MAE-540: Advanced Product Design Method

Business Plan by '*Smart Solutioneers'*

SMART REFRIGERATOR SHELF

Team-5

Harshad Sarode (ASU ID: 1209459339)

Nitish Kajrolkar (ASU ID: 1210425213)

Maitreyee Joshi (ASU ID: 1211379959)

Rohan Thakker (ASU ID: 1211377112)

Bharathi Venketraman (ASU ID: 1209474289)

1. BUSINESS OPPORTUNITY

1.1 INTRODUCTION

Being a student, often there are times that we are preoccupied with our coursework. We are constantly juggling between academics, part time job and social life. After the busy day, we are either very tired or lazy to keep the track of even the simplest things like essential groceries. There are many times when you are out of the items you need every day and you don't want to go out to get it. If you already knew which items are needed to be restocked, you can get them while you are out. This allows you to focus on other priorities and not worry about groceries. So, we wanted to develop the product which keeps the track of the items automatically and alerts you as and when you are under-stocked.

Smart refrigerator shelf will benefit the students all over. It can also be used by anyone who is preoccupied with other important things. The entrepreneurs, working people can be greatly benefit from the product. The Refrigerator OEM and Apartment management will be interested in the product to boost their business.

1.2 BUSINESS OVERVIEW

'Smart Solutioneers' is a venture by students of Arizona State University located in Tempe, Arizona. Our primary product of selling is the 'Smart Refrigerator Shelf' which keeps the track of your grocery consumption and alerts you of the consumption that helps you with the tracking of the usage. Our initial goal is to create a unique position in the market as the provider of a smart solution at affordable price. After we penetrate the market, we plan on introducing customized solutions for the consumers along with the maintenance and installation facilities, product guarantee to attract the larger consumer base.

1.3 BUSINESS OBJECTIVE

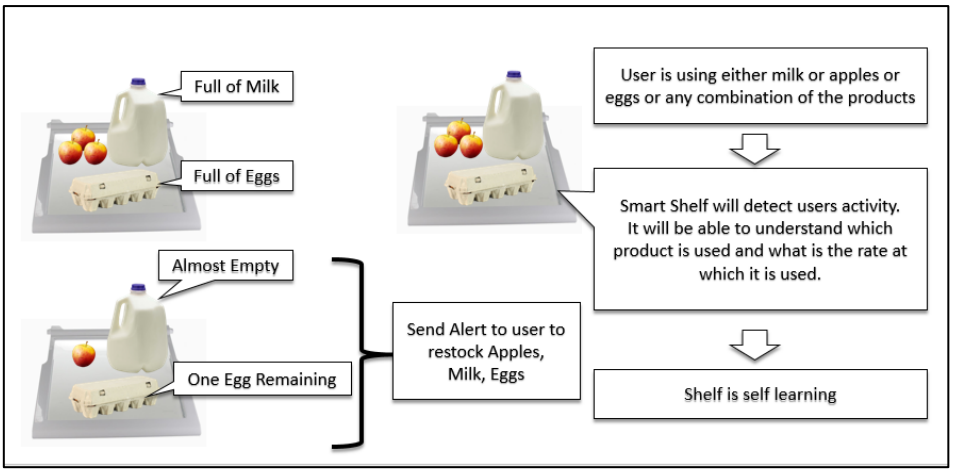
a. Achieve 2% market penetration by the end of the two years
b. Limit the recovery period and start making profit by the end of three years
c. Get 50% revenue from the Refrigerator OEM by five years
d. Maintain the product quality throughout and create a brand name that stands for quality

1.4 PRODUCT DESCRIPTION

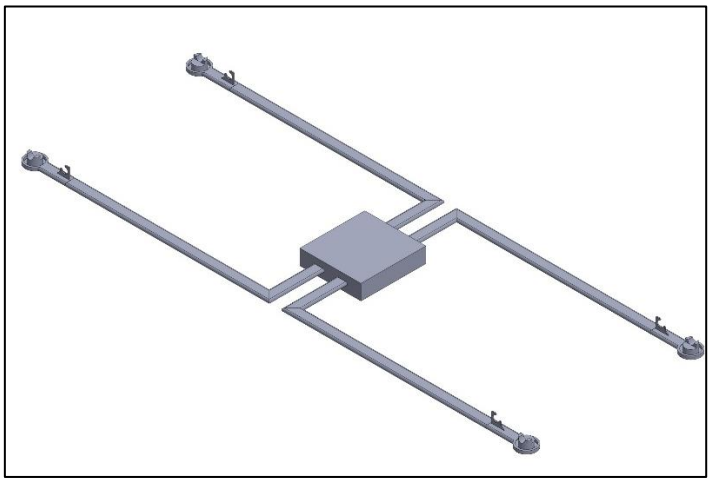
A Smart Refrigerator Shelf is a shelf that automatically detects items on it, sends you alerts which item is being used and is taken out at that time. It can keep the track of the multiple items.

