

DESIGN BOOK OF COFFEE GRINDER

SYSTEMS ENGINEERING

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INTRODUCTION TO THE SYSTEMS ENGINEERING APPROACH

A system is defined by the International Council on Systems Engineering as: “An arrangement of parts or elements that together exhibit behaviour or meaning that the constituent parts do not” and an engineered system is “designed to interact with an anticipated operating environment to achieve one or more intended purposes while complying with applicable constraints” [1].

THE SYSTEMS ENGINEERING APPROACH IS A STRUCTURED DESIGN METHOD FOR ANY ITEM IN QUESTION; WHETHER IT IS A DISCRETE PRODUCT SUCH AS A BOLT, A SYSTEM WITH MANY SUBSYSTEMS LIKE A FIGHTER JET OR EVEN A SYSTEM COMPRISING OF MANY SYSTEMS AND SUB-SYSTEMS, FOR EXAMPLE A TRANSPORT NETWORK. THIS APPROACH IS STRUCTURED TO ENSURE THAT THE STAKEHOLDER REQUIREMENTS OF THE SYSTEM ARE AT THE FOREFRONT OF ALL DESIGN CHOICES. IT ALSO ALLOWS FOR A HOLISTIC, MULTI-PERSPECTIVE VIEW AND MULTIPLE POTENTIAL OUTCOMES TO BE EVALUATED [2].

Figure 1 demonstrates how system complexity can rapidly surpass what a single human mind can manage [3]. In all complex systems, their designs will be broken down into manageable sub-systems and components that will all be subject to the same systems approach.

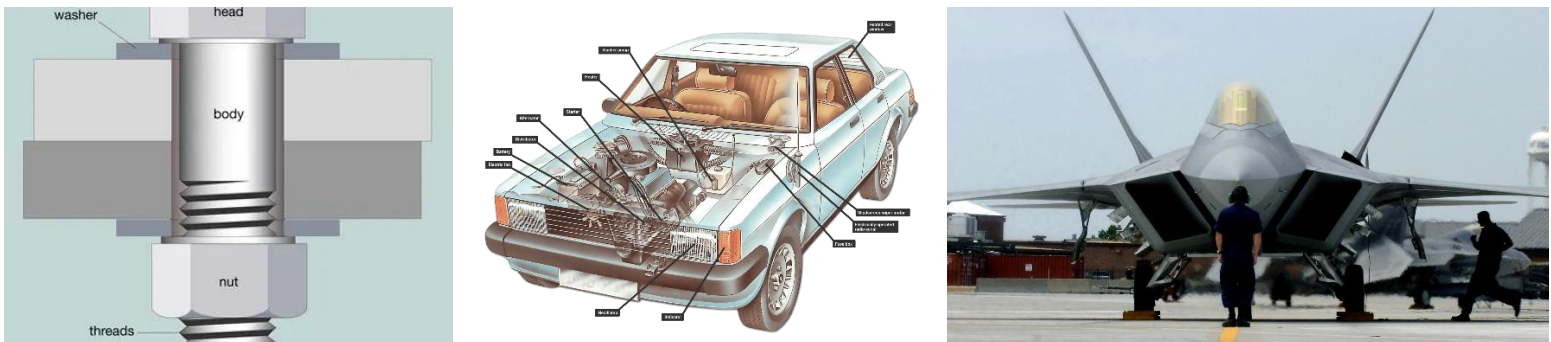


FIGURE 1 - INCREASING SYSTEM COMPLEXITY [4] [5] [6]

Systems engineering as a methodology originated from the Bell Telephone Laboratories during World War 2, as it was found that in complex systems, individual components may satisfy their respective requirements but when amalgamated, failed to meet the overall system requirements [7]. New ways of thinking were developed in the 40s, 50s, and 60s to meet the rapidly evolving engineering challenges of systems for instance military radar, the Apollo program and Intercontinental Ballistic Missiles. Systems fail because of three main factors: complexity that is not identified and therefore not controlled; ambiguous or failed communication; lack of understanding of different viewpoints and making assumptions about said views [8]. Conventional thinking can fall into a variety of traps when it comes to complex systems; for instance, failing to see interconnections; assuming causes; missing perspectives and a focus on outcome instead of beneficial change to processes [9]. The Systems Engineering approach delivers a common design language and best practices through compliance with the standards ISO/IEC/IEEE 15288 that is used throughout the systems lifecycle across planning, acquisition, modification and sustainment [10]. Complying to the standards allows for clear communication inter and intra organisational and induces confidence in the stakeholders by demonstrating the quality and stringency of work that is carried out [8]. This common language is System Modelling Language (SysML) which was derived from Universal modeling language in 2003 [11] and is vitally important for large programs of work such as the F-35 Joint Strike Fighter which is supplied by over 1900 organisations across 10 countries [12]; where mistakes cost millions of dollars, have a large impact on delivery time-frame, have the potential for catastrophic operational failures and finally cause great reputational damage that will affect future business. Systems engineers will, with their oversight and knowledge of the overall system; bridge the gap between the various engineering disciplines that are involved such as Mechanical, Electronic and Software Engineers [13].

A system will have a top-level requirement that encompasses the whole objective of the systems design. This top-level requirement feeds in to: Functional requirements, how the system must physically function; Performance requirements, how well these functions must perform; Implementation requirements such as statutory or standards compliance; and Systems requirements to state what it must do.

The Boundary will define the scope of the system and this can be physical, conceptual or defined by the stakeholders individually or collectively. A well-defined boundary allows key aspects of the system to be understood such as what elements are treated as inside and outside of the boundary as well as key interfaces that allow the system to interact with or be interacted upon by the user or outside world [8]. It must be noted that different stakeholders will view the boundaries of the system differently and this must be identified and deconflicted. For example a car may initially seem to be a discrete system element but the operator must also expand the boundary to the availability of fuel, garages for servicing, roads to travel upon and so on. A line must be drawn upon a certain boundary to enable the design team to control what they are able to regarding the system element. To that end some system elements will rely upon external enabling systems to fulfill the stakeholder requirements such as using pre-existing engines or braking systems to reduce development costs and the burden upon parts supply for servicing.

Stakeholders are people or organisations that influence the system by means of needs, responsibilities and interests which must be reflected within the requirements [14] and they can be categorized into Customers, External and Suppliers [8]. Examples of stakeholders for military systems are: the end user, the purchasing organisation, the generals that want a capability, the Ministry of Defence, Parliament, Legislation, the manufacturer, industrial base and NATO. This variety of stakeholders must be managed and this can be done through a stakeholder expectations process flow diagram seen in Figure 2.

