

Redesigning the Modern Microwave

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Abstract

This report looks into what systems engineering is as a whole, starting from its fundamental ideas to the history of the subject and where it has been implemented in the world today. It also details to re-design process of a household microwave using systems engineering techniques ranging from the initial requirements from the customer to in-depth analysis using QFD 1 and QFD 2 to name a couple of examples.

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1.0 Introduction to the approach of Systems engineering

The international council on systems engineering defines a system as “an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not”. This gives a brief overview of what an overall system is and does however a system that is “engineered” is “designed to interact with an anticipated operating environment to achieve one or more intended purposes while complying with applicable constraints” [1].

In essence to approach something from the view of a systems engineer is to ensure that the holistic approach is undertaken to ensure the whole picture/problem is viewed. The benefit of doing this when creating a new product is that if planned correctly in the early design stages the overall outcome should have less issues and hiccups. It has been seen time and time again in the world of engineering where products are recalled or are unreliable due to the manufacture not undertaking the practice of having good systems engineering principles. An example of this includes the Challenger space shuttle disaster which saw the loss of seven astronauts due to a small O-ring failure and in turn allowed hot gasses to escape and cause breaking up of the shuttle. It has been noted that due to the overlooking of certain parts deemed to be less important than others this accident was almost set to happen from the very beginning. If a more holistic approach was undertaken in the design and manufacture process the seven astronauts may still be alive today [2].

To expand greater on safety in systems engineering, the book “Engineering a safer world” by Nancy G. Leveson states that safety and reliability are different proprietaries and that one does not imply nor require the other [3]. In simple terms a whole system can be extremely reliable however it can then be very unsafe too and vice versa an increase in safety can impact its reliability. In relation to the challenger incident, by manufacturing the shuttle to withstand outside heat and arrive at the destination reliably it is clear that safety in small areas were overlooked hence the breakup of the shuttle.

In complex systems that have multiple subsystems accidents can occur due to the incorrect interaction between them which again goes back into the case study of the Challenger incident as the hot gases expelled from the booster which is one system, this then interacted with the O-ring subsystem thus subsequently causing catastrophic failure. This can be looked at as each subsystem only satisfying their individual requirements which is not a positive thing as if each system was designed with the other in mind it would not have failed [3].

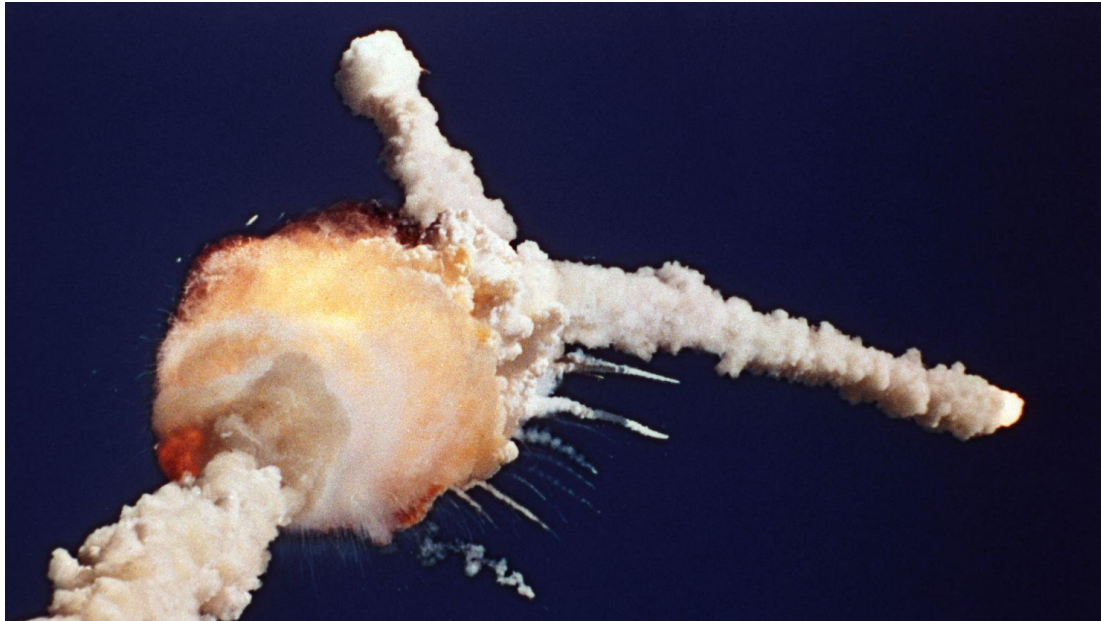


Figure 1 Challenger Disaster

Over the past hundred years technology has advanced quicker than ever and an outcome of this is the complexity of systems. This can be evidently seen from the invention of flight, as in 1903 with the Wright brothers successfully took to the skies. However 66 years later humans put the first man on the moon which is such a small time frame when you think of how slow technology had advanced previous to the industrial revolution.

So to put it simply the complexity of systems has well advanced and still is advancing quicker than us humans can comprehend. In a complex system sub systems are created to allow the design and manufacture process to become more manageable however this approach is used regardless of how complex the system is. The figures below demonstrate how far the complexity of systems have come in terms of flight, from the first ever plane to a 1960s SR-71 Blackbird which was used for reconnaissance at Mach 3+ and was far ahead of it's time to finally a Sukoi Su-57 6th generation Fighter Jet which is at the cutting edge of today's technology.



Figure 2 the advancements of Aircraft

To touch briefly on the idea of systems engineering, the phenomenon dates back to the 1940s with a company called “Bell Telephone Laboratories” where it is understood that during World War II the concept was implemented to try and speed up technological advancements at a rapid rate as it was needed for the Allies to have an edge.

The founders of systems engineering defined it as a function with five phases. The first being programme planning which encompasses the whole idea and requirement. The next is exploratory planning which includes aspects such as problem definition, system analysis and selecting the best system. The third is development planning which is essentially the previous step but analysed into further detail. The fourth step is studies during development which essentially looks into the study of what is being developed, how it is going to be integrated into the system and the overall testing which is vital to ensuring each part of said system will function as required. The fifth and final step is current engineering, to put it simply this is done while the system is in service and being used. It looks at how it performs with the end user and helps iron out any issues that may have arose when implemented into the real world. Generally speaking this is where most of the teething issues and recalls happen as unexpected problems that have not been thought of before may occur [4].