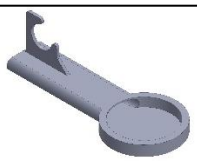
Our product can make any regular shelf a smart shelf. It is like an attachment to the existing. The product is very easy to install which comes along with the very clear installation guide. The maintenance required is almost negligible apart from the battery change that is required.

The main working of the product can be seen in the figure below.



The design of the product looks as shown in the figure below. The product consists of four force resistive sensors, one Arduino Yun board and Battery. Basic design has the covering for Arduino board, batteries and Force resistive sensors. The channels that run from the housing to the sensors cover the multiple wires that connect everything and get the product working.



	Housing to keep the force resistive sensors safe from wear and tear
	Plunger that distributes the weight uniformly over the force resistive sensors
	Battery and Arduino Housing. It houses the essential part of our product that is Arduino which is like a brain of the product.

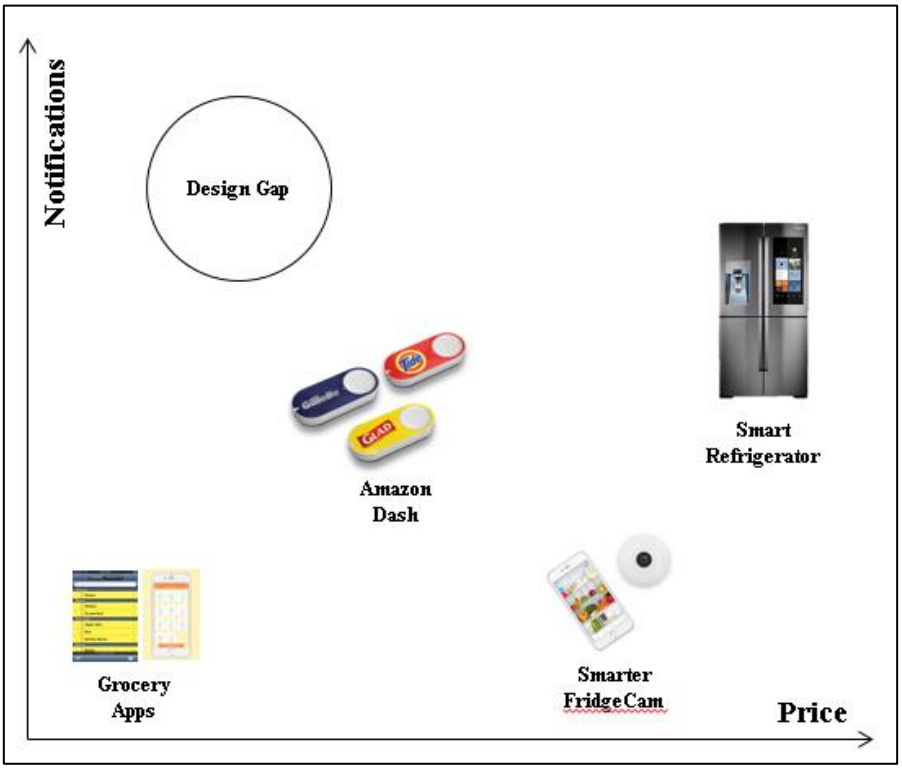
The product records the total weight of the all items. Every time the product that is taken out, the weight difference is taken as the reference to predict which item is taken out and alerts the user with which product is being used.

With these alerts, anyone who manages the inventory will be updated all the time with what is being used. This will make sure that even if someone else uses the items or the same shelf is being collectively used, it is easy to keep track of when the items are needed to be restocked.

1.5 MARKET ANALYSIS

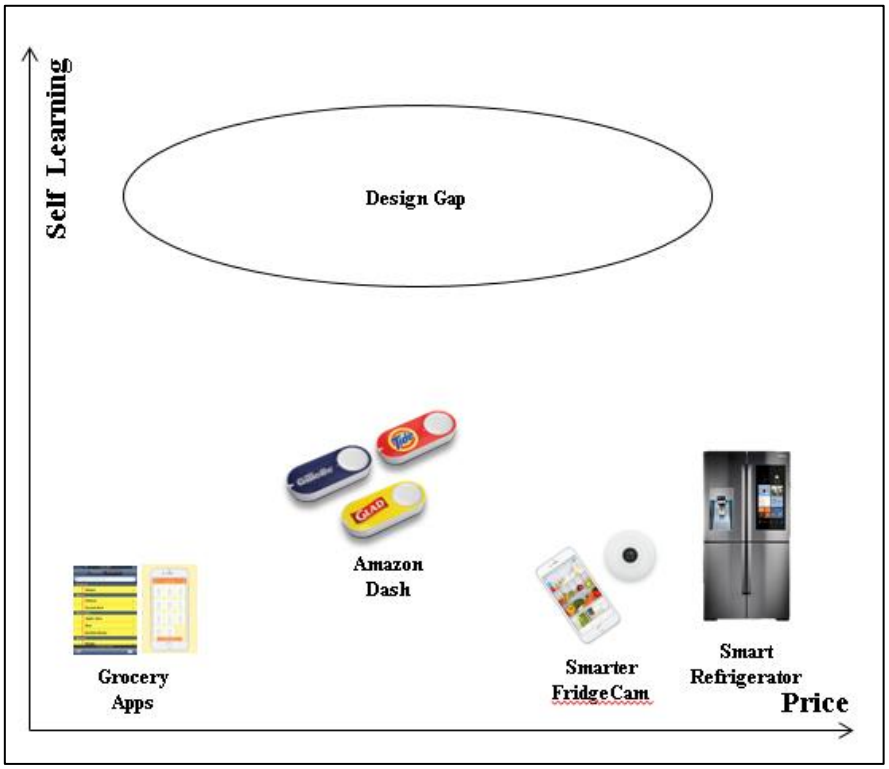
To launch any product in a market, understanding the market of the existing products is very important. The design attributes which are integral to our product need to be compared with the existing ones. The features that these products offer and at what price, will also affect the attributes of our product.

