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Advancing Retail Experience with Smart Shopping Carts: A Design Process Perspective for Bangladesh

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Abstract

Supermarkets are becoming the preferred choice for basic needs due to modernization and urbanization. Tracking product sales and issuing receipts are crucial for store officials. This work addresses two significant issues in Bangladeshi supermarkets: long checkout lines and efficient inventory management. An intelligent shopping cart system that records purchased items and facilitates online payments using Radio Frequency Identification (RFID) Technology and Arduino incorporated in this work. RFID technology automates billing by reading RFID tags attached to each product with a sensor on the cart. IoT facilitates real-time communication by connecting the intelligent cart to the store's network and delivers product and payment data to a store system. The Kano Model and Quality Function Deployment (QFD) are employed to develop the product, focusing on customer satisfaction with RFID technology with automatic billing, built in scanners, rechargeable battery, while also prioritizing cost minimization and improving software integration and inventory management. Stress and thermal analyses ensured durability and safety. This smart can improve customer experience by reducing wait times and increasing operational efficiency.

Keywords: Smart Shopping Cart, Product Design, RFID, QFD, Inventory, Design.

1. Introduction

Bangladesh's retail industry is changing quickly due to urbanization and the growth of supermarkets. Nevertheless, obstacles such as inefficient inventory management, lengthy checkout lines, and product location challenges continue to exist. Integrating smart shopping technologies helps to settle those challenges. Smart shopping carts integrated with RFID, IoT, and AI technologies provide functionalities such as automatic billing, product recommendations, and anti-theft systems [1]. These carts significantly improve the browsing experience by streamlining the process of purchasing and providing real-time inventory updates [2]. Additionally, this technology assist retailers in their efforts to enhance security, optimize operations, and minimize losses [3].

While previous research focuses on the technological features of smart carts such as RFID and ZigBee integration for mobile payments and product identification [4] [5], the market dynamics, manufacturing processes, and business potential in Bangladesh remain unexplored. This smart cart can improve that gap by examining consumer demand, market analysis, cost-effective production, and the practical implementation of smart shopping carts in the local market.

2. Literature Review

A review of current technologies illustrated the advancement of smart shopping carts, while offering features like automatic billing, product recommendations, and anti-theft mechanisms. The proposal [1] suggested a system that utilized RFID tags for product detection and Li-Fi for billing. A product identification device (PID) with an RF transceiver module, buzzer, keypad, LCD, RFID reader, and microprocessor was part of the cart. It included ZigBee, IoT, and face recognition for improved functionality, as well as mobile banking, product suggestions, anti-theft measures, and energy harvesting through wheel motion [1]. An RFID reader, Raspberry Pi, and LCD were used to track the total cost and send data to the billing counter in an effort to help consumers proceed to their budget limits [2]. Another study focused on the display of product information on the cart's LCD, the real-time updating of inventory and billing status, and the collection of data from aisles using IR sensors and microcontrollers [3]. An alternative approach employed barcode scanning in place of RFID, while online payment options allowed the cart to automatically reset itself upon processing a payment and eliminate any products removed [4]. According to another study, RFID technology enabled minimal-touch shopping that was safe, contactless, and reduced the need for cashiers [5]. By integrating components such as embedded computers and

laser scanners through modular systems, researchers developed intelligent user interfaces [6]. Additional research investigated RFID and IR technologies for cart location, relevant product details, and efficient billing processing, with a focus on clear tracks for accurate identification. The system included Cart Location Detection Units (CLDU), Server Communication Units (SCU), User Interface and Display Units (UIDU), and Billing and Inventory Management Units (BIMU) [7]. RFID made inventory control and consumer mobility easier, allowing for faster checkout times and more efficient inventory management [8]. Carts were connected to servers and banks for a flawless shopping experience through integration with ZigBee and other wireless technologies. An advanced system integrated RFID and ZigBee for product recommendations, expiration date information, anti-theft features, and alternative goods [9]. A different idea combined RFID technology with a centralized server to handle product identification and billing. It also had anti-theft measures at the exit door and a reset option for the cart after payment [10].

