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Integrating Renewable Energy and Customer Insights: A Systematic Approach to Solar Power Bank Design

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Abstract

Demand for renewable energy-based power sources is increasing over time as the world is facing a crisis in non-renewable energy and is concerned about future sustainability and environmental safety. The solar power bank can be a great solution in this context, as the power bank is one of the most demandable devices and the integration of solar energy, which is regarded as an easily accessible renewable energy, makes the device more sustainable and independent of non-renewable energy. In this study, a model of a solar power bank has been proposed. To ensure that the product aligns with the customer demands, a comprehensive survey was conducted collecting data on the usage behavior, expectations, and preferences of the customers. The collected data was analyzed to determine the significant customer demands which were then reflected in the objective tree and functional structure. A Quality Function Deployment (QFD) was employed through which the customer requirements were translated into measurable engineering specifications, and the acceptable ranges of values were proposed. Based on the engineering specifications, the required components with necessary specifications were suggested and a digital model was formed in the Computer Aided design (CAD) software namely SolidWorks. The material selection of the power bank was done using the Digital Logic Method (DLM) by which the materials were evaluated and finally, the top-ranked material was selected for the power bank which was PVC in this case. The integration of customer-driven insights was reflected in this proposed solar power bank with the promotion of renewable energy utilization which can be a great support during emergencies like natural disasters.

Keywords
Sustainability, Environmental safety, Solar power, QFD and Digital Logic Method.

1. Introduction

Energy shortage is a major issue worldwide. Moreover, excess usage of non-renewable energy sources has detrimental effects on the environment and health (Ansari et al. 2017). Renewable energy emerges as a transformative solution to these problems because renewable energy is greener and 10-40% of energy consumption can be minimized through the usage of renewable energy (Farghali et al. 2023). Among various renewable energies, solar power is easily accessible. On the other hand, portable power storage devices such as power banks are becoming popular day by day. However, the conventional power bank is not sustainable because they do not include solar power storage capability. Presently, through advancements, the inclusion of solar power storage feature in the portable power bank has been possible which leverages the use of renewable energy by reducing extra pressure on the energy supply to charge electric devices. This feature makes the power bank independent of the power supply so during emergencies, or in remote areas, the solar power bank can be a great option for a power source as it generates and stores electrical power automatically. (Agarwal et al. 2016). To ensure customer satisfaction and the quality of the power bank, determining their expectations on this product is a primary requirement before the manufacturing process. In this case, the Kano model is considered a useful tool for understanding customers' preferences and categorizing their demands based on importance. Kano model gives insights into how customers feel about a particular feature of a product (Bhardwaj et al. 2021). To translate the customer requirements into relevant engineering specifications and then fix the acceptable ranges for the specification for further manufacturing process, the Quality Function Deployment (QFD) can be another convenient tool (Ishak et al. 2020). The next step involves the selection of proper material for the final manufacturing process. In this regard, the Digital Logic method can be insightful as all the material selection criteria focusing on customer requirements with their relative importance and the properties of each primarily selected material are precisely considered to determine the most preferable material in this method (Hotma et al. 2024).

A systematic approach to the design and development of solar power banks has been proposed in this study. The focus was designing the solar power bank in such a way that the highest number of customer needs could be satisfied. And to ensure this, special techniques such as the Kano model and quality Function Deployment were used in order to hear the voices of customers and convert their demands into quantifiable engineering units. The Computer Aided design was done in the well-known CAD platform namely Solid Works, where the stress analysis has been conducted to simulate the load tolerance capacity for ensuring the durability and sustainability of the power bank. Importance was given to the selection of material as it's crucial for the robustness of the device. The Digital Logic Method, which involved finding the weights of criteria or customer requirements and the degree of satisfaction of customer needs by the primarily selected materials, was applied in order to determine the best preferable material having the highest weights.

1.1 Objectives
Solar power banks can be a good economical and ecofriendly alternative to regular power banks. This study aimed to identify the key customer requirements through a customer survey and to integrate these into its design and development with the help of the Kano Model and QFD analysis. By proposing the design of the product this study aimed to provide an energy-efficient, durable, and user-friendly solution suitable for both outdoor and emergencies.