Two most important features of our product are that it sends notification and that it predicts the item that is used which is self-learning. We have conducted the market analysis for these two features as shown in the figures below.



As it can be seen in the graph, there are many products which can offer such a feature, the plot of accuracy and level of detail of sending notifications v/s the price at which it is offered is shown. As it is seen, the product which alerts the user about which item is being used and at a very low price is missing from the market. Even though the products like Amazon dash

track the item, the button has to be bought separately for each item. Smarter fridge Cam and Smart Refrigerator offer similar characteristics, but the price for which it is offered is really high.



In the image shown above, for our other important feature, we plotted the quality of self-learning v/s price, to understand the market. The products which are available right now are not self-learning i.e. they do not predict which item is used on its own. So, this created a huge market gap where we can venture into.

After the market analysis, we found the great gap in the market with the products which are alerts the user or send the notifications and is self-learning at the same time, at the low or affordable price. The analysis showed that the product had a good chance in the market considering above factors. Our product will compete with these existing products and we are sure, it will create the unique position in the market with the products that self-learning and notification.

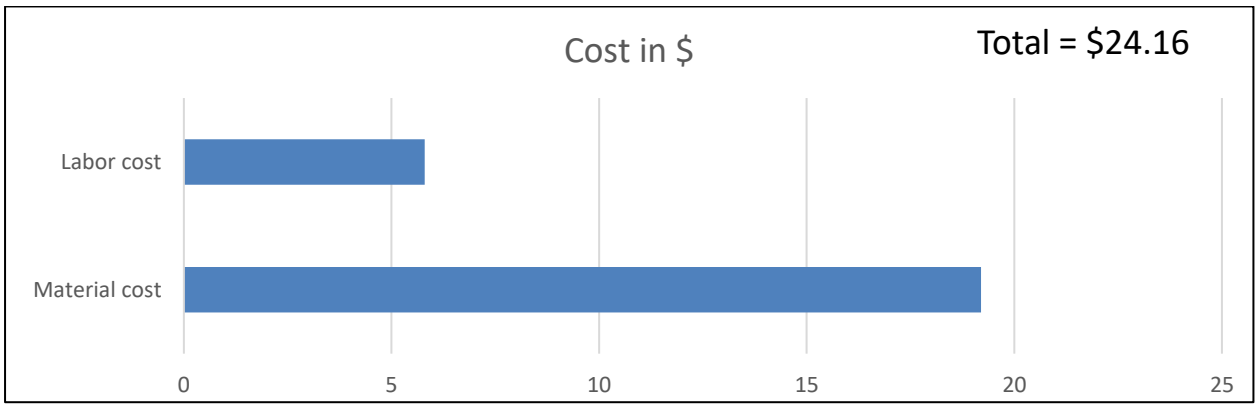
1.6 MARKET ESTIMATION

We have considered US as market for our product. There are 125.82 million household in US in 2016. We think that every household has at least refrigerator are our product is retrofit to the refrigerator. We are assuming conservative estimate of 1% these refrigerator owners to be interested in our product. This accounts to 1.2582 million market size for products like our product smart fridge refrigerator. We are taking conservative estimate of 2% of market

penetration. This accounts to roughly 25,000 products in year one. We have also considered that our sales will increase by rate of 10% for next five years.

1.7 CAPITAL AND PERSONNEL RESOURCES

Initially, we prepared a Bill of Materials (BOM) and started searching for vendors selling those parts. We used the "Alibaba" website as it has millions of sellers and allows us to verify if the sellers are legit. After some careful research, we narrowed down on some vendors. We took the quotations for the price and calculated the cost of producing 1 item. The material cost was found out to be $19.2. Simultaneously, we also found as estimate of the market size for our product. We were expecting to sell 25000 units of our product after the initial year of development with 10% increase in sales each year. This gave us the material cost for each year.



After arriving at the figures above, we started detailing the manufacturing costs. We decided that we need an electronic workstation, a computer and an assembly workstation. For producing 25000 units a year with 2 workers working in tandem, we would require them to produce 100 units per day (assuming 250 work days in a year). We decided that we would have 1 line manager as well. The salaries were decided to arrive at an assembly cost of $4.96 per unit. This brought the total cost of the product to a total of $24.16. In addition to the staff above, we decided to get a marketing expert, business administration expert and a business manager.

