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Geometric

Design for Performance

Identify and Correct Design for Performance Related Issues Early in the Design Cycle

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WHITE PAPER

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Contents

Introduction to Design for Performance

Let us start with the basics to understand what is designing for performance. A part or assembly designed for performance must:

- Perform as intended over the projected life and intended environmental conditions
- Meet the appearance requirements
- Be as cost effective as possible. This applies not to just the assembly cost but the total cost which includes:

○ Direct Costs
▪ Development Costs
- Design resources
- Prototyping
- Testing
▪ Tooling Costs
- Prototyping
- Soft or Preproduction Tools
- Final Tools
▪ Manufacturing Costs
- Manufacturing the individual part
- Manufacturing the sub assembly
- Manufacturing the final product
▪ Qualification Costs
- Changes to the tools
- Pilot runs
- Preproduction runs
- Repair and Recall Costs
- Warranty Costs
- Opportunity Costs

The following graph depicts various stages of sales growth and decline over the life of a product.

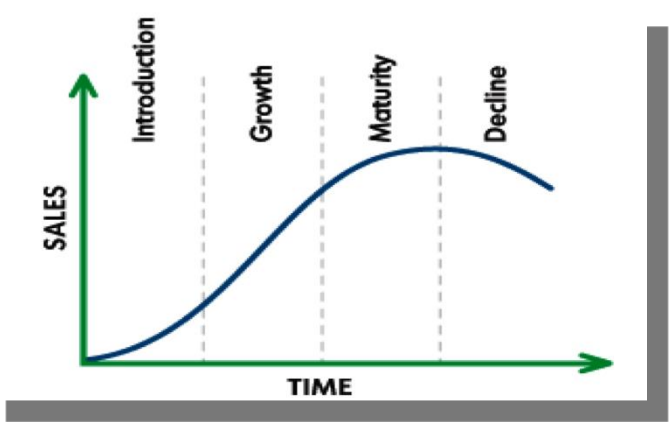

Figure 1

The dotted line depicts that a delay in product introduction of even four weeks can dramatically reduce its overall sales volume because it has lost a substantial window of opportunity due to the combination of the missed timeliness and the effect of the competitors introducing similar or better products during the window. The sales can be further eroded by introducing a less than ready product in trying to meet the marketing and sales deadlines. Even otherwise loyal customers may be lost to other suppliers because of poor product performance. Finally, a product should have a rapid, efficient, smooth, dependable transition from the preliminary concept to mass production.

Plastic is Not Metal

Plastic components may offer many advantages over metal and are gaining high acceptance across a wide variety of industries. However the properties of plastic parts may vary over a far wide range than ~~all~~ metals and therefore require extra attention when designing plastic parts. A quick look at the difference in physical and environmental properties between the two types of materials will help understand why we need to pay extra attention to plastic parts.

Different Basic Physical and Environmental Properties

For the direct comparison of most basic properties of metals with plastics, let’s take two of the most common alloys: AISI 1000 Series CR steel has a yield strength of up over 900 MPa and modulus of elasticity of over 200 GPa and 6000 series aluminum has a yield strength of over 400 MPa and modulus of elasticity of over 70 GPa. Compare these properties with that of a plastic material such as polycarbonate, which has yield strength of 60 MPa and modulus of elasticity of 2,400 MPa – significantly smaller in magnitude. Almost all plastics will melt and burn before they reach anywhere near the high end of the operating temperature ranges of any of the metals. While you can take the metal data properties ‘to the bank’, the property data for the plastics is meant only as a guide and will vary tremendously depending on the design, processing conditions, environmental conditions, operating temperatures and rate of loading.