2. Literature Review
The design of a solar-powered portable power bank, which used solar power as its ultimate power to charge mobile phones, was analyzed in a study (Agarwal et al. 2016). Two 6V solar panels were used for charging a 12V battery, where the process was controlled by a microcontroller with a relay circuit to ensure safe charging of mobile phones by cutting off the power supply in case of overcharging. Power was supplied using a USB port, with voltage & charge level displayed by means of LED, and was utilized in the prototype. It was found that bright and sunny weather was needed to charge the battery efficiently, and the panel wings had to be placed under direct sunlight.

A 5V solar panel, a 5000 mAh battery, an ATMega 328 microcontroller, an LCD display for battery monitoring was used in another study (Ismangil & Susanto 2019). Two mobile phones, Xiaomi Redmi 3 with 4100 mAh battery and Xiaomi Redmi 4A with 3120 mAh battery were charged for an hour and charge percentage increased by 26% and 22% respectively. A power bank with similar construction is demonstrated in another study (Sharma et al. 2015).
A power bank consisting of 3 mini solar panels was studied in a paper (Stanlee et al., 2024). Testing between 09:00 and 13:00 when the sunlight peaked, 1855mA of current and 3962mV of voltage was generated, which was enough to charge a smartphone battery from 20% to 100% within 4 hours. On the other hand, testing between 14:00 and 18:00 when the sunlight was peak, 1246mA of current and 1454mV of voltage was generated, which was enough to charge a smartphone battery from 20% to 75% within 4 hours. Raising energy storage capacity, advancement of efficiency under changing sunlight conditions and weather, developing design & compatibility with wider ranges of devices were suggested to be studied in the future.

Integration of Photovoltaic (PV) cells into the mobile batteries was proposed by a study (Malla et al. 2016), which will provide continuous charging. The voltage output decreased with reduced irradiance, which was coped up using a buck-boost converter to meet the charging requirement of the battery of the mobile phone. The study was simulated in MATLAB and the outcome was validated experimentally, making it a promising solution.A project named MULTIPORT UNIVERSAL POWER BANK is showcased in a study (ALTELMESSANI, 2024), focusing on the importances of the portable solar powered power bank. Benefits like easier access to electricity in remote areas, significance in the time of power outage, ability to charge multiple types of devices, suitability with on-the-go activities like camping or emergency situations are highlighted. The importance of renewable energy-based charging systems is also emphasized in another study (Chowdhury et al. 2021).

A power pack was developed to charge laptop and other electronic devices in a study (Anyanor, 2023) conducted in Nigeria. The materials needed to construct the power pack was easily available in Nigerian market. This system had a charging power of 72 Wh and used 12.5V lithium battery for backup, where 50W photovoltaic solar panel was used to provide energy. A total efficiency of 83% was shown by the system. A power bank of 10000 mAh capacity was simulated and experimented in a study (Onah, 2016). The quick charging and normal charging mode utilized 20% and 10% of the battery capacity, respectively. Charging efficiency of above 95% is observed from both simulation and experiment.

Kano Model analysis was carried out on an automotive product to evaluate the customer needs and customer requirements in a study (Bhardwaj et al. 2021). By providing a predefined set of customer requirements for the targeted market, the customer needs can be fulfilled more effectively which will bridge the gap between the manufacturer and the customer, as suggested in this study. Integration of Kano Model and Quality Function Deployment to improve product quality was highlighted in a review paper (Ishak et al.2020). The Kano model was found to be a widely used tool to understand customer needs and to analyze the effect of fulfilling customer needs on customer satisfaction levels. To translate customer requirements into technical specifications, quality function deployment is used. The overall quality of the product is increased by the relationship between Kano model and quality function deployment. Material selection for low-cost manufacturing of electric motorcycle platforms was evaluated by Digital Logic Method (DLM) in a study (Hotma et al. 2024). Material was selected comparing the aspects of strength, deformation, stress, density and weldability, and finally ranking different materials to find the best one. Based on this literature review, an attempt to propose a design of a solar power bank suitable for the market is made in this study.