For the location of the production facility, we decided to select Tempe. Tempe is a college town, so it gives us access to the huge talent pool from Arizona State University. The rent is also relatively less in Tempe allowing to obtain a big space at low cost. Furthermore, the cost of living is less compared to other places in the U.S. With all these benefits, Tempe was an easy and obvious choice for location of our facility.

We added miscellaneous costs like electricity, office material cost, phone and internet cost, etc. to arrive at the final figures. These are given in detail in the next section. With all the costs calculated, we decided to aim for getting $750,000 as an initial investment.

2. FINANCIAL DATA

2.1 CAPITAL EQUIPMENT AND SUPPLY LIST

Part List	#	$	Total
Arduino UNO Wi Fi OEM	$ 1.00	$ 10.00	$ 10.00
Force Resistive Sensor	$ 4.00	$ 1.26	$ 5.04
3D Printed Parts	$ 1.00	$ 2.00	$ 2.00
Wires	$ 20.00	$ 0.10	$ 2.00
Battery	$ 1.00	$ 0.16	$ 0.16
Material Cost			**$ 19.20**
Labor Cost			
Assembly of product			$ 4.96
Cost per unit			**$ 24.16**

Manufacturing (equipment, transportation, set-up)					
Name	**Use**	**Cost (initial)**	**Cost (per year)**	**Cost Per Part**	**Details of Cost**
Electronic workstation	Manufacturing	$1,500			
Computer	Manufacturing	$500			
Top Assembly Station	Manufacturing	$500			
Line Worker 1	Manufacturing		$24,000	$1.92	$12/hr, $1.92/ part
Line Worker 2	Manufacturing		$24,000	$1.92	$12/hr, $1.92/ part
Line Manager	Manufacturing		$28,000	$1.12	$14/hr, $1.12/ part
Salaried Worker 1	Marketing		$50,000		
Salaried Worker 2	Business Administration		$50,000		
Salaried Worker 2	Manager		$60,000		
Production Space	Property	$15,000			
Office Materials	Office Needs		$350		
Part Material	Manufacturing			$19.20	
Phone/ Internet	Office Needs		$400		
Energy Cost			$1,200		
Unexpected Cost			$400		
Shipping Additional				$0.84	
Number of Parts annual	**25,000**				
Total		**$17,500**	**$ s238,350**	**$25.00**	

Fixed cost	
Development costs (engineering, industrial design, marketing)	$23,500
Engineering	$10,000
Industrial Design	$1,000
Marketing	$10,000
Manufacturing (equipment, transportation, set-up)	$2,500
Fixed operating cost (per yr)	
Employee (salary)	$236,000
Administrative (rent, utilities, insurance)	$16,950
Operating (maintenance, sales, marketing)	0
Manufacturing cost (per unit)	
Material cost for all parts	0
Labor cost (assembly, transportation, testing, ...)	$76,000.00

Part are chosen based on the price and quality. We have projected 25,000 units at the beginning this make sourcing parts from China easier because of heavy discounts on the mass purchase. Tempe is location for our company and cost for production space, energy cost and phone / internet is considered based on location.

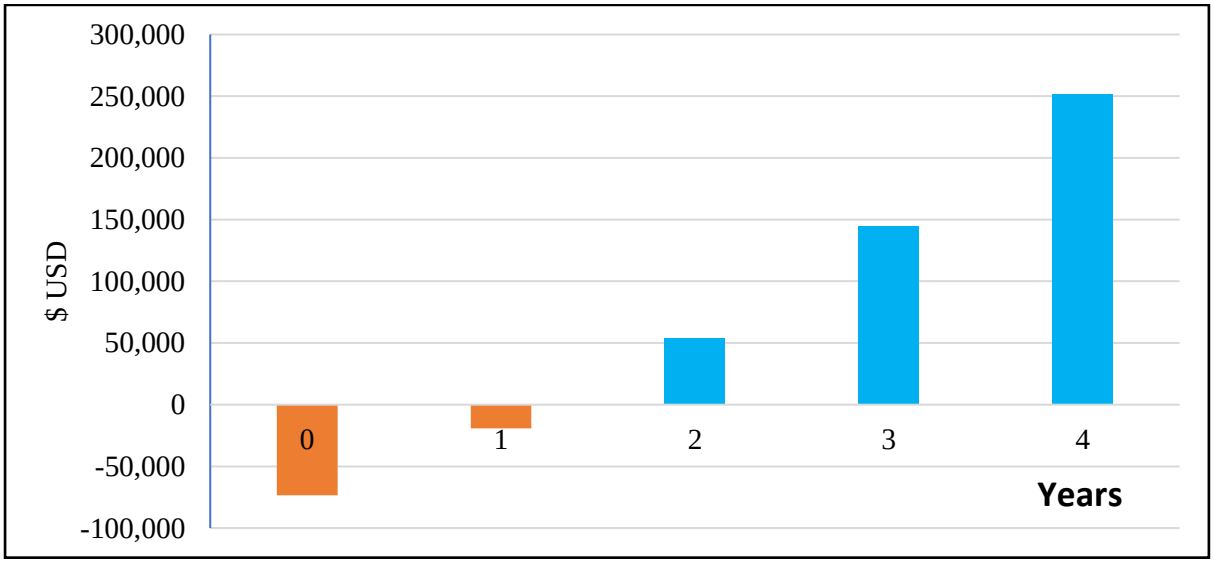
2.2 PRO-FORMA INCOME AND COST PROJECTION