Latent Defects

Common production processes to produce metal parts such as casting, die-casting and stamping will result in almost zero latent defects and, even if present, can be easily detected with the help of conventional QC tools. Even the porosity in die-castings can be non-destructively detected through an X-Ray. (Refer Fig. 2. & Fig. 3)

Figure 2 - Obvious Porosity

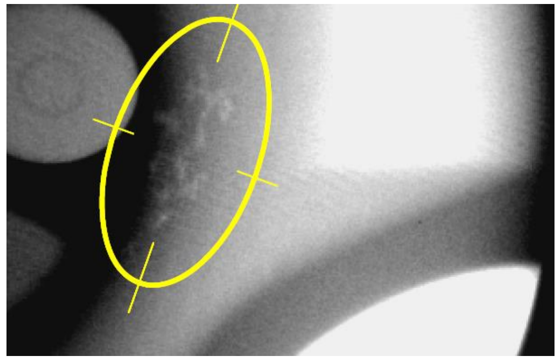

Figure 3 - X-Ray of Porosity [1]

Plastics on the other hand may carry latent defects that are not measurable without very special equipment and/or costly destructive techniques. For all of the above reasons, it is very important for the designer to have a holistic approach to plastic product design. In the case of plastic products, the “individual parts” are materials, design, tooling and processing. This can be akin to the four wheels of a car in which high performance is equally dependent on the relative performance of all four wheels.

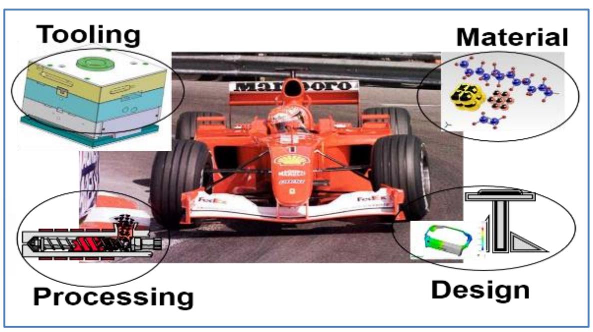

Figure 4

Fortunately for the design community, there are relatively simple guidelines (empirical and data based) that, if followed, can make the design as robust as possible.

A powerful design analysis tool like DFMPro can quickly analyze the solid model and identify most of the design deficiencies before the plastic part goes into manufacturing. This easy to use module is available to be used with most popular CAD platforms such as ProE, NX and SolidWorks. At any stage during design, DFMPro can analyze the design and identify areas that can lead to downstream performance, manufacturability and assembly issues. These tools and techniques provide a big leap forward for designers in producing a design right the first time that has all the characteristics of good design. A good design is the solid foundation that can be further optimized downstream using molding simulation tools.

The Importance of Good Design

Leading author David Wright in his book “Failure of Plastics and Rubber Products” has mentioned that material, design, processing and service are the leading causes of plastic part failure. In the following chart (refer Fig 5) he also outlines the percent contribution of each of these in the failure.

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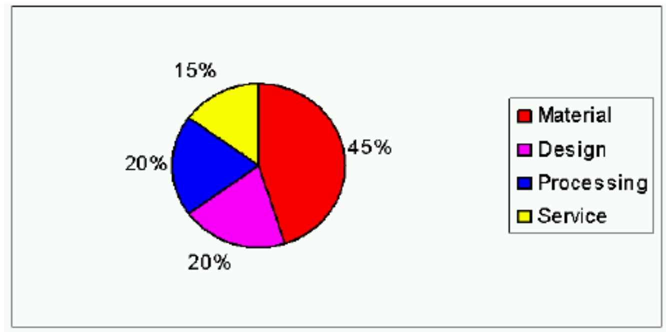


Figure 5

As we can see, design issues account for almost 20% of the failures. However what is not obvious from this data is that design errors can almost always cause issues that manifest themselves as material, tooling or processing related issues. To illustrate this, an informal review of some failed parts showed following defect categories (refer to Fig. 6)

