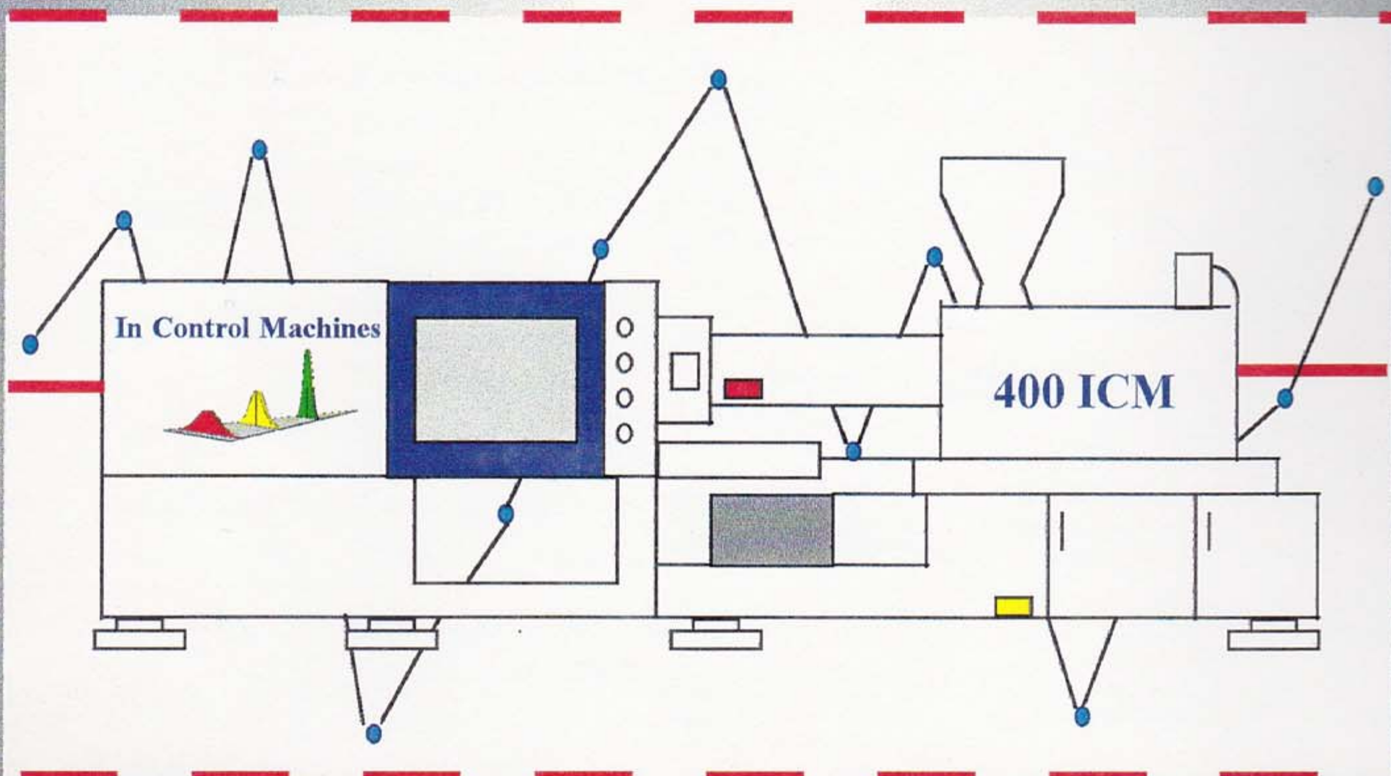
IMPLEMENTING SPC



A GUIDE TO SUCCESSFULLY IMPLEMENT STATISTICAL PROCESS CONTROL WRITTEN SPECIFICALLY FOR INJECTION MOLDING OPERATIONS

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correlation of machine parameters and/or cavity pressures to part geometry.

Preface

According to Juran, the majority of companies that even *try* to implement an SPC based preventative quality strategy do so for one of two reasons:

- One of their biggest customers is threatening to move business if they do not.
- They are on the brink of bankruptcy.

There has been enough material written on statistics and how to formulate control charts to fill a warehouse. My experience with most injection molders has shown that they usually have someone in-house with enough knowledge to both create control charts and train their other employees. Many molders have had unsuccessful attempts to implement SPC for two fundamental reasons: 1) they do not understand how it will benefit their operation (so management does not make it a top priority), and 2) they do not understand the scope (so quality departments are told to "start an SPC program"). Throwing variable control charts alone at a process will not *fix* anything. A higher level of operational discipline must accompany the charts with an involved commitment from the top management of the organization to be successful. Hopefully, this document could be given to the key players in a molding operation and they would gain an understanding of both how out-of-control they really are and also what the path forward should be to regain control over their operations.

The tone of the chapters are directed at the management of injection molding operations. They follow a path of what it takes in incremental steps to truly implement a preventative quality philosophy utilizing SQC tools and techniques, as opposed to an appraisal quality philosophy attempting to inspect quality into products. I have attempted to describe what the environmental factors were that allowed state of the industry to get in the shape it is in, placing emphasis on fixing systems instead of blaming people, always striving to find root cause and propagating a philosophy of continual improvement. The focus on the majority of these articles is on management commitment, because without it, the cultural change necessary to succeed will never happen.