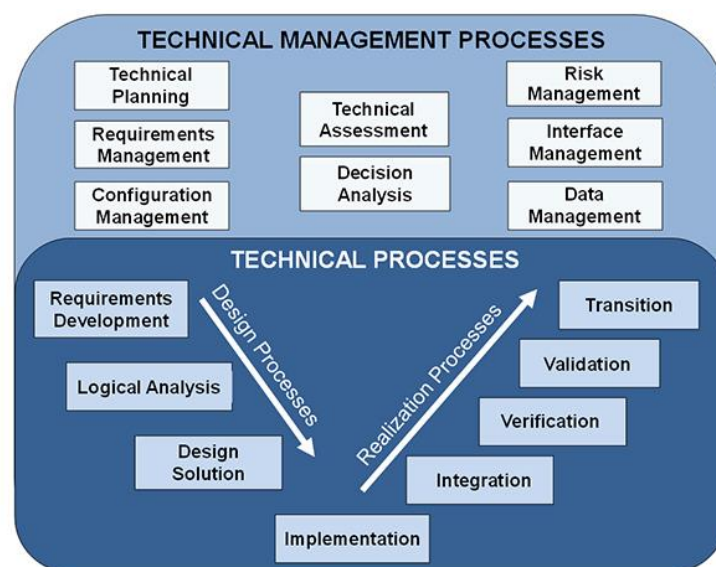


Figure 3 Table detailing technical processes during system design

When designing a new system there is an overall main purpose for the customer, this aligns with the functional requirement and encompasses the need to have this system in the first place and how it should perform [5]. As you move down the tree the next key step is the performance requirements which is where the question of how well does this system need to perform comes into play as without knowing this crucial areas may be missed in the design process. To give an example on performance requirements, if an aircraft is being designed the features that ensure it works as intended by the customer must be correct, at this stage the type of Aircraft will already be decided on in the functional requirement section (does it need to be a passenger plane or a multi role fighter jet). If in this example

the customer requires a fighter jet it must be decided how this jet must perform, does it need to have vertical take-off and landing (VTOL) so it can deploy from a sea carrier that has not got a slingshot system, what type of radar cross section does it require as it may be used for stealth bombing missions and what type of thrust vectoring does it need if any as 3D thrust vectoring is a new technology adapted over the years to allow a jet to manipulate it's pitch, yaw and roll from the engine alone [6]. The final important part of this tree is implementation requirements, what standards are met during implementing this system. To reference back to the fighter jet, is this system proprietary of the country who manufactured it such as the F22 Raptor where only the Americans can operate it or will it be able to be sold to NATO countries such as the F35 and if so what adaptations need to be made to ensure the customers can operate such an Aircraft.

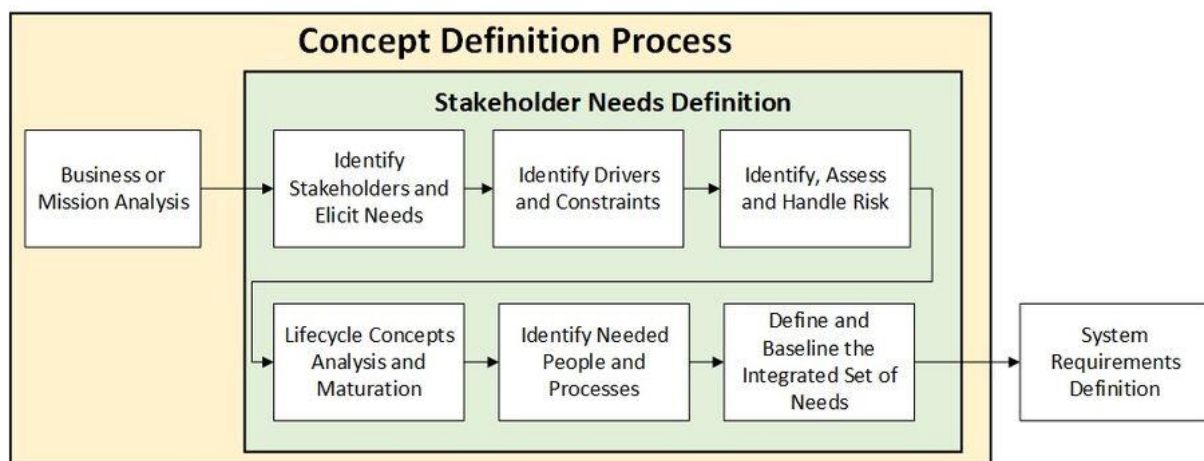


Figure 4 Concept Definition Process in relation to key Stakeholder requirements

Stakeholders is another area to think about when designing a system as the significantly influence areas of the design and manufacturing process. To put it simply the stakeholders in the design of a car can range from senior managers overseeing the project, material/parts suppliers from other companies and the end user of said vehicle once it rolls off of the assembly line. Therefore in the process the company has to think about appeasing all stakeholders and managing the influence they have to ensure budgets are not overspent and lead times are kept to a minimum [7].

Relative to Org	Stakeholder	Typical Expectations
External	Customer	Expected level of product quality, delivered on time, affordable, life cycle support & services
	Subcontractors/vendors	Well defined requirements
	Local, State, National Public	Products must not contaminate the environment
Internal	Org Management	Internal Commitments met (cost, schedule), good status provided, compliance with org policies, directives and procedures
	PM	Expected technical work products delivered on time and can be used for decision making
	Technical Team members	clear tasks, job security, rewards, teamwork
	Functional Organizations (e.g., test)	Test support products available, clear test requirements, recognition for project help

Figure 5 Table depicting typical stakeholder expectations

The figure above gives a good indication as to what is generally required by stakeholders from external (stakeholders outside the company) to internal (stakeholders who generally work within the company). It should be noted that just because certain stakeholders are not in said company commissioning a project it does not mean they have any less influence in how the product is designed as without continuous feedback from say a customer the commissioner has no changing/challenging requirements to work to.

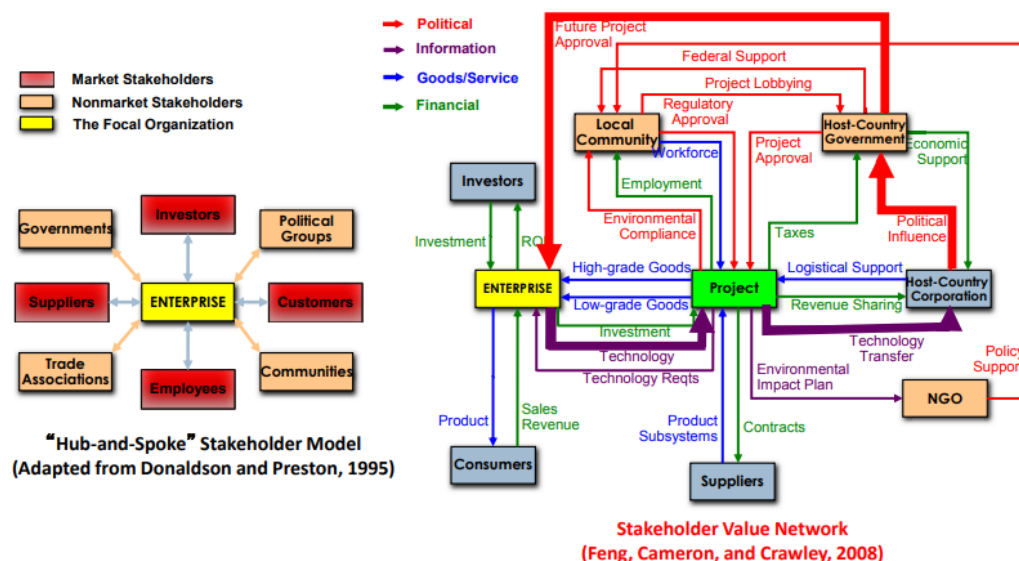


Figure 3 in Wen Feng; Edward F. Crawley; Olivier de Weck; Rene Keller; Bob Robinson. "Dependency structure matrix modelling for stakeholder value networks". Proceedings of the 12th International DSM Conference, Cambridge, UK, 22.-23.07. 3-16.DSM 2010. CC by-nc-sa 3.0.

