ENGINEERING AND
R&D SERVICES

HCL

Incorporating Value Engineering Right at the beginning of Design Cycle

- Vikram Bhargava

WHITEPAPER

e2 Engineering experiences

Acceleration | Value | Technology

Table of Content:

1.0 Summary

The total cost of a product comprises of normal costs, avoidable costs and opportunity costs.

It is important that while developing products, value engineering be incorporated from the initial design using a holistic approach.

Material, design, tooling and processing are as important as the four wheels of a high performance of a car. Use of simulation tools play an important role as well.

This paper also throws light on DFMPro – a design assistant solution. DFMPro provides a rule-based approach to information on direct and indirect aspects of design performance and cost.

DFMPro is a CAD-integrated design for manufacturing software that helps identify and correct downstream issues early in the design stage, leading to reduction of cycle time and, in turn, high-quality products with lower product development and final costs.

The paper also provides an understanding of the DFX and Cost views.

2.0 Introduction

What Is Value Engineering?

Value engineering (VE) is a systematic method to improve the "value" of products and service. Value, as defined, is the ratio of function to cost. Value can therefore be manipulated by either improving the function or reducing the cost. It is a primary tenet of value engineering that basic functions be preserved and not be reduced as a consequence of pursuing value improvements. [a] As a common example, the use of plastics is reducing the cost of manufacturing, improving the fuel efficiency of the vehicles and adding to passenger saftey[1]. In other words, it is a win-win for both the customer and the stake holder.

Value Engineering vs Cost Reduction

Value engineering should not be confused with cost reduction. Pure cost reductions may just help reduce cost to the stake holder. The reduced cost product may in fact reduce the value to the customer. Here is another automobile example. It used to be that the automobile manufacturers provided a spare tire which had the same specifications as the other four tires. In the eighties the auto manufactures starting using a “donut” tire to reduce the cost. This tire is meant to be driven only for a limited number of miles at a reduced speed and needs to be changed as soon as possible. Cost reduction for the manufacturer and a great inconvenience to the customer!

Figure 1: An Example of Spare Tire Provided by Automobile Manufactures

To keep everyone on their toes regarding COGS (Cost of Goods Sold), most corporations judge project success on three “Ons.” Everyone who is a part of the project is rewarded or penalized based on how these three are met.

---

[1] *Fuel efficiency is estimated to go up 6 to 8 percent for every 10 percent of a vehicle’s weight that is cut….A study by the National Highway Traffic Safety Administration (NHTSA) reported that innovative safety technologies, many of which included the use of plastics and composites, saved an estimated 613,501 lives between 1960 and 2012. A study by the Insurance Institute of Highway Safety showed that driver deaths dropped to 28 per one million from 87 over the period from 2002 to 2011 as safety features advanced. [b]*

2.1 Traditional Value Engineering

It is very common for corporations to incorporate value engineering after the product has already been in the market. They even have on going teams dedicated to value engineering. This is good. It is a fact that some value engineering opportunities reveal themselves only after the product has been used for a while. Also, a certain technology or material may have not been available when the product was initially designed and introduced. Another reason is to leverage from the competitors' products (in an ethical and legal way, of course).

To keep everyone on their toes regarding COGS (Cost of Goods Sold), most corporations judge project success on three "Ons." Everyone who is a part of the project is rewarded or penalized based on how these three are met.

<u>These are:</u>

- On time

A fully functional product is ready for the market when it was committed to be launched at the beginning of the project. To meet these time deadlines, products may be launched with many cost optimization opportunities "left on the table." The logic is "we will come back" to reduce the cost. Yeah, right! The high costs are built in forever in most situations.

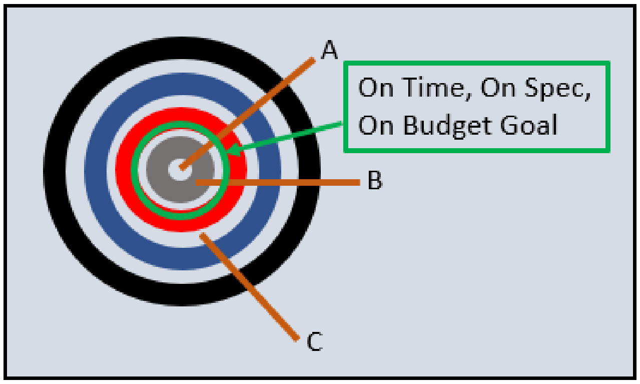
- On budget

    - Cost of the product
    - Cost of development

This one is obvious. Both the cost of the product and the resources spent on the development need to be controlled.

