Multek's VARIATION REDUCTION Initiative

Implementing a quality system across multiple facilities is an enormous task. How a top 10 PCB company developed its statistical-based defect elimination and cycle-time reduction program. **by MARIO PEREZ-WILSON**

In the past few years Multek has embarked on a quality initiative that has made it a significant leader in merging PCB manufacturing with statistical-based quality. At a time when many organizations fell in love with Six Sigma, Ben Robinson, Chief Operating Officer of Multek contacted me – president and founder of Advanced Systems Consultants and one of the original developers of Motorola's ground-breaking Six Sigma program – to tailor a statistically based quality system specifically designed for PCBs. To underscore its commitment to the program's success, Robinson recruited me as corporate vice president of quality for all Multek sites worldwide, in charge of the entire initiative and to implement our proprietary methodologies for process characterization, optimization and control.

In 2000, following three solid months of due diligence in development of implementation plans, visiting Multek sites, talking to management and engineers, and understanding their critical business issues, it was time to name Multek's new variation reduction quality system. The name I proposed was the Variation Reduction Initiative, or VRI.

The VRI was announced to Multek's executive leadership in October 2000, at the GM Conference in Macao, China. This executive overview clearly described the VRI and set the tone for elevating the organization to higher levels of excellence. At its core the VRI is comprised of three essential strategic objectives:

- Total process characterization: characterizing, optimizing and controlling all processes in the factories.
- Defect elimination: defining and understanding links between defects and the interactions of materials, processes and design rules in the fabrication of high-end boards.
- Total cycle-time reduction: positioning the entire organization to be consistently and reliably responsive to market demand by emphasizing the need to understand and reduce production cycle-time.

In essence what the VRI commits Multek to is PCB processes that are characterized, capable, stable and predictable, in order to make them reliable and defect-free, but equally significant, to make them short-cycled, so they can be flexible and sufficiently robust to consistently meet market changes. That October, the critical question challenging Multek was: How can this commitment be achieved?

Quick, Solid Execution

Speed in execution is an asset, but support from leadership is equally necessary when implementing programs. In this case, this meant site leaders throughout the corporation. How could these leaders be persuaded to commit to significant change? The answer was to invite them to a focus meeting and establish a two-way communication, with focus presentations and training, clear goals and rules, and a definite set of business performance expectations.

It had been four months since I had joined the organization. The year was coming to an end. Most site leaders were already planning their holidays. But it was necessary to commit the site leaders to a buy-in of the VRI before they set off on vacation in order to have full deployment of the initiative at the start of January 2001. We booked a resort for a week to hold the first VRI Conference for all site leaders and their respective directors and vice presidents. Flying in from almost every continent, we were all finally able to place voices heard many times over the phone with their respective faces. We focused intensively on training, workshops, discussion, interaction and consensus. The week culminated with the GMs presenting their committed plans for VRI implementation at each site.

On the last day, a film crew was brought in to record the

GMs' presentations. These images were later incorporated into a video that was shown to all levels of the organization to evidence the corporation's worldwide commitment to the VRI.

By year's end, all the leadership groups across the organization had received training in the VRI. They understood its elements and what it could do for the organization. And, most importantly, they were committed to its implementation by identifying resources, processes and organizational changes necessary to facilitate its deployment.

At the outset of the new year the VRI was launched at every site worldwide with full fanfare, accompanied by the premiere of the VRI Executive video. This was a 20-minute clip featuring the CEO, COO Robinson and myself, who explained the what, how, who, when and why for the changes in the organization, especially at a time when things were going very well. A clear and concise description of the VRI, its elements and the three strategic objectives were explained, followed by clips of every site management commitment presentation. Everyone in the organization saw the video. The rationale: to avoid the "I heard it through the grapevine about the new program *they* are putting on" reaction, which often is offensive to employees and damaging to the organization's change initiative. The video address sparked many groups to initiate their own improvement projects, almost like announcing it was open season for fixing things.