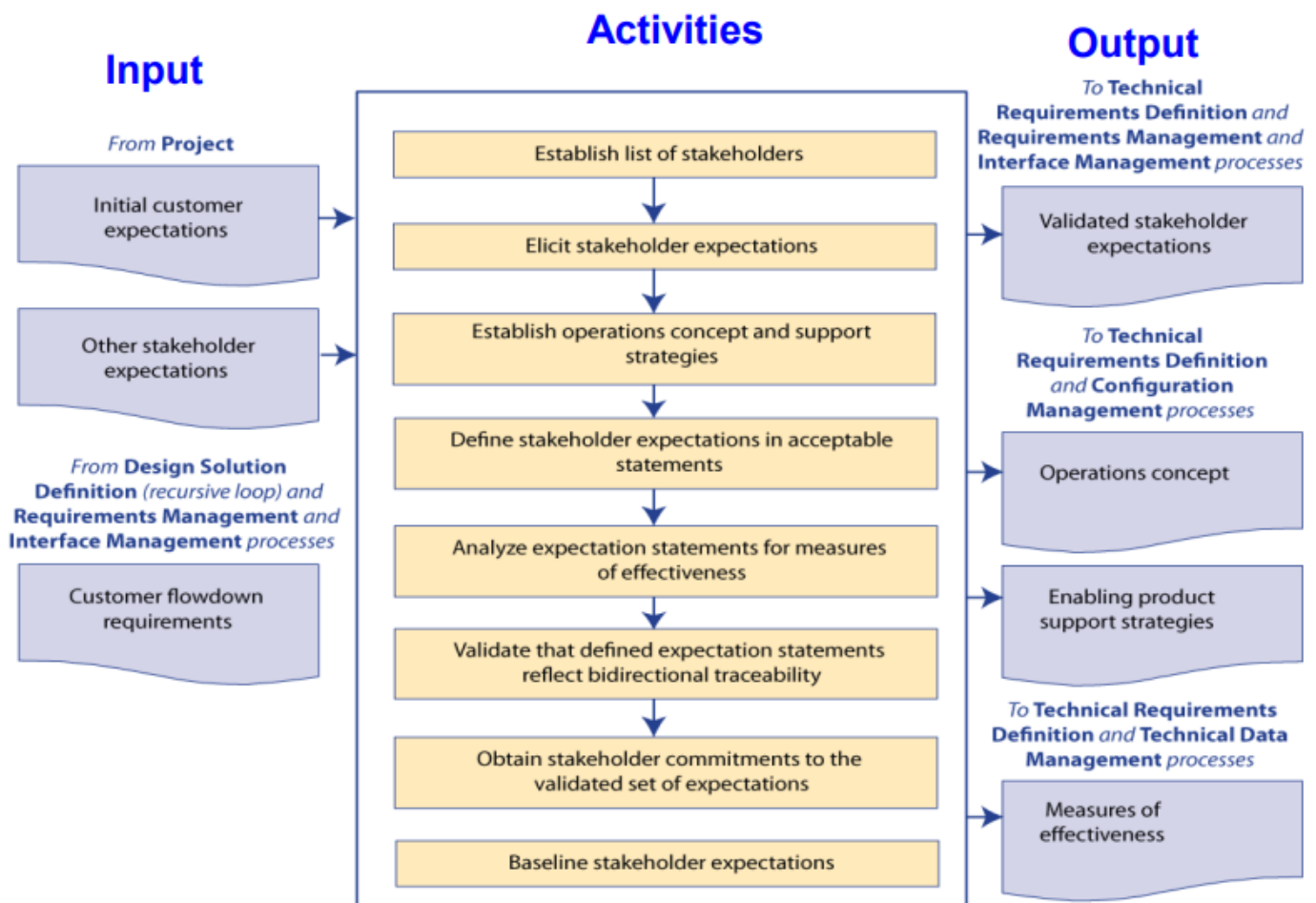


FIGURE 2 - STAKEHOLDER EXPECTATIONS PROCESS FLOW DIAGRAM [15]

The requirements can be categorized into user and system requirements for the operational user and designer respectively. This is crucial to understand the perspective of how the requirements develop and how the designer must support them as the user requirements define what the system must supply as an end product of the system; whereas, the system requirements constrain what the system must be. User requirements must be simple and non-technical so that they can be easily understood and corrected. In the case of more technical users, their requirements may be too dominant and solution oriented which may technically excel but fail as an overall system [14].

“Normal people believe that if it ain’t broke, don’t fix it. Engineers believe that if it ain’t broke, it doesn’t have enough features yet.” – Scott Adams

The systems requirement will cascade and evolve from the user requirement to have a more discrete and technical objective such as a user requirement for a tank shell evolving from: ‘A round that can destroy an enemy position’ to ‘A round that can destroy light armour and structures at a range <3km and complies with NATO standards’. To carry out the systems engineering approach these requirements will be split up so that they can be prioritized, specified and designed for appropriately.

The systems approach also enforces traceability of design choices throughout the project lifecycle, Figure 3. This traceability highlight the justification for each design choice due to its impact on fulfilling the user requirements and can be later referred upon in large scale systems that take many years to develop.

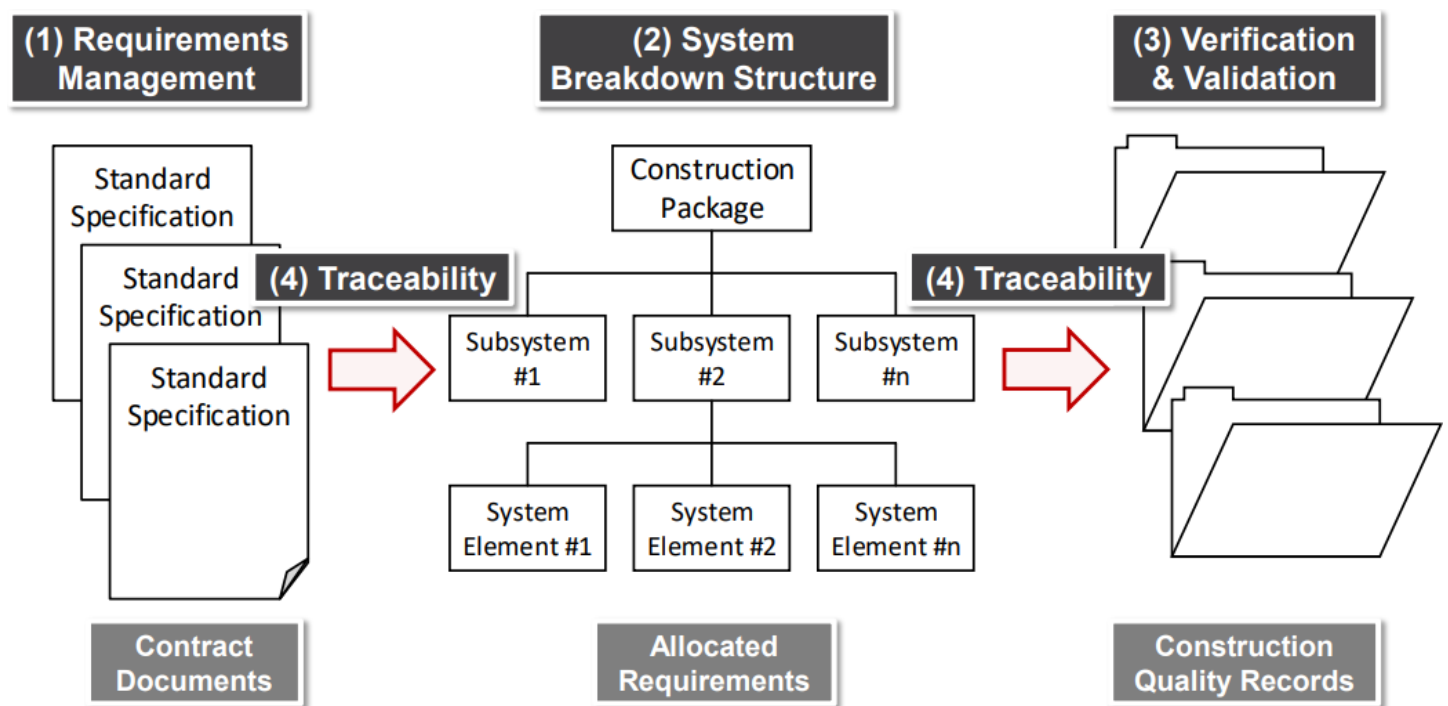


FIGURE 3 - FOUR STEP TRACEABILITY APPROACH [16]

Following the Systems approach will reduce overall development costs by identifying and managing undesirable, emergent behaviour that results from system elements varying, being suboptimized or through dynamic feedback. Resolving design errors in the later stages of development results in exponentially increasing costs as can be seen in Figure 4.