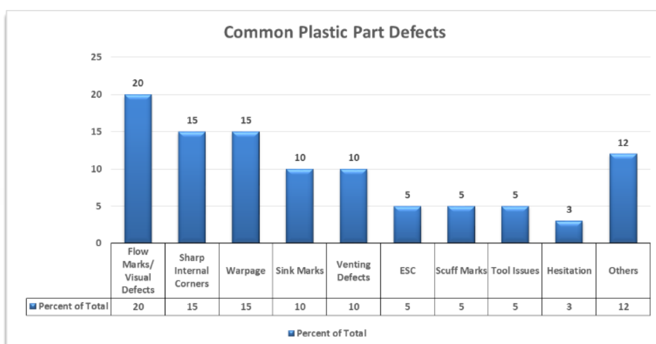


Fig. 6- Common Plastic Parts Defects

With the following cause and effects (see Table 2 for cause and effect codes):

Defect Type	Percent of Total	High Level Cause	Effect
Flow Marks/ Visual Defects	20	1, 2, 3, 4	A, B, C,
Sharp Internal Corners	15		B, C
Warpage	15	1, 2, 3, 4, 7	A, C
Sink Marks	10	1	A, C
Venting Defects	10	2, 4, 5	A
ESC	5	2, 3, 5,	H
Scuff Marks	5	6	A
Tool Issues	5	7	A
Hesitation	3	2, 5	A, C, H
Others	12		
Total	**100**		

Table 1. Defect Cause and Effect

Cause Type	Code	Effect Type	Code
Rib Thickness	1	Low Yield	A
Wall Thickness Variation	2	Drop Failure	B
Sharp Corners	3	Environmental Stress Cracking	C
Long Thin Ribs	4	Burnt Material, Incomplete Filling	D
Thin to Thick Flow	5	Short Shots, Hesitation	E
Inadequate Draft	6	Warpage	F
Steel Height to Base Ratio	7	Scuff Marks	G
		Premature Failure	H

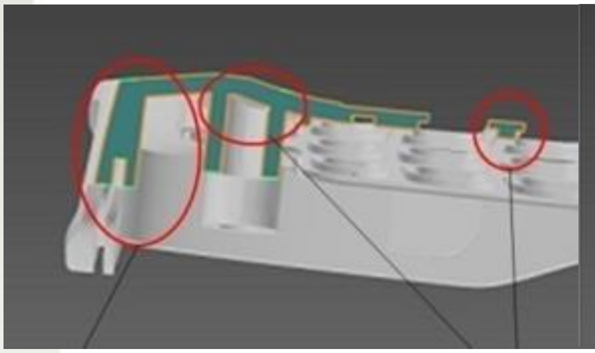
Table 2. Cause and Effect Codes for Table 1

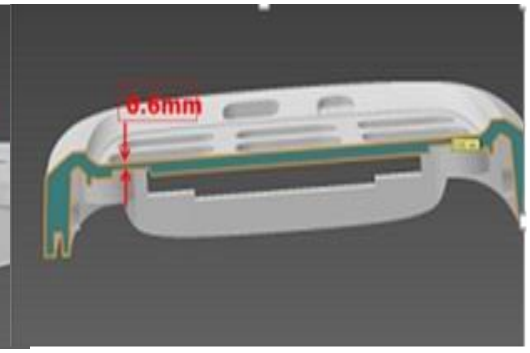
Below is an actual case study of a part that was analyzed using DFMPro prior to flow simulation and before the start of tooling process. Refer to table 3 for a summary of rules that failed

Rule	No. of Instances	Importance
Minimum Radius at Base of Boss	4/4	High
Uniform Wall Thickness	48/140	High
Minimum Radius at Tip of Boss	4/4	High
Minimum Draft Angle	78/78	High
Recommended Rib Parameters	4/16	High
Mold Wall Thickness	23/23	High
Undercut Detection	121/121	Medium