Researchers conducted numerous studies on smart shopping carts, utilizing technological advancements such as RFID (radio frequency identification), ZigBee, and the Internet of Things (IoT) for features like automatic billing, product recommendations, and anti-theft mechanisms. However, none of the studies had any interest in market conditions, manufacturing processes, safety features, or the commercial viability of those technologies in retail sectors. With this study, we tried to fill that gap by providing an in-depth market analysis as well as the most cost-efficient material selection for industrial production. This study also incorporated engineering design aspects to enhance product efficiency and align with consumer needs.

3. Methodology

This methodology explored the feasibility and effects of deploying smart shopping carts with a dual-segment survey that aimed both super shop owners and consumers.

Survey

A consumer survey was conducted with 125 respondents across urban areas of Bangladesh, including Dhaka, Rajshahi, Chittagong, Sylhet, Rangpur, Mymensingh and other regions. The sample included 67 females and 113 males, primarily aged between 36-50 years (58.1%), followed by 28-35 years (28.6%). The survey explored shopping behaviours, awareness of smart shopping carts, and adoption factors. Key findings revealed that 60%of respondents preferred supermarkets due to organized layouts, and 71% preferred smart shopping carts with integrated automatic billing and payment. To capture perspectives from individuals directly involved in retail operations, we also conducted a survey of 30 super shop owners. The majority of these store owners expressed an immense desire to integrate digital technology, particularly smart carts with features like RFID tagging and automatic billing, and emphasized challenges such as busy checkout lanes and manual product scanning. Additionally, 67% of store owners recommended durable shopping carts.

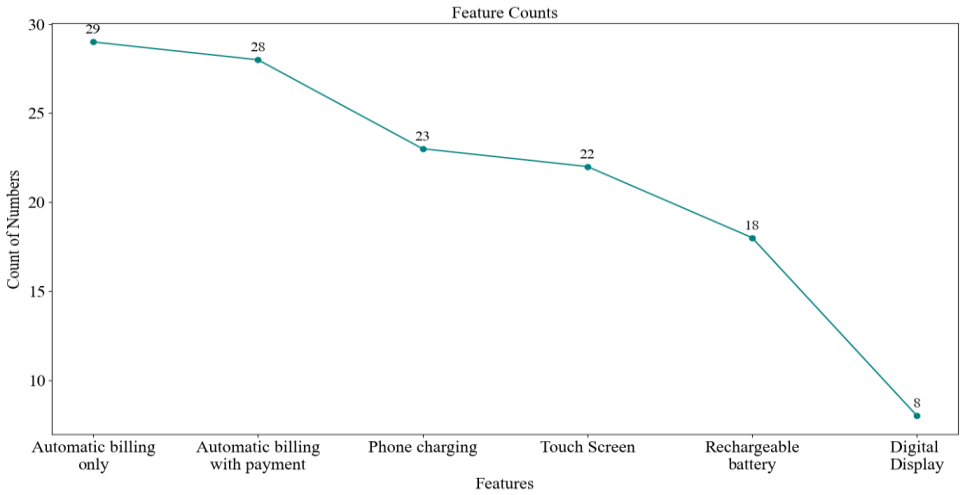


Fig.1. Features of the smart shopping cart

Kano Model

We performed a Kano model study to determine how to differentiate the potential features of smart shopping cart based on consumer needs. The significance of this model resides with its ability to identify features that are mandatory, notable, and subsequently contribute to user satisfaction by categorizing features into Must-be (basic

needs), One-dimensional (performance needs), and Attractive (excitement needs) and indifferent (neutral). Based on our survey we had identified 7 essential feature and asked 20 Appellant to answer a pair of functional and dysfunctional perception questions for each feature. In order to achieve a deeper insight into user needs and satisfaction, we did the discrete analysis in combination with continuous one.