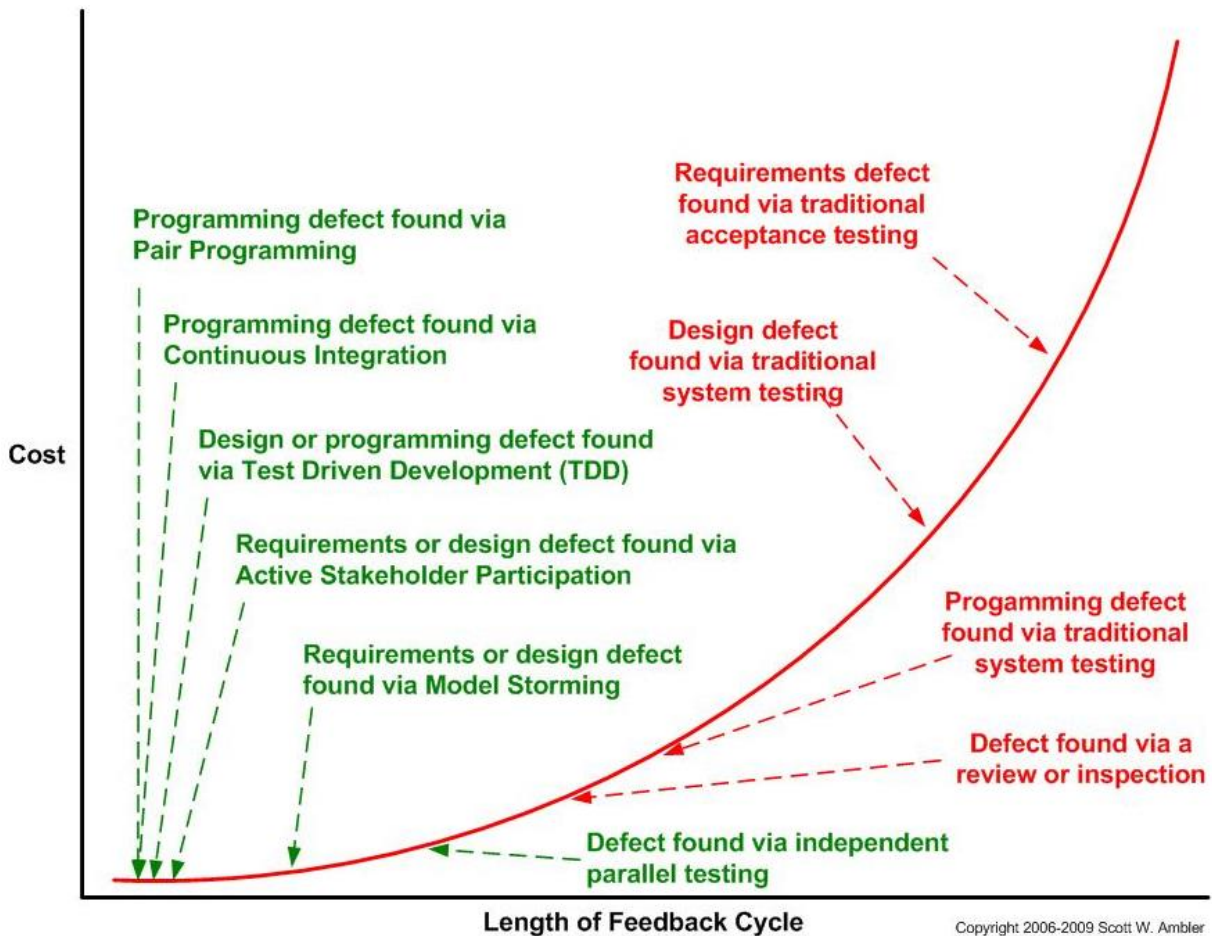


FIGURE 4 - COST OF REWORK THROUGHOUT THE DEVELOPMENT CYCLE [17]

The Systems V-Model, Figure 5, represents how the Systems approach is used to verify the system meets its requirements and qualifies the design elements as well as validating that the correct process and methodologies were utilized in development [18].

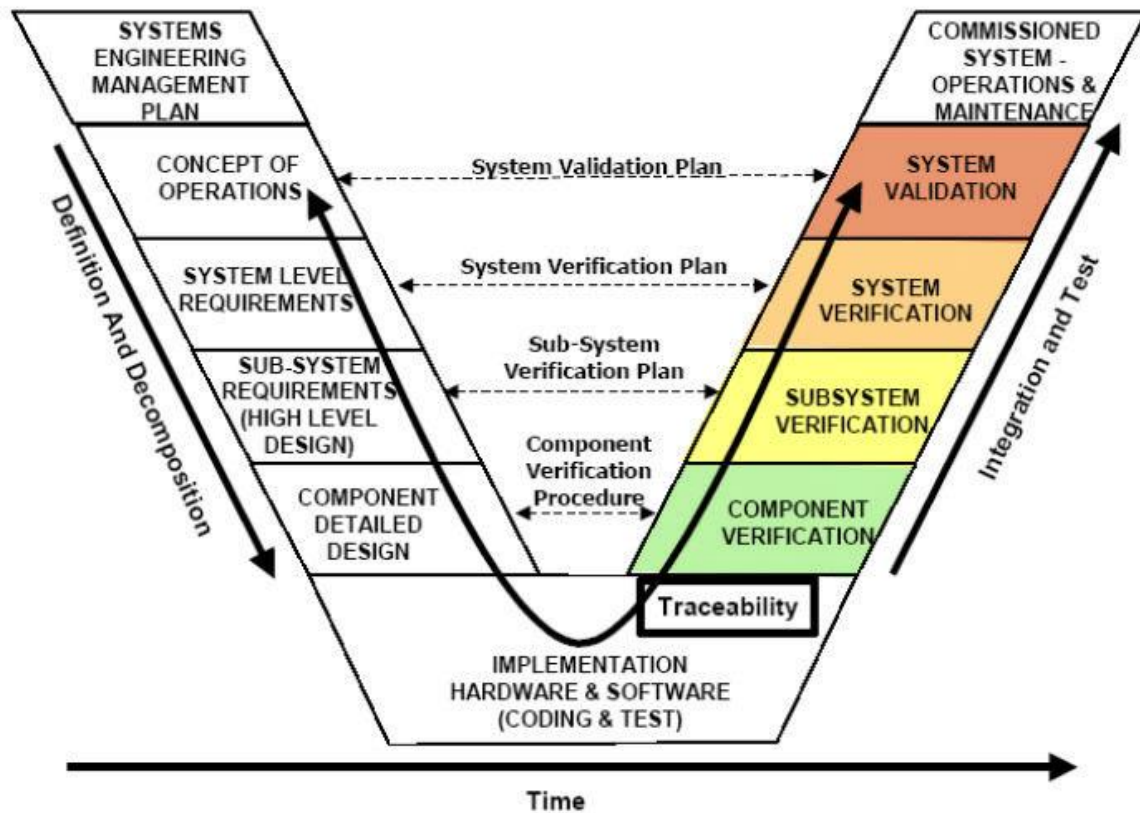


FIGURE 5 - SYSTEMS ENGINEERING V-MODEL [18]

Unfortunately many organisations do not evolve their design approach to systems thinking as their current approach 'works' [19], depriving them from adopting new approaches, making mistakes and subsequently learning from them.