The document could be rewritten for any specific commodity. The same problems in respect to: tampering with processes, lack of root cause analysis, poor preventative maintenance, unreliable quality data, etc. exist in virtually all manufacturing commodities. Sources of variability must be known to develop profound knowledge (as Dr. Deming put it) of any process. That variability must be controlled, and continual improvement must be the culture, for a company to successfully compete against “World Class” operations.

Foreword

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Statistical Process Control, or SPC, is a loosely used term usually applied to any situation where statistics are employed. This Division has chosen to separate the application of Statistical Quality Control, or SQC, from SPC to be more definitive:

- SQC is totally dependent on after the fact part measurements. There is some time elapsed between the time the part is manufactured and when it is measured.
- SPC is done in-process, as close to real time as possible. The ideal is closed loop manufacturing where variables are known and adjusted *while* the part is being manufactured. If correlation between machine parameters (or cavity pressure curves) has been established to part geometry, part measurement should theoretically be unnecessary in this application.

Chapter 1

WHY TECHNICIANS TAMPER WITH PROCESSES

Tamper 1. To interfere in a harmful manner. 2. To meddle rashly or foolishly. 3. To bring about an improper situation or condition by clandestine means.

A major paradigm that I am routinely faced with as the Plastics Quality Auditor for a large user of injection molded plastics is convincing technicians in molding operations that tampering with qualified processes (otherwise known as "tweaking") is almost always the wrong thing to do. Since the inception of the first injection molding machine, it has always been felt that the only thing that keeps parts going out the door is the skill of the technician to constantly adjust the machine to compensate for all of the variables present in a molding process. Molding is viewed as more of a "black art" than a science.

Hopefully, the end result of this article will be that management begins to look at molding as a science that has assignable causes of variation that can be controlled, as opposed to an art form that is dependent on the ability of technicians to process out all of the problems. This will require the establishment of a vision, and strategic planning to achieve that vision. The leadership in most molding operations is so involved in the day-to-day firefighting associated with production that it is difficult for them to plan for a permanent reduction in the level of chaos.

In most molding operations, processing out problems has been the norm for decades. Blaming poor workmanship for these problems is much easier than improving the process or fixing systems that have been in disarray for years. If management would take the necessary steps to understand and control sources of variability, the constant adjustment of process parameters would not be necessary. Sources of variability are so rarely understood, and so little discipline is applied in most molding operations, that constant tweaking really *is* necessary to overcome part problems just to keep parts going out the door. This is true regardless of whether or not the parts are of dubious quality, what kinds of yields are being generated, or whether the business is even profitable.

Production demands usually dictate that the machines keep running, because management does not clearly communicate the concept and benefits of fixing the root cause of the problems. Customers screaming for shipments of late orders apply constant pressure. Orders can be late for many reasons; 1) the molder has to rerun an order that the customer returned for poor quality, 2) a machine broke down, 3) the tool had to be put back in the press because inspectors found a problem with completed inventory, 4) the swing shift operator did not show up for work and the job could not run. All of these problems have a root cause that could be remedied by fixing what is wrong with the system that allowed them to occur.

Machines get "band-aided" back together, and technicians process out all of the problems through constant adjustments to processes. This philosophy feeds on itself; the more processors are pushed to keep the machines running, the less often processors ever even try to look for the root cause of the problem. Maintenance people are understaffed and can never prevent anything from breaking down because they are too busy repairing broken equipment that has put even more pressure on production to meet delivery schedules.

Technicians tweak processes because they have to, not because they have nothing better to do, or because they are trying to make bad parts. Rarely do you find a technician with a few spare minutes on his hands. Usually they are running around putting out fires at every turn. Every technician I know is trying to make the best parts they can; the problem is that they are a victim to everybody else's lack of attention to detail. Specifically, management has not put in place systems and expectations that support doing anything but tweaking processes. SQC will never be successfully implemented without that commitment.

Many people in molding operations are familiar with the term Cp, or process capability. It is rare to find anyone paying attention to what the Cp is telling them. In calculating Cp, the process itself tells us what it is capable of producing; the number generated is merely a ratio between the width of the specification and the width of the distribution of the parts that are measured. A Cp of 2.0 tells us that the specification range is twice as wide as the part distribution.

Many people are also familiar with another process capability index Cpk, which I refer to as process targeting, or process aim. Cpk is dependent on several variables: how wide the specification is, how wide process capability is, and also where the mean (X double bar) of the process is actually running in relation to the specification. The number that is generated is a measure of how far the edge of the part distribution is away from the closest specification in standard deviation units. This is about where most people start to get lost in the topic of SPC, so I typically do not spend much time on the mathematics. The important thing is to gain an understanding of what the numbers mean; this is usually best communicated graphically (chapter seven focuses on this topic). Cpk is a bit more difficult to interpret, since a Cpk of 2.0 can look either close to or far from the nearest specification, depending on how tight the part distribution is in relation to the width of the specification. Goals for Cp of 2.0 and Cpk of 1.33 are commonplace in the industry.

A normal distribution of parts perfectly centered on the nominal with a Cp of 1.0 will also have a Cpk of 1.0, since Cp and Cpk will be equal when a normal distribution is perfectly centered. In this scenario, you can expect 99.73% of the parts to be within specification, provided they are also kept in control, which is rarely the case. Since the intent of this paper is not to define process capability indexes, let's talk about a couple of processes more representative of what actually happens in the industry. One would be a situation where the Cp is less than 1.0, and thus not capable of molding all of the parts within specification, even if the distribution is perfectly centered Another could be a process with a Cp of 1.3, but it is not centered well, and has a Cpk of 0.3. These are not unusual situations, since most molders do not mold to control limits or look at process capability indexes.