3. Methods

The methodology adopted for the design and development of the solar power bank is structured into systematic ways including a kano model for feature prioritization, an objective tree, quality function development (QFD), functional structure development, stress and deformation analysis, materials selection.

Kano Model Needs Assessments

The Kano model is a framework design where features are compared based on the customer's priority. A customer gives feedback on a feature of being functional and dysfunctional. Based on the priority scale there are five types of customer needs: 1. Must be (M): Its absence produces absolute dissatisfaction and its presence does not increase satisfaction. 2. One-dimensional (O): Its fulfillment increases satisfaction and vice versa. 3. Attractive (A): It leads to greater satisfaction but it is not expected to be in the product. 4. Indifferent (I): Its presence or absence does not contribute to satisfaction. 5. Reverse (R): Its presence causes dissatisfaction and vice versa.

Objective tree

An objective tree represents the design objectives of a product in a hierarchical figure in where the design objectives are divided in clusters. The objective tree is generally done on the base of customer survey.

Function Structure diagram

A function structure diagram is a graphical representation used to break down the functions or tasks of a system, product, or process into hierarchical levels of detail. It is a top-down approach that shows how the overall functionality is divided into sub-functions, and further into more specific tasks or operations.

Quality Function Deployment (QFD)

QFD is a method to obtain major pieces of information required for the understanding of the Problem. Quality function deployment (QFD) is a quality technique which evaluates the ideas of key stakeholders to produce a product which better addresses the customer's needs. In House of Quality, Customer requirements gathered into a visual document which is evaluated and remodeled during construction so the important requirements stand out as the end result.

Material Selection

The material selection is done on the basis of the Digital Logic Method. The Digital Logic Method involves determining the relative importance coefficients of the criteria, scaling properties of the materials, and finally the performance index of the materials. The steps are shown below:

Step 1: The relative importance coefficients of the selection criteria were determined
The relative importance of each two criteria was evaluated in each column. For example, if the relative importance between Cost and Lightweight was evaluated, and it was found that Cost is more important than Light Weight, hence cost was given 1, while Lightweight was given 0. Similarly, all possible combinations of the criteria were evaluated and value of relative importance coefficient (α) for each criterion was calculated by this formula.

$$\alpha = \frac{Total\ Positive\ decision\ for\ a\ particular\ criteria}{\Sigma(\text{All criteria Positive Decision})} \tag{1}$$

Step 2: The scaled properties for each material were determined and finally their performance indexes were calculated
The Scaled properties for the materials were determined using the following formula.
if property values for all materials are known

$$\beta = \frac{Minimum\ value\ in\ the\ list}{Numerical\ Value\ of\ property} \times 100 \tag{2}$$

if property values for all materials are unknown

$$\beta = \frac{Numerical\ Value\ of\ property}{Maximum\ value\ in\ the\ list} \times 100 \tag{3}$$

4. Data Collection

Data was collected from potential customers like travelers, students, service Holders, freelancers, and military & law enforcement personnel by the help of google form. The data collection was in two stages where the first stage was to identify customer requirements, key features and demand for this product. 184 people participated in this survey. In the second stage, the survey was done to accomplish the kano model needs assessments. 133 responses were found in this.

Survey

A survey was conducted targeting a diverse demographic group of 184 participants to gather information on customer requirements. Most percipients were aged between 19 to 26 years, and 86.9 percent participants were interested in using solar power bank. Additional features like display, multiple ports, high charge storage capacity, portability, lightweight, durability, etc. were prioritized based on customer satisfaction. It was noticeable that the customer wanted a portable, lightweight solution for charging that can work in emergency situation as well as a eco-friendly product.