Figure 6 Hub and Spoke stakeholder model

The figure above depicts a hub and spoke model which visualises which stakeholders interact and influence one another with the key in the corner depicting what type of interaction they may have for example the project in the middle providing jobs to the local community which will have a positive impact on the area's economy while also trying to comply with environmental factors as new factories/infrastructure usually will be built to accommodate a large project.

When designing a new system and subsystems it is clear that due to numerous factors failure is almost certainly inevitable in some degree however using the FMEA (failure modes and effects analysis) method, issues can be ironed out before hand as it is better to design the right thing than design the thing right. This phenomenon will be touched on later in the report in respect to the design case, below is a figure displaying the universal process of FMEA and its steps will be implemented into the microwave interface re design [8].

Process for performing a universal FMEA	
Step	Activity
1	Identify Item (System, sub-system, part, process step) and determine boundary
2	Determine function of the item
3	Determine for each function: • potential failure modes • effects of potential failure modes • failure mechanisms of potential failure modes • causes of potential failure modes • current employed prevention or detection methods
4	Tabulate and assign ratings to: • seriousness of occurrence • probability of occurrence • detectability of occurrence
5	Calculate Risk Priority Number
6	Determine corrective actions where appropriate
7	Assess Corrective Action

Figure 7 Universal process for performing FMEA

2.0 Design Case

This section of the report looks into the design of a modern microwave interface using systems engineering principles.

2.1 Customer Requirements

The overall requirement from the customer is that they have a microwave with an interface that is easy and efficient to use in a small timescale therefore a complete design overhaul is required to ensure the usability of the microwave is better which may affect the larger system as a whole. The reason for this system requirement derives from the customer stating that “The current microwave at work is cumbersome to use with a multitude of complex buttons and operations that the average user struggles to use, due to this precious break time at work is being taken up by something that should be fairly simple to use”.

In terms of system boundaries the microwave is the main boundary with the input being food and the output is having the food cooked to a near perfect temperature with the interaction with the interface being quick and efficient. To outlay the stakeholder it is clear that the main stakeholder is the operator and other main stakeholders include the general public who may purchase this system.

Level 1	Originator	Level 2	Level 3
Performance			
	User	The user requires that the microwave is able to be used in a quick and efficient process	NFS
		The user requires that the microwave has all standard features of a microwave	NFS
		The user requires that the microwave can heat a large variety of foods	NFS
		The user requires that the microwave can heat food efficiently with a stable power supply	NFS
User Friendly			
	User	The user requires that the microwave can auto set the timer and heat depending on food	NFS
		The user requires that the microwave does not have an excess of buttons and is easy to use	NFS
		The user requires that the microwave has an easy to read screen with ability to observe the food cooking	NFS
Safety			
	User	The user requires that the microwave has a low db level to keep excess noise to a minimum	NFS
		The user requires that the microwave has safety features such as auto stop if the door opens	NFS
		The user requires that the microwave will shut off if it overheats or power surges during operation	NFS

Figure 8 Table detailing different requirements

The figure above depicts the requirements of the system in an easy to read format. Level 1 dictates the initial sections that need to be considered in the design such as performance and safety. Level 2 breaks down what sub system requirements need to be included in relation to the user and intricate design. Level 3 denotes what sections of Level 2 are non-functional systems (in this case all of them are).

The importance of outlining the initial customer requirements is key as it allows for the designer to have a set list of subsystems that need to be included in their best form. This also ties into the theory of FMEA and reliable engineering due to being able to problem solve and find solutions for errors from the beginning.

2.2 Pairwise Comparison

Pairwise comparison of requirements											
1 = No Preference, Reciprocal = 1 2 = Slight Preference, Reciprocal = 0.5 5 = Preference, Reciprocal = 0.2 9 = Strong preference = 0.11											
	The user requires that the microwave is able to be used in a quick and efficient process	The user requires that the microwave has all standard features of a microwave	The user requires that the microwave can heat a variety of foods	The user requires that the microwave can heat food efficiently with a stable power supply	The user requires that the microwave can auto set the timer and heat depending on food	The user requires that the microwave does not have an excess of buttons and is easy to use	The user requires that the microwave has an easy to read screen with ability to observe the food cooking	The user requires that the microwave has a low db level to keep excess noise to a minimum	The user requires that the microwave has safety features such as auto stop if the door opens	The user requires that the microwave will shut off if it overheats or power surges during operation	
	1	2	2	2	5	5	5	5	2	1	Row Product
The user requires that the microwave is able to be used in a quick and efficient process	1	2	2	2	5	5	5	5	2	1	10000
The user requires that the microwave has all standard features of a microwave	0.5	1	1	2	5	1	5	9	2	1	450
The user requires that the microwave can heat a variety of foods	0.5	1	1	1	5	5	5	5	2	1	625
The user requires that the microwave can heat food efficiently with a stable power supply	0.5	0.5	1	1	5	2	5	5	1	1	62.5
The user requires that the microwave can auto set the timer and heat depending on food	0.2	0.2	0.2	0.2	1	1	2	2	1	1	0.0064
The user requires that the microwave does not have an excess of buttons and is easy to use	0.2	1	0.2	0.5	1	1	5	5	2	1	1
The user requires that the microwave has an easy to read screen with ability to observe the food cooking	0.2	0.2	0.2	0.2	0.5	0.2	1	2	2	1	0.00064
The user requires that the microwave has a low db level to keep excess noise to a minimum	0.2	0.11	0.2	0.2	0.5	0.2	0.5	1	1	1	4.4E-05
The user requires that the microwave has safety features such as auto stop if the door opens	0.5	0.5	0.5	1	1	0.5	0.5	1	1	1	0.03125
The user requires that the microwave will shut off if it overheats or power surges during operation	1	1	1	1	1	1	1	1	1	1	1
											nth root of row product
											Total Normalised
											21.0616251
											15.4458969
											15.9617271
											12.6788505
											5.05952652
											8.38478399
											4.01892477
											3.07494354
											5.92893762
											8.38478399

Figure 9 Pairwise comparison table of requirements

The figure above utilises complex math functions to allow the requirements to be inputted and compared with one another. The key shows that the higher the 1-9 number is the stronger the preference in comparison to another. As an example there is a high preference that the microwave as a whole can be used in a quick and efficient process over all opposed to the microwave needing to have a low Db level. This all ties in with the initial customer requirements and their need for having the redesign of the microwave.

