# A NEW PARADIGM FOR DESIGN THROUGH MANUFACTURE

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T E C H N O L O G Y A R E A

W H I T E P A P E R

Working through the New Product Introduction (NPI) flow between product design and manufacturing is usually a challenging process, with both parties being experts in their own fields and inextricably linked in the flow of getting a new, differentiated product from an idea into physical, profitable reality. Suggestions intended to reduce costs and improve time-to-market are often met with reluctance due to an inability to effectively communicate between these diverse technology cultures.

PCB systems design follows basic or generic manufacturing rules, but still, the manufacturer will find many issues or "opportunities to improve" in each design. Any one of these opportunities can be result in significant cost savings; a small correction up-stream can result in a huge saving when scaled by the volume of manufacturing. The cost of the design iteration "spin" however is also high and potentially delays the product release.

Another factor is the quality of information passed to the manufacturer from the designers. In most cases this is, for example, basic Gerber data format, which must be reverse-engineered, introducing potential for errors and variation. Time needed to reverse-engineer the data results in the reported opportunities to improve often coming too late and less effective than they could be.

A breakthrough, practical methodology to represent and communicate manufacturer's needs, capabilities, and preferences upstream to the design process would reduce or eliminate the need for respins. Conversely, going down-stream, the manufacturer wants all of the information required to set and prepare processes without reverse engineering.

This paper explores manufacturing needs, and benefits to both design and manufacturing as well as the benefits of efficient transfer of key information from design into manufacturing, eliminating reverse engineering. Together these define a new paradigm for Design to Manufacturing.

## THE OBJECTIVES

Making a profit these days in the electronics industry is a more rare case than most people might imagine. The marketplace for electronics products is crowded, with many competing products, and consumers are more and more often using tools on the internet to find the most competitive prices. Many companies find that their major profit contributions derive from "hit products." These products come to the market with some new innovation or unique functions and technologies that customers, whether consumers or professionals, are keen to buy and are willing to pay the prices asked. There is often only a very short window of opportunity in which these products can be sold in the market while making a reasonable profit. Competitive products soon appear and even the most once compelling "hit products" struggle to sustain their profit margins. The quicker the product gets into the market, the longer the enjoyment of this success. Whether a company is the first to market with a hit product, or is one of the companies coming to the market with alternatives, the lead-time and cost from concept to product reality are critical factors to the business.

Carrying a very large part of the technology of the finished product, the design stage of the PCB comes under heavy pressure to deliver completed designs so that manufacturing process of the PCB and assembly of the product can start. Such pressure leaves the PCB design team little time to consider manufacturability issues. Manufacturing has remained relatively far away from other design priorities. Looking from the manufacturing perspective however, there are elements of every design which cause issues. These issues either need to be avoided by the change of the design, or, money spent to adjust the manufacturing processes to cope with the issues. Changing the design over and over as these issues are found takes time as well as money. The more unexpected the issues are, the more expense and delay caused.

The objective then is to complete the design process "right first time" from a manufacturing perspective so that PCB manufacturing-related design changes are reduced — or eliminated — which reduces the overall costs and minimizes the lead time for new product introduction. This is what Design for Manufacturing (DFM) is all about.

When looking at manufacturing however, consideration also has to be given to how and where the PCB will be manufactured. Conditions and even motivations will be different in each location.

## THE NPI SUPPLY CHAIN

Almost every PCB design is made is made in-house by the original creator. Outsourcing of design is rare. Much of the innovation and technology of products is created through the design process and therefore has great value. This value must be managed and controlled.

PCB manufacturing, on the other hand, is a commoditized process, almost always performed by an outsourced supplier. A fundamental requirement of PCB manufacturing is the data and details of the design so that the PCB can be manufactured correctly. The responsible manufacturing business needs to ensure that they can provide a service that is competitive in the market and still enable them to make profits for their own shareholders. The biggest threat to this service is unexpected issues. Manufacturers try to find issues relating to a design using some kind of NPI (New Product Introduction) check process. Where elements are detected that could cause problems in the manufacturing process, the choice is to spend money to cope with them, or, to request that the design is changed to avoid them.

There is then a trade-off discussion that takes place between manufacturer and designer about how to manage these issues, impacting cost and lead-time. The manufacturer may also decide however, especially if the issue is not found during the initial NPI process, to apply changes to the design in order to make the fabrication process work more effectively without communicating back to the designer. There is a clear difference between the interests of the designer and the interests of the PCB manufacturer, some examples of which are shown in Table 1.