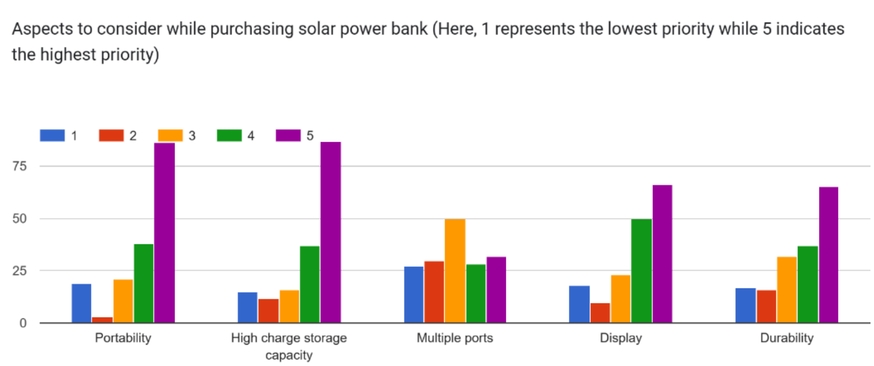


Figure 1. Customer Requirements of Solar Power Bank

5. Results and Discussion

Kano Model Needs Assessments

A customer survey was done for our 8 selected features based on the survey and 133 responses were obtained about functional and dysfunctional perceptions for each feature. The responses from the customers were then assessed in Table 1, the features are grouped in order to contain the highest percentage of the respondents.

Table 1. Findings of Kano model need an assessment

Features	M	O	A	I	R	Q	Evaluation
Display	32.81%	3.13%	24.22%	17.99%	15.63%	6.25%	Must be
Multiple Ports	32.03%	3.91%	26.56%	17.97%	14.06%	5.47%	Must be
High charge storage capacity	4.69%	1.56%	37.5%	35.94%	15.63%	4.69%	Attractive
Portability	4.69%	3.13%	34.38%	33.59%	16.41%	7.81%	Attractive
Durability	7.03%	0.78%	30.47%	38.28%	14.06%	9.38%	Indifferent
Warranty	7.03%	0.78%	27.34%	38.28%	15.63%	10.94%	Indifferent
Low-Pricing	3.91%	0.78%	31.25%	38.28%	13.28%	12.5%	Indifferent
Lightweight	3.13%	3.13%	28.13%	41.41%	13.28%	10.94%	Indifferent

Based on this, the kano model need assessment of features are shown graphically in Figure 2.

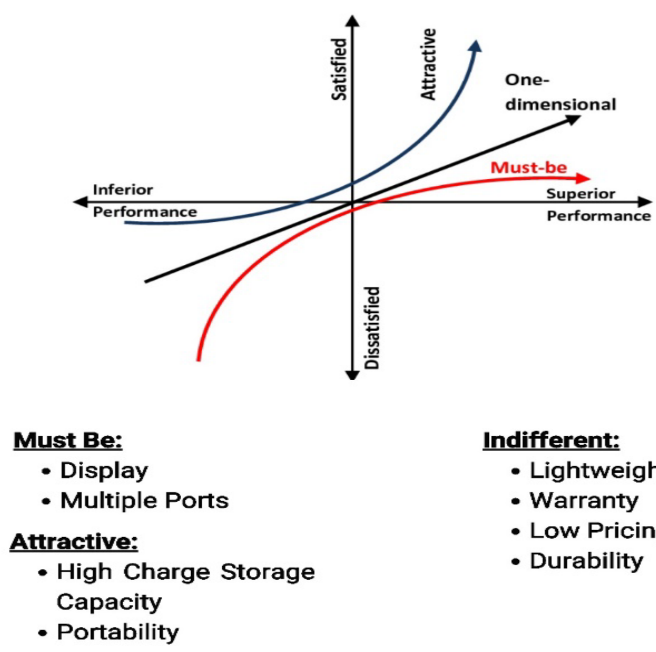


Figure 2. Kano Model Needs Assessment

Objective tree

Based on the customer survey an objected tree is illustrated in Figure 3.