"A fool with a tool is still a fool" – Grady Booch

Systems thinking is only a tool for a human or team of humans to record their thoughts and decision making and humans all have their own biases, perspectives and motivations. A successful system deployment could be considered to be the result of "70% people, 20% process and just 10% technology" [20] and thus, the tool is not infallible especially when there are many ways to use tool incorrectly and few ways to use them correctly [21]. The Systems Approach is extremely dependent upon good requirement definition [3] which can oft be unsatisfactory or even dynamic during the development which may have costly and time consuming effects, like with the case of the AJAX programme [22].

DESIGN CASE

CUSTOMER REQUIREMENT & BOUNDARY DEFINITION

The customer requirement this design book intends to improve the design of a coffee grinder that can be used to support an external system: coffee brewing. The top-level statement of requirement is: "A coffee grinder is required that is quick to use, accurate, consistent and requires minimal effort and cleaning." This system requirement comes from the deficiencies of the users current coffee grinder, taken by surveying the user. The current grinder is a screw adjustable, ceramic conical-burred hand grinder which is cheap, but time-consuming to use.

The boundary of the system is defined by the coffee grinder itself; therefore, the external input is coffee beans, and the external output is coffee grounds, for use in a brewing device. The stakeholders of the system are: the user, the brewing device, the purchaser and the 'public' (in this case, the housemates)

The stakeholders were consulted to develop key customer requirements, some with discrete criteria (see **Error! Reference source not found.**)**Error! Reference source not found.**

Error! Reference source not found. demonstrates the limitations of the simplistic method of a basic survey of the stakeholders in order to solicit requirements as it is constrained by what the stakeholders can think of themselves and misses out on implementation requirements such as food safety and appliance manufacture standards. The solicitation of requirements will also depend upon market aspect of the product being broad or narrow such as a consumer electronic product where the manufacturer tries to ensure the requirements will fit what the customer's needs; whereas, complex systems will have customers bringing requirements to the designer.

REQUIREMENT COMPARISON

The stakeholder requirements were then subjected to a Pairwise Comparison by preference. This allows the Systems engineer to prioritise requirements on what will have the biggest impact to the stakeholders. However this tool does not rank the stakeholders 'importance' or how these requirements interact with each other. While it should utilize information surveyed from stakeholders, where this is not possible, it will be the systems engineer anticipating preference unilaterally. This can however be overcome somewhat by distributing a standardized questionnaire to the stakeholders.

When gathering requirements, the user stated that they considered the time efficiency of the grinder to be the most important requirement. However, completing this comparison process resulted in the cost effectiveness of the solution being ranked as the most important requirement (see Figure 6). Grind size adjustment is ranked as the second most important requirement; however it is noted that the features needed to provide that requirement necessitate an increase in the cost of the grinder. As the top two requirements are therefore in contradiction with each other, the balance of requirements must be carefully considered, and the extent to which one or both of the requirements is satisfied may have to be limited in order to satisfy the overall system requirements to a level that is acceptable to the user.

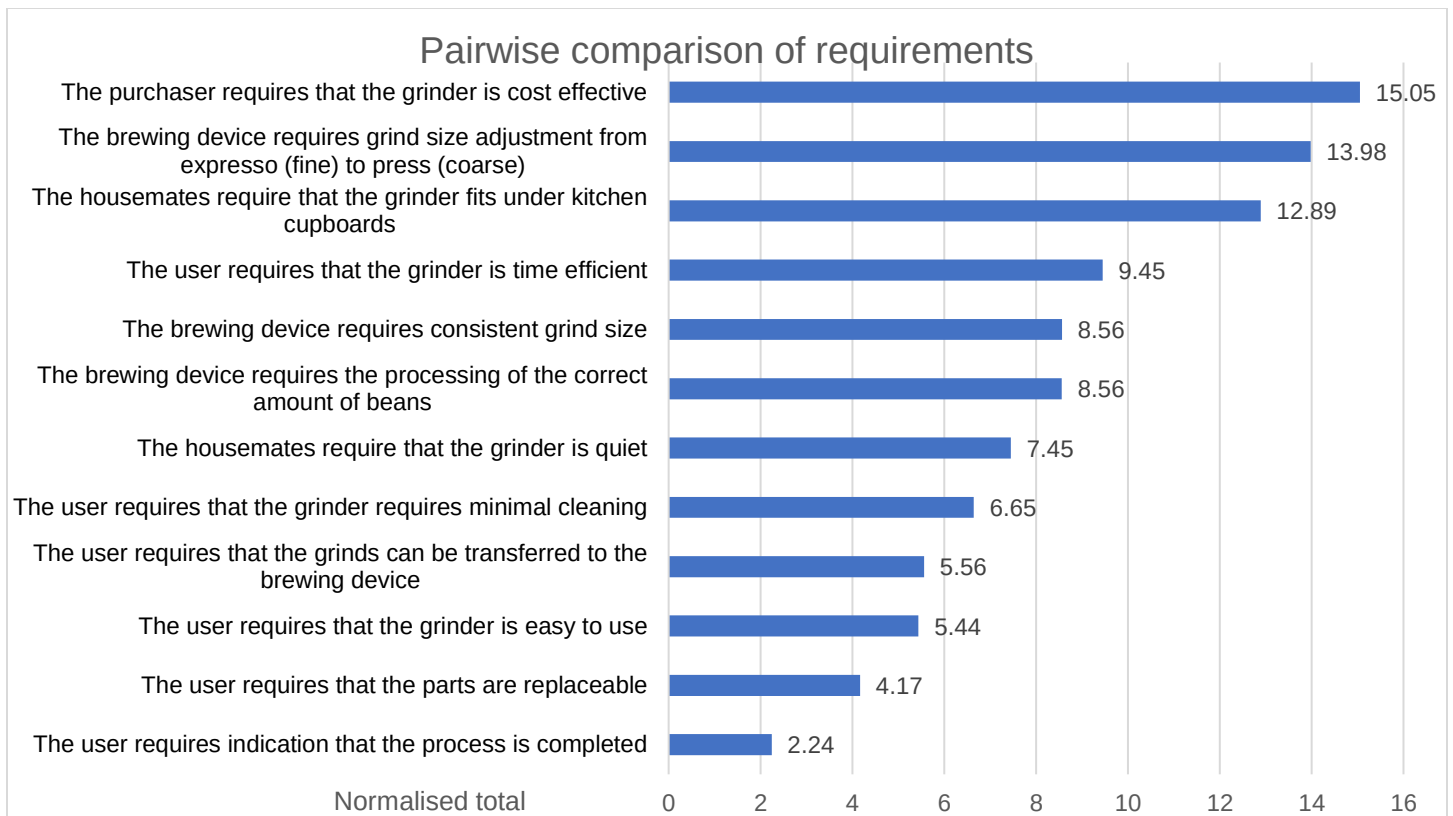


FIGURE 6 - PAIRWISE COMPARISON OF STAKEHOLDER REQUIREMENTS

The data for Figure 6 can be found in Appendix A – Rationalised requirements Pairwise Comparison.

FUNCTIONAL ANALYSIS

In order to fulfill the stakeholder requirements a functional analysis was conducted initially by the systems engineer's view of the process flow. A behavioral observation was then carried out on an operator using an in-service coffee grinder to ensure that all required functions are present in the design book.

Function	Key
Adjust grind setting	<i>From Use case</i> <i>Added after behavioural observation</i>
Measure beans	
Insert beans to grinder	
Close hopper	
Grind beans	
Settle grounds	
Remove collector	
Transfer grounds to portafilter	
Remove waste	

TABLE 1 - FUNCTIONAL ANALYSIS

The results in Table 1 are the functions that must be performed by the system to fulfill the requirements and are designed for at a system element level later on in the design process.

QUALITY FUNCTION DEPLOYMENT 1

The purpose of the QFD 1 is to quantify a value of how the functions fulfill the stakeholder requirements in relation to the pairwise comparison ranking of requirements.

