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Cost-cutting QFD:
How to reduce non-value added costs in goods and services

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Abstract

Since the 1960s, Quality Function Deployment (QFD) has been used by companies around the world and in numerous industries to add quality, value, and customer satisfaction during the design and development of new products and services. Through a linked series of analytic tools, the Voice of the Customer can be deployed into design, build, and delivery specifications and identify the critical tasks to achieve them. We define value to customers as the "magnitude of my problem" divided by the "price I pay to solve it," Though most QFD studies focus on improving customer satisfaction by increasing the functionality or performance of the product, in these difficult economic times it may also be necessary to look at reducing price.

Price is defined as cost plus profit, and traditional cost cutting approaches include value engineering to reduce design cost or lean activities to reduce manufacturing waste. With QFD, an additional approach can be to remove functions and adjust performance that add little value to customers - in other words, bring features in line with the benefits they give the customer, as defined by the customer. Actually, Cost Deployment was integrated into QFD by Dr. Akao in the 1980s but it has never gained much traction outside Japan. This paper will re-visit Cost Deployment as well as review additional tools for Cost-Cutting based on Reverse-QFD, Value Engineering, and others methods.

Key words

QFD, Cost Deployment, Value Engineering, Reverse QFD, VA/VE

Introduction

Cost reduction has been the basis of Total Quality Management from its earliest roots in Shewhart's methods of statistical quality control at Western Electric in the 1920s. From this start in reducing variation in manufacturing processes, the quality discipline has addressed further upstream processes as sources 333of variation as well. In QFD, we begin with reducing variation resulting from misunderstanding customer priorities and from here, can investigate further upstream variation in market potential and competitive threats when setting product development plans, and further downstream in setting product performance requirements, detailed design, suppliers, and then link to manufacturing, service, and other delivery activities. This paper will focus on these downstream activities of misunderstanding customer priorities, setting design requirements, and manufacturing quality. Specifically, we will show ways to use QFD to realize customer driven cost-cutting opportunities through:

1. Initial product functionality reduced by design with cost deployment and reverse QFD
2. Reduced initial product performance by design with cost deployment and reverse QFD
3. Reduced reliability and durability of function over time by design
4. Reduced parts cost, and comparing parts cost vs. system cost by design, including commonization and reuse of parts, volume purchases
5. Value Analysis/Value Engineering (VA/VE)
6. Reduced assembly cost by design
7. Managing variation in design and manufacturing
8. Managing variation in customer usage through better understanding of scenarios, user training, built-in monitoring (performance, maintenance, service)

1. Initial product functionality reduced by design with cost deployment and reverse QFD

The founder of QFD Dr. Yoji Akao, in his seminal book *QFD: Integrating Customer Requirements into Product Design*[1], introduced his comprehensive model that included several main deployments, among them technology, cost, and reliability.

The cost deployment uses the importance of each customer need, and deploys it via (the importance ratings and strength of relationships) weightings to the functions. Through additional transformations, the weightings are allocated eventually to the parts. This methodology can insure that the part cost is reconciled to the relative importance of user needs.

Akao's basic deployment flow is to adjust customer needs weights by factoring in competitive preferences and selling points (figure 1), which could result in components that help differentiate the product from competitive offers being allocated a higher cost profile. In this example from the Host Marriott bagel case, the three traditional adjustments are applied – importance to customer, competitive benchmarking, and sales point. Due to computational limitations, early Japanese examples misused ordinal scale values but were quickly corrected once the Analytic Hierarchy Process (AHP)[2] was calculable on personal computers in the late 1980s. Unfortunately, this was after the QFD method was established in the West, and many non-Japanese practitioners are still misapplying ordinal numbers even today. Detailed instructions for this up-graded quality planning table are included in the QFD Green Belt® and QFD Black Belt® courses, but germane to this paper is that when allocating cost, product differentiation and market conditions can be factored into the weighting of customer needs.