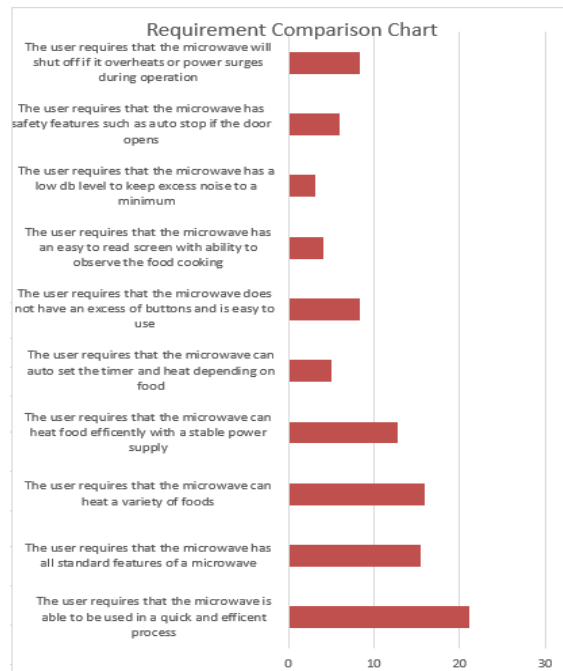


Figure 10 Pairwise comparison chart of requirements

The figure above shows the pairwise comparison graph chart, in this view it is much more simplified and easier to understand. This chart will allow the systems engineer to work out what requirements have the biggest impacts on stakeholders and in turn prioritise said requirements accordingly. In this example the feature with the most importance to the engineer was that the microwave was quick and efficient overall, therefore tying in with the customer requirements, however this had a knock on affect to certain safety features such as auto stop if the door was opened or shut down if the microwave became too hot. This shows that a balance must try and be found between what is thought to be important to the customer and other subsystem features that other stakeholders may find important themselves, in this instance safety bodies and the local fire brigade may not be too fond of a microwave that could catch fire at a moment's notice.

2.3 Functional Analysis

Functional analysis is essentially a top down process that translates system level requirements into detailed functional and performance design criteria. The product of this is a highly defined functional architecture with system requirements traceable to each system function [9]. The microwave must ensure that all required features are set out beforehand therefore a behavioural observation had to be carried out to ensure the design had said required features.

Operations
Open door
Place food on turning plate
Close door
Select time
Select heat
Heat food
Open door
Remove food

Figure 11 Function Analysis Table

The table above shows the individual functions that the microwave has to have to allow the user to have desired result of heated food.

3.0 Quality Function Deployment (QFD 1)

QFD stands for “Quality function deployment 1”. Its main goal in Systems Engineering is to analyse a set of system requirements, it helps iron out the chance of having missing features. QFD 1 really focuses on the stakeholders requirements in cross comparison to the pairwise comparison tables and graphs. It should be noted that the customer’s voice is essentially integrated into the system and all solutions can be traced back to the stakeholder’s needs [10].

How	Importance	Heat Food	Door opens/closes	Adjust Heat	Select time	Audible bleep when finished	Turn table spins	Door sensor	Start/Stop
Requirements									
The user requires that the microwave is able to be used in a quick and efficient process	8.1	9	3	3	9	1	3	1	9
The user requires that the microwave has all standard features of a microwave	9.5	9	9	9	9	3	9	3	9
The user requires that the microwave can heat a variety of foods	9.6	9	1	9	9	1	9	1	3
The user requires that the microwave can heat food efficiently with a stable power supply	8.4	9	1	9	3	1	3	3	3
The user requires that the microwave can auto set the timer and heat depending on food	5.2	3	1	9	9	1	1	1	9
The user requires that the microwave does not have an excess of buttons and is easy to use	4.7	3	9	3	3	3	1	1	3
The user requires that the microwave has an easy to read screen with ability to observe the food cooking	2.8	1	3	1	1	1	1	3	1
The user requires that the microwave has a low db level to keep excess noise to a minimum	2.1	3	1	1	3	3	1	3	3
The user requires that the microwave has safety features such as auto stop if the door opens	5.7	1	9	1	1	3	1	9	3
The user requires that the microwave will shut off if it overheats or power surges during operation	6.8	3	3	3	3	3	1	3	9
		385	258	364	366	120	249	168	360

Figure 12 Quality Function Deployment 1 Table

The figure above displays the Quality Functional Deployment 1 requirements in comparison to the functions of the microwave. This table essentially maps out the strength of the relationship between each customer requirement and the expected functions of the microwave. To give further context, boxes showing the number 1 indicate a weak relationship, boxes showing 3 is a medium relationship and 9 for a strong relationship.

Expanding on this, one of the requirements is that the microwave is able to heat in a quick and efficient process, hence why the function of heating food and selecting the time are marked with 9 as this is fundamental and has a strong relationship with the original requirement.

It should be noted that QFD 1 is not as in depth as QFD 2 and therefore at this stage the QFD 1 is ensuring that there is some sort of relationship in the first place between the customer requirements and functions.

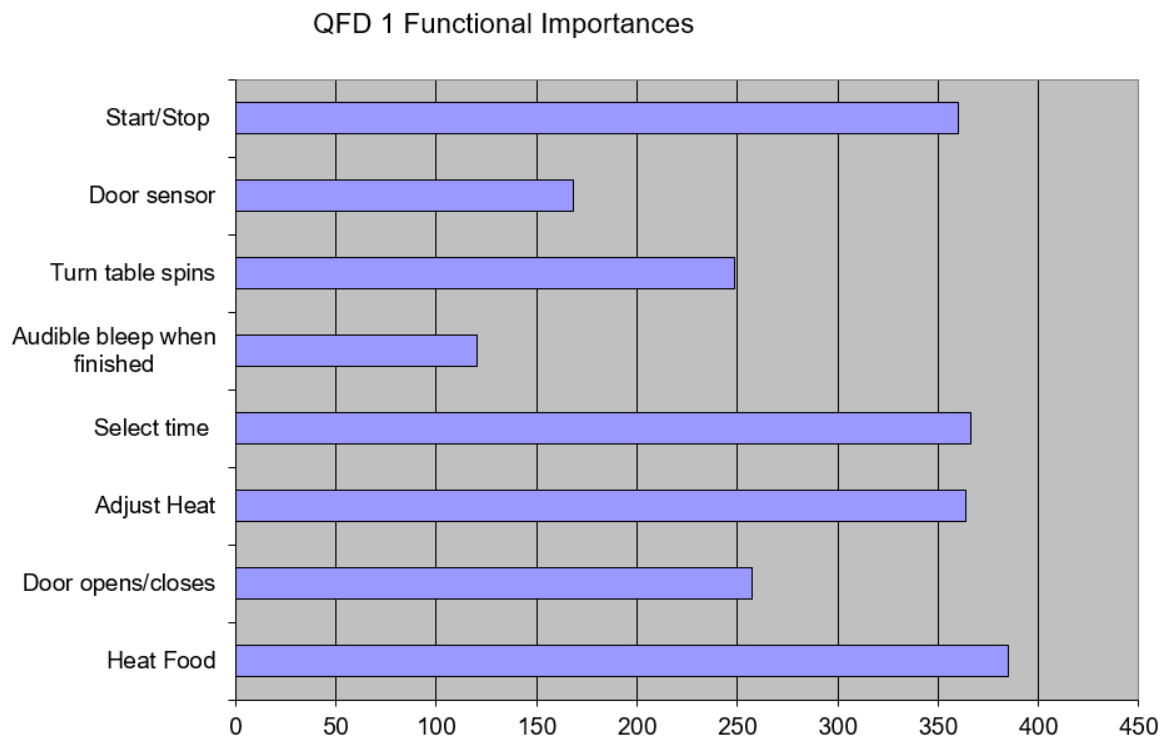


Figure 13 Quality Function Deployment 1 results in a graph

The figure above shows a simple graph overviewing data collected in the Quality Function Deployment spreadsheet. Here it is easier to see what functions had an overall stronger relationship in regards to requirements. It is evident in this format that heating food and selecting time were amongst the highest.