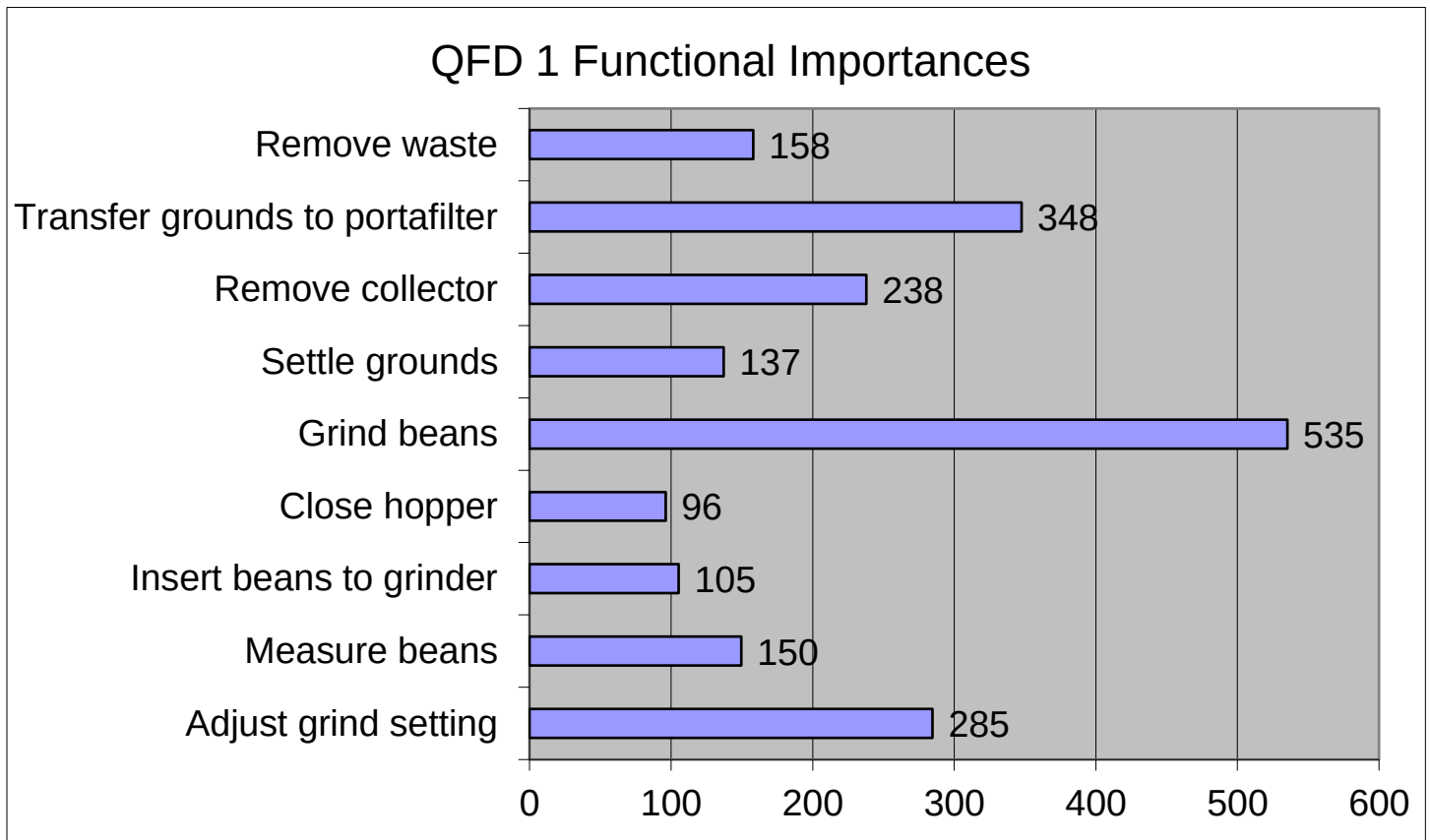


FIGURE 7 - RESULTS FROM QUALITY FUNCTION DEPLOYMENT 1

The results in Figure 7 are the result of the matrix found in Appendix B – Design Quality Function Deployment 1, in which the relationships between function and requirements are mapped by strength where 9 would be considered a strong relationship, 3 for medium and finally 1 for weak. This stage of the process also delivers a sanity check for both the requirements and functions by ensuring they must have at least 1 relationship and therefore are relevant to the design in question. Functions will not relate to all requirements but cross-dependency between unexpected requirements may emerge at this stage.

FUNCTIONAL MEANS ANALYSIS

Means of delivering the required functions were developed from studying existing systems, researching current market solutions and hypothesizing future technologies. These means were then categorized into the following categories: established solutions; solutions requiring development cost/time; effective solutions; step-change technologies and finally, no-go solutions that are prohibitive to implement due to effectiveness, availability and technology readiness level.

Function	Means					
Adjust grind setting	Adjustable height burr	Pre-set buttons	Particle size analysis			
Measure beans	Weigh external	Weigh internal	Graduated hopper (Volumetric)			
Insert beans to grinder	Pour in hopper	Vacuum extract from bag				
Close hopper	Flap	Seal	Threaded lid	Magnet	Lug	
Grind beans	Conical burr	Flat burr	Resonant acoustic grinding	Sieving	Orbital crushing planes (pestle & mortar)	Blade
Settle grounds	Shake	Whack	Air	Vibration		
Remove collector	Screw	Magnet	Lug			
Transfer grounds to portafilter	Collector diameter of portafilter	Spout	Shutter			
Remove waste	Shake	Whack	Air	Vibration		

Key	Established	Cost/time	Effective	Step-change	No-go
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TABLE 2 - FUNCTIONAL MEANS ANALYSIS AND KEY

These means were then down selected into four concepts: Established, Established+, Effective and Step-change.

Concept name	Established	Established +	Effective	Step change
Adjust grind setting	Adjustable height burr	Adjustable height burr	Adjustable height burr	Particle size analysis
Measure beans	Weigh external	Graduated hopper (volumetric)	Weigh external	Weigh internal
Insert beans to grinder	Pour in hopper	Pour in hopper	Pour in hopper	Vacuum extract from bag
Close hopper	Flap	Flap	Seal	Lug
Grind beans	Conical burr	Conical burr	Flat burr	Resonant acoustic grinding
Energy in to grinding implement	Hand crank	Electric motor	Electric motor	Vibration
Settle grounds	Shake	Shake	Whack	Vibration
Remove collector	Screw	Screw	Magnet	Lug
Transfer grounds to portafilter	Collector diameter of portafilter	Collector diameter of portafilter	Spout	Shutter
Remove waste	Shake	Shake	Whack	Vibration

TABLE 3 - DESIGN CONCEPTS FROM FUNCTIONAL MEANS ANALYSIS

FUNCTIONAL METRICS AND SYSTEM PUGH MATRIX

The purpose of the Functional Metrics matrix, found in Table 4, seeks to develop test methods for the respective functions to determine how well they fulfill the corresponding requirements. At this stage, through market/part research and standards, quantized test result targets and tolerances can be developed. These test results are later used in the V-Model to validate the design and ultimately the system before it is accepted by the user.