*Table 1 – Differing DFM Interests*

| Subject | Design Organization | External PCB Manufacturer |
|---|---|---|
| Product Costs | Minimize Costs | Maximize Profit |
| DFM "Trade-offs" | Control Of Decisions | Control Of Decisions |
| Form Factor | Miniaturization | Maximum Manufacturing Yield |
| Design Revision Spins | Minimize/Eliminate | Makes Money From Each Spin |
| Supplier Selection | Multiple Suppliers Bid & Build | Sole Source & Tie-in |
| PCB Design Integrity | PCB Built as Designed | Adjust Design for Process |
| Communication | Full Disclosure of All Edits | Communicate as Required |
| Component Sourcing | Control for Quality Reasons | Control for Profit Reasons |

With the manufacturer making changes to the design to suit their processes, an element of control of the design by the designers is lost and a degree of variability in the product introduced.

For assembly manufacturing, the situation is similar. Unlike PCB manufacturing however, the ratio of assembly is more evenly split between in-house and outsourced services. More importantly however, since the PCB has now been physically manufactured by the time that assembly is done, there is much less opportunity to change the PCB design to cope with any issues that may impact the assembly performance. The feedback loop usually has to wait for planned PCB design revisions. Assemblers also need to understand any issues about the manufacturability and so perform a similar NPI pre-process, and again, most often there is not the detailed information available up-front about the design. Most assembly issues are therefore discovered during the often long NPI process quite often founded on trial and error.

## THE 10X COST RULE

Throughout the PCB supply chain, issues originating and relating to the design of the PCB create the need for actions and counter-measures during the fabrication and assembly processes. There is cost, lead-time and compromise associated with these changes. Consider a simple common example of an issue which arises in the assembly process where due to some layout pattern, a high incidence of solder bridges occurs which is found during the AOI (automated optical inspection) process. Taking aside any issues of how or why the design was made in that way, consider the cost that is incurred by this fault. The fault may occur on perhaps just one board in ten due to the nature of fluctuation in the process performance; this kind of problem is often caused by features on the limit of design acceptability. For each of these failed boards however, the failure has a cost. When each board fails at the AOI process, it is likely to be routed to an inspection station where an operator confirms the fault and sends the board for repair. At the repair station the solder bridge is removed the defect recorded and the board then returned for re-test.

The tangible cost of this process can be calculated. The time and cost for the inspection, for moving the board between processes, for the repair and the disruption to the flow of the assembly processes as the board needs to go through the AOI process one more time. There are intangible costs also. There can be effects on the board due to handling by multiple people and damage caused as part of the repair process. Each has a potential impact on quality, each potentially creates subsequent failures and repair cycles, and even eventually, scrap. Consider on the other hand, the cost to have rectified the cause of problem at the design stage. Had the layout designer known about the potential issue, it would take a minute or two to move a couple of elements to ensure the problem did not occur. The difference in the cost between these two scenarios is very significant. As a rule, we find through experience that the cost to rectify issues rather than the correction of issues when found to be a problem is ten times larger for each intermediate process through which the issues passes until rectification happens. This cost can be avoided if the constraint had been fed back and known by the layout team ahead of completing the design as shown in Figure 1.