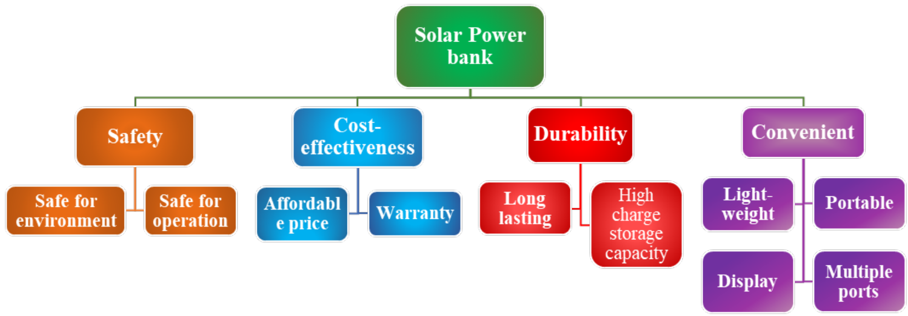


Figure 3. Objective tree for solar power bank

SWOT Analysis

To find out strengths, weakness, opportunities, and threats a SWOT analysis was done. By SWOT analysis, gaps in existing products were determined and areas of differentiation like durability and eco-friendliest were determined.

Table 2. SWOT analysis for solar power bank

STRENGTHS	WEAKNESS
❑ Renewable Energy Source ❑ Portability ❑ Multi-device Charging ❑ Battery Longevity ❑ Durability	❑ Dependent on Sunlight ❑ Slow solar charging ❑ Initial cost ❑ Limited capacity
OPPORTUNITY	**THREATS**
❑ Customizable Features ❑ Expanding Market ❑ Technological advancements ❑ Growing Eco-Conscious Market	❑ Competitive market ❑ Technological limitations ❑ Weather dependence ❑ Battery degradation

Function Structure diagram

Functional structure of our product is shown in Figure 4. in which Dual power input options (solar and AC), efficient energy conversion and storage mechanism, reliable energy output were the purpose of our product.
The functional tree diagram helps in understanding the functional relationships between different components and how they contribute to achieving the overall objective.
Primary Path: Sunlight → Solar Panel → Energy Conversion → Energy Storage → Energy Output.
Alternate Path: AC Power Input → AC Voltage Regulation → Energy Conversion → Energy Storage → Energy

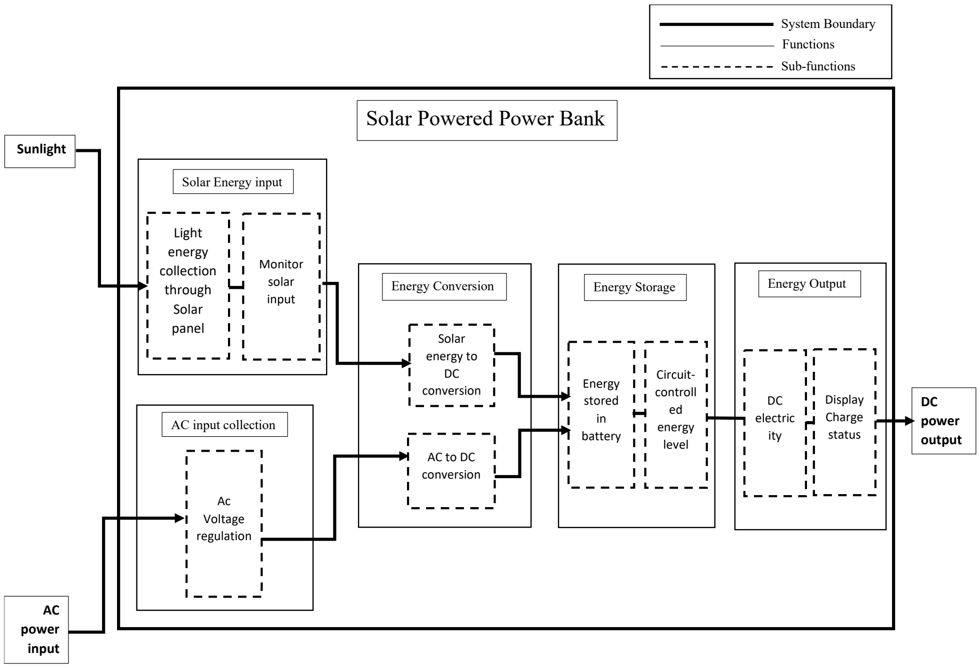
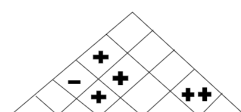