In the example, the most important customer need of "I can get a taste I like" is initially weighted 36.1% by consumers, but after factoring in their preferences for competing offerings and the opportunity to launch a major sales campaign around "taste," the need is adjusted to 51.6%. When deploying product cost, we can justify that more cost should be allocated to improving taste than to other areas of our new offering.

		factors														
		Customer			Customer Survey			Competition				Sales				Adjusted Priority
		Priority from HD	Re-normalized Priority from HD	Global Priority	Current	Competitor	Plan	Improvement	Weight	Local Priority	Global Priority	Sales Point	Weight	Local Priorоty	Global Priority	
Customer Needs		Customer		63.3%	Satisfaction/ Perception			Competition			26.0%	Sales			10.6%	
1.1.1	I can make a healthy choice	11.5%	19.3%	12.2%	3	2	3	-	8.8%	17.7%	4.6%	Minor	33.4%	29.2%	3.1%	19.9%
1.1.2	I can get a taste I like	36.1%	60.6%	38.4%	4	4	4	S	16.1%	32.3%	8.4%	Major	52.5%	46.0%	4.9%	51.6%
1.1.3	I can make an appealing choice	6.9%	11.6%	7.4%	3	3	3	S	16.1%	32.3%	8.4%	None	14.2%	12.4%	1.3%	17.1%
1.1.4	I can choose quickly	5.1%	8.6%	5.4%	5 sec.	10 sec.	8 sec.	-	8.8%	17.7%	4.6%	None	14.2%	12.4%	1.3%	11.3%
		59.6%	100.0%	63.3%					49.7%	100.0%	26.0%		114.2%	100.0%	10.6%	100.0%

Figure 1. Quality *Planning Table showing adjustments for competitive benchmarking and sales points.*[3]

In Akao's comprehensive QFD model, customer needs and their adjusted weights are deployed into weighted quality characteristics, which are then deployed into weighted solution-independent functions. New technology concepts can be considered for better and cheaper designs to deliver the high priority functions (mechanism deployment), and the selected concept is then deployed into weighted parts. The parts weights are then allocated to the target cost of the product (price – profit margin), thus yielding target costs for the parts. See figure 2. In this example of a plastic parts molding machine, "high die-mating rigidity" has an adjusted priority of 3.5% (quality planning table adjustments not shown) which is then multiplied by the target cost of 60 (million yen) to yield a target cost of 2.1 for addressing this need. The example deploys directly to functions (Akao also recommends deploying first to quality characteristics in some applications where what a product "is" is more easily defined than what it "does." The ◎ indicates there is a strong causal relationship between the function of "clamp against internal pressure" and the customer need of "high die-mating rigidity."

In cost deployment where a fixed target is distributed among its contributing factors (functions, mechanisms or subsystems, and parts), the impact of proper math is strong. Recommend best practice would have us evaluate the iconic scale ◎ symbol with AHP which would produce a ratio scale value of about 0.50. Then, instead of using the independent distribution found in traditional QFD, a proportional distribution is recommended under conditions of scarcity constraints such as when allocating a fixed amount of cost. In proportional distribution, the ratio scale values are normalized by dividing each into the row sum. Then, the function weights are proportioned to the "hydraulic energy generation" mechanism or subsystem. Since this function can address multiple customer needs, the distributed weights can be summed for each function and multiplied by the target cost to yield a function cost of 7.0. The mechanism weights can be likewise summed for each mechanism and multiplied by the target cost to yield a mechanism cost target of 3.1. Finally, the mechanisms are related to the component parts and the mechanism weights are distributed to the parts, such as the "hydraulic unit." Then, the weights can be summed for each component part yielding a target part cost of 9.3 (million yen). This is then compared to the current cost estimate of 16.4 (million yen), and since it is significantly higher, some cost reduction such as value engineering is initiated.

Thus, when designing a new product we can drive detailed costing based on importance to customer, competitive threats, and selling opportunities.