Discrete and Continuous Analysis

The responses provided by the customers were calculated and assessed for each characteristic of smart shopping cart. Fig.2 shows the features classified according to their proportion among the respondents. Since continuous analysis's cut-offs and numerical weights for various categories are not assessable for every study, discrete analysis is the recommended method for evaluating Kano results. In continuous analysis the average functional and dysfunctional scores of the respondents are calculated for comparing the features in four quadrants: Must-be, One dimensional, Attractive, and Indifferent.

Function Structure Diagram

Figure 3 below illustrates a function structure diagram representing the functions performed by the smart shopping cart on its inputs and outputs. The primary function of the cart is to enhance the shopping experience by detecting items with an RFID reader and validating them with a weight sensor. The system uses an Arduino microcontroller to process inputs, communicate with the market server via Wi-Fi, and assist in inventory management by automatically updating stock levels. The cart is powered by a battery, which supplies energy to all components, ensuring smooth operation and supporting online payment options for a seamless checkout process.

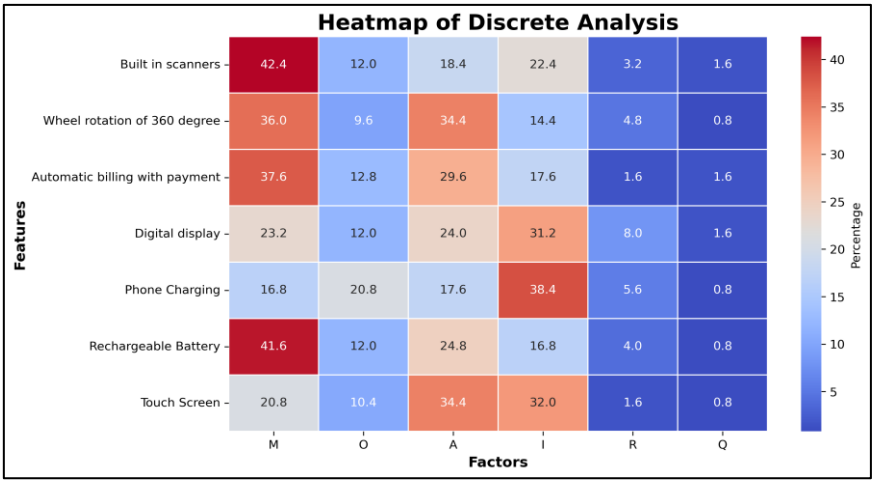


Fig.2. Heat map of discrete analysis

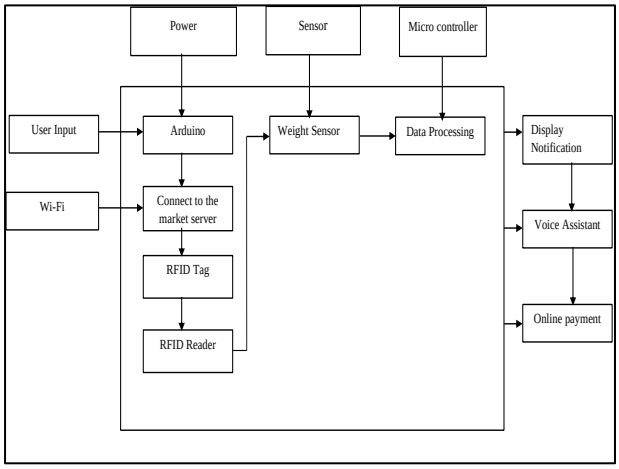


Fig.3. Function structure diagram

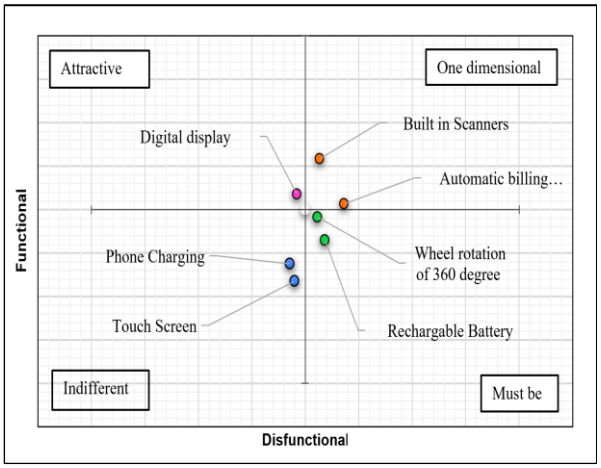


Fig.4. Continuous Analysis

Quality Function Deployment

Quality function deployment (QFD) is a methodology that provides a clear framework for addressing customer needs, beginning with a matrix called the House of Quality. Fig. 4 shows the quality house, and Fig. 5 shows the QFD findings. The radar chart visually represents the main features identified in the QFD findings for the smart shopping cart. The radar chart highlights the implemented scaling system, assigning a rating of 1 to "Minimize", a rating of 2 to "Target", and a rating of 3 to "Maximize". The chart compares features such as cost, RFID technology, API integration, inventory management software, and material quality, indicating the direction and priority of improvement for each. This approach provides a clear, comparative view of which areas require targeted or maximum focus for optimization.