- On specification – need to meet the product requirements

    - Cost to fix if not on spec



A: Met Minimum Specifications
B: Met Deadline
C: Met Maximum Cost

Figure 2: Traditional Value Engineering Example

In the rush to meet these "ONs," unfortunately many times real effort at value engineering is lost. Engineers tend to take these targets as goal posts in soccer rather than the target in rifle shooting. In the pictures below, in the case of soccer, there is no reward for B over A and C. While in the case of rifle shooting, while A and B clearly met the targets, A won over B. (C did not even get a raise that year)!

3.0 The Role of the Designer and Various Aspects of Value Engineering

A product designer is like the quarterback in American football. The quarterback is responsible for the outcome of each individual play and his successes and failures can have a significant impact on the fortunes of his team. Even the strongest offence and defense team cannot make up for the deficiency of a quarterback.

Figure 3: A product designer is like the quarterback in American football

Likewise, the design engineer plays a major role in the performance of the product including its value to the customer. The others in the team such as the material supplier, the tool maker and the manufacturer cannot make up for the deficiencies in the design or the cost. A clear majority of the apparent material, tooling, processing and abuse issues and costs can also be linked back to design errors.

As designers, we take pride in creating robust products at the optimum cost. Every design should obviously be robust enough to meet or exceed the functional requirement over the projected life, intended environmental conditions and the physical appearance. However, considering the competition and changing consumer preferences every designer should also ensure that the product has been value engineered from the get-go.

Let's look at what makes up the total cost of a product and what costs can be avoided or eliminated.

3.1 Normal Costs

- Development costs (reasonable CAD, analysis, prototyping, verification costs)
- Tool, tool development and qualification costs
- Total part cost – n X the reasonable individual part cost ('n' being the total number of products manufactured)

3.2 Avoidable Costs

Avoidable costs are those that are attributed to the direct and indirect costs (scrap costs, wasted engineering resources cost, tooling costs, etc.) that occur due to design errors and engineering changes that could have been avoided. Figure 1 depicts the traditional cost of design change curve for the product lifecycle. As one can see, the cost of a design error and change increases exponentially, the later it occurs in the development lifecycle.

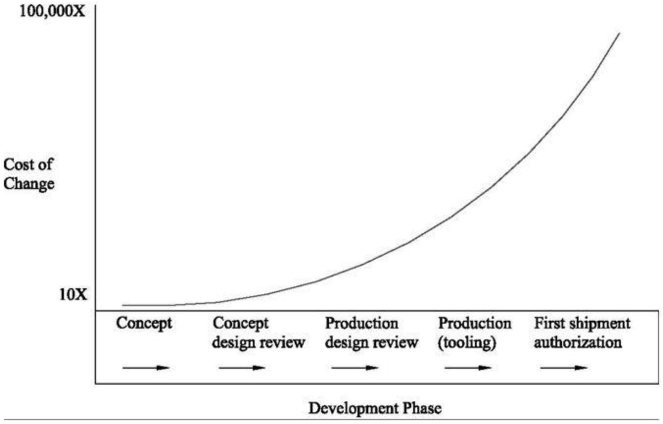


Figure 4: Cost of change vs Development Phase

Companies pay even a bigger price if errors are detected after the product is delivered to customers. It not only leads to expensive recalls but can completely damage a company's reputation.

The General Motors recall due to the faulty ignition switch is a recent example of how a simple design error led to huge losses for the company. The cost for getting the switch designed right in the first place would have been 57 cents [g]. The total cost of the recall was $4.1 billion as of Feb 4, 2015 [d].

3.3 Opportunity Costs

The figure below represents a commonly acceptable life span of a product.

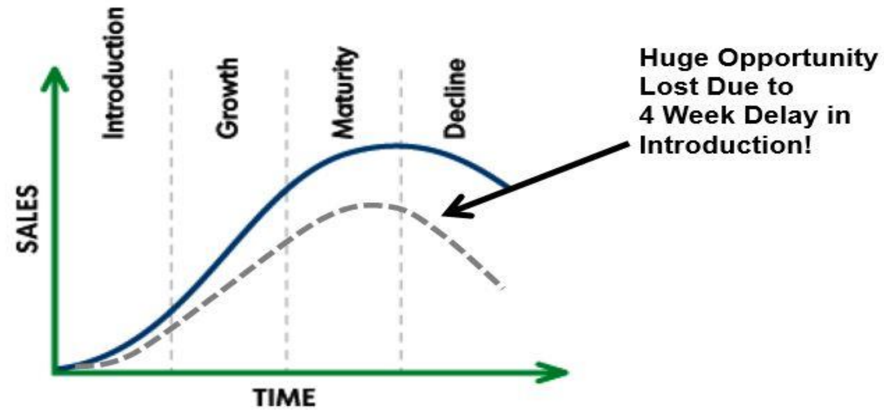


Figure 5: commonly acceptable life span of a product

The solid line shows the total anticipated sales for a product over its intended life. The dotted line represents what may happen to sales if the product release is delayed by 4 weeks. The difference between the integrals of the two curves potentially represents the total revenue loss or the total opportunity costs and may run into millions of dollars.