Function:- (Insert Specific function here) Test method and relationship to requirements	Importance	Grind size adjustment range test	Grind size adjustment accuracy test	Bean holding mass test	Operation time test	Cleaning time test	Step quantity test	Budget acceptance test	Noise level test	Size constraint test			
Requirements													Add requirements detail and definition in here.
The brewing device requires grind size adjustment from espresso (fine) to press (coarse)	13.4	9	9		3		1	3		1			300µm for fine - 1500µm for coarse
The brewing device requires consistent grind size	8.21	3	9			1		1					±50µm
The brewing device requires the processing of the correct amount of beans	12.4			9	3	1	3			3			18g
The user requires that the grinder is time efficient	9.05			3	9	3	9		3				Load and process in <1 min
The user requires that the grinder requires minimal cleaning	6.37	1			3	9	9			1			0
The user requires that the grinds can be transferred to the brewing device	5.33			1	3	3	3	1		1			Spout 51mm diameter to fit portafilter
The user requires that the grinder is easy to use	5.21	9		1	3	3	9	3	1				0
The user requires indication that the process is completed	2.15								1				0
The user requires that the parts are replaceable	3.99							1					0
The purchaser requires that the grinder is cost effective	14.4							9					Max budget £100
The housemates require that the grinder is quiet	7.14							1	9				Max 90dB
The housemates require that the grinder fits under kitchen cupboards	12.4									9			<850mm tall
		198	194	149	210	137	252	210	99	173	0	0	

TABLE 4 - FUNCTIONAL METRICS MATRIX

The Pugh Matrix (Table 5) allows for the comparison of multiple design concepts on how they best meet the requirements [23]. The Pugh matrix is time efficient and simple to use although, like with the other tools, relies upon the subjectivity of the designer. The granularity of the comparison is a strength of the tool, however as can be seen in the results; it can also be a significant weakness. The step-change concept has a far greater ranking than the other concepts, but contains a particle size analyser as one of it's functional means which would cost 10s of thousands of Pounds [24]. Considering that the most important requirement was cost

effectiveness of the solution with the max budget being set at £100; the importance of engineering judgement and consideration throughout the design process has been highlighted unmistakably by this tool.

	Relative Importance Equal	Established	Established +	Effective	Step change
WHATs - Customer Requirements					
The brewing device requires grind size adjustment from espresso (fine) to press (coarse)	13.3949472	0	0	0	2
The brewing device requires consistent grind size	8.20686672	0	0	0	2
The brewing device requires the processing of the correct amount of beans	12.3669401	0	0	0	1
The user requires that the grinder is time efficient	9.05369302	0	1	2	2
The user requires that the grinder requires minimal cleaning	6.3686869	0	0	0	0
The user requires that the grinds can be transferred to the brewing device	5.32994547	0	0	1	1
The user requires that the grinder is easy to use	5.21232833	0	2	1	2
The user requires indication that the process is completed	2.1504747	0	0	0	0
The user requires that the parts are replaceable	3.9927676	0	0	0	-1
The purchaser requires that the grinder is cost effective	14.4266386	0	0	-2	-2
The housemates require that the grinder is quiet	7.14219426	0	-2	1	-1
The housemates require that the grinder fits under kitchen cupboards	12.3545172	0	0	0	-1
Development cost	1	0	0	0	-2
Purchase cost	1	0	0	-1	-2
Availability	1	0	0	0	-2
	Ranking	0	5.19396	5.93858	31.0898

TABLE 5 - PUGH MATRIX

Further analysis of Table 5 - Pugh Matrix led the designer to consider Established+ to be the desired design choice as while the Effective concept did rank marginally higher, it was deemed to be an insignificant gain in relation to impact upon cost effectiveness which was the highest ranked requirement.

QUALITY FUNCTION DEPLOYMENT 2

A second QFD process is completed to discover which means have the most impact on meeting the product design requirements and identify key design characteristics [25].

Feature Importances

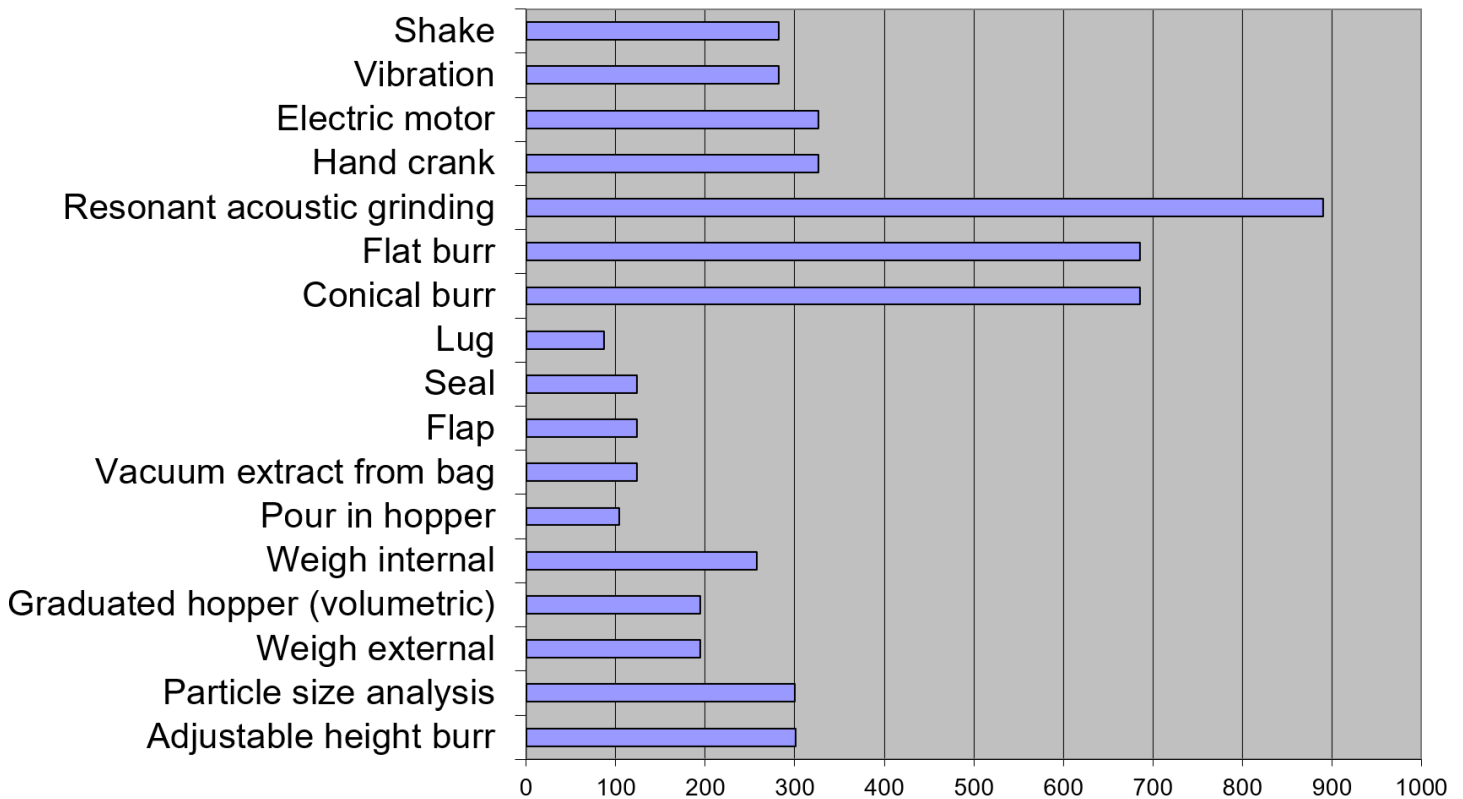


TABLE 6 - QFD 2 FEATURE IMPORTANCE GRAPH, REFER TO APPENDIX C – QUALITY FUNCTION DEPLOYMENT 2

PRIME “WHAT WHY”

The next step is to map out the factors affecting performance of the system: inputs, noise (external, unit to unit and deterioration), control factors and outputs. This can be found in Appendix D – P-diagram. These factors are then used in a “What Why” matrix, Table 7, to generate control and noise factors charts. Seen in Figure 8 and Figure 9 respectively.