Price	$45.00				
Cost per unit	$25.00				
Starting sales	25000				
Sales growth rate	10%				
Tax rate	39%				
Discount rate	6%				
Project year	0	1	2	3	4
Income					
Investor contribution	$750,000.00				
Total sales	0	25000	27500	30250	33275
Sales revenue	0	1125000	1237500	1361250	1497375

We have considered that year 0 is for product development and engineering. The tax rate is 39% for Tempe location. Price for the product such that break- even is achieved in 3 years. Discount rate is 6 % and sales growth to be 10% year from year one onwards.

2.3 BREAK-EVEN ANALYSIS

Expense					
Initial cost	$23,500				
Cost of product	$0.00	$625,000.00	$687,500.00	$756,250.00	$831,875.00
Fixed operating cost	$50,000	$338,950	$338,950	$338,950	$338,950
Net profit	$676,500.00	161050	211050	266050	326550
Post-tax profit	$676,500.00	98240.5	128740.5	162290.5	199195.5
Running cash balance	$676,500.00	$774,740.50	$903,481.00	$1,065,771.50	$1,264,967.00
Present value conversion	$676,500.00	$730,887.26	$804,094.87	$894,842.30	$1,001,972.34
Breakeven	-$73,500.00	-$19,112.74	$54,094.87	$144,842.30	$251,972.34



3. SUPPORTING DOCUMENTS

3.1 EXISTING PATENTS AND REASONS FOR WHY OUR PRODUCT WOULD NOT BREACH THEM

3.1.1 Smart refrigerator, refrigerator system including the smart refrigerator, and control method thereof (WO 2014016212 A1)

Description: A smart refrigerator is presented, which includes: an image capture device, disposed inside the refrigerator and used for capturing an image of an object stored in the refrigerator, and a control device, used for receiving an instruction to control the image capture device to capture an image, receiving the captured image, and sending the received image to a remote terminal. Based on the smart refrigerator, a refrigerator system including the smart refrigerator and a control method thereof are also presented. By adopting the technical solutions of the present invention, the user's demand of a smart refrigerator, a storage situation of which is remotely obtained to arrange purchasing, can be met. Dissimilarities are given below:

a) Our product does not use image capturing device.

b) Our product notifies when it is time to restock an item.

c) It uses MATLAB code to understand what items are stored and quantify them.

3.1.2 Refrigerator with a function to confirm items stored therein (US 20020066279 A1)

Description: The refrigerator has a reader/writer for writing information in and reading information from a contactless memory medium, an information holding device for storing information read by the reader/writer, and an information display device for displaying the information stored by the information holding device. As a result of the invention of the refrigerator, the number of items such as foods that can be unconsumed and discarded because of the arrival of their consume-by dates is reduced in a refrigerator, and items such as foods stored in the refrigerator can be confirmed without opening the door. Dissimilarities are given below:

a) Our device does not require manual entry of data every time an item is used.

b) Our product sends notifications via IoT.

c) Our device detects items present in the fridge and monitors their quantity.

3.1.3 Method and apparatus for keeping a check on the storage time for goods in a storage (WO 2002015073 A1)

Description: The invention refers to a method and an apparatus for registering and supervision of the positions and time of storage of articles entered into a cabinet or other

delimited space. A preferred field of application is refrigerators in which one or several cameras at selected occasions take pictures of the interior of the refrigerator. These pictures are treated in an image analyzer which transfers clear pictures of all articles stored on each shelf in the refrigerator to a computer for registration. In the computer, there is stored for each article information on the time of entry in a list containing article denominations. For distance communication, the computer can be connected to a central computer having information about all articles marketed on a national basis and including both pictures and denominations. It is possible to establish a remote connection, via Internet or via mobile phone, to the computer for collecting information on the content of the cabinet, for example when shopping in a store.

a) Our device does not record position and time or storage of items in fridge.

b) Our device does not use camera.

c) Our device does not allow user to check quantity of item whenever required.

3.2 TECHNICAL ANALYSIS:

The problem of developing the complicated product like the smart shelf comes with the challenges of its own. There are two main parts of the product development: Hardware and the logical Algorithm part.

As the product is the shelf of the refrigerator, the difficulties that are faced are the Low temperature and the Stress induced on the shelf when there is a weight on the shelf. For this reason, structural analysis while taking the low temperature as a constraint. Also, the natural frequency of the shelf should not match with that of the natural frequency of the compressor. If the resonance takes place, then the amplitude of vibration increases.