Figure 4. Function Structure Diagram of a Solar Power Bank

Quality Function Deployment (QFD)

The house of quality is the main feature of a QFD. The house of quality is shown in Figure 5. shows and the findings of QFD are shown in table 3.



Improvement	Direction
Increase	▲
Decrease	▼
Does not matter	Blank

Customer importance rating	Direction of Improvement (▲,0,▼) / Functional Requirements (How) → / Customer Requirements (What) ↓	Number of Information shown in Display ▲	Number of ports ▲	Battery Capacity (mAh) ▲	Dimension (cubic cm) ▼	Weight (g) ▼	My Product	Xiaomi	Geeoo	Allpowers	RAV power	Green Lion	Sharge
10	Display	9	0	3	3	1	9	8	8	8	7	7	10
9	Multiple Ports	0	9	0	1	1	8	9	8	9	8	7	7
8	Battery Longevity	0	1	9	0	0	7	6	6	7	7	6	7
8	Portability	0	0	1	9	9	9	9	9	7	9	9	7
7	Durability	0	0	1	0	0	9	7	6	8	7	7	8
6	Warranty	0	0	0	0	0	6	4	7	8	8	6	7
6	Low-Pricing	1	1	3	3	3	8	6	9	5	6	8	4
6	Lightweight	0	1	1	9	9	8	8	7	5	9	8	5
	Technical Importance Score	96	101	141	183	163	Total Weight					684	
	Importance	14%	15%	21%	27%	23%							
	Priority Rank	5	4	3	1	2							
	Xiaomi	4	4	20000	17.5x8.5x2	500							
	Geeoo	4	4	10000	15.5x8.5x2	500							
	Allpowers	5	1	10000	19x10x3	750							
	RAVpowers	4	1	20000	16x8.3x3	550							
	Green Lion	4	4	30000	15x7x2	269							
	Sharge	12	1	25600	23x13x3	450							
	Target	3-6	2	5000-10000	18x8x3	550							

Types of correlation	Symbol	Types of correlation	Symbol
Strongly Positive	++	No Relation	0
Positive	+	Weak Relation	1
No Correlation	Blank	Moderate Relations	3
Negative	-	Strong Relation	9
Strongly Negative	- -		

Figure 5. Quality function deployment of our product

Table 3. Findings of QFD

Feature	Target	Relative Importance Weight (%)
Number of Information Shown in Display	3-6	14%
Number of Ports	2	15%
Battery Capacity (mAh)	5000-10000	21%
Dimensions (cubic cm)	18´8´3	27%
Total Weight	550	23%

Material Selection

Primarily three materials were selected: Aluminum, 304 Stainless Steel and PVC (Poly Vinyl Chloride) Rigid. To find the most preferable material for the power bank, the Digital Logic Method was applied.
Seven selection criteria were fixed for selecting the material: Cost, Light weight, Compressive Strength, Fabrication Property, Modulus of elasticity, Carbon footprint, Dielectric strength.

Table 4.Material Properties

Properties	Aluminum	304 Stainless steel	PVC (Rigid)
Cost ($/kg)	2.645	4	.823
Compressive Strength (MPa)	570	205	66
Modulus of elasticity (MPa)	70000	193000	2700
Carbon footprint (CO_2 released per kg production)	12.46	6.15	3.43
Dielectric strength(kV/mm)	14.6	0.0001	20

Some properties were unknown for which a relative evaluation chart was formed in order to give the properties numerical forms.