		NOISE FACTORS														Relative Importance of noise in meeting performance via control factor
Design control parameters	Weighting	Unit to Unit Variation			Deterioration					External						
		Manufacturing ring	Manufacturing ring	Supply	Raw material	Raw material	User	Manufacturing ring	Manufacturing ring	Environment	Supply	User	Supply	Supply	Total	
		Variation in bearings	Variation in grinder surface	Variation in bean input	Bearings	Hardness of grinding surface	Cleanliness	Adjustment mechanism	Driving device	Quantity of beans	Hardness of beans	Operator input	Power inputs	Contaminants		
Grind setting	9	1	9		1	9	3	9			3	9		3	47	423
Amount of bean input	1			9		1				9		9		3	31	31
Power input	3	9	3	3	9	3	1		9		9	3	9	3	61	183
Relative importance of noise factor:		36	90	18	36	91	30	81	27	9	54	99	27	39		

TABLE 7 - WHAT WHY MATRIX

Control Factors

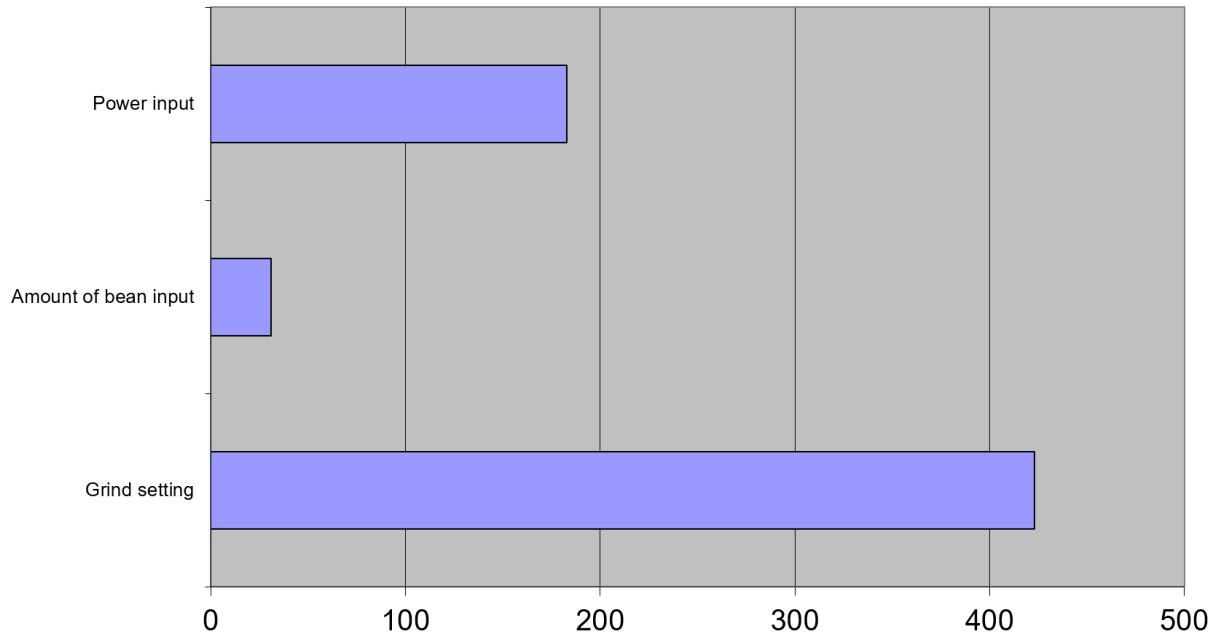


FIGURE 8 - CONTROL FACTORS CHART

Noise Factors

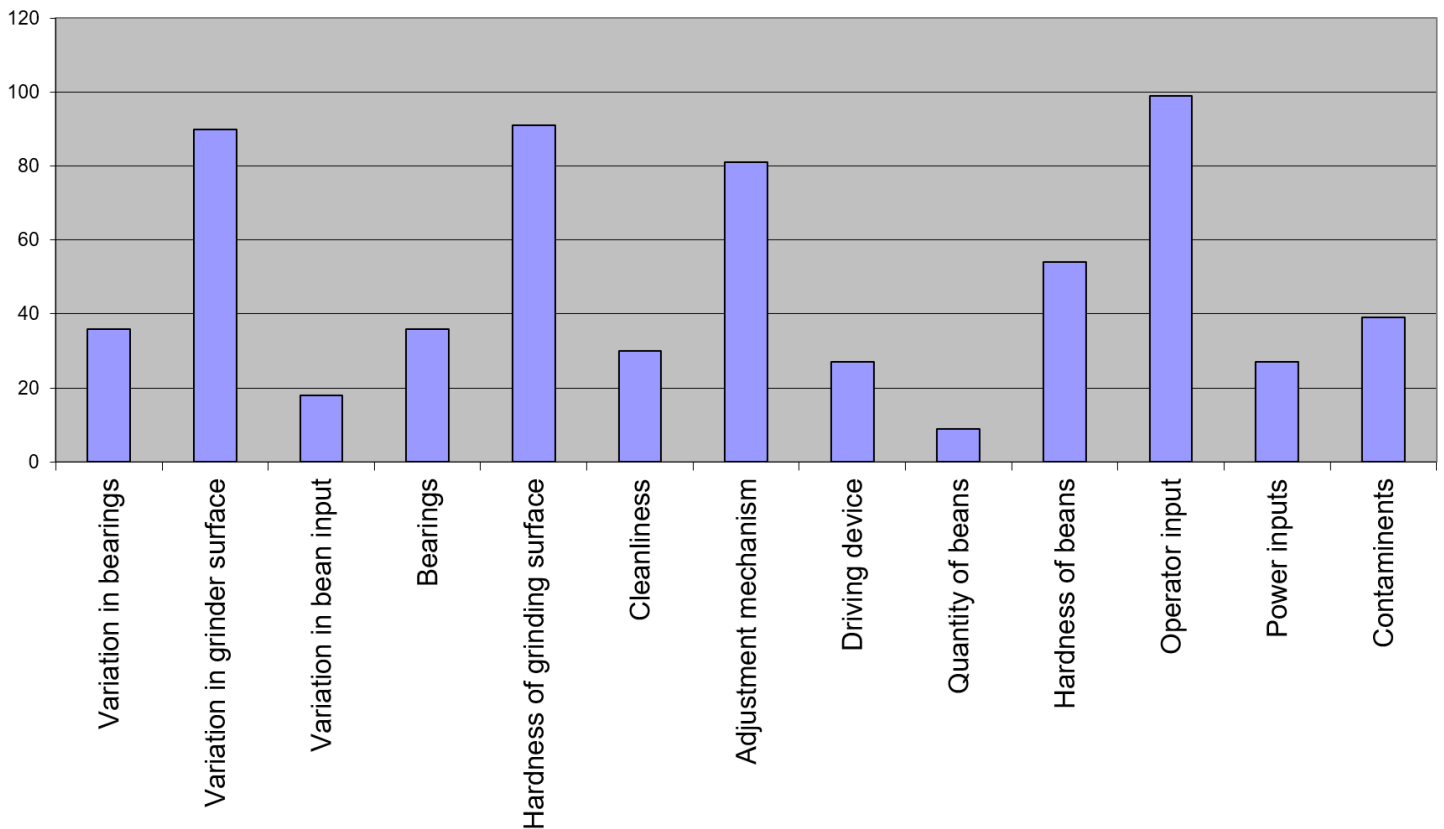


FIGURE 9 - NOISE FACTORS CHART

From these charts we learn that particular design attention must be devoted to the grind setting feature and ensuring the systems operator inputs are well managed to reduce noise.