Leading aircraft manufacturer, Boeing had to temporarily halt the deliveries of Boeing 787 because of the battery overheating issues. This cost the aircraft manufacturer approximately. $600 million [e] in direct costs. As large as this figure is, it may still dwarf compared to the loss in opportunity costs. Having lost the sale of even 5-6 aircrafts to the competition might have meant revenue losses of over a billion dollars.

(Please see my article “Eye-opening Impact of Simple Design Errors on Product Costs”, Plastics Engineering, Oct 2016).

4.0 A Holistic Approach to Design and Incorporating Value Engineering from the Initial Design

In what follows I am going to mostly talk about designing plastic parts as they have the most dependence on materials, design, tooling and processing for the ultimate performance of the parts and assemblies. The same logic can be applied to metal parts to a lesser extent.

Consideration to the following is essential for a well-designed and value engineered plastic part or assembly:

- Material
- Design
- Tooling
- Processing including Secondary Operations

This is analogous to the four wheels of a high-performance car.

In his book *Failure of Plastics and Rubber* [c], David Wright conducted an analysis on 5,000 failed parts and came up with the causes for the failures shown in the figure below.

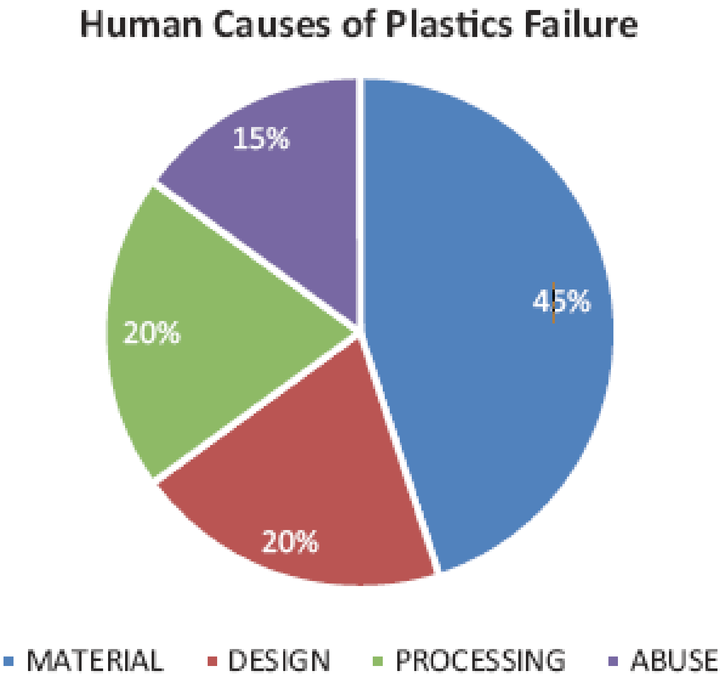


Figure 6: Human Causes of Plastic Failure

Therefore, a designer may conclude that he or she is responsible for only twenty percent of the failures or cost overruns. What appears as materials, processing, tooling, or misuse issues may in a lot of cases can be traced back to fundamental design issues that may manifest themselves as the former.

Let us look at *just a few very common* examples.

4.1 Material

A previous part cracked in use. The designer working on a new project assumes that it was material weakness on the part and changes it to a different and possibly more expensive material.

In the example below, the reason for the crack was not the material. It was the sharp corner in the corresponding inside walls.

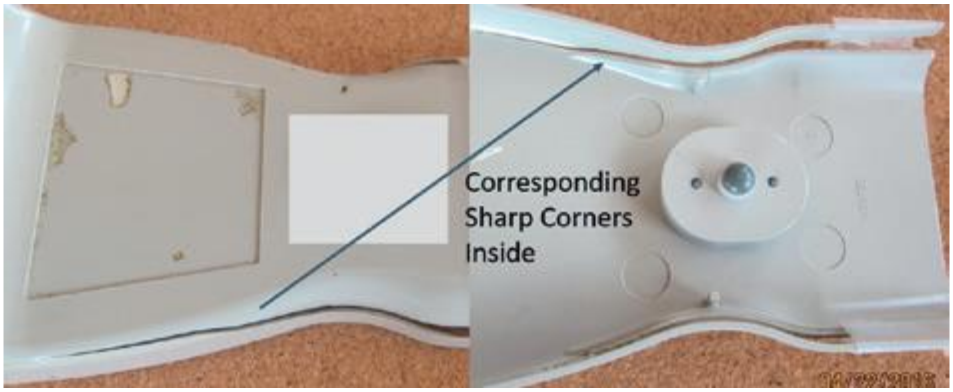


Figure 7: A crack due to sharp corner inside wall.

