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Tech-Clarity Insight:

Leveraging the Digital Factory

Enhancing Productivity from Operator to Enterprise

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Executive Overview

The old adage of measuring twice and cutting once means taking the time to do things right the first time in order to save time (and money). This is more true in manufacturing today than ever given intense global competition and the need to keep costs in check in an uncertain economy. In this case, "measuring" is developing, prototyping, and validating manufacturing plans before "cutting," or putting in place new plants, lines, tooling, or processes which cost time and money. Like cutting a piece of wood, once new manufacturing equipment and infrastructure are in place the opportunities to correct a mistake can be severely limited. The analog in manufacturing – known as "Manufacturing Processes Management" or "MPM" – is to digitally prototype plant layouts, material flow, production lines, workstations, and work assignments to perfect plans before committing to physical changes.

As Bill Campbell, Global Manufacturing Plant Layout Lead Engineer for General Motors explains, "*We execute a 'virtual validation build' to catch potential problems in a virtual environment. It really helps to validate plant layout, robotics, and conveyor lines virtually before committing to construction. MPM is one of the biggest enablers in reducing structural cost, but also helps to improve time to market and drive quality up.*" Manufacturers are leveraging MPM to improve both the productivity and performance of their manufacturing process planning, resulting in significant cost savings that are extremely compelling to manufacturers of all types.

> ***MPM is one of the biggest enablers in reducing structural cost, but also helps to improve time to market and drive quality up.***
> *Bill Campbell, Global Manufacturing Plant Layout Lead Engineer, GM*

MPM tools provide facility engineers, industrial engineers, and manufacturing engineers the tools they need to design and implement optimal manufacturing processes. MPM is becoming a critical element of initiatives designed to improve product innovation and engineering by improving the productivity of manufacturing engineers as well as manufacturing itself. The results speak for themselves. "*The net result of our MPM program was a double digit improvement in productivity, it was absolutely astounding,*" said Pat Frey, Vice President Production Control and Logistics for Android. "*Over the top outstanding,*" he added.

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Leveraging the Digital Factory

Effective MPM has multiple benefits. MPM helps improve time to market, and also helps enhance productivity and drive down cost. This is particularly important because today's economic climate requires getting the most out of manufacturing resources. Efficiency and cost control are mandatory for manufacturers competing in competitive, global markets and in uncertain financial times. Many manufacturers have already adopted "lean" manufacturing concepts to enhance productivity. One core essential of running a lean factory is reduction of non-valued-added (NVA) work. MPM can play a very significant role in improving both engineering and manufacturing productivity through the reduction or automation of NVA work. "*Manufacturing companies can gain from MPM by going after waste. To be profitable, we have to improve constantly and reduce waste, incidents, and damages that can happen to the product if designed or assembled incorrectly*," explains Gilles Bouyer, Senior Director IS North American Manufacturing for Case New Holland (CNH). "*MPM can reduce time to train people and reduce time for a manufacturing engineer to absorb a new product, and it can also reduce quality issues,*" he concluded. By reducing waste in both the plant and within Engineering, MPM helps drive up productivity on multiple fronts simultaneously.

MPM can play a very significant role in improving both engineering and manufacturing productivity through the reduction or automation of non-value-added work.

One of the core fundamentals of MPM is to design and validate manufacturing plans early while flexibility is still high and cost to change is still low. Once facilities, lines, and tooling are in place, the production process is constrained by the assumptions and decisions to date. By analyzing and testing these decisions in advance, changes can still be made before permanent obstacles are introduced. As the product development and introduction moves forward, the windows of opportunity for change begin to close as the implications of past decisions are put into place (see Figure 1). Changes made in a virtual environment are much easier than changing a physical plant or even changing processes once material handling and production personnel are trained. The key is to catch problems early and correct them before costly decisions have been made. "*We went from the paper car to the paper factory as a part of our bill of process (BOP). Now that we are doing the virtual factory, it all works when it starts up,*" explained Android's Pat Frey.