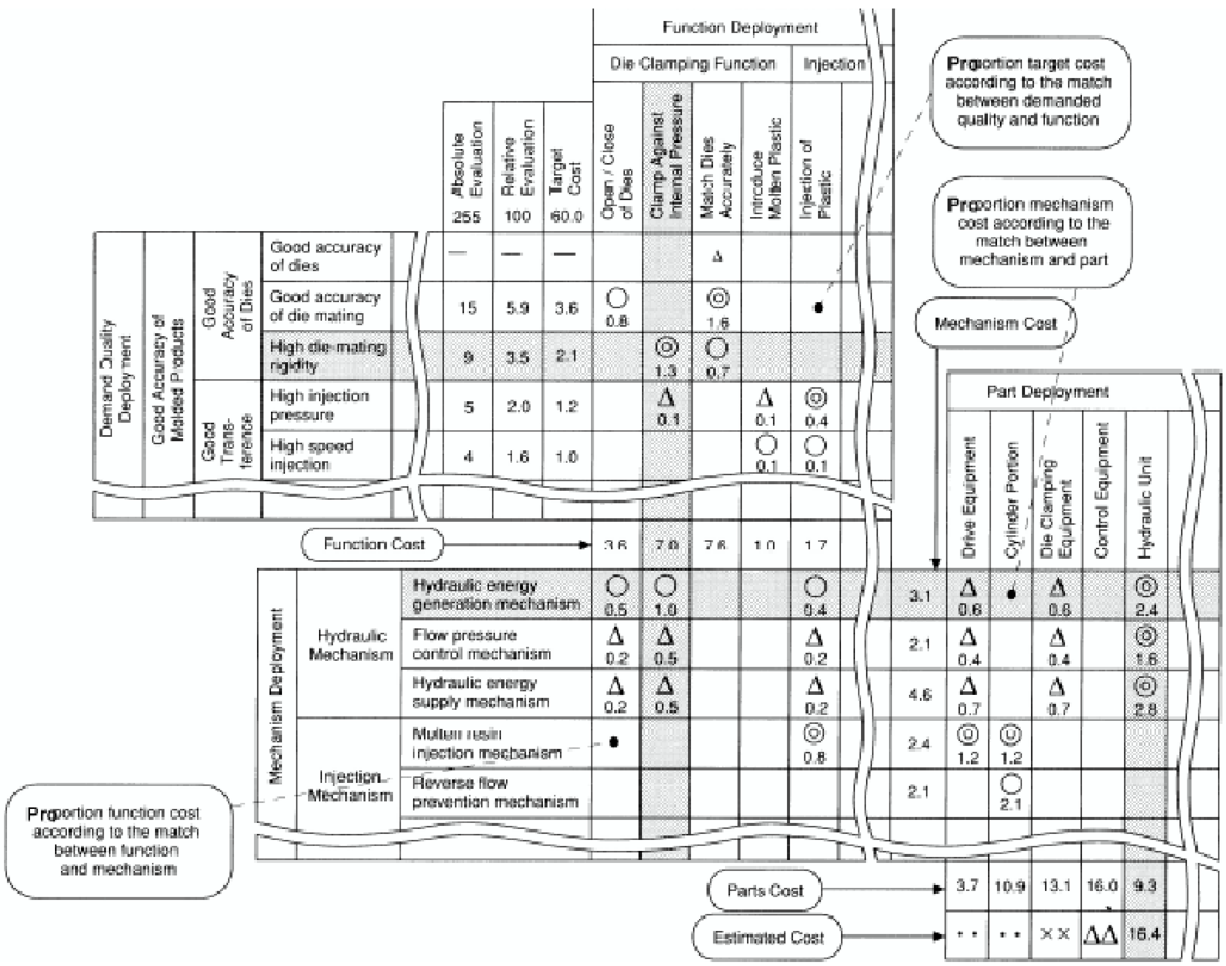

Figure 2. Toyoda Machine's cost deployment model showing proportional distribution.[4]

2. Reduced initial product performance by design with cost deployment and reverse QFD

Reverse QFD cost deployment starts with the existing design with the goal of reducing cost without negatively impacting customer satisfaction of critical needs. In essence, the bill of materials (parts) and assembly costs are worked in reverse through mechanisms, functions, and quality characteristics to the customer needs to which they most strongly relate. These needs are then prioritized by customers, and components not strongly related to high priority needs can become candidates for cost reduction activities, such as value engineering.

3. Reduced reliability and durability of function over time by design

It is helpful to differentiate the typical q, R, D terms (quality, reliability, and durability) from performance over time. The classic manufacturing definition of quality is the number of initial problems in a product; reliability is the probability of failure during the time between initial and end of life; and durability is the failures at or near end of life. A “bath tub curve” is a way to show how failure rate changes with respect to time (figure 3).

Each of these types is reported with different measures. Quality is typically the number of problems or a ranking relative to competition. Reliability is measured in percent reliable or the probability percentage of success. Durability is typically measured in miles or time (hours to years). The word “Quality” as used in the name Quality Function Deployment is not a measure of problems, but rather a measure of goodness. It is important to understand the difference between this quality of goodness and the quality of problems. When consumers talk of “product quality”, they can mean either goodness or they can mean lack of problems, or a combination of both, so the context of the statement must be known. To understand what customers mean, we must ask them; it is a common mistake to use internal definitions to explain consumer words. Often you will hear products advertised as having the highest quality rating. This is usually a ranking of fewer problems than other products rather than a rating of customer satisfaction. When you hear advertisements about highest customer satisfaction, it is usually measured by “goodness.”