To complement the video, an executive directive was sent to everyone. The directive reinforced the what, how, who and why, and made the following clear and inclusive declaration: "Each and every one of us will be responsible for reducing variation in our own processes and facilities worldwide and meeting our ultimate corporate quality goal."

Now, with the first impression of the VRI firmly and decisively cast, the standard training curriculum for everyone followed, along with the VRI Site Implementation Plan set by leadership. The Site Implementation Plan identified and defined in great detail the most critical processes, the teams and team members, and the deliverables and progress schedule at each stage of the standard process characterization methodology, or "M/PCpS."

The "M/PCpS" methodology – an ASC proprietary methodology – became the *de facto* standard used by all employees for characterizing, optimizing and controlling gauges, tools, equipment and processes. In other words, one method, one approach, one solution and one strong execution are what the methodology brought to engineering. This standardization made communication between engineers from all worldwide facilities, clear, smooth and flawless. Everyone knew all the steps involved in characterizing their processes, and that short cuts were unacceptable. Comparing all processes became possible. Transferring processes and production lines overseas became smoother, given the documentation of the M/PCpS studies and their reports had all the details about the process parameters, product flow, equipment, gauges, etc. (**FIGURE 1**).

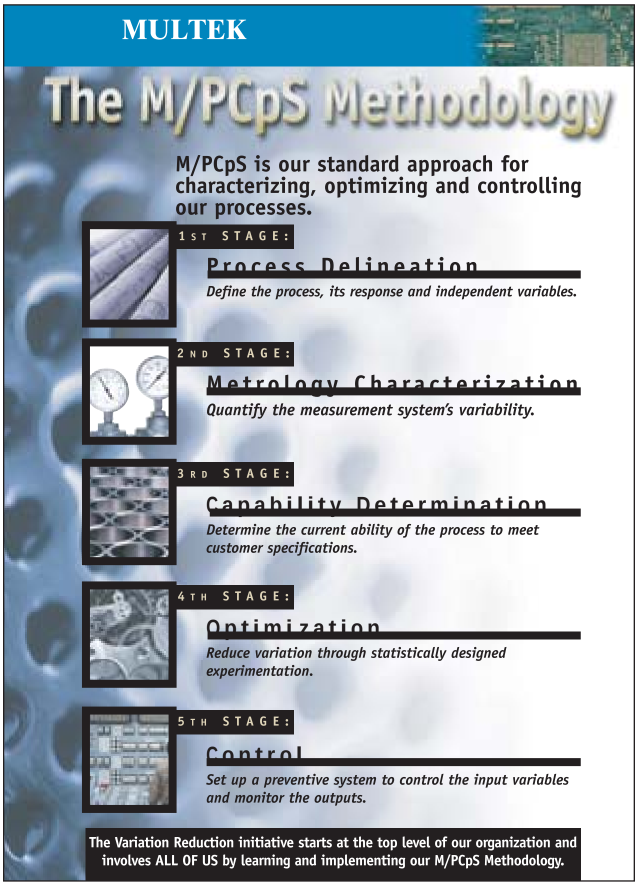

FIGURE 1. In pursuit of variation reduction, Mutlek characterized and standardized every one of its PCB processes.

Standard Engineering Reports

If you find engineering reports are mostly written in capital letters because Excel is being used as a word processor, with no particular attention paid to grammar, style or punctuation, it's likely you have a problem in engineering. Engineers are taking short cuts. Given this, it's also possible, if not likely, the engineers are also taking short cuts in the operational processes to which they are assigned. Doing things right must be a basic requirement at every level of the organization.