A frequently seen situation in molding operations is technicians attempting to make good parts from incapable processes. A process can be incapable for many reasons, such as poor tool design, poor material, a poor processing window, or an excessive amount of variability arising from sources such as insufficient equipment maintenance. If a perfectly centered process had a Cp of less than 1.0 (say 0.8), the best thing a molder could do is to leave the process alone and throw away the parts that are produced out of specification. Is this ever a reality in practice? It should be, since the only way to improve the process is to reduce variability. Management has ownership for fixing systems and reducing variability, while responding to out of control conditions is a local responsibility (the technician). In this scenario, the parts can be in control, but out of specification. The expectation is that variability will be reduced so that the control limits are within the spec. limits.

What inevitably happens in these situations though, is that the Q.C. inspector measures some parts that fall outside the specification and goes to the technician to tell him that the parts are out of specification. The technician realizes immediate action is required, so he tells the inspector he will be over right away (as soon as he is done putting out the fire he is currently working on). Regardless of whether the parts are too large or too small, virtually any technician can remedy this situation in a matter of minutes with one of two knobs; the injection pressure or the shot size. The next parts inspected are back within specification, and the technician has demonstrated his “black magic” once again. Operators, inspectors, and management stand in awe of his skill. Realize several things about what occurred in that situation:

- The next parts measured would probably have been in specification anyway, since the distribution was perfectly centered; the parts that were out of specification were representative of normal variation.
- The technician did not improve the distribution; the only way to do that is to remove variability. All he did was re-target the distribution and guarantee more parts out of specification. This will probably show up on the next shift. He most likely would have been better off to throw those bad parts away and leave the process alone.
- Q.C. probably quarantined a ton of parts and 100% inspected them, until they were confident that they had found the majority of the bad ones. This took time away from measuring other parts and trying to correct problems.
- The processor most likely did not record the change he made or why, giving the technician on the next shift no place to look for information into what is going on. He will turn the knobs the other direction.
- This scenario will repeat itself as long as they are molding that part. The customer will remain disgusted with their incoming part quality, yields will remain poor, rework will continue to be done, and profits will continue to get flushed out of the system.

Why did the technician respond the way he did? Because the expectation is for him to keep parts within specification and keep the machines running, not to take time to find out what is really wrong with the process. If the technician found out what was really wrong with the process, he would figure out that the problem probably could have been avoided if a preventative quality philosophy existed. Nearly every molding class, book on troubleshooting, and training video available all tell technicians to do one thing when problems are encountered: tweak the process. Let me reiterate; if variability is reduced and controlled, they will not need to tweak the process.

A similar situation repeats itself countless times a day throughout molding operations all over the country. An operator alerts a technician for an attribute related defect (such as flash, short shots, burns, splay, or sticking parts), and the processor turns knobs on the machine until the problem goes away. Then he goes off to put out the next fire. Experience has shown that several things will occur in reaction to the processor changing the process:

- The problem went away, but the changes that were made to the process will cause another problem.
- The next problem may not show up until the next shift.
- The processor on the next shift will have no idea what caused the problem (since processors usually are not expected to write down the changes they make), and will turn knobs to get rid of the new problem.
- The situation will repeat itself until the end of time, or until a preventative strategy and use of SQC tools are bought into by the leadership of the organization.

Everyone associated with the molding industry has heard of the situations where the first thing that a processor will do is come in and set up the machine to the parameters that he feels are correct. They do this to establish some kind of a baseline, since nobody observes a single process, and it is always changing. They also do this out of self-defense; at least they know the machine has produced decent parts at those settings in the past before the other technicians started tampering with them. From our perspective, if the process is always changing, the part geometry is always changing, and we are not getting the best possible part.

I equate this situation to chefs in restaurants making vegetable beef soup. There are countless recipes to make this soup *look* the same, but there is only one recipe for the "best" soup. If the restaurant wants to consistently serve the best product, all of the chefs had better agree upon and use a single recipe.

There are countless combinations of machine parameters that can yield a part that looks good. The problem in molding is that everybody thinks they are the best chef. There is only one “best” process, and it should be arrived at before the tool goes into production. Current practices involve the use of windowing studies, capability studies, part measurement correlations, DOE's, and other tools to ensure that we are doing everything possible to arrive at the optimum process. After investing this much time, effort, and money into a process, the last thing we want to see happen is some technician come along and change it the first time they have a problem.

I have been in many facilities where there were as many as 5 or 6 set-up sheets at the press, or perhaps there was no set-up sheet at all. It is the rare situation where the machine settings bear any resemblance to what is called out on the set-up sheet. This is true despite the fact that many operations have Process Engineers who establish the best process, and customers who approve that process. When I audit a facility, or help in the implementation of an SQC program, the first thing we establish is that the process will run to a master set-up sheet, with the expectation that machine settings will match the master 100%, unless the change to variability that caused the problem is known, and the change is recorded.

So if tweaking in the scenarios discussed earlier was not the right thing to do, and we admit that the technician was a victim who was left with no recourse but to tweak, what should be done? Put in statistical terms, variability must be identified and eliminated. If an XbarR chart existed for this process, the control limits would be outside of the specification limits. An easy rule of thumb to remember is that special causes are a local responsibility (the technician must resolve out-of-control signals on the charts), and common causes (or "noise") are a management responsibility.