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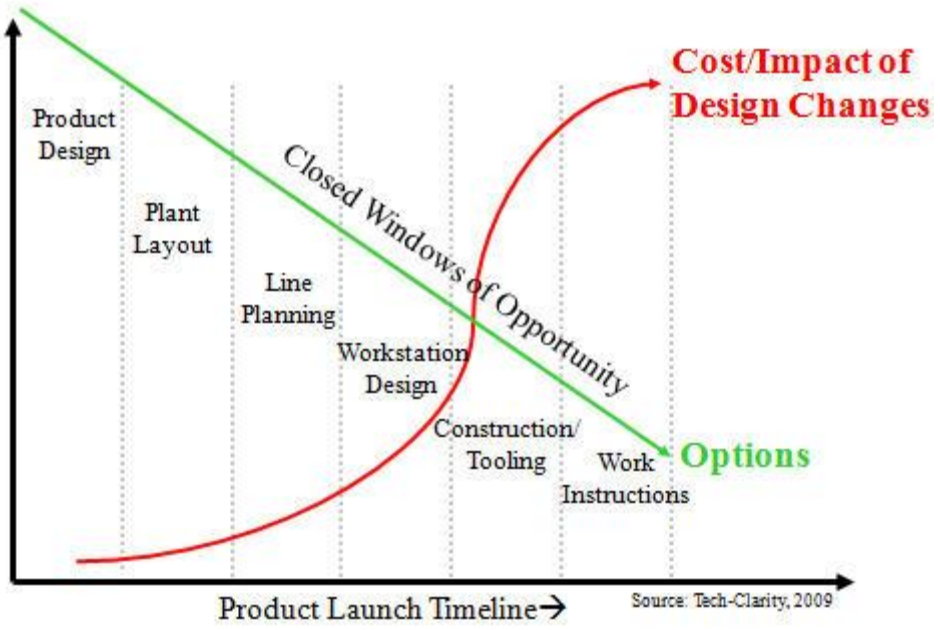

Figure 1: Closing Windows of Opportunity

By modeling manufacturing digitally, companies can evaluate and validate multiple concepts in new facilities (greenfield sites) before breaking ground. This allows companies to increase efficiency, flexibility and reduce cost from the start. "*MPM gives us the opportunity to try so many scenarios and play a lot of what if games. We could see the guy taking lots of extra steps walking around the vehicle, so we were able to change sequences to reduce overhead,*" said Bob Burns, who works as a consultant for a major automotive OEM in his role at Production Modeling Corp (PMC). MPM solutions also allow manufacturers to validate changes in existing facilities (brownfield) sites before committing to cost and disruption. After all, creating change orders on a digital prototype is virtually free and easily reversible, where changing physical facilities is costly and disruptive. In a virtual environment engineers can freely simulate and prototype to understand the impact of new and innovative manufacturing approaches.

Perhaps for a simple process, engineers could use simplistic tools like a spreadsheet to accomplish the planning and analysis they need. Many manufacturers, however, have hundreds or thousands of parts and production steps. The challenge is all that more difficult with increased product complexity and a wide number of product variants. "*One benefit of MPM is the ability to go through multiple iterations of planning the lines and work instructions,*" says Gilles Bouyer of CNH. "*With a mixed line making different products and models, instead of spending days to replan we are done in half a day or a few hours.*"

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Again, the goal is to get the plan right the first time. The days of building a plant or a line that is "close enough" and then improving over time is not good enough anymore, because some changes are simply past their window of opportunity due to prior decisions and constraints. Further, most companies can't afford the luxury of slow line speeds or suboptimal productivity at product launch, driving further need for leveraging the digital factory. "*A lot of people made their careers by being fire fighters because they could fight out of a desperate situation, but those days are gone,*" explains Pat Frey of Android. "*You used to learn based on your mistakes, but today people don't have that opportunity – one mistake can put you out of business.*"

Bill Mitchell, Manager North American Manufacturing Services for a construction and agricultural equipment manufacturer summarizes the benefits of a digital factory approach. "*MPM tools let manufacturing bring product data in to analyze how it will work in the plant and determine whether what they have committed to is possible. It's a bonus if design and manufacturing engineers do some concurrent engineering – that would be icing on the cake – but at a minimum it protects manufacturing.*" MPM and digital factory approaches offer numerous improvement opportunities for manufacturers. According to those that have invested in these initiatives, the results are impressive. "*Our conservative estimate was that we would save $1.1 million per brownfield program, and we have exceeded that,"* said GM's Bill Campbell. "*We are saving at least 50% of engineering change orders in the field – a huge savings. It is hard to quantify, but the savings are extreme.*"