3.1 Functional Means Analysis

Each function has to have a way of being carried out this is what is known as “means”. Some means are extremely simple while others very complex. This section looks at the functions and what means can be implemented to achieve them. Throughout history different means have been developed to find the best possible solution, in essence this is how technology ultimately develops as design Engineers will often “push the boat out” with “Wallace and Gromit” style ideas to try and come up with ground breaking solutions.

Function	Means			
Heat Food	Magnetron emits microwaves	Steam Injection	Solid state RF heating	
Door Opens/Closes	Push button mechanical mechanism	Electromagnetic locking	Touchless gesture	
Adjust Heat	Power level buttons	App controlled heat profiles	Smart sensor feedback	
Select Time	Numeric Keypad	Rotary dial	Voice Control	Barcode Scanning
Audible bleep when finished	Standard buzzer	Light and Sound	Voice assistant	
Turn table spins	Motor with a spindle	Removeable multi speed tray	Magnetically levitated platform	
Door sensor	Mechanical switch	Magnetic reed switch	Optical sensor	Sensor detecting human hand
Start/Stop	Button	Voice activation	Motion detection	

Figure 14 Functional Means Analysis table

Key	Current in service solution	Advanced solution occasionally implemented	Complex solution rarely seen implemented
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Figure 15 Functional Means Analysis Key

The figure above gives an insight into functional means. Anything highlighted in green is a baseline standard mean that is implemented/established into the current system. The cells highlighted in yellow are more complex means which may be able to be included into the microwave system, however they have limited factors such as negatively impacting cost effectiveness or being too complex for the average consumer. Finally the boxes highlighted in red are highly complex (Go-No Go) solutions, this can be due to lack of technological advancement and being too over Engineered. As an overall conclusion to this table, multiple means have been considered for implementation into the system.

3.2 Functional Metrics

This section of the report looks into the data collated in the aspects of Functional Metrics and Pugh Matrix. The main purpose of the Functional metrics table is to build on different test methods for the functions detailed in the QFD 1 section of the report and how well they correspond with the original customer requirements.

Function:- (Insert Specific function here) Test method and relationship to requirements	Importance	Heat efficiency test	UI usability test	Sound level test	Turn table test	Auto heat function test	Door latch stop test	Overheating stress test
Requirements								
The user requires that the microwave is able to be used in a quick and efficient process	5	9	3	1	9	9	1	3
The user requires that the microwave has all standard features of a microwave	5	3	9	1	3	9	3	3
The user requires that the microwave can heat a variety of foods	5	9	1	1	3	3	3	1
The user requires that the microwave can heat food efficiently with a stable power supply	5	3	1	3	3	3	1	9
The user requires that the microwave can auto set the timer and heat depending on food	5	3	9	1	1	9	1	1
The user requires that the microwave does not have an excess of buttons and is easy to use	5	1	9	1	1	9	3	1
The user requires that the microwave has an easy to read screen with ability to observe the food cooking	5	1	3	1	3	1	3	1
The user requires that the microwave has a low db level to keep excess noise to a minimum	5	3	1	9	1	1	1	3
The user requires that the microwave has safety features such as auto stop if the door opens	5	1	3	1	1	1	9	3
The user requires that the microwave will shut off if it overheats or power surges during operation	5	3	1	1	1	1	3	9
		180	200	100	130	230	140	170

Figure 16 Function Metrics Table

The table above shows a comparison between the original system requirements and tests that could be implemented to develop them. To get specific the auto heat function test ranked the highest and this may be due to the main requirements of the system needing the microwave to be used in a quick and easy manner, which therefore ranks this test higher when compared.

The sound level test ranked at the bottom of the pile as it has the least purpose in the system when compared with the requirements. It should be noted that it is still on the designer of this system to choose and prioritise what is more important, this format however makes it more seamless and efficient to do so.

4.0 Quality Function Deployment 2 (QFD 2)

QFD 2 is much like QFD 1 however it focuses on the deployment of built up research and how it is implemented into the system from a more technical standpoint. To give some more context, QFD 1 is done before hand to set out areas such as initial requirements from the customer etc. Whereas QFD 2 looks at deploying this in an engineering manner, so areas such as “purpose” move from understanding what to build but rather how to build it.

Design feature	Importance		Importance	Magnetron emits microwaves	Push button mechanical mechnasim	Power level buttons	Numeric Keypad	Standard buzzer	Motor with a spindle	Mechanical switch	Button	Steam injection	Electromagnetic locking	Rotary Dial	Light and sound	Removeable multi speed tray	Magnetic reed switch	Voice activation	Solid state RF heating	Touchless gesture	Voice control	Magnetically levitated platform	Optical sensor	Motion detecting	Barcode scanning
Functionality																									
Heat Food	616	10	61.629724	9		3	1		3			3		1		1			9		1	1			
Door Opens/Closes	485	10	48.508853		9			1		9	9		3		1	1	3			3	1		3	3	
Adjust Heat	367	10	36.696284	3		9	9		1		1	1		3				1	1		3				9
Select Time	29	10	2.8981622	1	1	3	9				1			9				3			3				9
Audible bleep when finished	54.8	10	5.4846846		1			9		3			1		9									3	
Turn table spins	147	10	14.743364	1					9	1						9						9			
Door Sensor	402	10	40.214925		3					3	3		9				9			3			9	3	
Start/Stop	291	10	29.127521		3					3	3		1				3			9	9		1	3	
				682	653	524	418	98	354	676	684	222	542	198	98	243	595	45	591	528	491	194	537	370	356

Figure 17 Quality Function Deployment 2 Table

The figure 17 above shows a table very similar to that of QFD 1 however the functions of the microwave are compared to certain means. This allows the designer of the product to understand what mean is more suited to each function and how much importance they hold to one another respectively. The 1, 3 and 9 box method is used again here, where none/1 shows little impact and 9 showing the most.

Overall this summary displays what is more likely to be included in the final design from a more technical and in depth standpoint rather than looking at basic customer requirements.