In the first example, it should have been management's responsibility to reduce the common causes. The out of specification points would most likely actually have been in control. This is why I am of the opinion that technicians are usually a victim to the lack of detail practiced by everyone else, and have no choice but to tweak. Furthermore, they are rarely consulted for ideas on how to make things better in the long-term, and they are not given training in any way to respond to situations other than to tweak processes to satisfy short-term production goals. In the second example on attributes, the leadership has not strategically planned for the training of processors or looked to manufacturing for anything other than maintaining the status quo.

The philosophy that management is responsible for developing and implementing systems allowing people to do quality work is the key to understanding this concept. Whether it is Deming or Juran who is correct on the percentage of problems that should be associated with poor systems or blamed on employees at 85/15 or 95/5 is a moot point. In a given injection molding facility, experience has shown that management has done a lackluster job in controlling variability in the following ways:

- **VISION AND STRATEGIC PLANNING** Most molders have a difficult time maintaining the status quo, much less coping with growth. A decision to strive for World Class status requires that a great deal of work be done in addition to continuing to deal with the day-to-day chaos. This requires thorough planning and a commitment to a vision from the top down.
- **FAILURE TO PROPERLY USE SPC TECHNIQUES** The "vision" that SPC will be a good thing is usually not adopted until one of two things happens: 1) the organization nearly goes bankrupt, or 2) a major customer tells them they had better, or they will buy their parts from someone who does use SPC. Most molders who are using SPC are only doing it to satisfy customer demands, or to use their quality department as a marketing tool. Most of those who do variables charting do not react to any condition other than out of specification. Using specification limits as control limits leads to tweaking and only makes things worse. Expecting the quality department to "go start an SPC program" without commitment is doomed to fail.
- **APPRAISAL VS. PREVENTION STRATEGY** The shift from an appraisal quality strategy (inspect quality into a product) to a preventative quality strategy (do it right the first time) rarely happens. This is in large part due to a widely believed fallacy that it would be more trouble and more costly to develop and implement than could ever be justified. This is totally incorrect; preventative strategies lead to lower costs and higher profits. Quality cannot be economically inspected into parts.

- **LOWEST COST AND HIGHEST QUALITY?** Leadership in most organizations do not understand that far from being mutually exclusive, these two concepts have an inverse relationship. In the past, customers had to choose whether they wanted high quality or low cost when selecting a supplier; now they demand both.
- **MAINTENANCE** Most molding operations have in place a variable maintenance schedule based on priority. What this means is that the next thing they fix is the broken thing they need the worst. A worn-out screw, barrel, or check ring will make the idea of consistent part-to-part dimensions a pipe dream. For the technician, it leads to a day-to-day nightmare. The same holds true for marginally functional dryers, die heaters, grinders and autoloaders. Machines that get the oil filtered and changed on a routine basis are the exception, rather than the rule, although machine life and uptime are dramatically enhanced by preventative maintenance.
- **ROOT CAUSE ANALYSIS** Have you ever seen a situation where a technician drastically changed a heat profile to fix warp when the problem actually turned out to be a broken thermolator? How about changing injection speeds and pressures to correct burns when the vent in the tool was plugged? Or, processing out flash that was actually due to tool damage? These process changes occur because it is not an expectation to look for the root cause, very likely because the benefits of doing so are either not recognized or communicated.
- **TRAINING** Good processors, set-up techs, operators and inspectors are not born. It takes much more skill and knowledge of a process to find the root cause for a problem than it does to twist a knob to Band-Aid it temporarily.
- **STAFFING** The most obvious variable cost in a molding operation is labor. Management too often tries to control costs by compromising adequate staffing. The use of SPC has led to the need for less labor in the long-term. Implementing SPC techniques is difficult if there are not enough operators to attend gates, set-up technicians to bolt up tools, processors to start up machines, or inspectors to measure parts. The first position that usually gets cut back is maintenance, which only serves to compound problems.

In conclusion, I hope it has become obvious to the leaders of typical molding operations that technicians are doing the best job they can with what is available within their span of control. Commitment has to start at the top; without it, any effort to implement SQC will fail. The focus must change to managing for long-term success instead of being sucked into fighting the day-to-day fires. There is a path out of the forest, but strategic plans to attain a vision must guide the way instead of running around in circles.

I am convinced that the only way that molders are going to remain competitive both domestically and globally is through a demonstrated total commitment to quality. This commitment must be demonstrated by implementing the appropriate systems based remedies to the aforementioned symptoms. SPC how-to information is available everywhere you look. Major users of plastic products do not hope they get both high quality and low cost parts from molders any longer, they are demanding both. Molders who have not adopted a preventive quality strategy would be well-advised to start looking at the concept very closely if they want to remain competitive in the precision molded plastic parts marketplace.

Chapter 2

PREVENTATIVE MAINTENANCE

("Fix it before it breaks.")

Prevent 1. To keep from happening; avert. 2. To anticipate or encounter in advance.

Maintenance 1. The work of keeping something in proper condition.

The mantra of many production personnel is the phrase "if it ain't broke don't fix it." That viewpoint has cost injection molding operations untold profits in unnecessary downtime, lost machine capacity, poor yields, poor part-to-part quality, and unnecessary adjustments and baby-sitting of presses by processing technicians. One of the cornerstones of a quality operation is an effective maintenance program that seeks to control the variability arising from machines and auxiliary equipment.