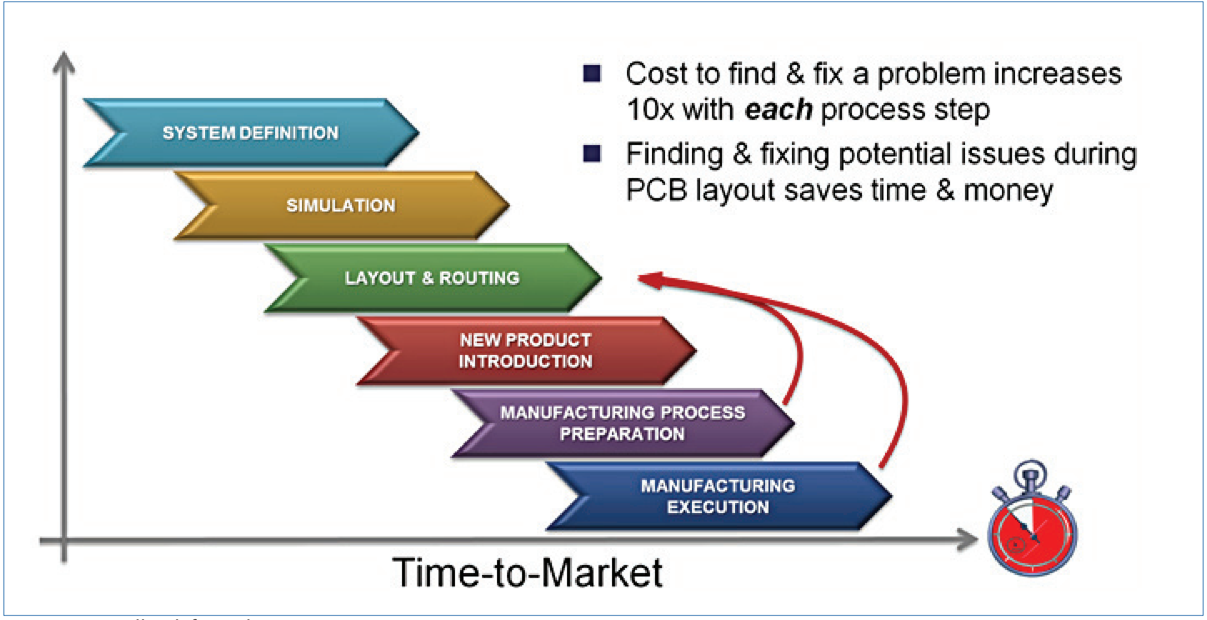


*Figure 1: Feedback from downstream-processes saves 10x cost per process*

## COMPREHENSIVE DFM ANALYSIS

DFM tools are available that go a long way to allow issues in the PCB design to be detected at an earlier stage. State of the art tools provide many hundreds of automated design checks and examine design related data such as the Bill Of Materials (BOM) The effectiveness of these tools however comes from the knowledge and the sophistication of rules that are set up within them, the DFM algorithms, which understand and know what to look for in the design. This knowledge and rule-set differs depending on where the DFM is applied, who is running DFM and why, as well as product related differences in design rules and tolerances. Looking at the NPI process as a whole there are three different angles of NPI; the final stage of design, the start of PCB manufacture and the start of assembly manufacturing. The NPI at the end of the design is where DFM can be used very effectively to discover areas where design rules have been violated. No matter how good a layout engineer is, it is not humanly possible to perform the millions of checks necessary on a complete layout, which is a time factor more than a skill factor. Any issues found by the DFM process become opportunities for correction and improvement of the design layout.

The DFM process run by the PCB manufacturing process is going to be quite different to that used by the layout designer. The PCB manufacturer prioritizes the DFM to discover issues that impact their own processes in terms of efficiency, start-up lead-time, productivity, and output quality. The effectiveness of the manufacturer's DFM is very much dependent on the quality and level of detail of data received about the design. The DFM analysis will therefore potentially be far less automated and managed, with reverse engineering of data required in cases where formats of data are provided that contain little more value than drawings, still being the normal case. Assembly manufacturing also has some form of DFM. The data they receive from the design team is often much more limited again. Unless the assembly operation can get access to additional information, the NPI operation is done based on the physical PCB and a list of the parts and positions on the board. The assembly NPI operation is then a long and hard process unless better data can be sourced and specialized tools can be adopted.

*Table 2 – Comprehensive DFM Analysis*

| DFM Area | Categories |
|---|---|
| Fabrication | > 250 |
| Assembly | > 250 |
| Packaging Substrate | > 100 |
| Micro Via | > 45 |
| Panel | > 35 |
| Net-list Validation | 100% |
| BOM Validation | 100% |
| AVL Validation | 100% |

To conduct a comprehensive DFM analysis, the needs of all three of our views should to be taken into account. Such a comprehensive DFM must consist then of a combination of categories of checks that represent the whole NPI cycle. The areas and categories that comprehensive DFM should include as a minimum are summarized in table 2. Only then can the DFM functionality reach its true potential benefit.

## COMPREHENSIVE DFM CHALLENGE – MULTI SOURCING COMPONENTS

Another dimension to comprehensive DFM is the challenge posed by the need to multi-source components. There are significant variations in the body sizes and pin forms of components from different manufacturers versus what would be identical materials from an application perspective — representing a single internal part number as far as the designer's BOM is concerned. The issue of variability in the component supply has been constrained to an extent by assembly through their purchasing policy where, ideally, only a single trusted source of components was sourced. This purchasing policy is becoming less effective now due to several factors. Many products are now made for the global market and so are manufactured in different geographic locations and in many cases by different out-sourced companies. There is pressure to be able to use the local component suppliers to reduce cost and lead-time as well as the risk of delivery delay. Following recent world events such as the earthquake in Japan and flooding in Asia, many manufacturers are now having to dual or multi-source components from different suppliers in different parts of the world to ensure a guarantee of availability.

The component information available at design is most likely a "normalization" of the actual physical dimensions and attributes, a representation of the real components likely to be used in manufacture. As demand for miniaturization continues, there are very few opportunities in design to be over-generous with component size allowances.  These factors combine to increase the risk of assembly issues related to sourcing of components with different physical attributes.