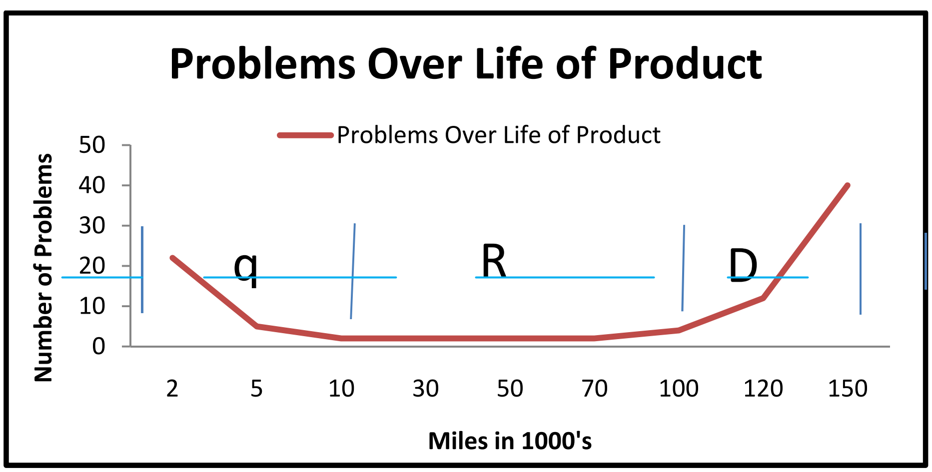

Figure 3. Bath tub curve shows failure rate vs miles.

Most mechanical development projects set a durability or useful life goal for engineering to achieve. The project must also target initial quality and customer satisfaction, which some companies set as design requirements and others allow them to be the result of design and development activities. However, though understanding customer expectations for product performance over the life of the product is rarely obtained, it is just as important to define those customer expectations so the product is properly designed - neither over- nor under-designed. So, what is acceptable or expected performance over each segment of use from initial to end of life? Can the performance deteriorate, as in oil consumption in an automobile engine or exhaust system sound or even vehicle ride, or does the performance need to be constant over time? An example of this could be braking performance (figure 4). Although braking performance does change with tire tread wear and road surface conditions, safety related products should be designed to perform at some acceptable level under specified conditions. The way brakes are designed today requires the system to be refreshed by installing new friction material (brake pads or shoes) after the material is worn to some minimum dimension. Brakes and interior noise level illustrate a good contrast. Whereas braking is expected to stay constant, interior noise level is more dependent on the product strategy and the customer. If the product performance over time has not be seriously defined for all characteristics, extra cost may find its way into the product's design. Clearly, this means defining performance over time at the functional level when a loss of function is typically considered a product failure.