My college professor used to say, “A good design is one that performs as designed AND costs as little as possible.” In that vein, the designer has to keep the cost in mind.

A TV enclosure that can withstand the normal use requirements in a high impact polystyrene (HIPS) should not be designed in PC, which may cost three times or more.

Another common example is the temperature resistance of plastics. See the figure below. Materials with higher temperature resistance, cost more.

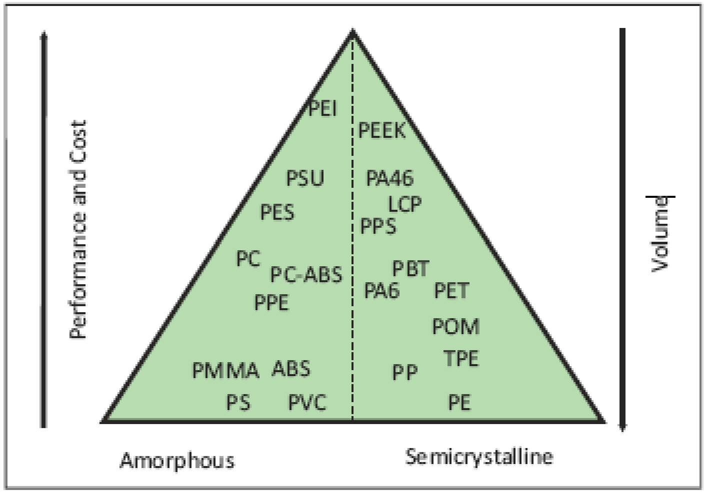


Figure 8: Materials with higher temperature resistance, cost more. [f]

The common clear cold drink cup is made from polystyrene. One could use polycarbonate for the application, which would make it almost impossible to break and suitable for hot coffee. The cost, however, would be significantly higher both in terms of material and processing.

Switching to metals for a moment, an electrical contact can be made out of beryllium copper, phosphor bronze or brass with very high to low costs respectively. Before selecting beryllium copper, have, we made sure that brass cannot be used with a little more creative design?

4.2 Design

Poor design, besides resulting in higher material, tooling and processing costs, will result in many avoidable costs and opportunity costs as described above. The cooling portion of the molding cycle time is roughly proportional to the square of the thickness.

Looking at the figure below, the cooling time for a wall thickness of 2.0 mm is about 3 seconds. For 4.0 mm it is about 12 seconds approximately (or 3×2^2). The molding rate for a small tonnage machine in the U. S. maybe $30/hour. The extra approximate 9 seconds cost $30×9/60/60 = $0.075 or 7.5 cents. While this may be an increase of only 10 % for a large part costing about 75 cents, it may double the price of a part costing 8 cents!

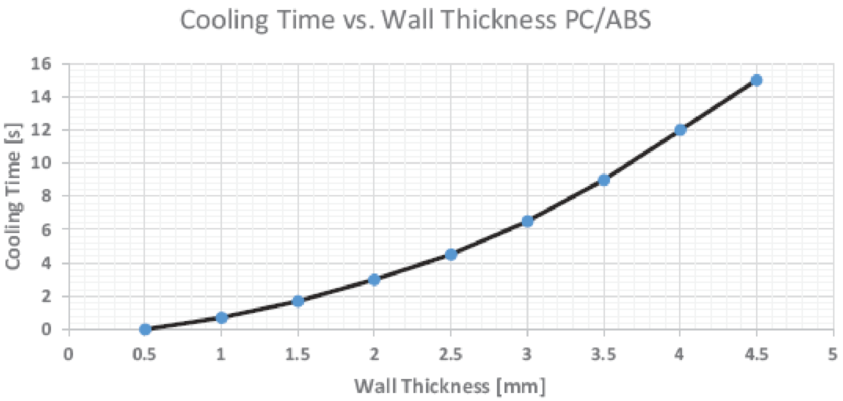


Figure 9: Cooling time Vs Wall Thickness PC/ABS [f]

The figure below (left) shows the ubiquitous latch for the folding tray table found on many commercial planes. The section in the middle is not cored out as far as I can tell. Using ABS for the material, if this were molded on a single cavity mold, the cost of the cooling portion of the molding cycle would be about 2.5 cents (3 seconds cooling time) if the section were cored out. Because it is not cored out, the cooling time is approximately 12 seconds with a cost of 10 cents—about 7.5 cents more. If the material were ABS at about $2.50/kg and the part weighed 10 g, the material cost would be about 2.5 cents. With a 15 seconds total cycle (12.5 cents), the cost of the cored part would be 2.5 + 12.5 = 15 cents. With the additional cooling time of 9 seconds, the cost goes up by 7.5 cents for a total of 22.5 cents or 50 %!
The figure on the right is a much better design.

Figure 10: Ubiquitous latch for the folding tray table found on many commercial planes.