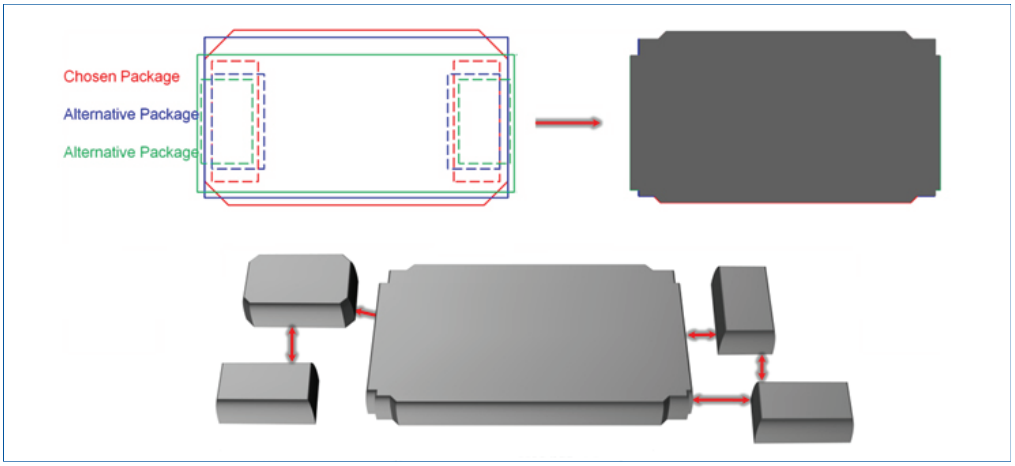


*Figure 2: Enveloping takes into account the "worst case" size of all possible components.*

The solution to this scenario is to consider all of the potential component candidates that may be sourced, overlay them, and take the "worst case scenario". This process is called "enveloping", as illustrated in Figure 2. The composite shape is created by superimposing the shape attributes of all designated alternative packages. The composite shape includes the component body composite and also composites of the leads and any other physical attributes. These composite shapes can then be used as part of the normal DFM process. The result is that the design can be proofed such that it can be assembled by any combination of components eliminating many of the issues faced on a daily basis of dual and multi component sourcing.

There is a requirement, however, for this kind of enveloping to be possible. The different size of all of the alternate parts needs to be identified accurately. Access to a sophisticated parts library is a key factor for enveloping to be practical. The selection and management of alternative parts and linking of the internal part numbers to the various vendor part numbers requires a management utility such as an AVL (Approved Vendor List) management tool.

## THE VALUE OF COMPREHENSIVE DFM

With the requirement of the AVL manager and the accurate component data library, as well as the need to set up the rules and parameters of the DFM checks, it may all seem like a lot of additional cost and time in the late stages of the design layout process. It should be remembered though that the 10x cost rule always applies. Bringing the ability to resolve issues up-stream as part of the earliest stage of the NPI process means a very large reduction of time and cost of the overall process.

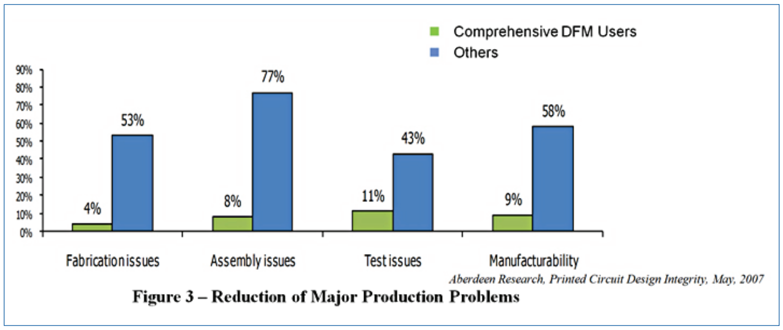


*Figure 3: Reduction of major production problems.*

As shown in figure 3, the reduction in number of overall major production issues is overall around 85%. Considering that this is a measure of issues that otherwise are found at later stages in the overall manufacturing process, this represents a cost saving at least an order of magnitude higher than any cost associated with the DFM process. When considering improvements to any operation, it is always important to take into account the effect on the whole process, which in this case it the complete NPI process and manufacture to the point that actual products are produced for the customer. The benefit in this case is very favorable and compelling compared to a small cost at the end of the design process.

# INFORMATION INTELLIGENCE

One of the key challenges to enhance DFM to be able to resolve issues at source is the utilization of intelligent information. Design systems today provide the ability to perfectly create and model the product intended, to be able to simulate and check everything necessary to make a design that will quickly become the intended successful product in the market. What still happens today however is that immediately after the design process, the design is sent for PCB manufacture most often as a set of very unintelligent files. The Gerber format is still the most widely used, but based on the language of a 1980s plotter which is basically just conveying a drawing. Perhaps many years ago, this was enough to describe what was required for the PCB manufacturing process, but with the advanced technology contained within today's PCBs, it is simply not enough.