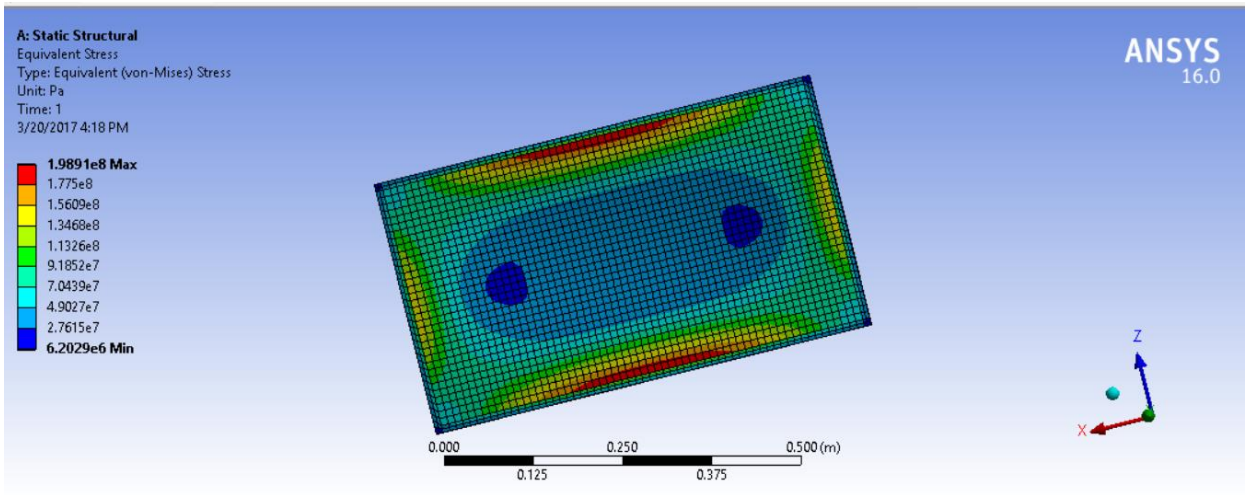
The refrigerator shelf problem has the following objectives:

a) Minimize the volume of the refrigerator shelf.
b) Maximize the first natural frequency of the refrigerator shelf to avoid resonance with compressor.

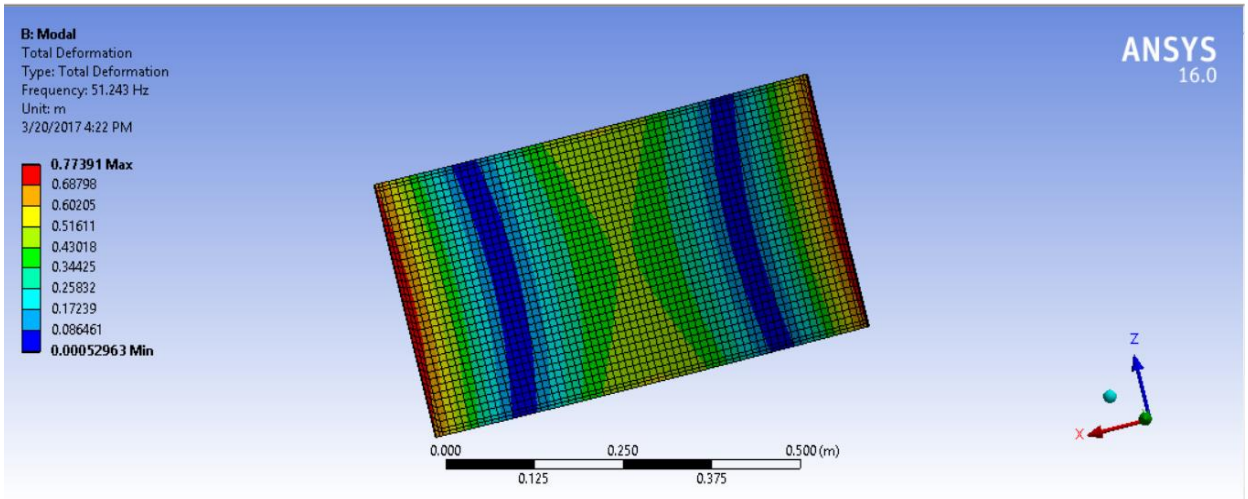
After the basic analysis, Design of Experiments and Response Surface Optimization are performed to find the optimal solution. The yield stress of the material is taken as the maximum limit of the induced stress and minimum limit of the frequency is given for the optimization.

The length and width of the shelf are taken to be equal to typical refrigerator dimensions (630 mm x 360 mm).

Yield stress of material (We have taken structural steel which has a yield strength of 200 MPa)



Equivalent Stress plot (Structural + Thermal)



Total Deformation plot (Modal)

Above are the final plots for the values of Equivalent Induced Stress and Modal Frequency. The geometry used for the final plots is obtained by the process of Design of Experiments and Response Surface Optimization.