Table 5. Chart for relative evaluation

Properties	Aluminum	304 Stainless steel	PVC (Rigid)
Light weight	3	2	5
Fabrication Property	3	3	5

Very High	5
High	4
Medium	3
Low	2
Very Low	1

Step 1: The relative importance coefficients of the selection criteria were determined by using equation (1)

For Cost, $\alpha = \frac{6}{21} = 0.285714286$
Similarly, rest are shown in table 6.

Table 6. Relative importance of Selection Criterion

Selection criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Positive decisions	Relative importance coefficient(α)
Cost	1	1	1	1	1	1																6	0.285714286
Light Weight	0						1	1	1	0	0											3	0.142857143
Compressive Strength		0					0					0	0	1	0							1	0.047619048
Fabrication Property			0					0				1				1	1	0				3	0.142857143
Modulus of elasticity				0					0				1			0			1	0		2	0.095238095
Carbon footprint					0					1				0			0		0		0	1	0.047619048
Dielectric strength						0					1				1			1		1	1	5	0.238095238
																						Σ(Positive Decision) = 21	

Step 2: The scaled properties for each material were determined and finally their performance indexes were calculated by equation (2) and (3).

For example, in table 4, the Compressive Strength of Al was 570 MPa, and the least value in the list was 66 MPa, hence the scaled property for Aluminum on basis of Compressive Strength was calculated as

$\beta = \frac{66}{570} \times 100$ = 11.57894737.

Then the weighted score (αβ) was calculated by, $\alpha\beta = 0.285714286 \times 31.11531191 = 8.890089126$

Again, in table 2, the Light Weight of Aluminum was 3 and the maximum value in the list was 5, so $\beta = \frac{3}{5} \times 100 = 60$. Similar calculations were repeated for other materials. Finally, the summation of the weighted score (αβ) for each material was determined and the material with highest value was chosen.

Table 7. Determination of Performance Index of materials

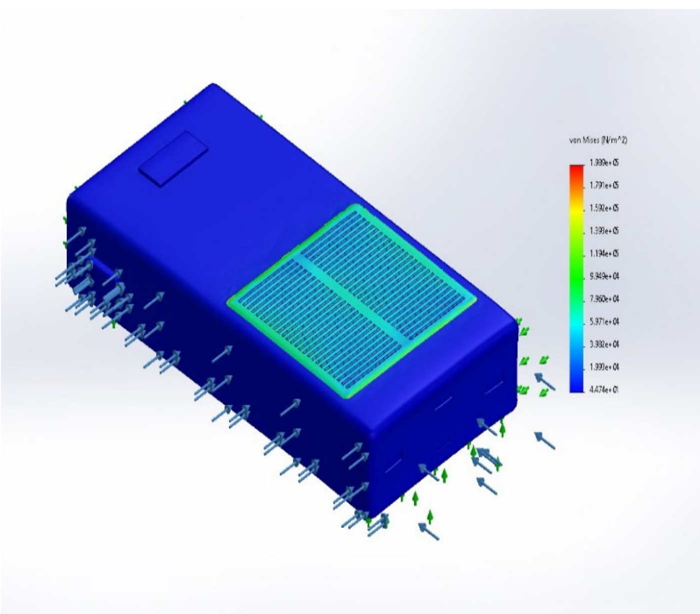
Selection criteria	Relative importance coefficient (α)	Aluminum		Stainless steel		PVC (Rigid)	
		Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ	Scaled Property, β	Weighted Score, αβ
Cost	0.285714286	31.11531191	8.890089126	20.575	5.878571434	100	28.5714286
Light weight	0.142857143	60	8.57142858	40	5.71428572	100	14.2857143
Compressive Strength	0.047619048	11.57894737	0.551378451	32.19512195	1.533101058	100	4.7619048
Fabrication Property	0.142857143	80	11.42857144	60	8.57142858	100	14.2857143
Modulus of elasticity	0.095238095	3.857142857	0.367346938	1.398963731	0.133234641	100	9.5238095
Carbon footprint	0.047619048	27.52808989	1.310861434	55.77235772	2.65582658	100	4.7619048
Dielectric strength	0.238095238	0.000684932	0.000163079	100	23.8095238	0.0005	0.000119048
Performance Index (γ)			31.11983905		48.29597181		76.19059535

The PVC (rigid) was found to have the Performance Index (γ), 76.19059535, hence, it was selected as the preferred material for the solar power bank.