What generally happens today is that a complete reverse engineering of the data — re-creating information that already exists in the design system, but was not part of the information package provided to manufacturing. Reverse engineering is necessary to get the information needed for the PCB manufacturing CAM systems for the PCB manufacturing to work. The PCB manufacturer will take time and expense to perform this reverse engineering, which contributes significantly to the cost and delay to the new product introduction. Another important effect is that through the reverse engineering process the reconstructed product information is likely not to match the original design. This introduces variability into the process. The product that comes out of the PCB manufacturing process will be slightly different to that intended by the design. This can result in performance and reliability issues in the end products.

Also, it may be necessary have PCBs manufactured in different geographic locations by different companies. This reverse engineering process means that in each of these locations, the resultant PCBs are certainly to be different from each other. The control of the product in terms of performance and quality is now out of control from the design perspective. A similar situation exists for the assembly. To set up the processes in manufacturing and test, information from the PCB again has to be reverse engineered from simple data formats, again adding time and cost and variability with the introduction of delays for the NPI.

The requirement to break this paradigm is the introduction of a single intelligent file format which incorporates all of the necessary information to describe the PCB needed to understand how it should be made in terms of PCB and assembly manufacturing. The single file format is important in order to keep the overall coherence and integrity of the data package, as well as being simple to manage. Inside the file however should be all of the necessary data elements to describe the all necessary attributes about the design.

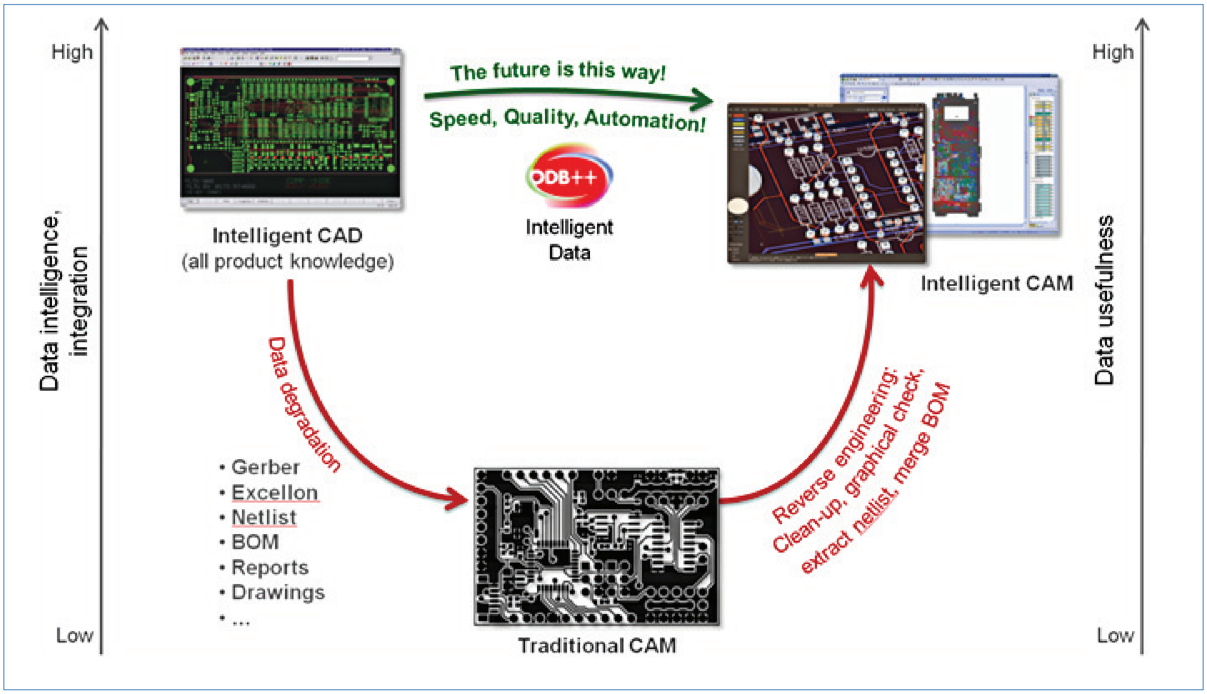


*Figure 4: Data flow options.*

There are often concerns about sending sensitive design data to a third party company such as the PCB or assembly manufacturer, in that it may expose valuable product Intellectual Property (IP ). This is a legitimate concern with some formats; certainly it is an issue with sending the native design data itself. An intelligent data format specifically created for the purpose of such intelligent information transfer, such as the ODB++ format for example, can be created such as to include only the specific information about the product and PCB which has to be known to the PCB and assembly manufacturer so they can perform their manufacturing process. It is in effect exactly the same data as they would have had to re-create themselves reverse engineering. There is, therefore, no additional risk of IP leakage as compared to the use of legacy formats plus of course in the case of assembly, the PCB itself.