For the analysis, the bottom 4 faces of the outer shelf (shown in green) are fixed i.e. zero displacements in the global X, Y and Z directions.

A temperature of 4 °C is applied around the entire body of the shelf to take care of load due to thermal contraction and reduced yield stress of the shelf inside the fridge.

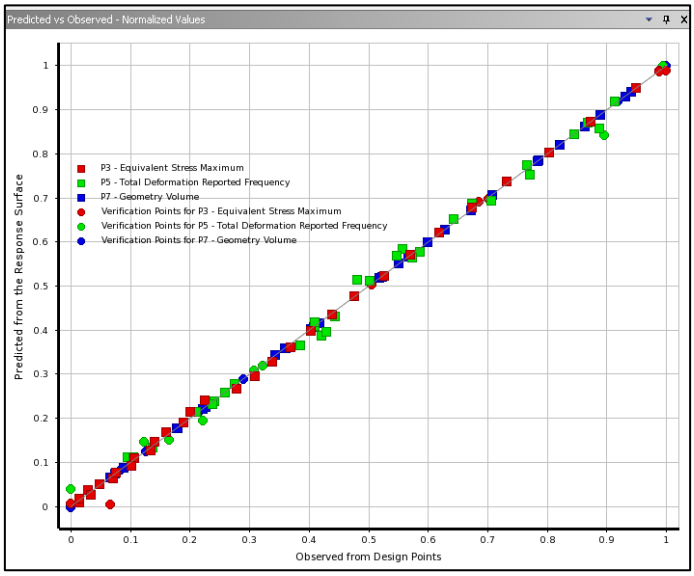
Design of Experiments (DOE) is performed to understand the influence of the input parameters by conducting series of experiments with a set of parameters, within a range, which minimizes the number of runs needed. The purpose of a Design of Experiments is to gather a representative set of data to compute a Response Surface, and then run an Optimization (for a Response Surface Optimization).

Method Used: Optimal Space Filling with user defined design points (30)

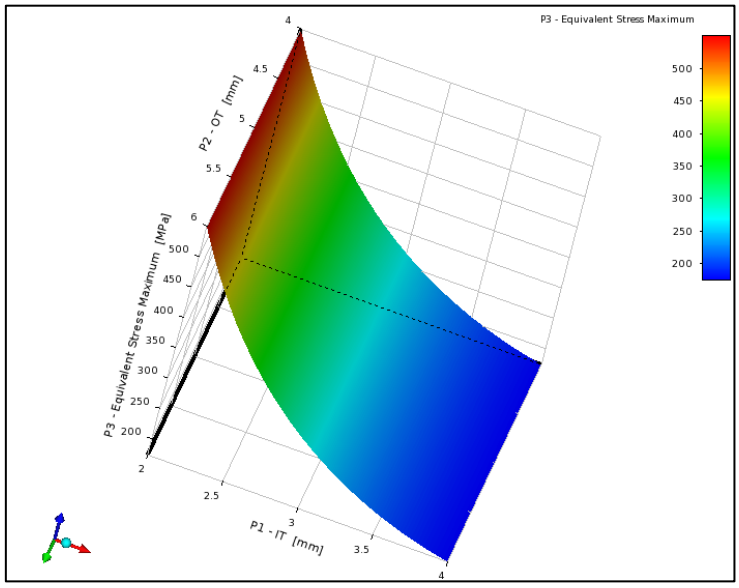
Design Type: Max-Min Distance

In the next step, Response Surfaces provide the approximated values of the output parameters, everywhere in the analyzed design space, without the need to perform a complete solution. A response surface is computed from the DOE results for each output parameter.

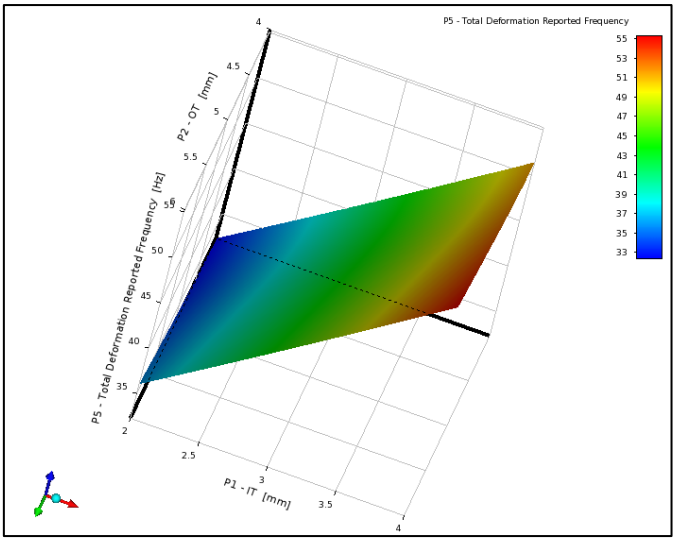
Response Surface Model used is standard response surface model with 8 verification points. This is usually a second order polynomial fit.