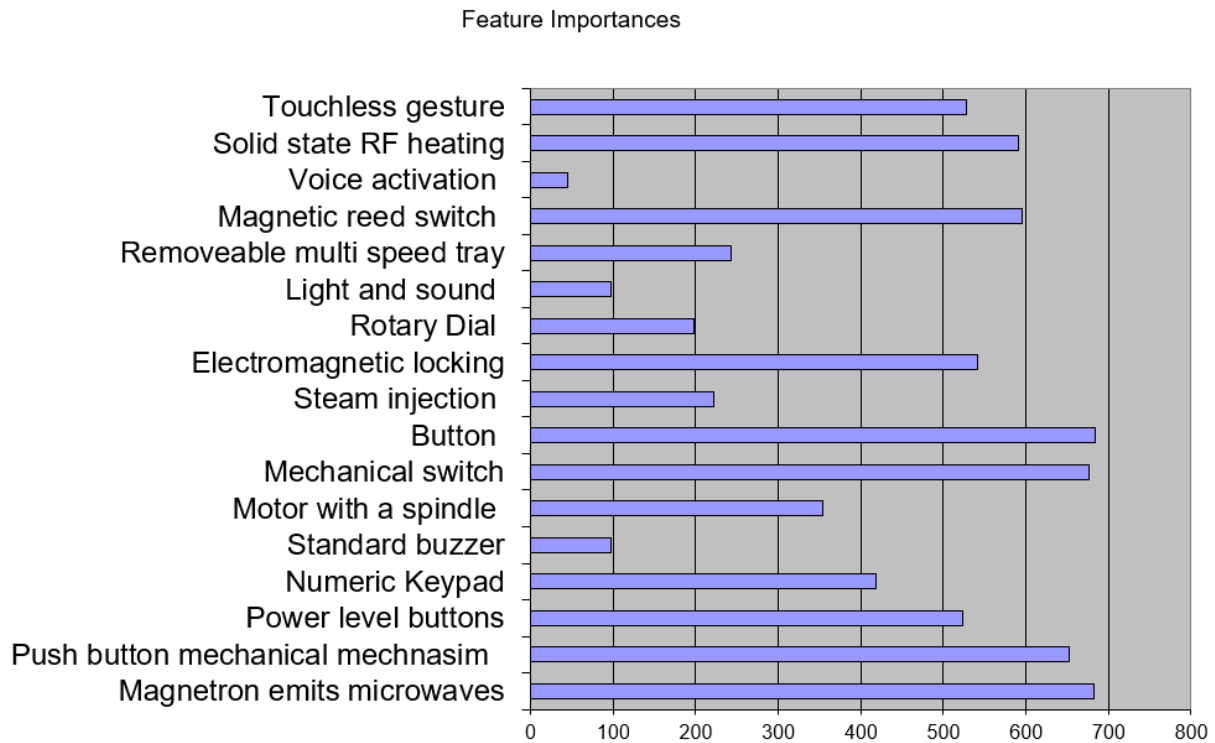


Figure 18 Quality Function Deployment 2 results in a graph

The figure above shows the QFD 2 table in a bar graph view for ease of reading. It should be noted that the Magnetron emitting the microwave ranked the highest and voice activation ranked the lowest, this could be due to over complexity or monetary costs.

4.1 Prime “What Why”

This section of the report looks to understand what features are affecting the overall performance of the system. The diagram in Figure 19 below outlines said factors (noise, inputs, external, deterioration, unit to unit etc.). These are then carried into the tables further on.

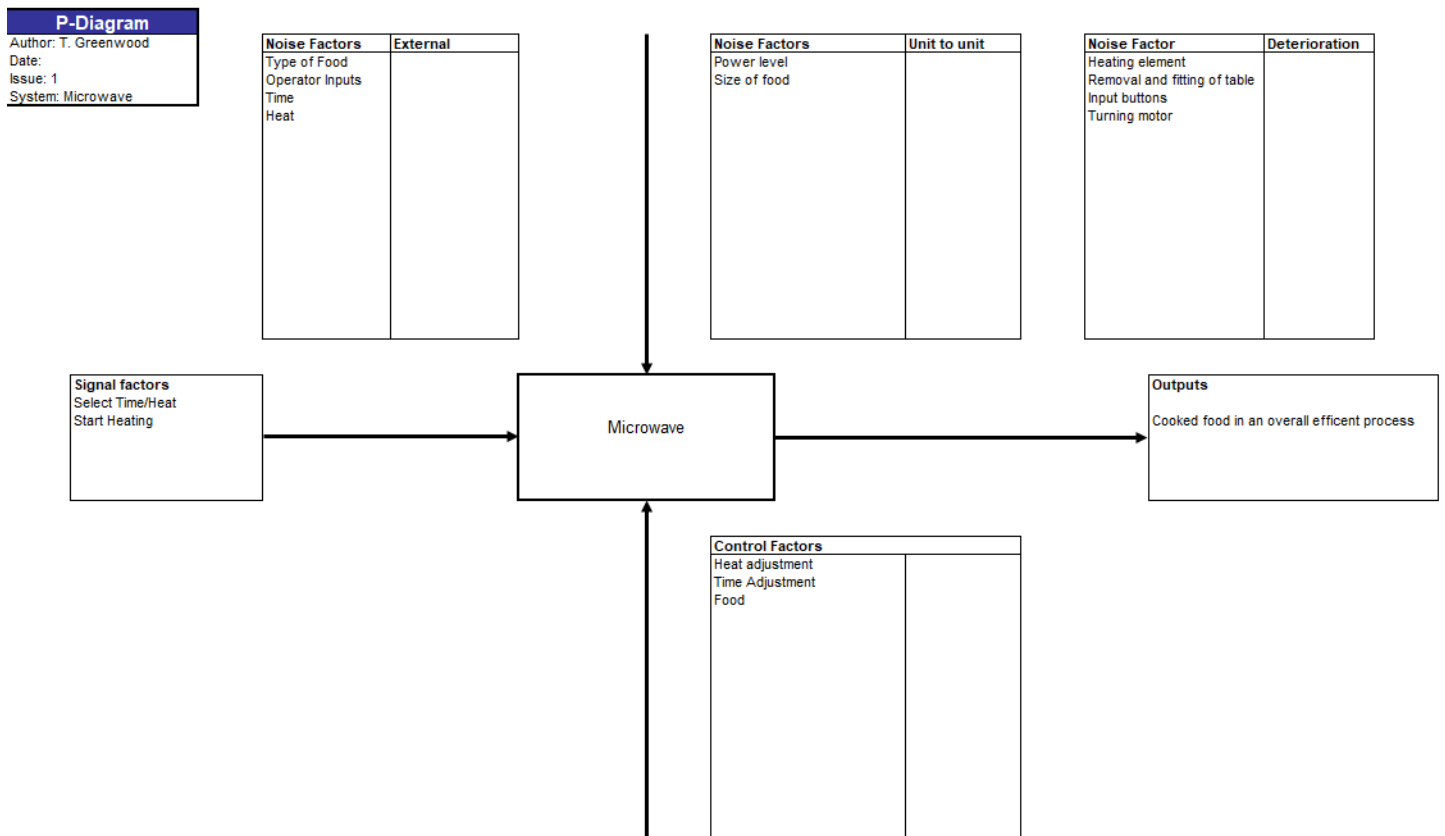


Figure 19 P Diagram

		NOISE FACTORS											Relative Importance of noise in meeting performance via control factor
Design control parameters	Weighting of design control parameter	Unit to Unit Variation		Deterioration				External					
		User	User	Manufacturing	User	User	Manufacturing	Environment	User	User	User	Total	
		Power Level	Size of Food	Heating Element	Removal and fitting of table	Input buttons	Turning motor	Type of food	Operator inputs	Time	Heat		
Heat Adjustment	1	9	1	9		3	3	3	1	1	9	39	39
Time Adjustment	3	1	1	1		3	3	3	3	9	1	25	75
Food	9	3	9	3	1	1	1	9	3	3	3	36	324
Relative importance of noise factor:		39	85	39	9	21	21	93	37	55	39		