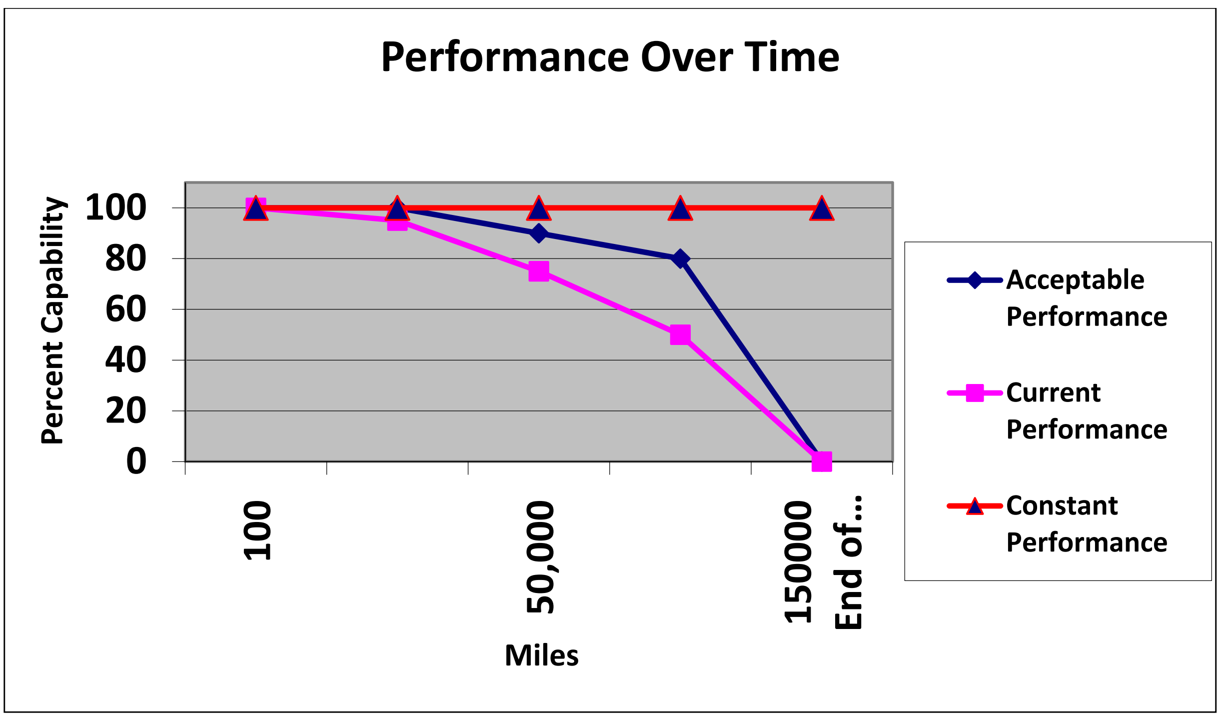

Figure 4. Performance capability at different mileages.

Reliability is typically defined as maintaining performance over time, but it is measured as the probability of loss of function, not performance. Even still, performance does not have to go to zero to be termed a failure if the level of performance is clearly below the user's acceptance. Thus, we can consider if performance deterioration might still be acceptable to the customer. If the car engine cranks longer before it starts after 5 years than it did when new, is this acceptable? As long as the engine starts, it is not a failure, but product confidence and customer acceptance may still be questioned.

The actual design is typically modified by material selection to maintain the desired performance level, but since the characteristic that is typically changing is wear, but will it need to be defined for each product?. Even stress levels that are managed in engineering that can predominately effect durability or loss of function, may not be the predominate control for the type of performance we are addressing in this topic because the failure modes are different.

4. Reduced parts cost, and comparing parts cost vs. system cost by design, including commonization and reuse of parts, volume purchases, Value Analysis/Value Engineering (VA/VE).

VOLUME – NUMBER OF TOTAL PARTS MADE – EFFECTS

Another way to decrease product cost is optimizing the total parts used or the “volume effect” or the total number made. Unit cost for a few parts is more expensive than for a large number of the same part because regardless of the quantity, the design cost is about the same, as is the testing/ validation of the design. That leaves the cost to make the part the significant difference. The tooling for a few parts may be universal or temporary, but high volume parts have dedicated tools. If assembly is required, low quantity parts are designed to be self locating with tabs, holes, or contours incorporated into the parts, while high quantity parts do not put those features into the parts, but instead have dedicated fixtures that hold the parts in position and use cheaper fastening methods (welding or adhesives). Thus, if the manufacturing of the parts can be more efficient by eliminating time and number of operations associated with low quantity parts, savings can be realized.

Of course, manufacturing methods are a function of the application, but in general the set up time and fabrication time for dedicated tooling depends on the number of parts to be made, so the optimal solution is to have a set of machines and people working full time on producing the same parts. Thus, the cost drivers consequently change from time to make a few versus the cost to have dedicated tooling. When tooling is dedicated, there are incremental savings and it is not necessarily true that more is better because there are economic limits and capacity constraints for tools, building size, etc. At these economic break points, the system then needs to be optimized and every constraint challenged. Should it remain a constraint or can be turned into a variable? However, because of the complexity that increases with the number of variables, the total number to optimize is significant. However, the greatest risk to profit may be predicting sales in a retail market, so determining whether to have low or high quantity of parts creates an appreciable challenge to determine the appropriate quantity to optimize. Market research and forecasting the market future environment is very valuable in getting additional information

COMMODITY AND COMMONIZED PARTS

The current emphasis is to use communized parts. "Commonized" by this definition means parts can be shared by other designs hence the emphasis on having architecture designs that purposely share or use some portion in another application. Another solution is to use commodity parts which are shared between companies and even countries. Batteries would be an example of commodity parts. We have all experienced the lower cost of replacing standard batteries such as AA or 9 volt versus purchasing a dedicated battery for a product, such as in laptop computers or mobile devices. Dedicated batteries are unusually expensive not because the service department is trying to get rich but because the price of the part reflects unique design, manufacturing and inventory costs. Early laptops used dedicated RAM (Random Access Memory) which was very expensive to increase the total number of bytes (capacity), in contrast to the current practice of using commodity RAM. Thus, the trend may be to have more parts incorporated in the design that are not optimized for the specific product because it is overall less costly when all the costs are shared by many products and companies. Companies should consider in their product strategy the use of commonized parts and commodity parts to minimize maintenance and upgrade costs. Interface design and standards are critical to support this strategy.