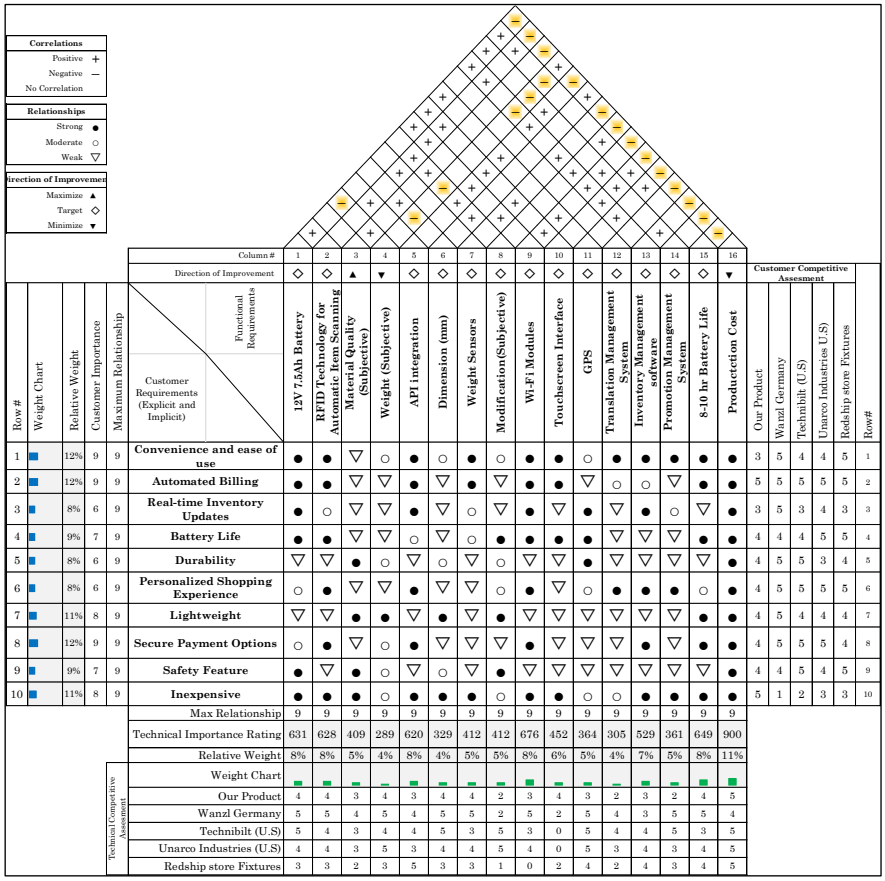


Fig.5. Quality Function Deployment

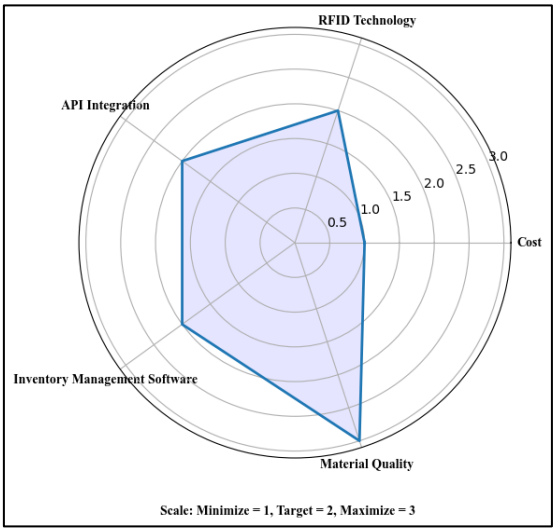


Fig.6. Findings from QFD

3D Modeling of the Product

A 3D model of the shopping cart was made using SolidWorks to ensure the design and integrity of the frame. After creating the 3D modeling of each part of the smart shopping cart using SolidWorks**,** we next proceeded to analyze the shopping cart frame to find out stress, strain and displacement. Specifically, we used heat analysis on the area of the smart shopping cart that will hold the battery. This allowed us to determine how the battery's localized heat affected the surrounding structure and made sure the frame would continue to be durable and functioning even in thermal conditions.

Structural Analysis

The performance of the shopping cart frame under actual loading circumstances was evaluated through analysis. The upper frame, which acts as a cantilever beam holding the basket, is welded to the main frame. The primary objective of our study was to analyze displacement and stress distribution. To simulate the weight of items (100-120 kg) based on survey data, a force of 1080N was applied to the upper frame. The frame exhibited the most significant displacement at the free end, located farthest from the welded connection, because it acts as a cantilever beam. Meanwhile, maximum stress was centered near the joint between the upper and mainframes, highlighting the crucial stress locations under loading.

Thermal Analysis

Lithium-ion batteries usually have an efficiency of around 85% or below, resulting in a corresponding energy loss of 15% or more. This loss is hypothesized to be transformed into thermal energy, considering variables such as internal resistance and chemical processes. Utilizing this assumption, we approximate that the thermal energy produced by a 12V 7.5 A lithium-ion battery during the charging process amounts to around 40 watts. which is more than it does during operating condition. The cart's frame temperature would be minimally affected by this heat, as the ambient conditioning in a supermarket environment is maintained at or below 25°C. The simulation verified that the temperature distribution remains within acceptable limits.