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The Bill of Process - Putting Manufacturing Processes First

Now that we have discussed the concepts and benefits of the digital factory, let's discuss the elements of MPM that deliver this strategic value. MPM starts with a product design, and typically an engineering bill of material (eBOM). The eBOM consists of the parts required to build the product, but has little resemblance to the sequence and structure that manufacturing requires to actually make the product. Manufacturing requires a process-centric view, also known as a bill of process (BOP). The BOP drives tooling, plant layout, all the way to the operator instructions. The engineering BOM serves a purpose, but is not sufficient to drive manufacturing (sequence, part/assembly hierarchy, etc.).

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In essence, the engineering BOM is part-centric, where manufacturing views a product in a process-centric way by defining the precedence, perhaps of thousands of steps, required to assemble a complex product. Parts are assigned to the processes, bringing with them the tooling and other important manufacturing attributes such as quality or FMEA documentation.

Manufacturing requires a process-centric view, also known as a bill of process (BOP).

The BOP is complementary to the product/BOM view, and needs to be associative to help manage change. As Pat Frey of Android says "*Our BOP helps us be nimble, you have to be nimble in this industry, or you'll be gone.*" A consolidated view of the BOP and all associated parts, tooling, and related manufacturing information allows for a rapid, thorough understanding of the impact a change will have on the plant. The tie between engineering change orders (ECO) and manufacturing change orders (MCO) requires special attention to ensure all product changes are implemented in the plant, and implemented efficiently in the context of the overall manufacturing process. A change can't be made effectively until the impact on tooling, layout, part flow, precedence, and manufacturing instructions are analyzed and implemented. The relationship between the engineering BOM and the BOP, and the associativity within the BOP, allows changes to be analyzed and implemented into the plant rapidly and accurately.

Laying out the Perfect Plant

At the macro level, manufacturing is "materials in - process - materials out." Understanding the processes and production sequence from the BOP helps design the flow of material through the facility. Early optimization of material flow helps to ensure efficient manufacturing and control costs. Unfortunately, material flow is not always considered as the primary driver when plants are designed. "*Often times material flow is not viewed as important, and the Materials Department is just expected to get the parts there,*" explains Debbie Spencer, Senior Director of Product Development & Supply Chain Engineering for MHSI. "*But the 'how you do it' part can be very expensive.*" It's important to get it right to keep costs optimized, and requires material flow to be a major consideration during manufacturing process planning. "*You absolutely need to include material flow in your analysis,*" says Android's Pat Frey. "*If you don't, once you start to put your facilities together, you start to erect monuments that constrain any productivity improvement going forward. Those decisions will force you to spend money to move monuments or forgo efficiency gains.*"

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The lean plant can't afford any non-value-added (NVA) work, and moving material is often one of the biggest culprits. Another wasteful consequence of inefficient material flow is compensating with excess inventory. Extra work-in-process (WIP) inventory can help smooth over problems, but at a cost. MHSI's Debbie Spencer explains, "*Without lean inventory, even the best processes don't help with cost.*"

To address this, manufacturers are using visualization technology to help spot conflicts and inefficiency. One form of this is the development of spaghetti diagrams that depict material flow throughout the plant. These diagrams provide valuable insight into the efficiency of material movement. Other uses of visualization include visual plant representations. "*We have built a 'Virtual Factory' – a 3D plant layout – to help us plan our manufacturing processes,*" says Steve Schuchard, Central Layout Technical Support for GM. These 3D layouts can include reuse of existing plant designs, as well as imported point clouds from 3D Laser scanning to get layouts and equipment details. "*We are using Building Information Management (BIM) and virtual validation from a manufacturing perspective,*" comments GM's Bill Campbell. "*Integrating digital models together allows us to conduct virtual layout validation reviews, we find hundreds of issues per session early in the process.*" In addition to developing more efficient plant layouts, it is also saving time and effort in engineering. "*It conservatively reduces development time 30% from feasibility to full installation,*" Mr. Campbell added, "*It is extreme.*"