DESIGN FAILURE MODE AND EFFECTS ANALYSIS (DFMEA)

Failure modes are the requirements of the system not being met and can be categorized into 5 modes: full failure, partial failure, intermittent failure, degraded failure or unintentional failure [26]. These failure modes can be further ranked by severity depending on the impact to the customer, typically through a 1-10 scale where:

- 2-4: Annoyance or visual defect which does not affect performance
- 5-6: Degradation or loss of a secondary function
- 7-8: Degradation or loss of the primary function
- 9-10: Safety and or regulatory implications

Function	Failure Mode	System effect	Effect Seen by user	Severity	Cause	Mechanism (If Known)	Occurrence	Detection / prevention method	Detectability	Rating	Suggested intervention
Adjust grind setting	No adjustment	Failure to adjust grind setting	reduced utility of grinder, may not be suitable for desired application	7	Burr height unchanged	Failure in screw mechanism	2	Grind size delta from setting	2	28	QA on grinder mechanism
					Burr mechanism decouple	Failure in adjuster	3	Grind size delta from setting	2	42	QA on adjuster mechanism
	Too much adjustment	Grind setting overshoot	Grind size inappropriate for desired application	5	Slop in adjustment	Inadequate tolerance	6	Grind size delta from setting	3	90	QA on adjuster mechanism
					Slop in grinder mechanism	Inadequate tolerance	6	Grind size delta from setting	3	90	QA on grinder mechanism
	Too little adjustment	Grind setting undershoot	Grind size inappropriate for desired application	5	Slop in adjustment	Inadequate tolerance	6	Grind size delta from setting	3	90	QA on adjuster mechanism
					Slop in grinder mechanism	Inadequate tolerance	6	Grind size delta from setting	3	90	QA on grinder mechanism
	Intermittent adjustment	Grind setting variance	Inadequate grind size consistency	5	Additional grinder movement during adjustment	Deterioration in mechanism	8	Grind size inconsistency	5	200	Locking mechanism implemented into adjustment
					Adjuster stuck or difficult to operate	Failure in mechanism	4	Adjuster difficult to use	1	20	Design focus on robust mechanism
	Unintended adjustment	Incorrect grind setting	Grind size inappropriate for desired application	5	Grinder movement during operation	Deterioration in mechanism	8	Grind size inconsistency	5	200	Locking mechanism implemented into adjustment

TABLE 8 - DESIGN FAILURE MODES AND EFFECTS ANALYSIS FOR THE 'ADJUST GRIND SETTING FUNCTION'

The example DFMEA in Table 8 primarily highlights the need for robust quality assurance on the component parts however it also suggest design features that had not been considered previously, such as, implementing a locking mechanism within both the adjuster and grinder.

DISCUSSION

The Systems engineering approach proposes a robust, holistic and traceable set of design tools to fulfill a design requirement as a system in ways the constituent elements do not. The design requirements are derived from stakeholder requirements, in this instance: “A coffee grinder is required that is quick to use, accurate, consistent and requires minimal effort and cleaning.”.

The supplied BAE Systems design book was followed to: rank the requirements; propose functions; relate these functions to requirements in QFD 1; analyze means to fulfill the functions; generate 4 concepts and rank their fulfillment of the requirements; propose test methodologies; rank the functional means in QFD 2; analyze inputs, noise factors, controls and outputs; and finally, understand the failure modes and effects of the system.

The Established+ and Effective concepts performed well in the Pugh matrix regarding their fulfillment of the requirements and ultimately the Established+ concept was selected as the succeeding concept due to its adherence to the cost/budgetary requirement that was ranked as most important during the pairwise comparison of requirements.



FIGURE 10 - ESTABLISHED+ CONCEPT

Unfortunately, during the systems design approach being carried out for the primary customer, they have since ceased the consumption of caffeine.

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APPENDIX A – RATIONALISED REQUIREMENTS PAIRWISE COMPARISON

1 = No Preference, Reciprocal = 1
2 = Slight Preference, Reciprocal = 0.5
5 = Preference, Reciprocal = 0.2
9 = Strong preference = 0.11

APPENDIX B – DESIGN QUALITY FUNCTION DEPLOYMENT 1

How	Importance	Adjust grind setting	Measure beans	Insert beans to grinder	Close hopper	Grind beans	Energy in to grinding implement	Settle grounds	Remove collector	Transfer grounds to portafilter	Remove waste	
Requirements												Detailed requirements
The brewing device requires grind size adjustment from espresso (fine) to press (coarse)	13	9				9						300µm for fine - 1500µm for coarse
The brewing device requires consistent grind size	8.2	9				9	1					±50µm
The brewing device requires the processing of the correct amount of beans	12		9	1	1	9		1		9	3	18g
The user requires that the grinder is time efficient	9.1	1	3	3	1	9	9	3	9	9	3	Load and process in <1 min
The user requires that the grinder requires minimal cleaning	6.4	1		1	9	3	3	9	9	9	9	0
The user requires that the grinds can be transferred to the brewing device	5.3							3	9	9	1	Spout 51mm diameter to fit portafilter
The user requires that the grinder is easy to use	5.2	3	3	9	1	9	9	3	3	9	3	0
The user requires indication that the process is completed	2.2					1			1			0
The user requires that the parts are replaceable	4	1				1			1	1		0
The purchaser requires that the grinder is cost effective	14	3	1			1	9			1		Max budget £100
The housemates require that the grinder is quiet	7.1					9	9	1	1	1	3	Max 90dB
The housemates require that the grinder fits under kitchen cupboards	12		1	1	1	1	1		1			<850mm tall
		273	181	105	96	550	362	136	228	371	164	

APPENDIX C – QUALITY FUNCTION DEPLOYMENT 2

Design feature	Importance		Importance	Adjustable height burr	Particle size analysis	Weigh external	Graduated hopper (volumetric)	Weigh internal	Pour in hopper	Vacuum extract from bag	Flap	Seal	Lug	Conical burr	Flat burr	Resonant acoustic grinding	Hand crank	Electric motor	Vibration	Shake	Whack	Screw	Magnet	Lug	Collector diameter of portafilter	Spout	Shutter
Functionality																											
Adjust grind setting	273	10	27.27	9	9									3	3	9											
Measure beans	181	10	18.09		3	9	9	9																			
Insert beans to grinder	105	10	10.52			3	3	9	9	9	9	9															
Close hopper	96	10	9.63						1	3	3	3	9														
Grind beans	550	10	55.04	1										9	9	9											
Energy in to grinding implement	362	10	36.22											3	3	3	9	9									
Settle grounds	136	10	13.56													3			9	9	3						
Remove collector	228	10	22.80																			9	9	9			
Transfer grounds to portafilter	371	10	37.05																3	3	1	1	3		9	9	9
Remove waste	164	10	16.40																3	3	1				3	1	3
				301	300	194	194	257	104	124	124	124	87	686	686	890	326	326	282	282	94	242	316	205	383	350	383

APPENDIX D – P-DIAGRAM

P-Diagram

Author: T Volpato
Date: 12/05/2024
Issue: 1
System: Coffee Grinder

Noise Factors	External
Quantity of beans Hardness of beans Operator input Power Input Contaminents	

Noise Factors	Unit to unit
Variation in bearings Variation in grinder surface Variation in bean input	

Noise Factor	Deterioration
Bearings Hardness of grinding surface Cleanliness Adjustment Mechnaism Driving device	

Signal factors: Select grind
setting, start grind

Coffee grinder

Outputs: Ground coffee of desired size

Control Factors	
Grind setting Amount of bean input Power input	