Virtually every piece of equipment manufactured in modern day society comes with a manual that outlines a preventative maintenance schedule. Following that schedule will both keep it from breaking down when you most need it as well as to dramatically extend its functional life. Most molding operations, however, have a "variable" maintenance schedule; I define this as being the next thing fixed is whatever broken equipment is needed worst. This Fred Flintstone philosophy to maintaining equipment that can easily cost tens of thousand of dollars would be ridiculous if the costs of quality were known.

When implementing an SPC preventative quality philosophy in an organization, the first baseline that must be established is the integrity of machines and auxiliary equipment. Everyone always wants to blame materials, measurements or processing technicians for their day-to-day chaos, when poorly maintained equipment is often the real culprit.

The problem with implementing control charts on poorly maintained equipment is that the variability inherent to the process is so vast that it makes the determination of root cause very difficult. Root cause analysis will drive machine repairs until the machines are made capable anyway. Experience has shown that the molder will be much better off to make the investment and bring all of the auxiliary equipment and molding machines (including the screw, barrel and check ring) up to recommended specifications at the beginning of the program than to try and catch up as they go.

Poorly maintained equipment manifests itself in many ways:

- A worn out check ring that will not hold a cushion, perhaps worn to the point where the check ring is about to slide over the screw tip.
- Excessively worn screws or barrels that cause huge variations in melt temperature and shot-to-shot material viscosity levels. Typical maximum recommended specifications for the gap between the screw flights and the barrel are in the 0.015" range; I have seen examples of molders operating with the gap worn to 0.060" on a side.
- Dull grinder blades that lead to high percentages of fines (which melt much faster) in regrind and turn up as black specks in the finished product.
- Worn hydraulics that cannot deliver consistent pressures.
- Contaminated oil that wears hydraulics and servovalves at a very fast rate, and has much different properties than were intended by the manufacturer.
- Machines leaking oil, directly impacting injection pressure.
- Temperature controllers that may actually deliver much more or less heat than displayed due to a lack of calibration.

- Tie bar stretch, unleveled machines, or platens out of square making accurate clamping of tools an unreliable concept.
- A drier with a failed desiccant, leading to drying material with hot air only.
- Proportional loaders that are not calibrated, and the percentages of regrind and virgin material that are in the hopper is anybody's guess.
- Plugged filters or malfunctioning thermolators causing warp.

The list could go on and on. How does this ever become a problem? One scenario is a molder that starts an operation with new machines and brand new auxiliary equipment. They do not bring in anybody for maintenance until 3-4 years later when their equipment is breaking down. By this time, catching up on preventative maintenance is a fantasy, because it is going to take a year to fix everything that is broken.

Another frequently seen situation is when cash flows become lean. When costs are looked at under a microscope, the first place many molders cut back on is preventative maintenance. This short-term thinking is rationalized by believing that the cutback is a temporary situation, when in reality the maintenance personnel are often never replaced. Operations thinking that a press 3 years old could not possibly be exhibiting wear are sadly mistaken. Operations that have let maintenance get away from them must bite the bullet and pay the additional overtime or hire the necessary personnel to catch it back up. The price of not doing so far outweighs the costs of doing things right.

Above all else, it never ceases to amaze me that maintenance supervisors are often the hardest to convince that a preventative maintenance program is a good thing. One would think that they would see the value in such a program, since they are often under the gun to fix things fast. I am not sure where they get the perception that oil does not need to be changed in molding machines more often than every 3 years, but believe me, most of them do not see any value in keeping up the machines to the prescribed schedule. If they do not advocate changing oil (or even testing it) any more often than that, how do you suppose they feel about keeping up annual maintenance schedules such as tie bar stretch or platen squareness?

In conclusion, expectations need to be put in place that the main role of maintenance people is to keep stuff from breaking down, as opposed to scurrying around and looking like a hero when they fix something to get production back up and running. Management needs to put into place a maintenance program that sets aside enough machine downtime for maintenance to take place. Management also needs to rewards consistent pm's instead of heroics. The short-term profits that a molding operation may enjoy by short staffing maintenance and avoiding periodic maintenance schedules will come back to haunt them at an exponential rate. The costs of inadequate machine and auxiliary equipment manifests itself in many ways, such as: poor yields, machine breakdowns, excessive variability, poor morale, overtime, and lost machine capacity. As an old advertising campaign for changing the oil filters in your car put it, "you can pay me now, or you can pay me later."

Chapter 3

QUALITY MEASUREMENT DATA

(Establishing the Second Baseline)

Quality 2 a : A degree of excellence.

Measurement: 1 : The act or process of measuring. 2: a figure, extent or amount obtained by measuring.

The first baseline that must be established in the implementation of SQC is a degree of confidence in machine capabilities as outlined in the preceding chapter. The second baseline is the integrity of measurements that are going to be used for capability study information and placed on the variable control charts. Quality managers are often aghast when I tell them that their inspectors are going to be expected to tell processors when processes start to run out of control. They feel that way because they do not have enough faith in the accuracy of their measurements to attempt to run to control limits, as opposed to telling processors when they are outside specification limits.