Table 3. Description of Rules that failed during analysis in DFMPro

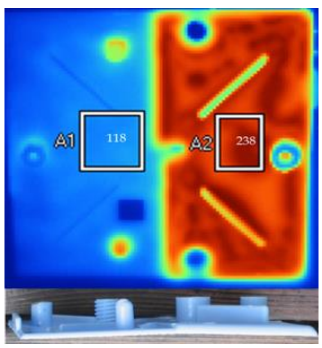
Some Close-ups



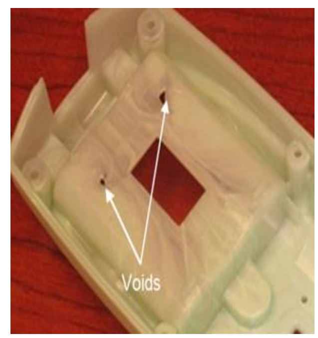


ers, rib bottoms > 50%

y thick wall leading to hesitation and short shots



s to warpage



d by thick causing hesitation and voids

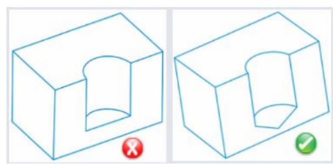
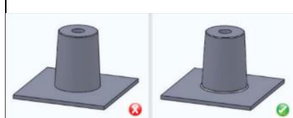
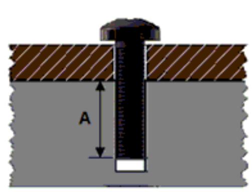
Non- Plastic Components

Even though detection of potential plastic failures is the most important, few engineering assemblies consist of only plastic parts. It is therefore important to be aware of potential failures in common mechanical components such metal stampings and machined components. Beyond that it is important to find deficiencies in the assembly as a whole. DFMPro goes beyond plastic design analysis to areas of metal stampings, machined parts and assembly.

Appendix 1 illustrates more than 30 design for manufacturing rules in DFMPro for which a design can be validated.

Case Study

Let us take an example of a simple assembly of a hand held computing device consisting of top and bottom plastic covers, a sheet metal chassis that supports the LCD display and four custom machined studs that are used to fasten the PC board to the bottom cover and the metal chassis. The selling price of this product is $300. The marketing plan calls for a total of 1,000,000 products sold over three years. In reality, the window of opportunity to realize the sales is only three years because of intense competition and threat of technology obsolescence. Of the over 30 rules that DFMPro checks, only six of the most common errors are referred to in the following examples:

SHEET METAL	
Minimum Hole Diameter	Hole diameter to thickness ratio >= 1.0
MACHINING	
Flat Bottom Holes	Blind holes should not have a flat bottom 
INJECTION MOLDING	
Minimum Radius at Base of Boss	Radius to nominal wall thickness ratio >=0.25 Minimum Radius >=0.4 mm 
Minimum Draft Angle	Draft angle for core >= 0.5 deg Draft angle for cavity should be >= 5.0 deg 
Uniform Wall Thickness	The maximum variation in the nominal wall should not be more than 25% for amorphous and 15% for semi-crystalline materials
ASSEMBLY	
Fastener Engagement Length	

Issues and Dollar Impacts:

Since there wasn't adequate draft, the part distorted during ejection. In order to reduce the distortion, the cycle time was increased from 30 seconds to 45 seconds to give enough time to the part to cool down. The part still had occasional difficulties in ejection, hence the yield rate went from 99% to 95%. Over the life of the product, this resulted in a total cost increase of $427,000.

Plastic Parts Costs

Part	Optimized Design							With Longer Cycle Time Due to Warpage				Total		
	Weight (gm)	Material	Cost/ Kilo	Cycle Time	Yield %	Molding Machine Rate ($/hr)	Cost	Cycle Time	Yield Percent	Machine Rate	Cost	Delta	Total No. of Parts	Avoidable Costs
Top Cover	100	PC	$6.00	30	99	$45.00	$0.98	45	95	$ 45.00	$1.19	$0.21	1,000,000	$213,317
Bottom Cover	150	PC	$6.00	30	99	$ 45.00	$1.28	45	95	$ 45.00	$1.49	$0.21	1,000,000	$213,317

One of the holes in the stamping was less in diameter than the metal thickness. This resulted in the punch breaking occasionally. It was decided to drill this small hole as a secondary operation resulting in an additional cost of $.15 and reduction in yield from 99% to 95%. The resultant increase in cost of $161,447.