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Optimizing the Lines

Once the plant layout has been designed, manufacturing and industrial engineers turn to balancing the production lines. Well balanced lines are important to productivity and cost, as well as maintaining good relationships with labor. The line plan takes into account the list of steps, process time, and operations to be performed based on precedence in BOP. The goal is to design efficient lines, workcells, and processes, but also work assignments that are fair and objectively validated. For this reason, line balances should be based on objective standards for operation times, and standardized to ensure consistency and prevent grievances.

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It is critical to get line balancing right, because it serves as the backbone for placement of workstations, operators, tools, containers, and materials. Equally dividing the work between operators and ensuring that no workstation is overloaded is a complex and time consuming task. This can be particularly complex for mixed model lines that run multiple products or product variants. If engineers just balance the line to the "worst case," they are leaving operators underutilized. "*We designed a solution that eliminated one job and added work to the one that was left*," explains Bob Burns of PMC. "*We were able to do this by understanding and optimizing the worst case scenario, but also considering and planning for the appropriate product mix.*"

We designed a solution that eliminated one job and added work to the one that was left … by understanding and optimizing the worst case scenario, but also considering and planning for the appropriate product mix.
Bob Burns, Consultant for Major Automotive OEM, PMC

Developing line plans is an iterative task that benefits from running multiple scenarios to ensure that each operation – along with the materials and tools it needs – is included and optimized. "*We run and save several scenarios based on different run rates,*" explains Erik Miller, Operations Program Manager for Electrolux Major Appliances. "*After we run the scenarios, we print job detail sheets and know the level of staffing we need for the line. What used to take a week to make changes now takes an hour or two.*" Companies are not only getting better answers to their line balancing problems, they are achieving them faster by implementing the appropriate tools for manufacturing engineers. Gilles Bouyer says that CNH experienced similar engineering productivity gains. "*To balance a line was a week of effort, but less than a day with an MPM system.*"

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What used to take a week to make changes now takes an hour or two.
Erik Miller, Operations Program Manager, Electrolux Major Appliances

Optimizing Workcells

Line balancing provides the information required to generate workcell layouts. The line balance provides the right data regarding parts, containers, tools, fixtures, and operators to allow engineers to define efficient workstations. "*Using the CAD layout, we can overlay very exactly where to place the bins and totes, where tools are hung, where the CRT is positioned if they need to touch the keyboard at the end of the cycle, and then slide things around the lines visually*," says PMC's Bob Burns. "*Then, we can accurately determine how many steps and the length walked, and how many seconds it should take.*" Basing work cell designs on actual CAD layouts allows for more accurate calculations that are more defendable with labor. Visualizing the work in the workstation allows

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engineers to spot inefficiency and reduce NVA work, such as excess walk times. "*Part and tool location and sequencing become obvious because of simulation and the ability to move things around visually on the CAD layout,*" Mr. Burns continues.

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Bob Burns, Consultant for Major Automotive OEM, PMC

Analyzing a virtual model of the tasks at a workstation helps develop more efficient layouts. It may be sufficient to simulate some workstations in 2D. For others, the use of 3D models allows engineers to digitally simulate over 3D designs, including clearance checking, to ensure that workstation layouts are optimized before committing to changes on the plant floor. Of course the digital prototype must accommodate tooling, plant layouts, and products that may have been developed in different CAD formats. Integrating plant layouts to workstation design allows engineers to leverage existing 3D models. "*All conveyors are parametrically designed,*" explains GM's Bill Campbell. "*This ensures that we follow standards and helps to reduce design checking time. But another advantage is that it also develops a detailed 3D model.*" In this way, macro level plant design is reused to plan workstation layouts.