Figure 10 (above) shows the ubiquitous latch for the folding tray table found on many commercial planes. The section in the middle is not cored out as far as I can tell. Using ABS for the material, if this were molded on a single cavity mold, the cost of the cooling portion of the molding cycle would be about 2.5 cents (3 seconds cooling time) if the section were cored out. Because it is not cored out, the cooling time is approximately 12 seconds with a cost of 10 cents—about 7.5 cents more. If the material were ABS at about $2.50/kg and the part weighed 10 g, the material cost would be about 2.5 cents. With a 15 seconds total cycle (12.5 cents), the cost of the cored part would be 2.5 + 12.5 = 15 cents. With the additional cooling time of 9 seconds, the cost goes up by 7.5 cents for a total of 22.5 cents or 50 %!

4.3 Tooling

Some quick examples:

While undercuts are a common feature in plastic part designs, they add cost both in terms of initial tooling and possible loss of yield due to the adds complexity of the mold. The figure below shows the undercut on a snap feature being formed two different ways. The one on the right can save the cost of a moving mechanical feature that may cost several thousand dollars.

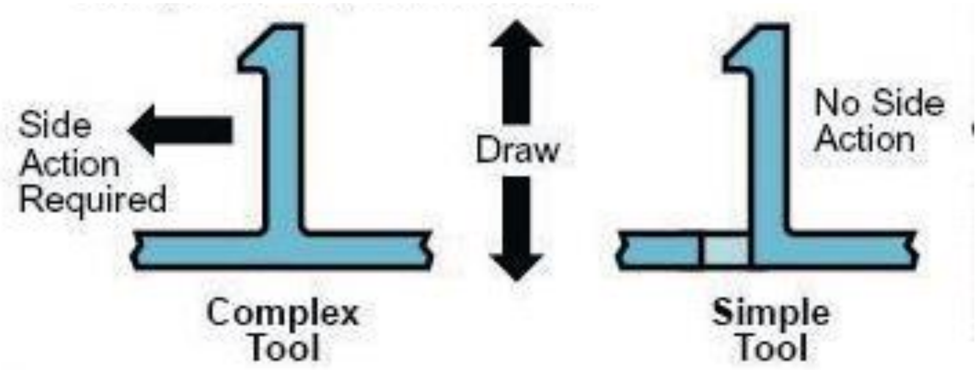


Figure 11: Undercut on a snap feature being formed two different ways. [f]

When the production quantities are high, building a multicavity tool may reduce the cost of the individual part. The chart below shows a very simple way to determine if a multicavity tool can be justified.

Here is typical piece price and tool cost data. [f]

Piece Price	Initial Tool Cost	No of Cavities Quantity
0.37	31,700.00	1
0.10	50,000.00	4

And here is a simple break-even analysis. The three curves show the total cost of the parts plus the tool for various quantities needed for one vs four cavities and the difference between them over these quantities. Clearly, if the quantities exceed 400,000, it pays to build a four-cavity mold.

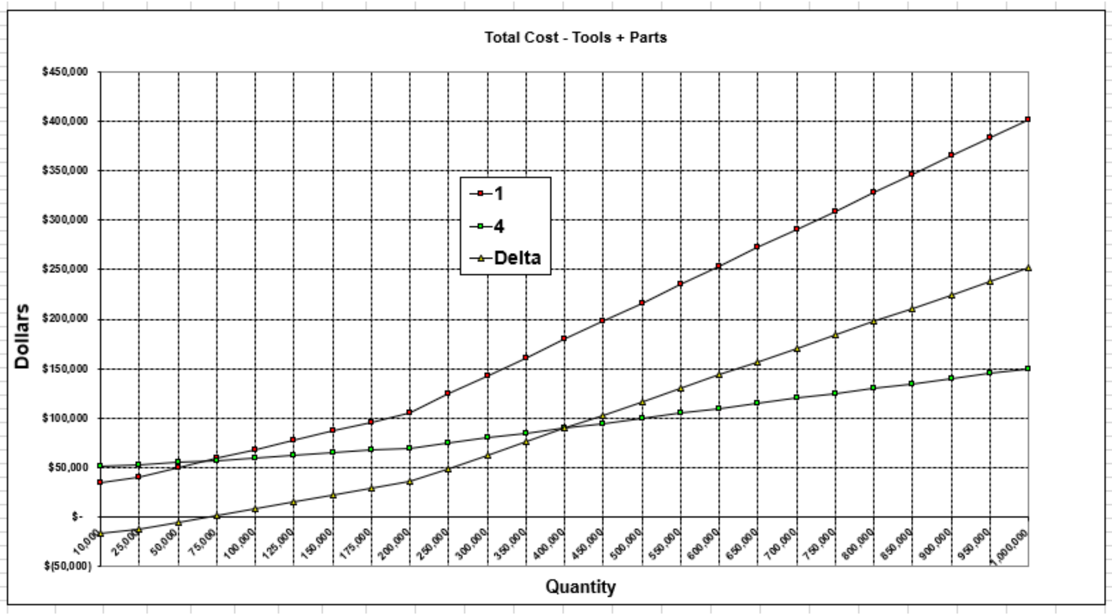


Figure 12: Break Even Analysis [f]

4.4 Processing

Even with the most advanced processing, inherent issues with the design can cause a significant increase in the cost due to poorer yields.