Production and quality departments in most molding operations (and most manufacturing operations in general) have an adversarial relationship. Much of this is due to the message that quality departments usually bring; parts are out of specification, and we require immediate attention. The natural inclination here is to kill the messenger. When parts are running out of specification, everyone associates those parts with the processors' skill; immediate reaction is necessary to resolve the problem. The processor then "tweaks" the machine so that it makes good parts while inspectors are sorting out the bad parts.

When the implementation of SQC starts to take root, processors begin to associate inspectors with something other than bad news. The news is not so bad because they had been running within control limits (which are hopefully well within the spec. limits), and the processor has some time to investigate the problem if the process suddenly goes out-of-control. If they have confidence in the integrity of the measurement data, they will understand that something has changed, and will attempt to isolate the problem for root cause.

Historically, processors have not trusted the measurements that quality departments present to them. All too often, they can remeasure the parts themselves and come up with a measurement that is within the specification limits. Processors then begin to discredit most of the information that comes out of the quality department, and the quality people become defensive about everything they say. Inevitably, quality people become second-class citizens on the molding floor, and are really only there because the customers insist that they have a quality control "program."

The implementation of SQC requires that everyone do their job appropriately. Processors are expected to stop tampering with processes and investigate problems for root cause instead of processing them out. If they are going to pull that off, they are dependent on: the toolmakers to build, repair and maintain the tools, the material handlers to mix and dry materials correctly, maintenance to take good care of all the machines and equipment, operators to let them know if anything out of the ordinary is going on, and the quality department to present them with data they can trust.

Quality personnel are often promoted from the operator ranks to the inspector level. How much training they receive after they are made an inspector is anybody's guess, but it is safe to assume that most do not start work as an operator with a great deal of metrology experience. The need for an effective training program for inspectors seems intuitive, but is in practice rarely well thought-out and implemented.

A good quality plan is the cornerstone to quality measurements, but one would be amazed at the lack of detail that is available to many of the people that are supposed to be doing the measurements. The quality plan should have the same level of document control placed on it as the actual part print is subjected to. Here is a sampling of what I have seen due to poorly communicated, documented and controlled quality plans:

- Inspectors using different tools to take the same measurement (calipers, micrometers, CMM, height gage, etc.).
- Some inspectors using fixtures, others not aware that they exist.
- Some inspectors measuring parts in inches, others in millimeters.
- Molders throwing away "out-of-specification" parts that were measured with poor fixtures, that actually turned out to be within specification.
- The use of measurement tools that have not been calibrated.
- Checking dimensions to spec. using the wrong print revision.
- One inspector measuring + draft, others measuring - draft.
- Shipping parts with black specks on cosmetic parts, or throwing away parts for black specks on non-cosmetic parts.
- Pulling tools out of production and throwing away parts for flash that was within specification.
- Incorrect subgrouping sizes and frequencies.
- Some inspectors cooling parts in the lab, others on the floor.
- Some inspectors letting parts cool for 1/2 hour, others for 2 hours.
- Measurement techniques that turn out to be neither repeatable (a measure of how much variability exists in one person taking measurements on the same parts) nor reproducible (a measure of how much variability exists between different people measuring the same parts).
- Repeating the same mistakes time after time because past problems are not communicated.

The list goes on and on; I am sure you have your own horror stories to add to the list. The point I am trying to make is that discipline needs to be applied to quality departments as well. When we kick off a Pilot Program for the implementation of SQC on a limited number of parts, I usually suggest that a Gauge R&R be conducted on all parts utilizing a fixture, or on any parts where measurement integrity is not absolutely assured. Gauge R&R refers to Repeatability (one operator measuring parts the same each time) and Reproducibility (different operators measuring the same parts the same). Most quality managers are familiar with the term Gauge R&R, but do not routinely practice them.

Information on Gage R&R's is plentiful, but Gail Stout, the Senior Editor of Quality wrote an excellent article on the topic in the September 1994 issue of the magazine. In it, he suggests that Gage R&R's should be conducted for all measurement processes, with investigation into poor results for root cause. Dr. Don Wheeler, from Statistical Process Controls, Inc. in Knoxville, TN presented "Problems with Gauge R&R Studies" to 46th Annual Quality Congress for the ASQC in 1992; that document provides additional insight into the topic.

Another key consideration in the measurement data for variable control charts is in the selection of the control dimension. Quality departments in molding operations can become resistant to control charting due to poor selection of control dimensions by their customers. Charting of unchanging dimensions with Cpk's of 6.0, 8.0, 10.0 and higher have been observed, but the charts serve absolutely no purpose since they do not represent process variability. Quality departments can also become resistant to charting because the customer refuses to make the necessary investments to fix fundamental tool problems, but that is another topic altogether. Complaining about these situations serves little purpose without data to support the argument or presentation of alternatives. Quality departments should be aggressive in identifying process capability and also the optimum control dimension through data collection and experimentation.

Most part prints come complete with identification of dimensions that are deemed critical, functional, and control. Control dimensions are typically used by molders for variable control charts, without discussion as to whether the dimension(s) are actually representative of process variation. Ideally, molders would be able to correlate part measurements to arrive at an optimum control dimension. In this ideal situation, the control dimension would be an accurate "voice of the process" and reflect process variation, as well as to move up and down in conjunction with the functional and critical dimensions. In actual practice, most molders take measurements of the control dimensions that are called out on the print without visibility as to whether they are representative of anything. It serves little purpose to chart a dimension with a Cpk of 12.0 that never goes out of control while critical and functional dimensions exhibit much lower Cpk's and vary wildly.