The contrast of design strategies for high volumes vs. low volume needs to be recognized as well for their consequences. If the product is very expensive, then the design strategy of coupling functions needs to be investigated. An example is a military aircraft versus a popular car. In the popular car, which is high volume, many of the product functions are combined into a single system or part. For example, the frame of the vehicle has the function of (1) carrying the payload, (2) provide mounting of the body, engine, and suspensions, (3) vibration and noise control, (4) energy absorption during a frontal crash, (5) bumper mounting and loads, and many other functions and performances. The advantage comes from creating value (function/cost) or what you get for what you pay. In a high volume application, having dedicated or separate systems for each of these functions would be much more costly. On the downside, the product can't be easily upgraded and must remain the same until retired or discarded. This is called a "highly coupled" design that is very difficult to optimize since many of those functions and performances are competing - what is good for one is not for the others. Changing the performance of any of the functions can cause the entire design to have to be redesigned to find an acceptable solution. That is one reason why an entire vehicle might be "totaled" after an accident because the system has been optimized for safety and not for low cost repair.

Another example is the automobile tire. It may seem that a tire is just a single part and not that complicated. But because of coupled design, it carries a supporting role in many other vehicle systems (support vehicle weight, ride, handling, braking, rolling resistance, styling/appearance) as well as properties it provides on its own (noise & vibration, wear, recyclability). This means the tire is sometimes a spring, a sticky foot, a frictionless wheel. Further, it must not generate noise or vibration; it must last for the required period, and be compatible with recycling. Needless to say, these are not necessarily positively correlated parameters. We say of rubber compounds that are soft and sticky, they don't wear well; and what is hard, doesn't stick well.

What is the importance of each of these vehicle functions? What is the contribution of the tire to that function or performance? What part of the tire cost is allocated to each? What is the actual cost of the tire to provide each of the functions? As discussed above, QFD and cost deployment can be useful in mapping and allocating these relationships and costs. Considering all the performance that a tire has to provide, the replacement cost of a tire seems reasonable. A new coupling is emerging because tire properties are becoming significant in automated vehicle control systems, such as General Motor's Stabilitrac which has the ability to bring the vehicle back under control if it is skidding either from braking, spin out, or a combination of them. This puts more demands on the tire and so it must be replaced with a tire that has the same performance properties in order to retain the original vehicle control and recovery capability. This is going from a commodity to a more dedicated replacement part. Aftermarket tires were never exactly the same as OEM (Original Equipment Manufacturer) because the belief by both replacement tire sellers and manufacturers was that the driver would not be able to recognize the changes in the vehicle from when it had the original tires, which was generally true, as that was about 30,000 miles ago.

Contrast this to a military fighter plane where the product cost is very high and increasing the useful life is one way to make the product a good value. Hence sub-systems are not incorporated into the same parts. This allows for the subsystem to be upgraded without upsetting the balance of the other subsystems in the system. Replacement of a desktop computer motherboard is another example of significantly upgrading system performance while keeping most of the original product. This is often referred to as "modular design".

5. Value Analysis/Value Engineering (VA/VE)

Cost is always an important factor in product development. Part cost is generally left out of the House of Quality due to its ability to skew/overshadow the importance of other characteristics. When incorporated into Cost Deployment, value analysis and value engineering allow you look at cost from an end users perspective or from an engineering point of view. This should help identify potential part reductions and possibly combine part functions to keep cost in line with value. The theory behind value analysis is to put cost into the areas that have the most value to the customer. The value analysis takes the parts percentage cost based on the total system part cost and distributes it against value of the part from the quality characteristic/parts matrix (figure 5). Value Engineering helps in determining which functions might be best combined into a single part. The VE analysis takes the parts percentage cost based on the total system part cost as a ratio of the parts percent function in the system. This can then be graphed to see where function/cost mismatches present opportunities for cost reduction efforts (figure 6). Parts that have function-to-cost ratios above the diagonal line indicate that the cost is higher than the functionality and are therefore candidates for cost reduction efforts, including commodity and communization as mentioned above.