Under the umbrella of the VRI, all site protocols were integrated. The form and structure for all engineering reports were standardized. A single word processing software was permitted, and everyone trained on it. Furthermore, a paperless electronic document management system, permitting global search across multiple site libraries, was established. This allowed any engineer to file engineering reports, characterization studies, experiments, gauge repeatability studies, virtually any document. They also had the ability to search by keys, which maximized the bandwidth for the dissemination of knowledge across all sites at the speed of the Intranet. In the past, a solution to a problem implemented in an overseas site routinely took several months before a traveling engineer or manager might happen to visit the plant and discover the improved method. With the global e-library, engineering globalization took place overnight. For example, when an engineer was studying a process for the first time, they could search on copper thickness or CMI, and a number of reports, characterization studies, repeatability studies, GR&R, or design of experiments (DoE) from all sites would show up instantly. This obviously required standardization, and all reports had to follow a single and unique format.

During the VRI Leadership Conference, all directors of engineering and general managers received training in M/PCpS. At the end of the conference a detailed implementation plan was presented. The plan ranked every PCB process in each factory according to the level of influence each one had on inducing variability and affecting critical business issues (CBI).

The implementation plan detailed each response variable needing to be optimized. The plan specified the order in which these critical processes should be studied, and further delineated when each of the studies should start and end. In addition, the plan stipulated when the teams should complete each of the stages of M/PCpS, and itemized the expected deliverables. A team leader and team members were also identified in the plan for each of the studies. With an explicit and clearly detailed implementation plan and a concrete, proven methodology, and a fully committed organization, the year started with training at every site.

In a synchronized manner, all sites started receiving training matching their implementation plans, and the VRI coordinators organized and facilitated the whole effort from the site level. Each site team soon became immersed in its respective M/PCpS study. The teams presented their progress on a monthly basis in the VRI monthly progress review. On a weekly basis, they received guidance from the VRI coordinator and from a few internal *cognoscenti* who thoroughly evaluated the data being generated, the statistical analyses and the documentation produced from the team studies. As each of the stages of the M/PCpS methodology was completed, it was documented and posted in the global e-library. This served to quickly disseminate information about the progress made. The guidance and coaching given to the teams was thorough and consistent. It could not be less so, given that the processes selected for characterization were among the most challenging. In numerous cases, the same processes were being studied at different sites. This approach was oriented specifically toward designing global test vehicles, maximizing board complexity, aspect ratio, board/panel orientation, pad size and location, artwork complexity and layer count, for the purpose of comparing and benchmarking process and technology capability by site.

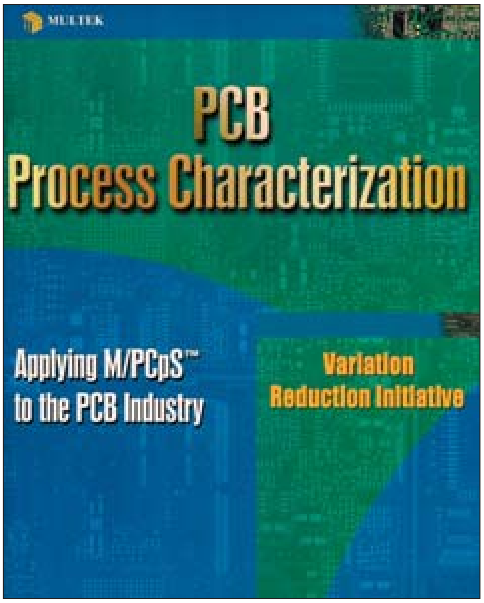

FIGURE 2. The PCB Process Characterization book, also known as the "PCB Cookbook," detailed instructions for characterizing and standardizing the most critical PCB processes.

In the first stage of Process Delineation, the teams started by implementing 5S (Seiri, Seiton, Seison, Seiketsu and Shitsuke, or housekeeping, workplace organization, cleanup, keep cleanliness, and discipline) and using decomposable mapping. They followed this by dissecting their assigned process into functional characteristics and forming C&E cross-reference tables between the response and ranked independent variables in the assigned process.

The Metrology Characterization stage was the speediest for the teams. The parallel efforts of characterizing the gauges and other measuring equipment, and of quantifying uncertainty in the measurement systems, was quickly undertaken. This was a primary VRI goal.