In conclusion, using statistics to monitor processes is all about measuring the correct things at the correct frequencies with the correct techniques; it is not about overinspecting, measuring unrepresentative dimensions, or charting just to show the customer some charts. A molder that takes ownership of the part quality and the successful implementation of SQC will try to measure the *exact* number of parts necessary to provide 100% good product.

Chapter 4

PROCESS ENGINEERING AND CONTROL

(Operational Discipline and Plastic DO Mix)

Process: 2 b : a continuous operation or treatment, especially in manufacture.

Engineering: 2b: the design and manufacture of complex products.

Process Engineering and control is the third baseline that needs to be established before the implementation of SQC has even a moderate chance of success, after baselines for preventative maintenance and quality measurement data have been resolved.. This chapter will describe the level of operational discipline that needs to be achieved to succeed.

Poorly engineered processes are commonplace in the industry, but we will come back to that later. A master set-up sheet of what process is being used to manufacture parts in many operations is usually either poorly communicated or it does not exist at all. I have witnessed operations where there were 5 to 10 set-up sheets present at the press, but an audit of the actual machine parameter settings did not match any of them. I have also audited operations where there was not a set-up sheet anywhere to be found. How in the world anybody expects to get consistent parts out of such a practice defies me, but I have seen it so often that I am no longer amazed by the reality.

Processors usually express disbelief when I tell them the expectation is that **all** of the machine settings will 100% match the master set-up sheet, and that every machine parameter needs to be documented on the sheet. I get all kinds of flack about it until I question them on what effect missing machine parameters can have upon part geometry. Does it matter whether:

- Back pressure is set at 50 psi. or 150 psi.?
- Screw speed is 33% or 80%?
- Transfer positions are a little bit different?
- Clamp-half parameters are not the same as the previous set-up?

Of course it matters, and yet I have audited many operations that only list a few key machine parameters.

I have also audited molders that only require that processors record changes to key parameters outside some arbitrarily set range; often 10 percent. Typically, injection pressures, back pressure, die heats, melt profiles, and injection speed are all that most people consider "key parameters", and are the only parameters that get any kind of attention. This is not a recommended practice either, for a variety of reasons. The biggest concern with this approach is that even varying within the 10% range can have huge impacts on part geometry and process control. Another main concern is that the 10% is not usually communicated as being total range (plus or minus 5% of the setpoint) or plus or minus 10% of the setpoint (20% total range). And of course, the parameters that do not get attention can have major ramification on process control.

Any experienced processor will tell you that there are countless ways to mold the same part and have it look the same. I agree wholeheartedly with that statement, but would add one caveat; there is only one **best** way to mold the same part to attain the optimum dimensions and process stability. If every processor molds the part with their idea of the best process, the customer eventually becomes disenchanted with the quality and consistency of the product.

In the initial stages of implementing SQC in a molder, I receive a great deal of feedback as to the supposed effect of the change. Things like "why should we have to write that down, this parameter has little effect on the part", or "changing this parameter 1% will not change anything" are commonplace. My response to those comments is to state that any change is significant, because if it had no effect, why change it in the first place?

Expectations need to be put in place that demand that **all** machine parameters be listed on the master set-up sheet and that any deviations from the master be listed on a process change log. Process changes should be reviewed daily by a process engineer to determine whether the change: a) appropriately addressed root cause, b) should be considered a temporary or permanent change, or c) was even remotely along the right thing to do. I have seen situations where one processor changes one parameter to get rid of flash or sink, while another processor changes 10 machine parameters. I have also seen processors do exactly the wrong thing, like turn up injection pressures to overcome sticking parts, changing die heaters temperatures the wrong direction to compensate for warp, and turn injection speed up to try and get rid of splay . If processors are never writing down what they do, training opportunities will be missed. Permanent changes need to be submitted to document control and a revision added.

Document control over the master set-up is another main factor in attaining a reasonable degree of operational discipline. Once a master set-up sheet has been established to an engineered process, it needs to be controlled. This seems intuitively obvious, but is rarely practiced. If master set-ups are not typed, processors just fill out a new set-up when they make changes, making the reason for the change invisible. If hard copies of the masters are not kept on file, many machines come equipped with software that allows molders to save the current set-up when they shut the machine down, complete with any changes that have been made to the process. The problem with this situation in most operations is that nobody reviews the changes to ensure that they appropriately addressed root cause; the technician processes out the problem and saves it as the new set-up. Another frequently seen scenario is the expectation that set-up sheets are for "reference only". This is giving the green light for anybody to make any change.

What follows is a list of expectations that I advocate for process control:

- **Optimizing the process through windowing studies and DOE's and generating a permanent master set-up sheet**. This master set-up sheet should satisfy the following criteria:
    - It should be typed, so people can't change it all of the time.
    - It should be approved by a central source, such as a Process Engineer.
    - It must include every machine parameter, including the clamp half.
    - It should include a revision block, so that when the process is permanently changed, people can look back into the reason why.
- **Establishing a process change log**. It should include the date, time, technician, the problem, the root cause and any process changes that occurred. Trying to investigate an out-of-control process without a history of process changes becomes very difficult; odds are that control charting will fail without this insight into what is going on out on the floor. Management will need to audit this area themselves, because I guarantee you that processors will not want to write down the changes they make.
- **Enforce a philosophy of looking for the root cause instead of processing out problems**. This is a major paradigm shift for processors. They are used to doing what they want when they want without anyone questioning their decision-making process. Continually processing out problems is a sure-fire way to ensure that chronic problems are never solved. This topic is covered in depth in chapter 8.
- **Developing a master run sheet for each tool/press combination**. Tools run differently in every machine; they cannot be scheduled by press range. The expectations may be different if a particular mold were going to be run in one of three machines that were purchased at the same time and three identical tools. This is rarely the case however;

molders usually want the latitude of scheduling any job in any one of the machines they have in the appropriate range, all of which may be different tonnages with wide variance in vintage and capability.