Material Flow at the Workcell Level

Similarly to macro and micro views of plant layouts, material flow follows the same pattern. Material flow is important at the macro level for plant layout, but once you have a line balance you can leverage it to plan materials at a micro level. The line balance is related to the material flow because it assigns parts to workstations, which determines where to deliver the parts. "*Your goal should be to eliminate disconnects between manufacturing processes and material handling, but most companies don't make the handshake between line balance and materials,*" says MHSI's Debbie Spencer. "*To improve total cost of production requires the handshake.*"

In another parallel to workstation layouts, the line plan is a critical driver to material flow analysis. The list of tasks, times and operations from the line balance drives the location materials will be consumed. Much the same way as developing a workstation layout, a material flow model can be created based on an overlay of the CAD layout. Engineers can run the model to determine the best way to deliver material, and then structure an appropriate routing and delivery system to deliver parts when they are needed. Another important aspect of material flow is containerization. Depending on the size and consumption rate of the part, intelligent use of containers might be able to reduce the number of required deliveries and improve overall plant efficiency.

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Communicating with the Plant (Work Instructions)

Manufacturing process planning, from the macro level of plant layout to the micro level of detailed operation steps at workstations, helps engineers develop the best possible plan to maximize productivity and eliminate waste. But unless the plans are followed, efficiencies will be lost. Some amount of the manufacturing process intent can be implemented physically by introducing the right plant layout and workcell design. Manufacturing processes, on the other hand, are dependent on people. Production techniques can vary based on the shift or operator if not clearly documented and communicated. "*If you have a new person, a new model, or people retiring then you need to transfer this knowledge and experience,*" says CNH's Gilles Bouyer. "*Formal work instructions help reduce training of people on the assembly line and reduce quality issues.*" In this way, formal work instructions help implement new manufacturing processes that can save time and boost productivity.

Formal work instructions help reduce training of people on the assembly line and reduce quality issues.
Gilles Bouyer, Senior Director IS North American Manufacturing, CNH

It should come as no surprise that to maintain efficiency and quality operators need to understand what is expected of them. Translating the line plan into a set of clear work instructions is only the first step to ensure that processes are followed. Visual work instructions that rely on images and video provide clearer, less ambiguous communication than written language. The existing 3D models can be reused in conjunction with the line plan to deliver more intuitive instructions such as fly-throughs of processes. In this way, the work instructions are a natural derivative of the BOP and the existing CAD models. Work instructions can also be used to communicate additional information to operators including FMEA, documents, animation, machine settings, quality checks, specifications, and other crucial production information.

We give the operators dynamically scheduled work instructions based on the particular unit coming down the line.
Bill Mitchell, Manager North American Manufacturing Services, Construction and Agricultural Equipment Manufacturer

Static work instructions may work for some plants, but may not suffice for plants with frequent product and model changes. Developing work instructions dynamically by tying them to the line balance provides the benefit of tailoring instructions to the scheduled product mix. "*Our products are built to order with high option variability,*" says Bill Mitchell. "*We give the operators dynamically scheduled work instructions based on the particular unit coming down the line.*" By integrating the line plan to the work

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instructions, companies can reduce the error that result in wasted time and materials or lead to costly quality defects.

Pulling it All Together (Integration and Associativity)

Integrating the line balance to work instructions is just one example of how an integrated MPM approach provides efficiency. This scenario points out the advantages of integrating the different elements of the manufacturing plan, starting from the original engineering BOM coming from a PLM or PDM solution. On one hand, MPM can be implemented incrementally as a series of tools that helps with individual tasks such as process planning, plant layout, material flow, line balancing, workstation planning, tool placement, material locations, and work instructions. But to gain even greater benefits from the solutions, manufacturers should develop a more integrated vision for MPM even if they implement it incrementally. More advanced MPM systems are designed to support this strategy by providing modular, integrated solutions centered on the BOP.

To gain even greater benefits of the solutions, manufacturers should develop a more integrated vision for MPM.