As each process characterization study approached the Optimization stage – the most intricate and proactive stage of M/PCpS – the team members' training became encyclopedic and utterly challenging.

The application of experimental design in PCB fabrication is very similar in complexity to the DoE applied in semiconductor fabrication. Nearly all experiments involved multiple processes in which randomization and replication becomes intricate. Most involved optimizing multiple responses. In these cases the independent variables were manipulated at multiple levels – often more than two – with a combination of both fixed and random factors, and often nested from within other factors. They were also crossed, requiring complex experimental design models, advanced analysis of variance and variance decomposition. This complexity necessitated elevating the knowledge of the personnel to advanced DoE, given the application of the typical full and fractional factorial designs were the exception and the rule was experimenting with complex mixed-effect design models.

As the processes were characterized and optimized, the front-end designers could design boards following improved design rules which, in turn, correlated with improved first-pass yields and lowered fabrication costs.

So, not only was the methodology (M/PCpS) for characterizing processes standardized, but so too was the software used for statistical analysis. Standardization was also done for the "global" test vehicles (TVs) for characterization, and the reporting and format of the documentation. However, there was still another level of standardization identified that would speed the execution of forthcoming studies to the immense benefit of the organization. And, no time was wasted in pursuing that higher level.

With the contributions of various site *cognoscenti*, I compiled a comprehensive document titled PCB Process Characterization. The book essentially defined detailed instructions for further characterization and standardization of each of the most critical PCB processes. With this "PCB Cookbook" – as it was nicknamed at Multek – the engineers and process teams were able to speed the execution of characterizing their processes in the same fashion across all sites worldwide.

Characterizing the processes using the same global TVs and the same approach, the individual site process was singularly isolated as the only major variable of difference for the same processes across all sites. And, as the TVs tested for design complexity and aspect ratio, executive management could objectively – with data, statistics, confidence and factored risk – compare the capability of similar processes at different sites. How would this capability translate into customer satisfaction? As new designs are evaluated, management can objectively determine which site can produce a board complexity, line width, layer count, and aspect ratio and what its final capability would be. In other words, process predictability would be objectively optimized.

Training Curriculum

A training curriculum was developed for all sites and for all employee levels. The training began the day the VRI was launched. At the staff level, training took several weeks and started with a thorough understanding of Multek's CBI and culminated in the development of their own set of implementation plans for initiating their own particular process characterization studies and engineering projects. The training embraced the full coverage of the five stages of M/PCpS: process delineation, metrology characterization, capability determination, process optimization and total process control. M/PCpS, a single, unified methodology, systematically incorporates all the tools and statistical techniques such as 5S, decomposable process mapping, cause and effect diagrams, vital variable ranking, Likert scales, destructive and nondestructive gauge R&R studies, DoE, multi-factor multilevel mixed-effect-model analysis of variance, multi-vari analysis, statistical process control, Positrol plans, etc.

Every director, manager, and engineer received the same level of advanced training in statistical methods regardless of their individual involvement with the VRI implementation plan. Why? Because there is no reliable, long-term benefit for an organization that has only one, or a few, well-trained, prepared and skillful individuals who are subject matter experts (SMEs) on critical business processes. Inevitably, when SMEs communicate with the rest of the organization, the non-experts do not understand them. The non-experts cannot even ask questions, factually challenge action-decisions, or propose informed, viable alternatives. And just as inevitably, this schism between the knowledge "haves" and "have-nots" yields internal frustration, conflict and the likely failure of the organization's change and improvement initiatives. The VRI had to be based upon an organization-wide foundation of knowledgeable and results-oriented employees who approached board fabrication as a science, not an art.

To unify all sites and to further promote "one-look, one-feel," corporate quality goals and objectives were established and published in a color, detailed brochure for internal distribution and external communication with Multek customers. The brochure, titled Our Quality Philosophy, explained why variation was the main focus of the quality philosophy. It elaborated on the methodologies used for achievement of each of the three strategic business objectives, as well as proclaiming the global quality goals and objectives. It also described the five stages of the M/PCpS methodology, and included a copy of the executive directive to evidence the seriousness of this initiative.