Here are some examples. [f]

Thick sections because of poor design (rib thickness at the bottom, for example) lead to higher cooling time (proportionate to the square of the thickness). In smaller parts, this may add significantly to the overall costs.

Poor yields, not meeting the dimensions, warpage, flow marks, sink marks, etc. are often blamed on poor processing. The truth is that many of the issues are caused by design errors.

The flow marks and lack of filling in the example below (left) are caused by a thin area of plastic surrounded by thick area (hesitation effect). The ugly lines on the right are caused by thick ribs on the other side of the wall. No amount of adjustments can totally get rid of these issues. The result will be a substantially reduced yield resulting in higher costs.

Figure 13: The flow marks and lack of filling (left) and ugly lines(right) in Thick sections

5.0 Use of Simulation Tools

Proper, timely and abundant use of tools such as FEA and Flow Simulation (MoldFlow, Moldex, etc.) is an indispensable aid to engineers and in shortening the path to optimized designs the first time every time. However, these tools should be used to confirm and enhance designs that are error free to star with. They cannot and should not be used to try to improve parts that have not already been designed with as much rigor as possible.

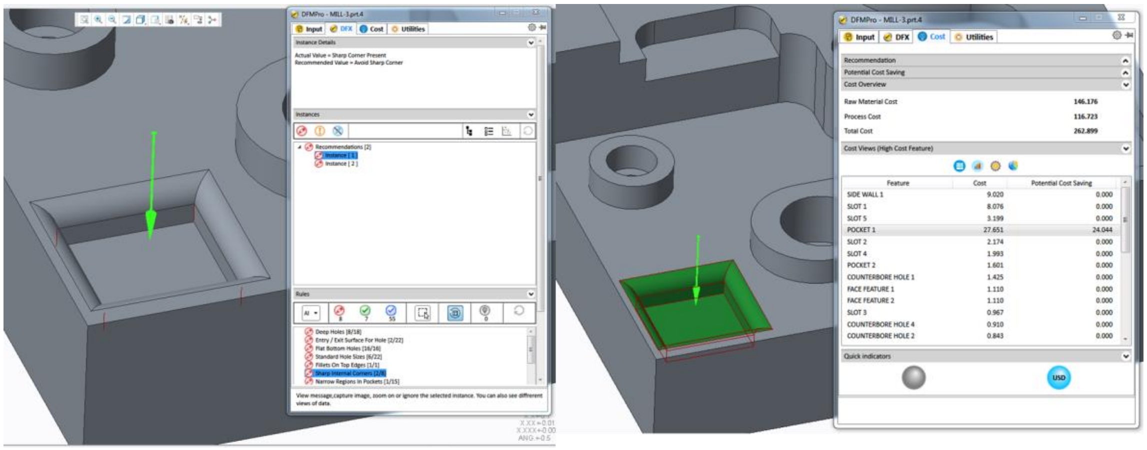
With that in mind, tools that help create error free design in the first place are very important. One such tool is DFMPro.

5.1 DFMPro – A Design Assistant Solution

Organizations need to have a good sense of the cost early in the design stage and cannot wait until a supplier has been selected. DFMPro provides the tools to estimate and optimize the costs right from the early stages.

5.2 Two Sides of the Same coin!

There are two aspects of design that impact costs, direct and indirect. The former consists of the material and direct manufacturing costs. Indirect costs are often hidden. These consist of costs such as ease of manufacturing, assembly, safety issues, etc. DFMPro provides a rule-based approach to provide information on both aspects.



Actual Value = Sharp Corner Present
Recommended Value = Avoid Sharp Corner

Deep Holes [8/18]
Entry / Exit Surface For Hole [2/22]
Flat Bottom Holes [16/16]
Standard Hole Sizes [6/22]
Fillets On Top Edges [1/1]
Sharp Internal Corners [2/8]
Narrow Regions In Pockets [1/15]

View message,capture image, zoom on or ignore the selected instance. You can also see different views of data.