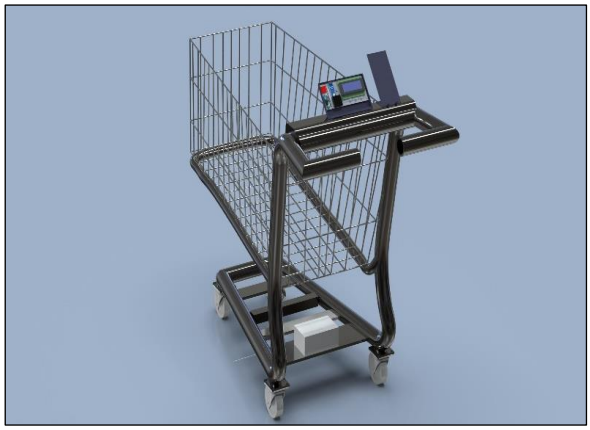


Fig.7. 3D Model of the Cart

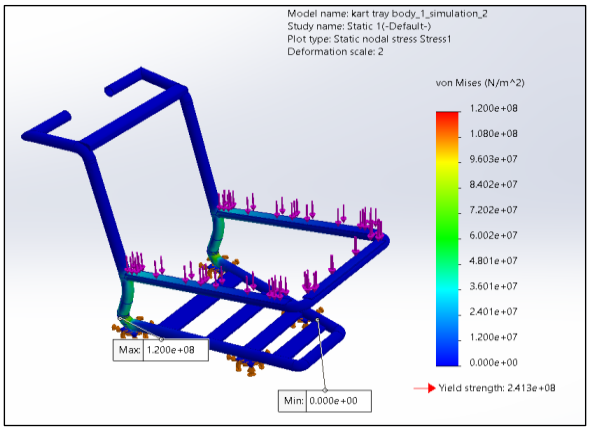


Fig.8. Stress distribution on Cart frame

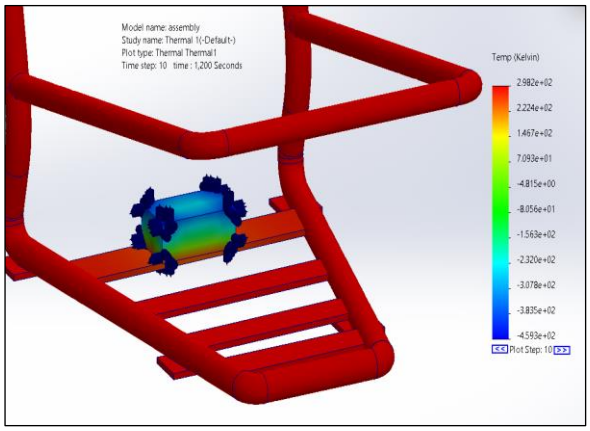


Fig.9. Thermal Distribution on Cart Frame Due to Battery Heat

Cost-Effectiveness Analysis of Frame Materials

Three materials were chosen for this study: HDPE, plain carbon steel, and cast alloy steel because these materials are generally used to make shopping cart frames. A comparison took place on these materials based on their cost per unit strength to determine the most cost-effective choice. Findings show that Plain Carbon Steel offers the optimal trade-off between cost and structural integrity, establishing it as the most economical option for practical uses. Although it is more costly, cast alloy steel is stronger and is therefore appropriate for high-stress situations. HDPE is less economical than steel alternatives, despite being lighter. The purpose of this analysis shows in Table 1 was to highlight how cost per unit strength plays a critical role in material selection.

Table. 1. Cost per unit strength of different materials

Material	Yield/Tensile Strength (Nm^{-1})	Frame Mass(g)	Specific Strength ($Nmkg^{-1}$)	Cost per kg (USD)	Cost per unit strength (USD/Nm)
Cast Alloy Steel	241,275,200	13814.22	31132.28	\$2.45- \$2.50	$\$7.86\times10^{-5}$- $\$8.030\times10^{-5}$
Plain Carbon Steel	220,594,000	13903.344	28281.28	\$0.55-1.00	$\$1.944\times10^{-5}$- $\$3.53\times10^{-5}$
HDPE	22,100,000	1729.0056	2278.35	\$0.94-1.40	$\$4.12\times10^{-4}$- $\$6.144\times10^{-4}$

4. Result

According to the analysis of the smart shopping cart's frame, the yield strength was 2.413e+08 Nm^{-2}, with a safety factor (FOS) of 2, allowing it to withstand loads up to 2160 N without losing structural integrity. This demonstrated the design's suitability for manufacturing. The temperature increase in the battery area was only 0.2°C, ensuring safe thermal operational efficiency. By selecting materials based on cost per unit strength, manufacturing efficiency could be further improved. Additionally, Kano model analysis and QFD supported the integration of advanced features, aligning with customer expectations and enhancing the shopping experience.

5. Conclusion

This study designs a smart shopping cart to improve the shopping experience where technologies such as automatic billing are integrated to reduce manual payment processing and checkout lines. It employs cost-efficient materials that maintain structural integrity while lowering manufacturing costs, making the product more affordable. Additionally, the research enhances retailer operational efficiency and stock control by implementing real-time purchase monitoring, improving inventory management. Plans include exploring sustainable materials and integrating artificial intelligence to boost consumer satisfaction and efficiency through personalized purchasing.

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