One of the primary values of integrated solutions is the concept of "associativity." Associativity is the process of linking related information together in a logical structure. In MPM, this means associating the majority of the information back to the manufacturing processes themselves. This provides a logical structure to the information, but also plays a crucial role in managing change. "*Our pain in line balancing was that everything was done in a spreadsheet. Whenever we changed a routing or a bill of material, we had to go through job detail sheets, update pictures, activities, and materials. If an operation moved from one step to the next in precedence, we had to update multiple sheets and it could take 1-2 weeks. Now, we use the power of the relational database so that tools, work instructions, and other information automatically move with the activity,*" says Electrolux's Erik Miller. "*That is what we like about the relational nature of our MPM solution. Beyond managing change, it also gives us the power to reuse data, for example reusing standard operations and operation times.*" In this way, implementing an engineering change order into a manufacturing change order ripples through other changes such as the line balance, work instructions, and times automatically.

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Erik Miller, Operations Program Manager, Electrolux Major Appliances

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Another advantage of integration is running analysis over the related elements of the BOP. "*Our goal is to start with observed or pre-determined work standards and connect them to the ergonomic analysis,*" says Bill Mitchell. "*When we change a task or a standard, it may take us over an ergonomic limit, but because it is interconnected, it will send up a repetitive motion flag automatically.*"

Getting to MPM

It's important to approach MPM strategically. Clearly, there are a lot of options for how MPM can help any individual manufacturer. Although MPM includes a number of valuable tools, it should be viewed as a suite of solutions. Beyond the boundaries of manufacturing, MPM should also be included in an overall PLM Program or initiative. At the same time, companies shouldn't try to do too much at one time. Once the bigger picture has been developed and the plans for an integrated solution are in place, manufacturers should focus on addressing troubled operations first versus fully simulating a plant. Implementations should also look to leverage existing assets, such as 3D plant and workstation layouts to give the project a head start.

Most importantly, companies need to focus on how people will change the way they work so they can improve productivity in engineering and in production. As Bill Mitchell of a construction and agricultural equipment manufacturer explains, "*The reason we are doing so well with virtual manufacturing is that we focus on two things together, the technology and the business.*"

Our goal was a 10% increase in efficiency… We blew by 10% very quickly, and two plants overshot 10% in the first 4 months.
Pat Frey, Vice President Production Control and Logistic, Android

Finally, set realistic goals with tangible ROI. "*Our goal was a 10% increase in efficiency,*" explains Pat Frey of Android. "*We blew by 10% very quickly, and two plants overshot 10% in the first 4 months.*" These are compelling savings for companies, particularly in challenging economic times. By approaching MPM both strategically and incrementally, companies can reduce cost with a series of tangible programs with the fast payback that is mandatory in most companies during uncertain financial markets.

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Conclusion

Manufacturing Process Management provides the processes and tools required to improve both manufacturing productivity and manufacturing engineering efficiency. By focusing on manufacturing processes as the cornerstone of the production plan, companies can develop efficient, integrated plans that reduce cost, improve time to market, and raise product quality. "*BOP is our roadmap, we believe it gives us a competitive edge,*" concludes Android's Pat Frey. "*We use MPM everywhere from the initial process planning, to the operator, and to the enterprise. We are making every effort to improve our awareness and load our toolbox – if you are thinking for today, you are already 3 steps behind.*"

Recommendations

- Put manufacturing processes first, using them as the central point of manufacturing process planning
- Digitally prototype the product and the plant in context to get production right the first time – before spending money and creating unmovable constraints (monuments)
- Consider the use of MPM for commissioning, but don't forget the importance of incorporating engineering changes in a controlled manner
- Leverage MPM solutions to support changes in production volume, moving products to new facilities, or other changes driven by a turbulent economy
- Apply MPM concepts at multiple levels of granularity – even at the macro and micro levels – from enterprise decisions down to individual operator tasks
- Look at adopting MPM on an incremental basis to solve specific problems, but don't forget the value of a fully integrated solution

About the Author

Jim Brown is the President and founder of Tech-Clarity, an independent research and consulting firm that specializes in exposing the true business value of software technology and services. Jim has over 20 years of experience in application software for the manufacturing industries, with a broad background including roles in industry, management consulting, the software industry and research spanning enterprise applications such as PLM, MPM, ERP, SCM and others.

Jim is an experienced researcher, author and public speaker and enjoys the opportunity to speak at conferences or anywhere that he can engage with people that are passionate about improving business performance through software technology.

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