Raw Material Cost 146.176
Process Cost 116.723
Total Cost 262.899

Feature	Cost	Potential Cost Saving
SIDE WALL 1	9.020	0.000
SLOT 1	8.076	0.000
SLOT 5	3.199	0.000
POCKET 1	27.651	24.044
SLOT 2	2.174	0.000
SLOT 4	1.993	0.000
POCKET 2	1.601	0.000
COUNTERBORE HOLE 1	1.425	0.000
FACE FEATURE 1	1.110	0.000
FACE FEATURE 2	1.110	0.000
SLOT 3	0.967	0.000
COUNTERBORE HOLE 4	0.910	0.000
COUNTERBORE HOLE 2	0.843	0.000

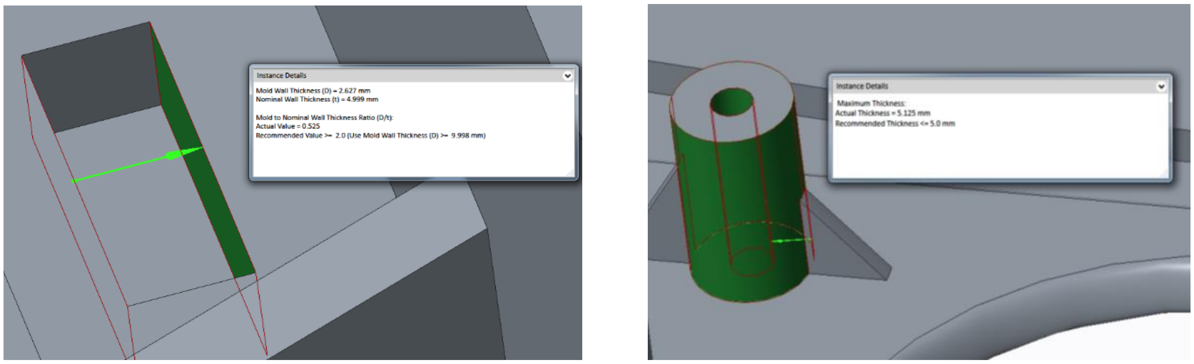
Figure 14: DFMPro provides a rule-based approach to provide information on direct and indirect aspects of design impacting cos

6.0 DFX and Cost Views

6.1 DFX View:

DFX provides a rule-based feedback. Organizational best practices that impact quality are configured in terms of smart checks which, at a click of a button, provide quick feedback on areas of design that violate the best practices. It not only identifies problems, but also suggests solutions to resolve the issues that will impact overall product cost. These impacts are mostly indirect through adverse impact on quality or addition of unnecessary complexity in manufacturing.

Some examples:
Case 1 below depicts a thin steel condition. The combination of the thin steel combined with sharp corners will result in a very weak condition requiring work arounds and/or frequent repair. This not only impacts the overall investment in tooling, but also adds unnecessary down time in in the production process resulting in additional costs.
Case 2 below shows wall thickness as the parameter. The wall thickness here directly impacts the cooling time for part. As stated before, the thickness increases the cooling time proportionately to the square of the thickness. Thus, if the cooling portion of the cycle time is 4 seconds for a 2 mm thick area, it will 16 seconds for a 4 mm thickness in the same part!



Mold Wall Thickness (D) = 2.627 mm
Nominal Wall Thickness (t) = 4.999 mm

Mold to Nominal Wall Thickness Ratio (D/t):
Actual Value = 0.525
Recommended Value >= 2.0 (Use Mold Wall Thickness (D) >= 9.998 mm)

Maximum Thickness:
Actual Thickness = 5.125 mm
Recommended Thickness <= 5.0 mm

Figure 15:
Case 1: Increase in tooling cost due to 'Thin steel' in tooling of plastics part
Case 2: Thick section in plastic will increase cycle time

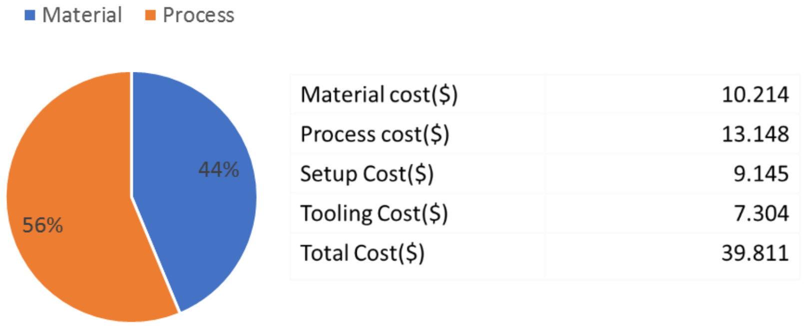
Hence the first step for the design engineer before looking in determination of the cost, is to look at the DFM parameters of the design as they may impact the cost that would be difficult to correct later.

Cost is the outcome of what gets decided at design stage. Early decisions are required by the design engineer to not just keep the cost below target but also to optimize the design to balance between the functional requirements and the product cost. This results in value being delivered to the customer. While the functional requirements are a ‘must’ in design, it is also imperative to fully evaluate the various alternatives to achieve them.

