppinger, *Product Design and Development*, 4th ed., Singapore: McGraw-Hill Education, 2007.

[4] Thought Co. (2016). How Much of Your Body is Water. Thought Co. New York, USA [Online]. Available: http://goo.gl/2O1Pw0

[5] Ministry of Public Health. (2017) Health Fact Sheet. Ministry of Public Health. Nonthaburi, Thailand [Online]. Available: http://goo.gl/Y94 3cA (in Thai).

[6] Thai Health. (2017). Thai Health Promotion Foundation. Thai Health. Bangkok, Thailand [Online]. Available: http://en.thaihealth.or.th (in Thai)

[7] J. Islam and Z. Rahman, "The impact of online brand community characteristics on customer engagement: An application of stimulus-organism-response paradigm," *Telematics and Informatics*, vol. 34, pp. 96–109, 2017.

[8] Statistic Brain. (2013, Jul.). Business That Can Make a Million US Dollars in USA.We Go Inter. Bangkok, Thailand [Online]. Available: http://goo.gl/A5Bfic (in Thai).

[9] M. Lucia, K. Harley, D. H. Wayne, and N. Bettina, "Emotional brand attachment and brand personality: The relative importance of the actual an the ideal self," *Journal of Marketing*, vol. 75, pp. 35–52, 2011.

[10] B. Cathy and P. L. S. Paul, "Decision support for the design of affective products," *Journal of Engineering Design*, vol. 20, pp. 477–492, 2009.

[11] M. D. Deana, D. Howard, and C. Jonathan, "Design and emotion," *Journal of Engineering Design*, vol. 20, pp. 433–435, 2009.

[12] K. Junsheng and J. Pingyu, "Product platform design for a product family based on Kansei engineering," *Journal of Engineering Design*, vol. 20, pp. 589–607, 2009.

[13] M. L. Saul. (2016). *Maslow's Hierarchy of Needs*. Simply Psychology. UK [Online]. Available: https://www.simplypsychology.org/maslow.html

[14] Prolifixent. (2005), Water Dispenser Servicing, Parts and Maintenance. Nairaland. Nigeria [Online]. Available: http://goo.gl/r8JWro

[15] B. S. Dhillon, *Maintainability, Maintenance, and Reliability for Engineers*. Florida: CRC Press, 2006, pp. 97–109.