3D Modeling and Stress Analysis:

Figure 6. shows the exploded view of the 3D modeling of the solar power bank

Figure 6. 3D model of solar power bank



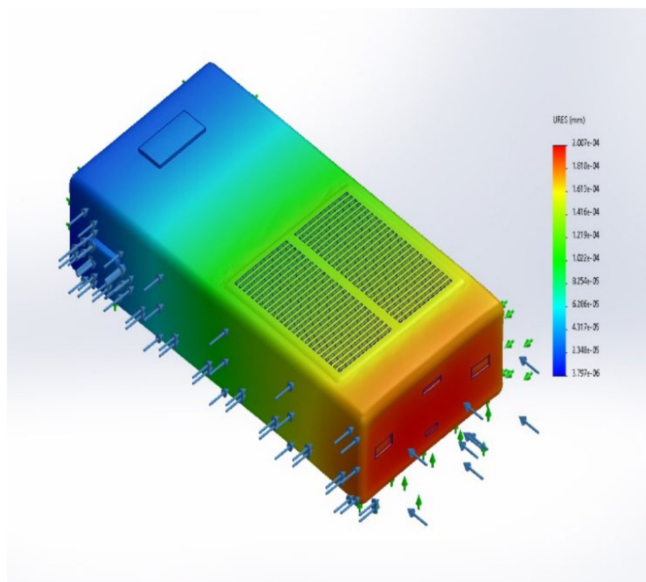


Figure 7. Stress analysis

Figure 8. Displacement analysis

The stress analysis of the proposed power bank was conducted to assess its structural integrity by identifying critical stress points. Areas with high stress were found in warm colors(red/yellow) and maximum stress was found as **1.989e+05 N/m^2** and minimum stress were found as **4.474e+01N/m^2**. The Factor of Safety was also measured to prevent failure due to in environmental factors such as wear fatigue and unforeseen stresses. Here, the maximum displacement was found to be **2.007e-04 mm** and the minimum was found **3.797e-06 mm**. High stress regions were highlighted in red or yellow, and low stress were highlighted in blue. Maximum displacement was observed to take place at the bottom of the power bank containing charging ports.

Finally, the proposed solar power bank successfully satisfies the customers' requirements by offering features like display and multiple ports, charging from both solar power and electric power supply. The highest stress was 1.989e+05 N/m^2 which was below the allowable compressive stress 6.6e+07 N/m^2. The maximum displacement was negligible with the value 2.007e-04 mm that ensures the stability under loading conditions without significant deformation. The material suggested for the product is PVC(rigid) which has higher availability and low manufacturing costs. Hence, the design is appropriate for manufacturing as the material suggested is cost-effective and has good fabrication properties. Moreover, the stress analysis validated that the product can be used after manufacturing as the stress and displacement were within safety range.

6. Conclusion

This study proposed a systematic strategy for the production of solar power bank which utilizes renewable energy sources for the global energy crisis. Incorporating customer-driven insight with the help of Kano Model, QFD, and Digital Logic Method (DLM), it guarantees that the proposed solar power bank meets all customers' preferences.
The assessment of the proposed model was done by a CAD-based model built by SolidWorks has presented proportioned indication. Stress analysis was done to confirm its structural integrity which is necessary for practical application as a means of determining the true practical reliability of the device. In selecting materials, DLM was applied which also indicated that the material proposed for this project is safe for the environment and can be used for a long time. The solar power bank is a versatile power source that promotes the use of renewable energy in both normal and emergency circumstances, as well as in remote areas. The proposed methodologies and systematic approach outlined in this study is utilized to establish a strong foundation for the development of long-lasting, customer-oriented products which aimed to contribute to environmental safety and energy efficiency.

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