Metal Parts Costs

Part	Optimized Design							With Additional Drilling Operation			Total		
	Weight (gm)	Material	Cost/ Kilo	Cycle Time	Yield Percent	Stamping Press Rate $/hr	Cost	Cost of Drilling Hole	Yield Percent	New Cost	Delta	Total No. of Parts	Avoidable Costs
Chassis	50	Stainless Steel 301	1.35	1	99	30	$ 0.07	0.15	95	$ 0.23	$ 0.16	1,000,000	$ 161,447

Lack of flute angle at the bottom of the hole resulted in an extra counter boring operation on the Swiss screw machine resulting in an increase of $.01. There were four parts per assembly resulting in a total increase in cost by $10,000.

Machine Parts Costs

Part	Number Required	Optimized Cost	Cost with Counter Boring Operation	Delta	Total Number of Parts	Total Additional Cost
Machined Studs	4	0.15	0.16	0.01	1,000,000	$ 10,000

The normal development resources are at the left. Each engineering change once the parts had been tooled added the resources to the right. This was relatively low because there were no parts in inventory that had to be scrapped. If parts were needed to be scrapped the cost would go up significantly. The total cost of additional resources was $19,200. More importantly, these resources were not available for the development of newer products.

Development Costs

	Normal Development Costs						With Avoidable Engineering Changes							
	Engg. Hours	Analyst Hours	Tool Engineer Hours	Other Services Hours	Overall Rate $/Hour	Total Cost of Resources	Engg. Hours	Analyst Hours	Tool Engineer Hours	Other Service s Hours	Overall Rate $/Hour	Total Cost of Resources	No of Engg. Changes	Additional Resource Cost
Top Cover	300	40	40	20	$ 100	$ 40,000	40	8	8	8	$ 100	$ 6,400	3	$ 19,200
Bottom Cover	300	40	40	20	$ 100	$ 40,000	40	8	8	8	$ 100	$ 6,400	3	$ 19,200

Each engineering change to the tool cost an average of $5,000 each for a total of $15,000.

Plastic Tooling Costs

Part	Initial Cost	Average Engineering Change Cost	No of Engineering Changes	Total Additional Cost
Top Cover	$ 50,000	$ 5,000	3	$ 15,000
Bottom Cover	$ 60,000	$ 5,000	3	$ 15,000

Because of an inadequate number of threads were being engaged at the four corner bosses, they were stripping even on smaller drops. Additionally, because of the sharp corners along the edges had a sudden wall thickness reduction by 50 percent, the covers were under high stress in those areas and were cracking due to the attack by sweat and lotions on the operators' hands. See previous blogs on environment stress cracking and stress concentration in sharp corners. READ

The table below show the cumulative warranty and repair costs totaling $1,650,000 to take care of the above failures.

Warranty Costs

Failure Type	Stripped Bosses	Environmental Stress Cracking
Number Recalled	50,000	50,000
Cost of Parts	$3.00	$3.00
Repair and Testing	$10.00	$10.00
Shipping and Handling	$10.00	$10.00
Administrative	$10.00	$10.00
Total Cost	$1,650,000	$1,650,000

Opportunity Loss:

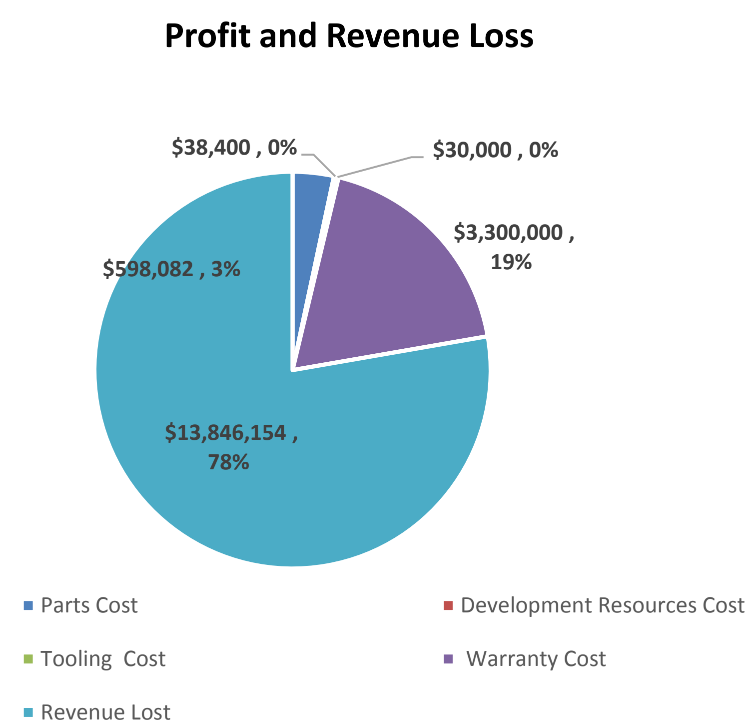
The engineering changes and the work-around after the tools were completed, delayed the introduction of the product by four weeks. The following table illustrates the loss in market share due to the delay. Total loss – $ 13,846154.

Delay in Weeks	Total Life of Product	Shipments			Shipments Per Week			Missed Opportunity*	Price /Unit	Lost Revenue
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3			
4	1,000,000	200,000	600,000	200,000	3,846	11,538	3,846	46,153	$ 300	$13,846,154

**Loss of four weeks of shipment in the peak period*

The table and the chart below outlines significant loss in profits and revenue for seemingly very insignificant design deficiencies. Total combined loss was $ 17,812,636 or almost six percent of the initially forecast revenue.

Parts Cost	Development Resources Cost	Tooling Cost	Warranty Cost	Revenue Lost	Total Loss
$ 598,082	$ 38,400	$ 30,000	$ 3,300,000	$ 13,846,154	$ 17,812,636
3.36%	0.22%	0.17%	18.53%	77.73%	100.00%



Conclusion

It is hoped that the foregoing convincingly demonstrates the significant loss to the revenue, company reputation, future sales and loss of resources to non-value added activities resulting in delayed introduction of newer generation products for seemingly insignificant design errors. These errors are due to a combination of lack of design knowledge and time pressures felt by the designer in the increasingly shorter cycle times available to develop new products. The routine use of DFMPro can avoid most of these pitfalls.

About Vikram Bhargava

Vikram Bhargava is a Fellow of the Society of Plastics Engineers and Past Chairman of its Product Design and Development Division. For 40 years, he has worked in the areas of development, manufacturing and management, especially in plastics. He retired as the Director of Mechanical Engineering Services at Motorola Solutions Holtsville, NY in 2014 where he was heading an international group of professionals and led several Six Sigma projects with millions of dollars in savings. He is a certified Motorola Six Sigma Black Belt and sought after trainer. He has trained thousands of engineers and suppliers in the proper design and manufacturing of plastic parts and assemblies in the US, Canada, China, Taiwan, and India. He is authoring a book on Robust Product Design with Hanser Publications, LLC, to be released early in 2016

About Geometric

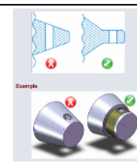
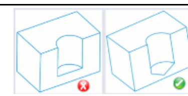
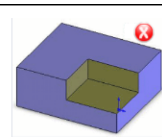
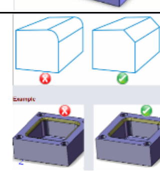
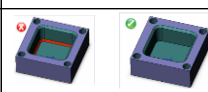
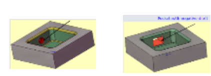
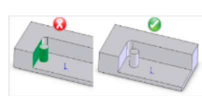
Geometric is a specialist in the domain of engineering solutions, services and technologies. Its portfolio of Global Engineering services and Digital Technology solutions for Product Lifecycle Management (PLM) enables companies to formulate, implement, and execute global engineering and manufacturing strategies aimed at achieving greater efficiencies in the product realization lifecycle.