## CHANGING THE PARADIGM

Looking at the current NPI cycle after the design layout process today, we see the typical long and difficult cycle as illustrated in figure 5. Data is being passed from design through to PCB manufacture in the many "un-intelligent" formats which leads to the necessity for the PCB manufacturer to reverse engineer.


*Figure 5: Current Paradigm.*

After the reverse engineering and analysis is done, it is usual to see on average around three cycles of requests for design changes going back to design from each PCB manufacturer. Three attempts have to be made with all of the associated costs and delays in order to get through the NPI process such a PCB that can be manufactured effectively.

One step in changing this paradigm is the utilizing intelligent information, which eliminates the costs and lead time of the reverse engineering, delivering consistent data, removing the unknown compromises, leaving the design team fully in control of the design. Utilizing intelligent information also enables a much improved communication mechanism so that changes required by the PCB manufacturing process can be very quickly implemented back in the design itself. This removes a very significant barrier which previously caused the changes to PCB without the designer's knowledge. The result as shown in figure 6 is a very significant change to the flow with very much quicker cycle times and consistency of results from different PCB manufacturers.

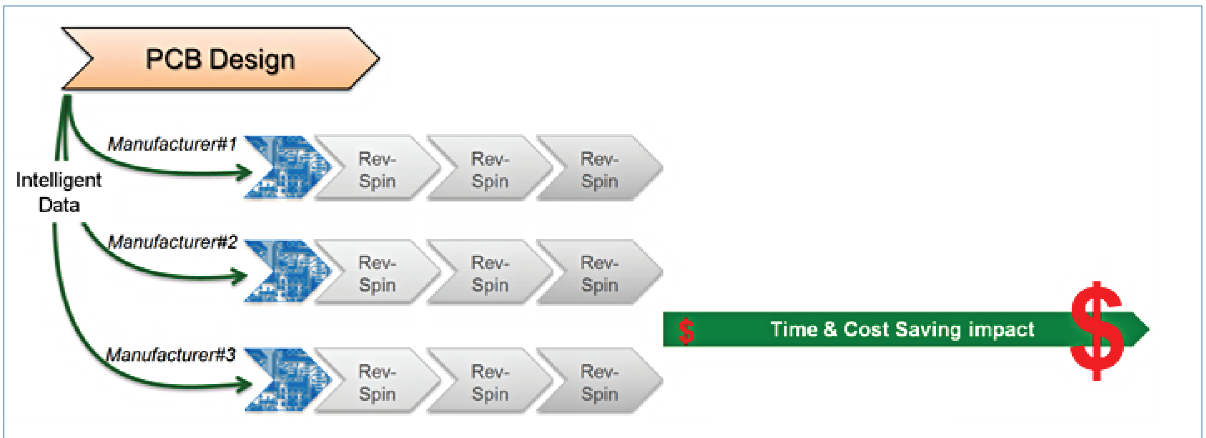


*Figure 6: Paradigm with Intelligent Information.*

The second step is to then take advantage of this strong and reliable information flow and communication. Going back to our comprehensive DFM model, the use of intelligent information means that the time to get the feedback from the PCB manufacturer is far shorter with changes communicated based on the real design as described in the intelligent information. Even with many fabricators working in parallel, there is clear opportunity to gather the knowledge and experience from the PCB and Assembly manufacturing processes to enhance and create advanced more detailed and accurate DFM checks. The DFM operation as executed at the end of the design process can now evolve to be able to find and eliminate the majority of remaining issues that were found as part of the manufacturing processes. The effect of this as shown in figure 7, is the reduction in the need for the revision spins.