6.2 Cost Breakdown:

For any manufactured product, the cost is divided into two broad areas, material and processing costs.

In case of die casting



Material cost($)	10.214
Process cost($)	13.148
Setup Cost($)	9.145
Tooling Cost($)	7.304
Total Cost($)	39.811

Figure 16: Die casting: Top level cost breakup view (%) and detailed view of cost parameters

6.3 Trade-offs:

At very early stages of design there are various options or alternatives available that need to be evaluated. Many of the inputs required to make these decisions may not be available in the beginning. However, based on some initial assumptions the Cost Add-on module can facilitate quick evaluation of the options and help select the most suitable one for analysis. In addition to these options, even the design features impact cost. As a result, as features are updated, their respective impacts on cost are immediately shown. Tradeoffs may be required to maintain the cost, as the design progresses from initial design to detailed design. With the built-in cost indicator, upward or downward cost trends can be automatically monitored.

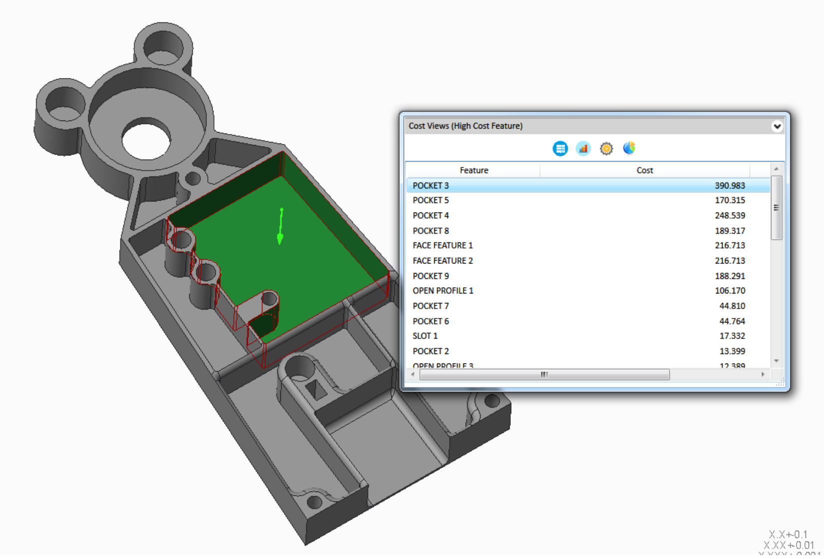
Some of the options design engineers can use for trade-off purpose are:

- Material type and grade
- Manufacturing process chosen
- Region of manufacturing (US, China, Europe, etc.)
- Special features

Apart from the above there are process specific options – for example type of runners (hot or cold) for injection molding, or sheet metal cutting processes such as stamping dies, waterjet, plasma or laser.

6.4 High Cost Features:

There are many variables in the design that impact manufacturing costs for features created on parts such as holes, slots, bends, sharp corners, fillets, etc. The impact of these is almost impossible to review manually during the design stages. This is where DFMPro shines by automatically sorting the costs allowing the designers to focus on the most robust design at the minimum cost.



Feature	Cost
POCKET 3	390.983
POCKET 5	170.315
POCKET 4	248.539
POCKET 8	189.317
FACE FEATURE 1	216.713
FACE FEATURE 2	216.713
POCKET 9	188.291
OPEN PROFILE 1	106.170
POCKET 7	44.810
POCKET 6	44.764
SLOT 1	17.332
POCKET 2	13.399
OPEN PROFILE 3	12.389

Figure 17: Feature-wise Breakdown of Costs

DFMPro is meant for design engineers to quickly evaluate design from the quality and cost point of view. The initial cost estimated at the time of design serves as a directional guide and there are no surprises after the design is released for manufacturing. While not necessarily meant for negotiation purposes, its objective is to optimize the design along with the cost. It also reduces the time to design by providing understanding on what parameters drive the cost and quality.

In a nutshell, DFMPro helps in reducing rework and provides great visibility and control over costs while ensuring organizations meet their timeline for delivering great products.

7.0 References:

[a] Value Methodology Standard"

[b] https://www.plasticsmakeitpossible.com/whats-new-cool/automotive/automobile-safety-using-plastics-more-than-ever/

[c] D. Wright; Failure of Plastics and Rubber Products, Smithers Rapra (2001)

[d] CNN Money

[e] http://www.reuters.com/article/2013/04/20/us-boeing-dreamliner-battery-idUSBRE93I11C20130420#oZ88YqvcqMifVimJ.97

[f] Figures and accompanying text taken/adapted from Robust Plastic Product Design, A Holistic Approach, Bhargava, Hanser Publications

[g] Associated Press - April 1, 2014