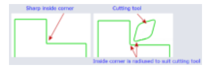
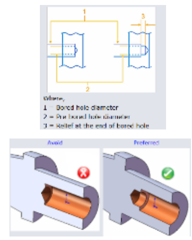
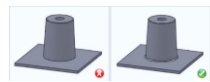
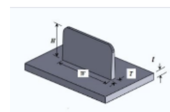
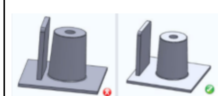
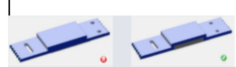
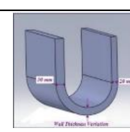
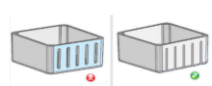
Headquartered in Mumbai, India, Geometric was incorporated in 1994 and is listed on the Bombay and National Stock Exchanges. The company recorded consolidated revenues of Rupees 10.95 billion (US Dollars 181.39 million) for the year ended March 2014. It employs about 4400 people across 12 global delivery locations in the US, France, Germany, Romania, India, and China. Geometric was assessed as CMMI 1.1 Level 5 for its software services and is ISO 9001:2008 certified for engineering operations. The company's operations are also ISO 27001:2005 certified. For further details, please visit www.geometricglobal.com

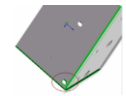
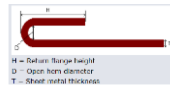
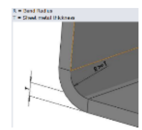
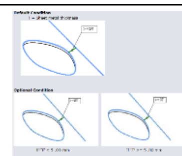
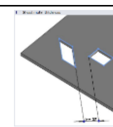
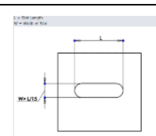
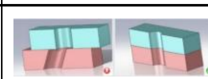
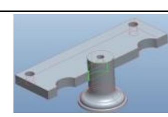
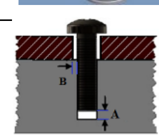
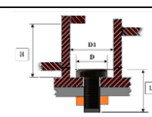
References

1. X-Ray Courtesy Domingo Mary, Santiago de Chile
2. Failure of Plastics and Rubber Products: Causes, Effects and Case Studies Involving Degradation, Smithers Rapra Press (January 1, 2001)
3. Photograph Courtesy of John Bozzelli, Owner Injection Molding Solutions, Home of Scientific Molding, Saginaw, Michigan

Appendix I

Module Name	DFM Rules	Default Values	Illustration	Recommendation
Drilling	**Deep Holes**	Hole depth to diameter ratio value <=8.0		
	Entry / Exit Surface For Hole	Drills should enter and exit surfaces that are perpendicular to the centerline of the hole.		
	Flat Bottom Holes	Blind holes should not have a flat bottom		
	Standard Hole Sizes	The standard hole sizes DB consists of drill sizes ranging from 0.15 to 45mm (which is by default selected). Also, a general DB of drill sizes ranging from 0.15 to 200 mm is provided which can be selected by radio button provided. option to add/remove custom drill size to DB is also provided.		Try to use standard hole sizes. Unusual hole sizes increase the cost of manufacturing through purchasing and inventory costs
Milling	**Deep Radiused Corners**	Mill tool length to Radius Ratio <= 16.0		Design milling areas so that longer end mills are not required to machine it. Longer end mills are prone to breakage and chatter and require longer machining times
	Sharp Internal Corners			Try to Avoid sharp internal corners
	Fillets On Top Edges			Edges on the tops of pockets, bosses, and slots should be chamfered and not filleted
	Pockets With Bottom Chamfers			Milled pockets and bosses should not have a chamfer between the side walls and the base of the
	Tool Accessibility			Features should be accessible to the cutting tool in the preferred machining orientation
	Narrow Regions In Pockets	Minimum thickness for narrow region >= 3.0 mm Maximum thickness between depth and narrow region thickness <= 10.0		Try to avoid features (or faces) too close to each other such that the gap between them is too narrow to allow the milling cutter to pass through. If narrow regions are unavoidable, then they should not be too deep