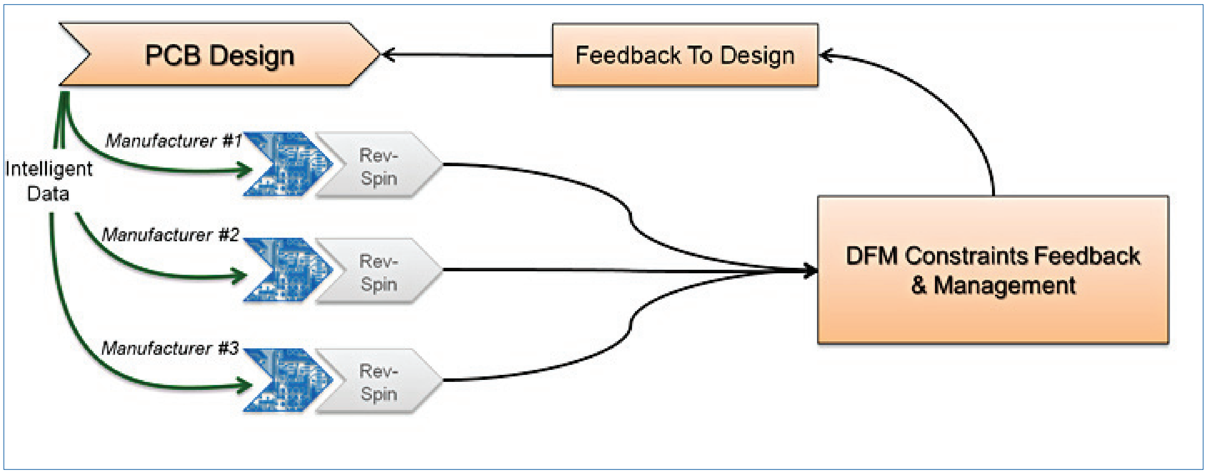


*Figure 7: New Paradigm with intelligent information to create more advanced DFM at design.*

## LIVING THE NEW PARADIGM

For the company now using intelligent information and comprehensive DFM, the NPI story is now no longer one of frustration and fire-fighting, but one of control and opportunity. As part of the layout process in design, the understanding of the PCB manufacturing and assembly needs are known and modelled by the rules contained within the comprehensive DFM tool. Without significant additional effort, the designer completes their design with confidence and passes it to the manufacturing processes through the creation of the single file intelligent information format. The PCB manufacturer receives the file, is quickly able to understand the manufacturing requirements and can quickly and accurately highlight any potential issues. These can be communicated effectively back to the designer to highlight and resolve any additional unforeseen issues. Perhaps one revision spin should be necessary. With the feedback being precise in this way, additional adaption and configuration of the DFM rules is made to ensure that for any issues, this happens only once. The next revision spin is likely to be perfect and usable. Even without the ability for quick design spin cycles, the logic also works in the same way for assembly manufacturers who are also able to understand the precise requirements for the manufacturing operations before they start, benefiting from the 10x rule where requirements known up-front can be catered for with much less cost than having to deal with the consequences later on in the processes. The NPI and ramp to volume time is much more managed with the impact to the operation as a whole greatly reduced.

## BENEFITS FROM THE NEW PARADIGM

The theory all sounds good, but how about the reality? The principles behind this new paradigm have been around for some time; it is now however that the tools needed to achieve this paradigm easily and efficiently are available. We can see in the market results from the early adopters of these principles as shown in figure 8.