Quality Characteristic / Front MC Parts				Mc Body	Clamp	Clamp Screws	Lever	Pivot Pin	Bushing (lever pin)	Retaining Ring (lever)	Sight Glass	Cover Gasket	P
Quality Characteristic	Physical	Lever	Ratio				◎						
			Width				◎						
		Other	Resistance lever apply force				◎	△	○				
			MC weight	◎	○	△	◎	△	△	△	△	△	
	Performance	Lever	Lever force vs Travel	◎			◎						
			Lever dead stroke	◎			△						
		System	Force vs Pressure	◎			◎						
			Stroke vs Deceleration (leve	◎			◎						
		Oth	Lever reach	◎			◎						
Absolute Weight				2.60	0.10	0.10	3.50	0.10	0.01	0.01	0.10	0.30	0.1
Part Weight				23.90	0.52	0.50	31.74	0.61	0.34	0.01	0.50	2.59	0.

Figure 5. Quality Characteristics-Front Master Cylinder Parts Matrix (partial).[5]

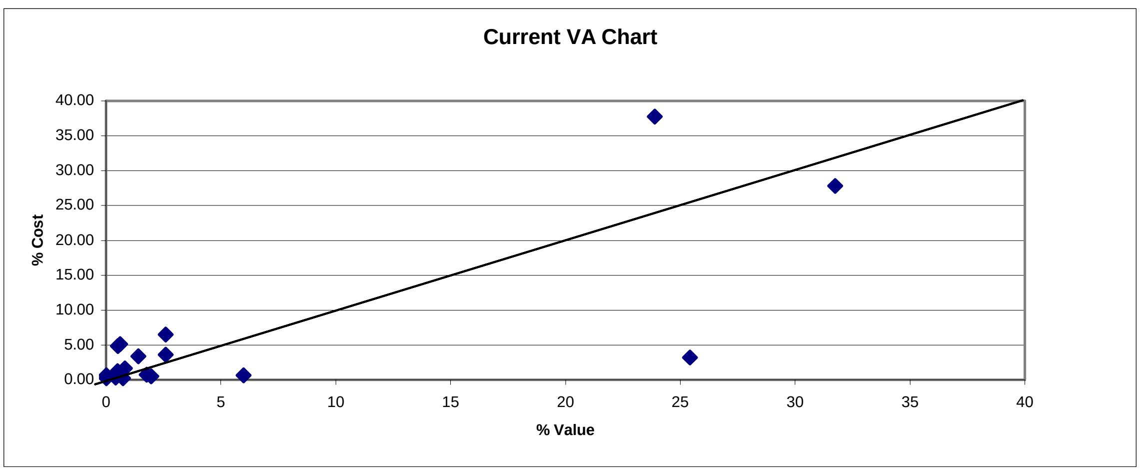

Figure 6. Value Analysis of Ratio of Current Master Cylinder Parts Cost to Value to Customer Demanded Quality (partial).

6. Reduced assembly cost by design

The labor cost of a part for assembly is directly related to time to complete the task. The higher the total labor rate (wages and benefits), the more significant this cost can be in the product. The design can be optimized to minimize the time for assembly of parts, using Design for Assembly (DFA), a methodology that specifically identifies and itemizes each step of the assembly process. Some examples of minimizing time is to provide “features” in the parts that help locate and orient parts to each other. Another technique is to use fastener types that minimize time. This includes screws with driving features that help hold the fastener such as torx head, a hex head, a tab or a "carrot" incorporated into the part (figure 7).

Figure 7. Illustration of a tab being used to locate and retain the front edge of a tail light

Another method is to combine parts at their point of manufacture so there are fewer parts to assemble. The ultimate DFA design with this method is to make it "one piece" as there is no assembly time. For assemblies that do not need to be serviced or are too costly to repair either because of the time and skill to make a diagnosis and repair, or the repair cost is a high percentage of the total part cost, the best design can be a throw-way and replace with a complete new unit. Choosing the best design is a case by case decision to optimize all the parameters, including initial and life cycle costs, but the elements considered in making that decision are typically the same.