Turning	**Minimum Internal Corner Radius**	Minimum corner radius >= 0.5 mm		Specify the largest possible radius on internal corners of turned parts
	Blind Hole Relief	Relief at the end of Bored hole >= 3 % of diameter of pre-bored hole		Blind bored holes should be defined with tool relief at the end of the hole (i.e., depth of bored hole = depth of pre-bored hole + relief amount).
Injection Molding	**Minimum Radius at Base of Boss**	Radius to nominal wall thickness ratio >=0.25 Minimum Radius >=0.4 mm		The suggested value for minimum required radius at the base of boss is 0.25 times nominal wall thickness
	Recommended Rib Parameters	Rib thickness to nominal wall thickness ratio <=0.4 or 0.6 Rib height to nominal wall thickness ratio <= 2.5 or 3.0 Rib width to nominal wall thickness ratio <=		Generally, rib height is recommended to be not more than three time nominal wall thickness. Similarly, rib thickness at its base should be around 0.6 times nominal wall thickness.
	Mold Wall Thickness	Mold wall thickness to nominal wall thickness ratio >= 2.0 Mold wall thickness >= 1.0 mm		Minimum allowable mold wall thickness needs to be decided based on process and material considerations. However it is normal to have clearances of one mm between features of an injection molded plastic part thus allowing a mold wall of that dimension
	Uniform Wall Thickness	Minimum wall thickness should be >= 2.0 mm Maximum wall thickness should be <= 3.0 mm		As a general guide, wall thicknesses for reinforced materials should be 0.75 mm to 3 mm and those for unfilled materials should be 0.5 mm to 5 mm
	Wall Thickness Variation	Wall thickness variation should be within 25 % of nominal wall thickness		wall thickness in a part should not deviate more than 25% from the nominal wall
	Minimum Draft Angle	Draft angle for core >= 0.5 deg Draft angle for cavity should be >= 5.0 deg		Generally a draft angle of 0.5 degrees is recommended for core and 5 degrees for cavity.
	Undercut Detection	NA		Undercuts on a part should generally be avoided. Clever part design or minor design concessions often can eliminate complex mechanisms for undercuts

Sheet metal	**Hole Distance to Bends**	Distance to thickness ratio >= 2.0		
	Minimum Hole Diameter	Hole diameter to thickness ratio >= 1.0		
	Open Hem	Hem radius to sheet metal thickness ratio >= 0.5 Flange height to sheetmetal thickness ratio >= 4.0		
	Minimum Bend Radius	Bend Radius to thickness ratio >= 2.0		
	Cutout Distance To Part Edge	Distance to sheet thickness ratio >= 2.0		minimum distance from a cutout to edge of a part should be at least 2 times sheet thickness
	Cutout To Bend Distance	Distance to sheet thickness ratio >= 2.0		minimum distance from a cutout to start of the inside bend radius should be at least 2 times sheet thickness
	Minimum Distance Between Cutouts	Distance to sheet thickness ratio >= 2.0		minimum distance between cutouts should be at least 2 times sheet thickness
	Minimum Width Of a Slot	Width to sheet thickness ratio>= 2.0 Length to width ratio <= 15.0		
Assembly	**Hole Alignment**	Maximum Gap between parts <=0 .5 mm		
	Interference Detection	User input required		
	Fastener Clearance	User input required		
	Fastener Accessibility	User input required		
	Fastener Engagement Length	User input required