Figure 20 What Why Matrix

Control Factors

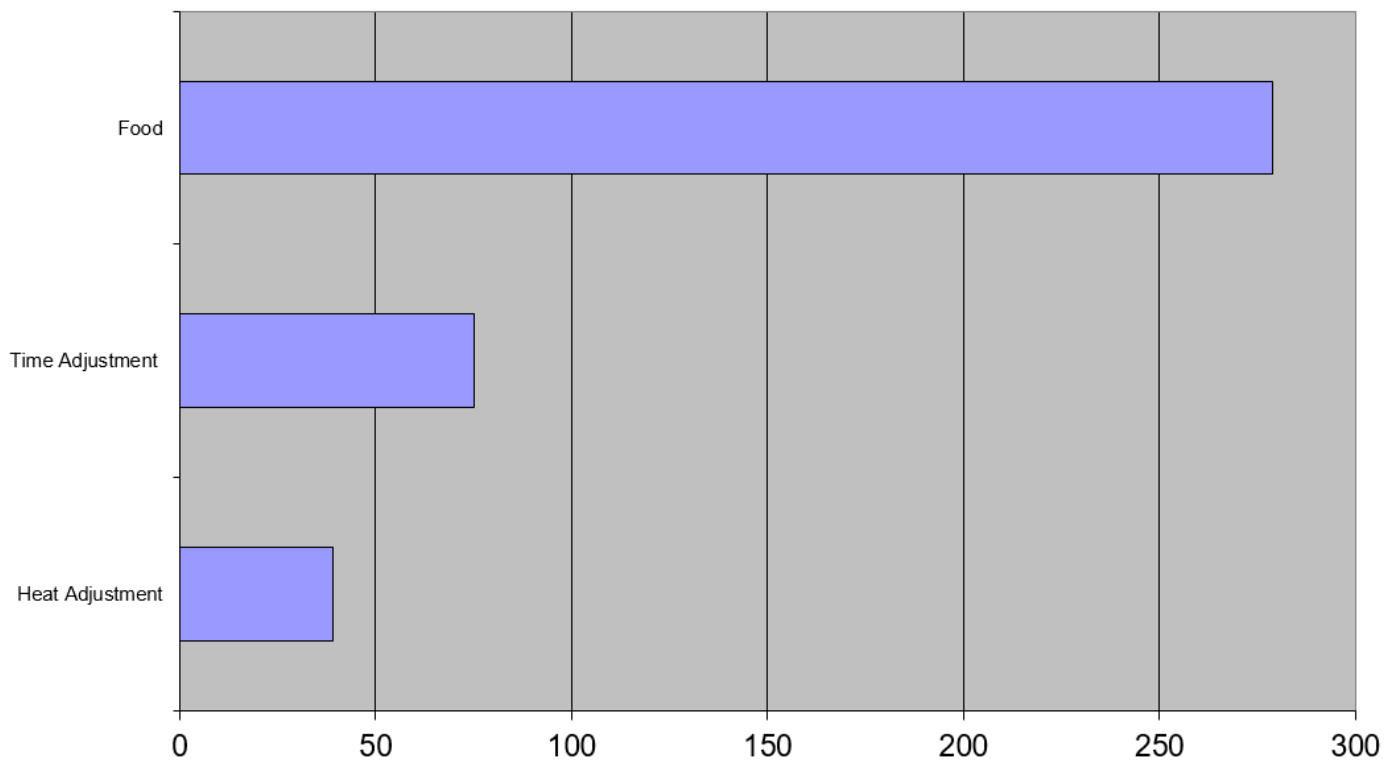


Figure 21 Control Factors Bar Chart

Noise Factors

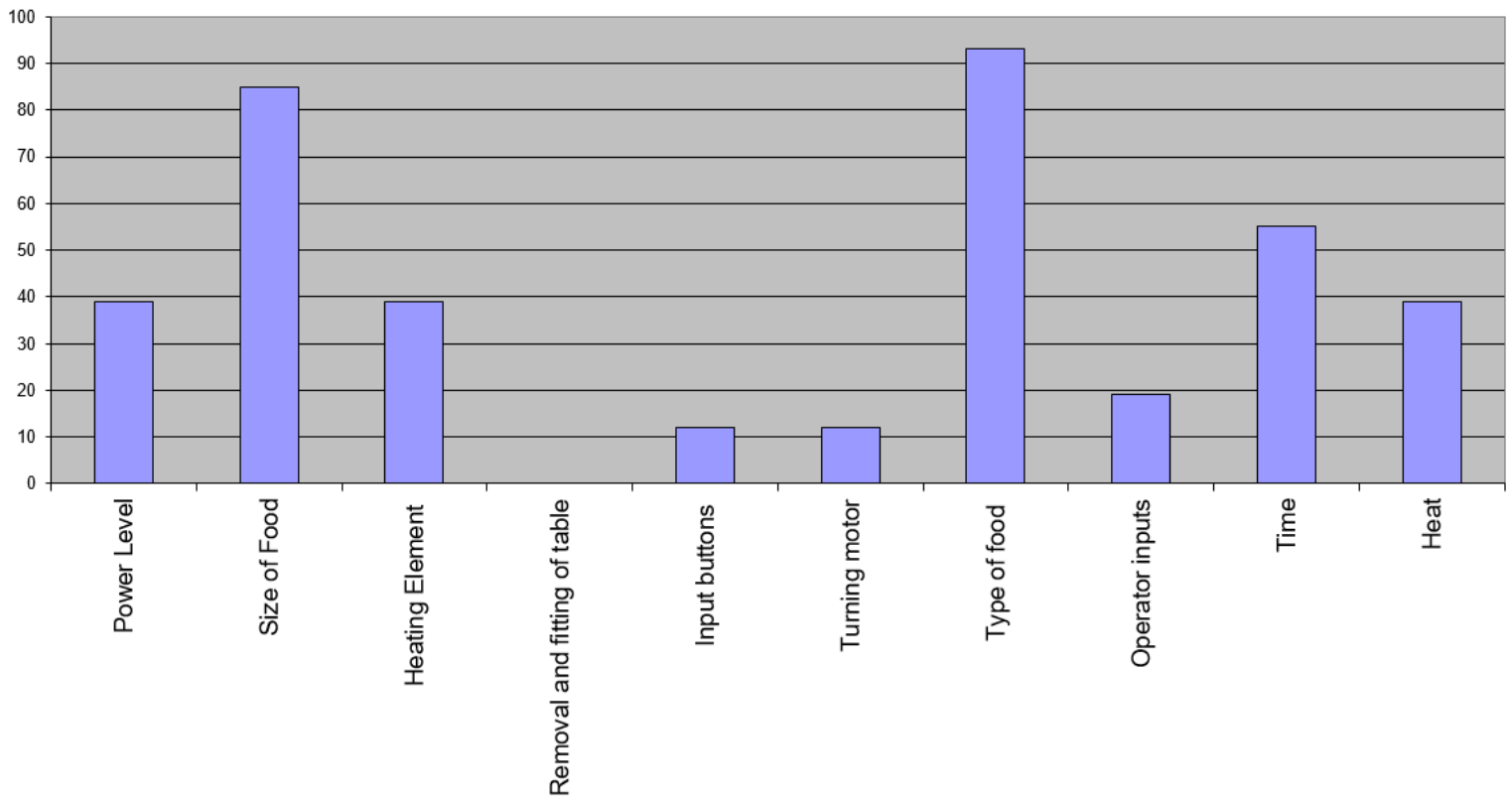


Figure 22 Noise Factors Bar Chart

The previous three figures show how the factors affect the system, in this case noise factors have been studied in detail. Figure 20 matrix takes into account design control parameters and compares them with noise factors using the 1 to 9 ranking system. Figure 21 and 22 collates this data into an easy to read bar graph where the factors are ranked in a bar format. Food is listed as the highest in control factors as this ultimately decides how long the microwave cycle will run for. Again type and size of food ranked highest in noise factors, for the same reason as the control factors chart.

5.0 Design Failure Mode and Effects Analysis (DFMEA)

In every system failure is bound to happen, by doing a proper DFMEA analysis, the potential causes of failure can be studied and improved on to ensure they do not happen often/at all. The table below gives a clear view as to what the function is, how it can fail, the impact of this failure on the system, the user observed outcome, criticality of the failure, cause, the mechanism that went wrong, how often it may occur, what measures can be put in place to control this, risk score and finally a proposed improvement to create a solution to mitigate the frequency of it happening again.

Operational Function	Failure Description	System-Level Impact	User-Observed Outcome	Criticality (1-10)	Root Cause	Underlying Mechanism	Frequency Rating	Control Measures	Risk Score	Proposed Improvement
Heat food	No heat generated	Food remains uncooked	Food stays cold	9	Magnetron malfunction	Power circuit or magnetron fault	3	Monitor power consumption	81	Component QA on magnetron, integrate thermal cut-off
Heat food	Excessive heating	Risk of burning or fire	Food burns or smokes	10	Temperature sensor failure	Defective thermal feedback	2	Thermal cut-off with alerts	40	Enhanced temp sensor reliability with auto shutoff
Rotate turntable	Turntable not rotating	Inconsistent heating	Cold spots in meal	5	Turntable motor jam	Gear slip or motor fault	4	Motor movement verification	80	Reinforce turntable drive with QA
Start cooking	Start command Failure	Microwave fails to initiate	Pressing start has no effect	6	Faulty input or firmware	Button or software failure	3	Self-check on control panel	54	Robust keypad design and software validation
Stop cooking	Unexpected door open	Potential radiation exposure	Door opens mid-operation	10	Latch mechanism defect	Failed interlock system	1	Dual interlock check	10	Add backup latch and run safety test
Display status	Unreadable interface	User cannot input settings	Display not visible	4	Display module issue	Power loss to display	3	Startup screen test	36	Improve display circuitry QA
Power cycling	Sudden power reset	Cooking session interrupted	Microwave shuts off randomly	7	Electrical instability	Loose internal wiring	2	Buffered power line	42	Stabilise power module and wiring checks

Figure 23 DFMEA Table