Goodness of fit for the workbench



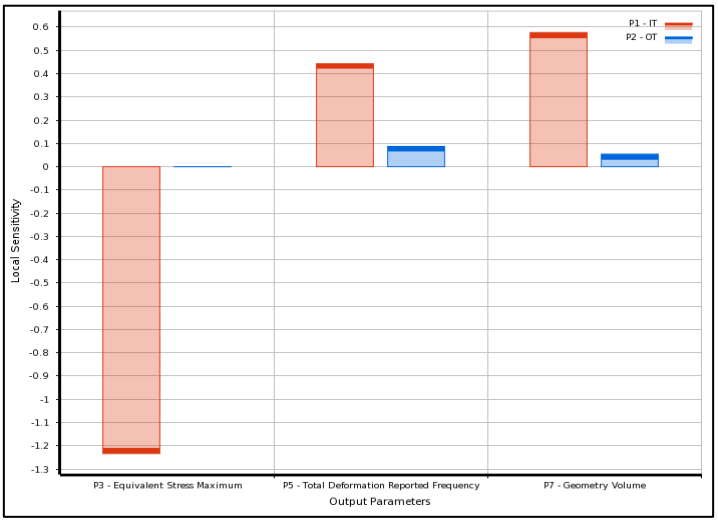
Response surface of equivalent stress maximum



Response surface of total deformation reported frequency

The above plot and Response Surfaces show that the method chosen for the Response Surface gives the close values to the actual, making it a good fit.

This analysis also gives us the sensitivity of the change in the input parameters on output parameters.



Sensitivity Plot

Last step is to optimize this response surface obtained.

Objectives to be optimized:
a) Total volume of the shelf
b) Total Deformation frequency
Constraint: Equivalent stress in the shelf

Algorithm Used: **Multi-objective Genetic Algorithm (MOGA)**

This algorithm is used when there are multiple objectives to be optimized. It simultaneously finds pareto-optimal designs. It is available for all types of input

parameters and can handle multiple goals. That is why we have chosen MOGA Optimization Algorithm.

Table of Schematic D4: Optimization , Candidate Points

	A	B	C	D	E	F	G	H	I	J
1	Reference	Name	P1 - IT (mm)	P2 - OT (mm)	P3 - Equivalent Stress Maximum (MPa)		P5 - Total Deformation Reported Frequency (Hz)		P7 - Geometry Volume (mm^3)	
2					Parameter Value	Variation from Reference	Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	◉	Candidate Point 1	3.59	5.9577	199.63	0.00 %	51.137	0.00 %	8.6015E+05	0.00 %
4	○	Candidate Point 1 (verified)			198.91	-0.36 %	51.243	0.21 %	8.6015E+05	0.00 %
5	○	Candidate Point 2	3.7979	5.9747	184.59	-7.53 %	53.211	4.06 %	9.0359E+05	5.05 %
6	○	Candidate Point 2 (verified)			183.55	-8.05 %	53.15	3.94 %	9.0359E+05	5.05 %
7	○	Candidate Point 3	3.9602	5.7953	175.53	-12.07 %	54.365	6.31 %	9.3378E+05	8.56 %
8	○	Candidate Point 3 (verified)			173.3	-13.19 %	54.244	6.08 %	9.3378E+05	8.56 %
*		New Custom Candidate Point	3	5						

The main objective of the design is to minimize the volume so as to maximize the space to keep the items as some space will be taken by the packaging of the weight sensor, Arduino and other hardware.

Improvements with the design optimization

Variable	Initial Value	Final Value
Volume	926600 mm^3	860150 mm^3

Other Challenges that Include is finding and calibrating the sensor to get the correct output. And developing and writing the algorithm that correctly guesses the item taken out.

Other main challenge is to calculate or gauge how much will be the error in further calculations if one guess that is made is wrong and how to correct it.

The results we have obtained are reasonable.

Variable	Initial Value	Final Value
1. Outside Thickness	6 mm	5.96 mm
2. Inside Thickness	4mm	3.6 mm

Optimization Results

3.3 BENCHMARKING

Following is the comparison study with the existing products and how we are trying to make it better in our product. We are trying to make it more cost effective with better monitoring ability and lesser installation and maintenance time compared to other available products in the market.

Products/ Attributes	**Refrigerator Shelf**	**Amazon Dash**	**Smart Fridge**	**Fridge Cam**	**Grocery Apps**	**Contract Sellers**
Cost (in $)	Upto 45	Upto 20	Upto 6000	Upto 200	Upto 10	Upto 30
Monitoring Ability	Advanced	Negligible	Intermediate	Intermediate	Basic	Negligible
Maintenance	Low	Zero	High	High	Zero	Zero
Quality	High	Intermediate	Very High	High	Intermediate	Intermediate

Smart refrigerator shelf has the better monitoring ability compared to any of the products available in the market and its cost effective considering the very high cost of Smart Fridge and FridgeCam. Where our product stands out is its Innovative food tracking technology which recognizes what food you have in, learning over time to better understand the contents of your fridge. Smart refrigerator shelf requires very less maintenance time as battery is the only part which is to be replaced after its expiry.