It's often been said that in real estate the three most important things are location, location, location. When implementing a successful corporate program, it might be said the three most important things are message, message, message. The message must be well considered. It must not in either fact or appearance conflict with other corporate initiatives. And the message must be reinforced in many ways and through as many media alternatives as may be appropriate, available and affordable. The VRI and the Our Quality Philosophy publication sent a clear and simple message: "Variation is the main cause for defects, scrap, poor production yields and for instability and unpredictability in manufacturing and production processes. Variation needs to be reduced." The implication of this message for every employee was equally simple: "You must reduce variation in your processes. We will teach you and show you how."

With everyone at every site in effect singing the same song, we worked diligently toward achieving the same objective. We promised our employees that we would teach them and show them, and we did what we said we would do. One example of proof of this fulfillment comes to mind. One global quarterly goal specified all gauges and measurement equipment had to undergo a test and analysis of uncertainty in measurement. We trained engineers and others on how to do the studies. We standardized the method, and we standardized the form for reporting. Every report had to include a digital photo of the gauge. And if they needed additional help, we flew to the site to provide them the needed support. In three months every single study was completed – over 560 studies! Each was finished and classified by a criteria based on the particular performance of the gauge or measurement equipment. Some were classified as world-class gauges, others capable, some needed close monitoring and a lesser number were quarantined for measurement and inspection. In many cases, the latter were replaced by newly acquired world-class gauges. In addition, we showed the personnel doing the studies what to do with the published studies. All such studies were published in the global e-library. A copy of the published study was laminated and elegantly placed where the gauges reside in the production area where such gauges are used. In this way, customers, production personnel and auditors could see the study, inspect it and audit the study method. Having these studies in the global e-library constituted, among other things, a potent ability for show-and-tell. First, everyone in the organization could access the file and review the study. But, even without any prior knowledge of the details of the study, any employee could instantly do a global search for all related studies to, let's say, copper thickness or CMI, and almost instantly all the relevant studies would appear, complete with all details, dates, personnel and facility involved, result, and all original support data. Customers were impressed, but also encouraged to ask questions and to expect more information. This only made for further opportunity to show and highlight some of the other equally impressive engineering that was happening. That particular quarter, all sites met their global quarterly goals and received their VRI bonuses.

We derived full benefit from Multek customers' usual practice of touring, auditing or qualifying their supplier sites. Posters were designed and produced in color emphasizing the VRI, the global strategic objectives, and the quality goals, tools and methods. Again, "message, message, message." These posters were placed in every factory, in English and along side were placed identical posters rendered in the language spoken by employees at that factory location. The posters further enhanced the one-look, one-feel ambiance and work performance orientation shared by all Multek sites. In addition, the posters served as a focal point, prompting customers to take notice and to ask questions about the VRI. This increased the customer's awareness of Multek's quality commitment, and provided an opportunity to explain and tout the work done at the site. On many occasions it was especially exciting when one or more VRI team members were present with the operators to explain what the VRI team had done to improve the work area and the processes. This direct, firsthand briefing was extremely powerful in the eyes of the customer. This was due, in large measure, to the fact that almost without exception, the employees conducting the informational tour for the customer, as well as the VRI team members, were not area supervisors and managers. These supervisors and managers – despite their earnest concern, involvement and awareness – may not have known all the details of the change initiative nearly as well as the employees who actually were responsible for realizing the change.

To encourage the sites to stay on track with the VRI implementation, their efforts were tied to quarterly goal rewards established by Corporate Quality. A percentage of site bonuses were linked to the successful completion of these goals.