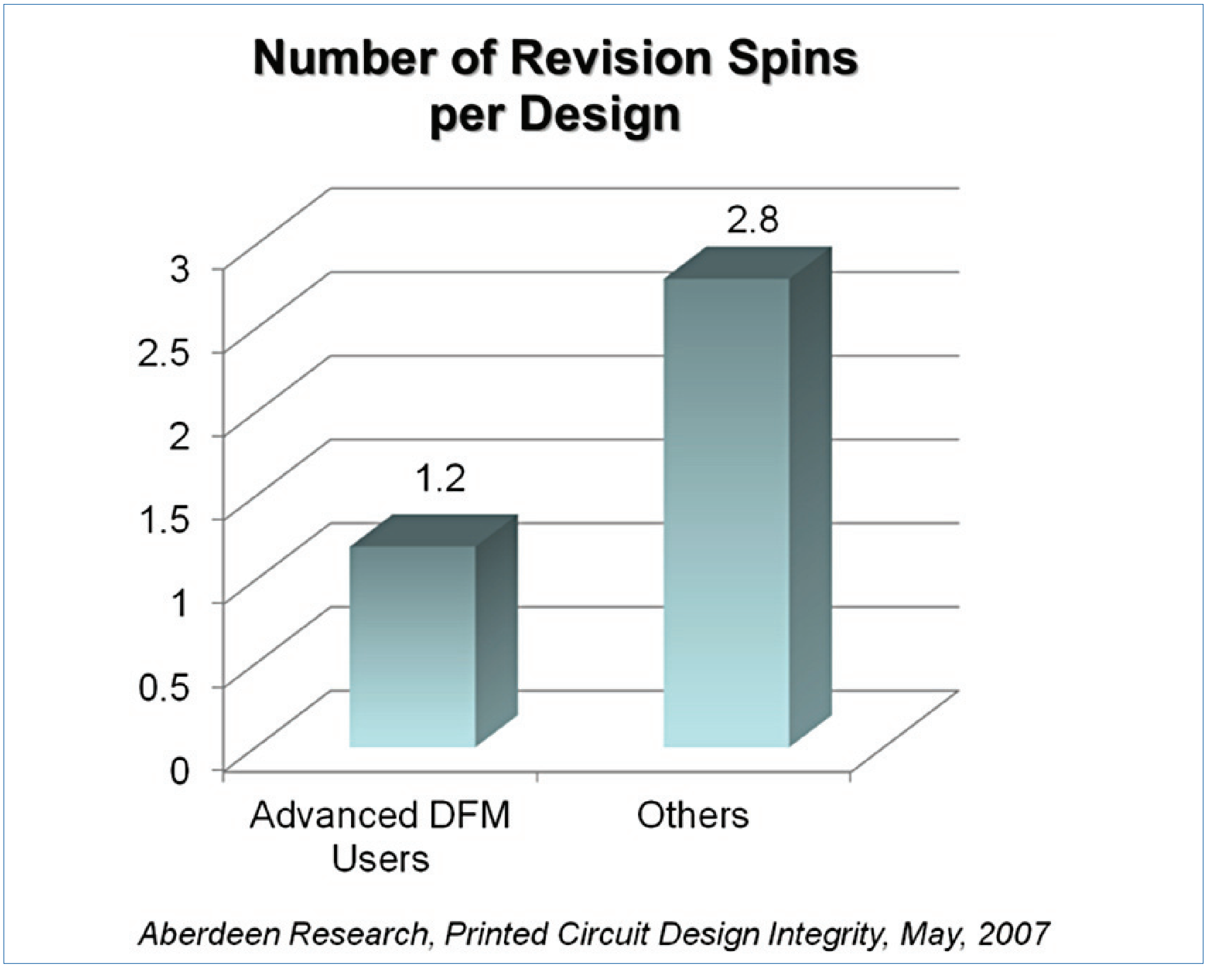


*Figure 8: The results of the New Paradigm in action.*

The tools to support this paradigm are the key trigger to wider adoption. The ability to represent the whole of the manufacturing data in one file format and to integrate the advanced comprehensive DFM operation into the design flow, benefiting from the direct and timely feedback from manufacturing operations.

Going back to our understanding of where profit is made in this competitive market for electronic products we can understand the effects that the benefits achieved from the adoption of our new paradigm will achieve. The major headline is the reduction of the time it takes to bring a "hit product" to market. Reducing the revision spins on average from almost 3 to little over 1 takes out a large and needless waste of time, and hence lost opportunity, from NPI process. We can also take out the reverse engineering time spent by the PCB manufacturer for their original design check and perhaps the one subsequent spin, another significant reduction of wasted time and resource. We can further add the reduction of similar issues and lead-time spent in the assembly manufacturing process. Using comprehensive DFM, around 85% of the manufacturing issues are detected and avoided with a cost saving of at least 10x. These are all clearly tangible benefits.

Further benefits, though less tangible, are also quite significant. The design now is in the control of the designer. Compromises that were made in the PCB manufacturing process are now eliminated. The risk of finding unknown issues is greatly reduced. The business model, the relationship, and communication from PCB manufacturer to their customer is greatly improved with a predictable rapid, high quality cost effective service being delivered rather than an imprecise service with inflated prices to cover needless work and "insurance" to cover unexpected costs.

Knowledge gathered from the end market in terms of reliability and performance of the design can be now more accurately understood and used for next-generation product improvement, since the PCB precisely matches the intended design and is consistent across all PCB manufacturers. PCB manufacturer performance can now be accurately rated as they are all using the same base manufacturing data, leading to the ability to improve quality and performance through selection. Quality improvement in the final product is another key benefit. DFM tests that had not been possible previously now eliminate many situations which had been "border-line." Cases where the PCB and assembly manufacturing had been possible, though perhaps with some compromise or work-around, but being on the edge of acceptable limitations had resulted in a higher incidence of defects than otherwise would have been achievable.

Quality is everything in today's electronics manufacturing industry, whether for critical products such as in the medical, automotive, or aerospace industries, or even in the consumer industry where hit products can quickly fail in the market if just a small handful of customers disappointed with a product's quality are keen to promote their views on social networks. Getting the "hit products" into the market ahead of competitors in a way that is dependable and reliable is the key to getting the profits from the innovative and new technology products in the market. This is the new Paradigm to achieve that goal.



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