Overall the table if used correctly can significantly aid the whole design case of the microwave and can also ultimately improve the advancement/future design features. This methodology has been used countless times in systems engineering and has played a huge part in the advancement of technology.

6.0 Discussion

Throughout this report, key concepts of systems engineering have been applied to the design of a microwave, ultimately this has allowed for a clear and concise approach to ensuring the system is designed correctly from the beginning. From QFD 1 where the customers' requirements were compared with functions to analyse the importance of the relationships between one another, to QFD 2 to where this was studied further from a more technical standpoint. Pairwise comparisons and functional analysis were also conducted to understand basic requirements and means for the system.

To finish off the design brief a DFMEA analysis was conducted to tie up any loose ends in the system design to ensure that failures were thought out beforehand which could in turn create a safer/reliable system which mitigates the chance of recalls. This end section references the systems Engineering overview at the start of the report where designing a safe yet reliable system was thought about too.



Figure 24 Artist Impression of what a future system could look like

Overall this report has given an overview to key Systems Engineering concepts with established functions that should be used in the microwave with a ranking of requirements, means and functions while understanding monetary and technological restraints. Above is an image of an Artists impression of what a future system in this field could look like.

7.0 References

- [1] J. M. D. M. R. G. D. D. D. K. Hillary Sillitto, "Systems Engineering and System Definitions," INCOSE , 8 January 2019. [Online]. Available: https://www.incose.org/docs/default-source/default-document-library/final_-se-definition.pdf. [Accessed 7 March 2025].
- [2] J. Wilkinson, "The Challenger Space Shuttle disaster," IChemE, 2016.
- [3] N. G. Leveson, "Engineering a Safer World," in *Systems Thinking Applied to Safety*, Cambridge, Massachusetts, The MIT Press, 2011, pp. 7-8.
- [4] D. Buede, "(Brief) History of Systems Engineering," Incose, 2000.
- [5] W. N. S. S. J. S. S. M. B. Alexander Kossiakoff, "Operational Requirements Analysis," in *Systems Engineering Principles and Practice*, Hoboken N.J, Wiley, 2011, p. 177.
- [6] "Thrust Vectoring: technology and functioning of engines with directional thrust," FlyaJetFighter , 8 November 2024. [Online]. Available: <https://www.flyajetfighter.com/thrust-vectoring-technology-and-functioning-of-engines-with-directional-thrust/>. [Accessed 31 March 2025].
- [7] P. O. L. d. Weck, "Fundamentals of Systems Engineering," MIT, Massachusetts, 2015.
- [8] D. S. Burge, "A Systems Approach to Failure Modes, Mechanisms," Systems Engineering .
- [9] AcqNotes, "Functional Analysis and Allocation," AcqNotes, [Online]. Available: <https://acqnotes.com/acqnote/careerfields/functional-analysis-and-allocation>. [Accessed 02 April 2025].
- [10] IncoseUk, "The Process for doing a QFD1," [Online]. Available: https://incoseuk.org/Documents/Omega_Guides/Omega_3.pdf. [Accessed 02 April 2025].

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