Strict discipline was kept. Every month, at every site, each site coordinator held a VRI monthly progress review meeting. Every team or individual involved in a process characterization study or an improvement project had to make a formal presentation and show the progress made from the previous month. The content of the presentation had to explicitly detail which process variables were manipulated in the context of a statistically designed experiment, at what levels, why they were chosen, what were the alternatives, what was the hypothesis being tested, what was the experimental design model, which variables were random or fixed, which were nested and which were crossed. And in most instances, in the decision-making discussions between presenters and attendees that immediately followed the presentations, questions on issues of confidence and risk were typical. It was customary and usual for most engineers at the site to attend these progress reviews, but the general manager and production, quality, engineering and process managers were always in attendance. The synergy generated by these progress review meetings is virtually indescribable: A collective body of shared knowledge and experience infused the cooperative experience and repeatedly triggered new and further inquiry into the printed circuit processes which, in turn, continually generated an enticingly tangible challenge to achieve full process optimization. Many process theories were challenged and many were confirmed by numerous experiments designed and tested to reduce variability and defects, and improve process outputs. The teams learned quickly not to blindly accept the performance parameters recommended by machine or other equipment vendors. Such recommendations did not guarantee optimized solutions. As a result, the process knowledge developed by the teams was no longer taken for granted, especially since the team members could often show how some vendors knew very little about statistically designed experiments and analysis of variance.

FIGURE 3. Every report on gauges included a digital photo of the equipment audited.

Integrating New Factories

Typically, acquired factories that have been poorly integrated into the larger corporate fold tend to each communicate and interface differently with customers when dealing with complaints and/or corrective actions. In a continuing effort to foster the integration of all sites and to promote the one-look, one-feel environment, I focused on designing a global corrective action system and merging it with a methodology for rapid problem identification, analysis, response and resolution.

A new global correction action procedure replaced all existing procedures and became standard operating procedure for all Multek sites. Among the required elements for a corrective action system to be effective is a clear escalation process for when individuals are not in compliance and fail to meet a deadline, fail to follow up with a customer, or fail to contain and correct a problem. At Multek, clear roles and clear expectations were set for all individuals involved in the corrective action process. To implement the new roles without leaving room for misinterpretations, names for the roles were introduced. They were: the Originator, the Corrector, the Verificator and the Auditor. All of these had clear instructions and timelines for their assigned actions. To facilitate the implementation of the global corrective action procedure, a Web-based software was developed. Loaded with a powerful database system, the software initiated, managed and edited all corrective actions and supported standard Microsoft Word formats in every factory. As a corrective action was initiated by an Originator, the system set and tracked all completion dates and subsequent e-mails the Corrector and others involved might generate. The system could also be configured so every time a new corrective action was originated, it immediately informed via e-mail a Superuser, such as a director of quality, as well as having instant visibility for the entire global organization. A query system also allowed Superusers to instantly see any corrective action, whether open, closed, or delinquent, from any factory and have the search filtered by product, part-number, OEM, CEM, EMS, customer, site, individual engineer, or other data segment.

As I interviewed engineers and managers for the Quality organization, I often heard them claim they had never seen a good corrective action report. I considered this nonsense. If engineers do not have a clear systematic approach to solving problems, they cannot produce good corrective action reports. So we first made sure the Corrector had – and followed – a good problem-solving approach. Then, the corrective action report had to contain the right elements to convince the customer. Problem description must precede containment, which comes before failure analysis, and somewhere later comes long-term preventive action and eventually verification of effectiveness. So, to be efficient, effective and complete, training at Multek focused on a problem-solving methodology, on a standard CA format, and on an Internet software solution.

We call this proprietary methodology Rapid Problem-Solving Methodology. RPM teaches all the steps necessary to correct problems. It was designed to speed the execution of problem solving, specifically when responding to a customer complaint or to a stoppage on a production line. When processes have been characterized, prior knowledge exists about cause-and-effect relationships, correlation, and also about which factors are the vital few or are otherwise, dominant. Sometimes the dominance of vital factors is lost or superseded by other factors that inadvertently alter the process. This search for a defining relationship is what RPM is all about.