7. Managing variation in design and manufacturing

There is and will always be variation in any human endeavor. Engineers often ignore variation by focusing on the nominal specification value when trying to get an initial design to work, and only later consider tolerances to account for variation. The source of variation is the process or making of the part. The best designs either minimize variation of the produced parts, and/or are robust to variation. Since a major part of the cost is a direct result of processing materials and assembly, manufacturing can select the type and amount of processing required which can result in variation. The interactive question is what amount of variation or tolerance can the design accept and still have system performance within the acceptable range. A good development process should continue to iterate the design and the processing to optimize cost, mass (for example), and performance. Practice has shown that the final design with the least variation is also the more preferred by the marketplace, and can also result in the q, R & D improved as well. Warranty issues can also be solved by reducing variation so cost should be measured not just in the narrow sense, but should consider the impact on life cycle cost. The effect on a brand's reputation when a product gets a negative association is difficult to measure when making product development decisions, but is very real concern over time. Thus, cost should be reduced by managing variation as a strategy, not by dealing with it after it appears. This is especially true for high volume, specific tooled parts, recognizing that a different strategy may be more appropriate when only a few parts are made. This is because there is no variation if only a single product is made - it is what it is. But if more than one is produced, variation will be introduced because they won't be exactly alike. Even when less than a dozen are made, there is variation. It is not about the number produced or the cost of the part - variation is real and needs to be recognized.

There are 2 strategies for managing variation:

1 Minimize it or don't cause it

2 Accommodate it in a robust design.

To minimize variation, a type of processing can be chosen that causes the least amount, the design can be modified to aid in the processing, or a combination of the two. To accommodate the variation, the design needs to "zero out" the variation instead of accumulating individual amounts, which can make the total large. This strategy usually requires more pieces in the design, but that may be the best system. An example of accumulation can be found in home construction. The effects of walls in a room that are not square or straight are well known. If the 2 x 4's are not straight, or they are not nailed in a straight line, the drywall being the most compliant will follow the contour determined by the wood framing. The industry practice is to use tape and dry wall finishing compound to cover the variation, but when counter tops, base-boards, and other moldings are added, they must either follow the exact contour or a gap results, which draws attention to the defect. If wall paper is then added, the paper must be cut to accommodate the out of squareness or straightness. So the effects accumulate and each layer of materials has to keep dealing with the variation. One way of managing this variation is to use steel 2 x 4's because they are straight and uniform, and the effect is a wall that is straight both vertically and horizontally. The corners at the walls, floor and ceiling are still a function of the assembly, and being installed square is a skill and measuring issue. If the wall is a divider between two rooms both sides maybe affected by the variation which must be adjusted repeatedly, and sometimes the defect cannot be covered up and is visually apparent. We have consequently been conditioned to accept that none of the walls are straight or square, but you can imagine the "cost" incurred over and over at each layer because of variation. To help mask the variation, moldings are used that would not be needed otherwise, adding additional pieces and cost because of the variation. The important thing is to have a variation strategy in the product planning stage and develop the product to it. QFD is a methodology that directly addresses managing quality by keeping track of the variation linkages and making them explicit.

8. Managing variation in customer usage

Another source of variation can be the user. Part of the design process is to determine the misuse and abuse limit for a product. The problem is that it can drive up the cost by overdesigning excess capacity or durability for the user. In the past, many vehicles were overdesigned because there were user caused failures that had to be "fixed." The result was a more reliable and durable product for that aspect because it was more robust to both product variation and user variation. But a more cost effective design addresses this variation. Users (customers) may use something however they choose, but the seller doesn't have to warrant or be responsible for all uses. The objective is to design a product that satisfies the number of people we wish to sell to for the price they are willing to pay. The user can be educated on how to best use the product via instructions and/or optional or required training. However, for mass produced products, this is generally an ineffective way to educate users. The new approach is to manage user variation by marketing to targeted consumers. This requires getting the voice of those customers to find out how they would use the product. Modern Blitz QFD® tools like the customers segments table and customer process model are designed specifically for this.[6] Price, color, styling can also be addressed using Kansei Engineering and Lifestyle Deployment,[7] and retail distribution and marketing are ways that targeted users can be selected based on their more homogeneous, hence more common, usage of the product.

Conclusion

The economic pressures on producers of products and services will continue to mount in the current economy. QFD can enable the developers of these products to view cost reduction from the perspective of the user and customer, not just the manufacturer. This paper has outlined several considerations and given examples of how both traditional and modern Blitz QFD® tools can be used to reduce costs in design, manufacturing, delivery, and usage. Upgrading the math used in QFD analyses using AHP is essential to proper allocation of priorities to design and cost issues. With QFD, costs can be determined by value to the customer based on what matters most to them.

About the Authors

Harold M. Ross is retired from General Motors after a 43 year career in product engineering. He has been involved with QFD since the early days of its introduction into the United States. He has led and supported many internal QFD projects and training, as well as setting up and developing tools and methods for its support and vehicle applications. Harold is a QFD Green Belt, and also a director of the QFD Institute and participates in the US annual QFD Symposium.

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