Ideally, we never want to have to use the CA system. That is why quality should always focus on preventive methods. In real terms, quality these days is all about the entire business experience as perceived from the customer's point-of-view. For example, when product quality is questionable and a customer complains, a supplier corrective action request (SCAR) may be issued. But is the issuance of a SCAR necessarily a good thing or a bad one from the customer's point-of-view? Going by the premise that when things are good, a customer will tell one person, but when things are bad, the same customer will tell 10, it's obvious: The customer doesn't necessarily see the issuance of a SCAR as a good thing. The SCAR is a consequence of an unexpected interruption in the flow of good product to the customer. Said another way, the SCAR is one indicator used by the customer to determine how adept the supplier is at anticipating problems, containing them, and proactively solving those problems before they impact the customer. But, should the customer be impacted, what that customer will be most concerned to know is what the supplier is going to do about the problem, when it's going to happen, and that the supplier will keep the customer informed throughout the process.

The globalization of Multek's CA/RPM system significantly improved response levels and interaction with customers, and raised the scientific professionalism of the organization when dealing with problem solving.

A typical problem experienced by many global organizations is the transfer of product to a low-cost facility after all the product's bugs have been worked out, usually at the product's facility-of-origin. In addition to the logistical problems inherent in making such a transfer, the transfer also can prompt feelings of resentment and consternation among those employees who originally invested their effort and energy in debugging the product. To avoid this problematic situation, an Inter-Factory Product Transfer Protocol was initiated. Eventually, the protocol was further developed into a global Intranet software program.

To achieve total customer satisfaction it is necessary to visit customers. Customers must be asked how they view their supplier. It's important to emphasize that personally visiting customers is essential, because what customers say in person often has more value than what they are willing to write on a survey. Given all the mergers and acquisitions of the past few years, established customers often report feelings of discomfort and awkwardness when visiting the newly acquired factories of their suppliers. Though the customer knows the newly acquired factory is now part of the established supplier's enterprise, they may still feel as if business is being conducted with a totally different company. Integrating newly acquired sites into a unified business culture is always a significant challenge. The VRI became the vehicle for just such an integration. The VRI gave customers that coveted one-look, one-feel ambiance and business culture. Consequently, when customers toured to qualify Multek sites, they saw the same methodology, the same approach, the same quality goals, the same professionalism, the same improvements and the same synergy.

Many customers and competitors tried to compare the VRI to Six Sigma. Six Sigma is ready-to-wear, regrettably practiced as a canned, one-size-fits-all program. If the program can't fit the organization, then make the organization fit the program! This is wholly unrealistic and impractical because not all organizations will fall neatly or readily into some small, medium or large notion of what an organization needs in order to be successful. The VRI is like wearing a custom-fitted suit. It's purposely designed for the particular client-organization with careful craftsmanship, knowledge, experience, due diligence, and careful attention to the business needs of the organization. The VRI takes into consideration all that makes the client-organization unique. The VRI complements and blends into the internal corporate culture and helps it to thrive and succeed.

Improvements at Multek abounded. Process yields increased. Scrap levels were reduced. Defects were minimized. Cycle times improved.

Ultimately, the best indicator of success is when the customer speaks on your behalf. On one occasion, Multek's CEO was asked to attend a customer's commodity meeting in Ontario. During the meeting a customer, a VP of procurement decided to lecture the CEO about the customer's expectations on quality. In mid-sentence, a colleague interrupted, saying, "No, not them, Multek has the strongest commitment on quality." The colleague then proceeded to explain the details of the VRI. When the CEO related this incident to me, he added, "I have never in my life gone to a customer meeting where the customer is defending me and speaking for me."

Another example: an e-mail sent in March 2002 by Flextronics CEO Michael Marks to the entire corporation, which read: "About a week ago, Solectron completed an analysis of their 34 PCB suppliers, and ranked Multek, our PCB operation, as first. Best in class!"

That's when I realized my work at Multek was complete. **PCD&M**

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