- **Communicating when process changes are allowed**. Changes should only be acceptable if they are in response to SQC data.
- **Developing a process for responding to out of control points on both variable and attribute charts**. This includes writing down the response on the control chart in a timely manner. It also includes buy-in from every area; you must be prepared to pull a tool and get it fixed instead of expecting a technician to process out major flash for example. Buy-in is required from Quality, Processing, Engineering, Tooling, Materials, Management, Production, and anyone else touched by the implementation of SQC.

Once the appropriate level of control is maintained over processes, the molder can focus on optimizing individual processes. This is similar to ISO expectations; you have to write down what it is you do and get everybody consistently practicing that method before you can expect change to be effectively implemented. The implementation of master set-up sheets, process change logs, tracking by tool/press combination, variable and attribute charts, and everything else associated with a functioning SQC system will provide you with permanent solutions to chronic problems originating from every area of the company if the focus is on correcting the system and finding and eliminating root cause instead of blaming poor workmanship or people for problems.

Here is a sampling of the chronic process-related problems alone that I have seen technicians try to process out that were eventually resolved:

- Poor purging procedures that continually cause contamination.
- Insufficient hold time where gates are not freezing off before pressure is released, leading to dimensional instability.
- Insufficient injection speed, which can lead to major variability being introduced to the part for small changes in material viscosity.

- Poorly balanced tools.
- Set-up technicians with 2 months experience being allowed to change processes.
- Inadequate gating.
- Inadequate ejection.
- Inconsistent set-ups, e.g.; quick disconnects, water lines, die heaters.
- Poor transfer times or positions, where the part is being packed with fill pressure or filled with pack pressure.
- Insufficient cooling times leading to warp.
- Poor control over regrind; material handlers not mixing it correctly, excessive amounts of fines or large pieces of runners and sprues, material fused together, etc.

There could be entire sections dedicated to the root causes found that originated from metrology practices (poor measurement techniques), cosmetic specification interpretation (throwing away good parts), machine maintenance (worn out screws, barrels and checkrings), toolrooms (insufficient tool TD&C's or in-press cleanings) and other areas as well.

The point of this chapter was to point out the benefits of applying a much higher level of operational discipline on the processing side of the molding operation. Processors will resist writing down changes they make and looking for root cause unless management makes the benefits of doing so known, and sets forth some very clear expectations. Processors will continue to resist this philosophy until their jobs become easier; if everyone participates, everybody's' job will become easier.

Chapter 5

VARIABLE AND ATTRIBUTE CHARTS

(Basic Rules and Avoiding Common Pitfalls)

Variable: 1. a quantity that may assume any one of a set of values.

Attribute: 1: an inherent characteristic.

Whenever I audit a company that is electronically preparing their variable control charts, I recall the words of Dr. Donald Wheeler, a noted SPC guru utilizing the concepts developed by Dr. Shewhart and Dr. Deming. According to Dr. Wheeler, "using a computer to generate a control chart is like driving to your neighbors house. It's probably a lot quicker to walk". About 90% of the value of variable and attribute charts is in the power of the graphs, so burying the data in the bowels of a computer in the quality lab never makes much sense to me. The purpose of this article is to define the purpose of control charts and the benefits of using them for molding operations, not to go over the mathematics and statistics that are associated with the charts.

To differentiate the purpose for charting variables from charting attributes can be a challenge to those not familiar with the terminology. Simply put, variable charts are for dimensions, attribute charts for defects; both are used for process control. Molders need to use both, because they serve different purposes. I have seen plenty of examples where a part will go out of control for shorts or flash on the attribute chart, but the process control dimension will stay within control. Conversely, it is not unusual for a part to exhibit excessive dimensional variability with no accompanying cosmetic problem.

Attribute charts can have a huge impact on a molding operation for minimal cost. Most molders do not think they have an internal yields problem until the defects are plotted on a chart. When the management can look at the chart (instead of a bunch of numbers) and see that a process went out of control at 5:00 p.m. and continued to run 50 to 90% defective parts until 7:00 a.m. the next morning, they begin to understand that perhaps they do have a problem.

One problem is the decision to throw away all of those parts or to rework them. Another problem is in regards to the lost machine capacity. Another problem is in material inventory. Scheduling overtime to fill the order is a problem, as is the fact that another customers order is now going to be late since the tool cannot be put in the press until the current (late) order is completed. I am sure you can think of quite a few additional problems associated with this kind of quality. Worse yet, the customer will probably have a problem, because the likelihood of all of those bad parts being caught in-process is pretty low. If the customer has too many problems you can rest assured that you will free up some capacity when they move their tools to another molder.

Variable charts are powerful for the way they graphically display process control. In response to the following data, (which I dry-labbed) can you tell me if it was in control? Can you tell what is happening over time? Can you tell me anything at all about the data, other than whether or not the individual parts were in specification?

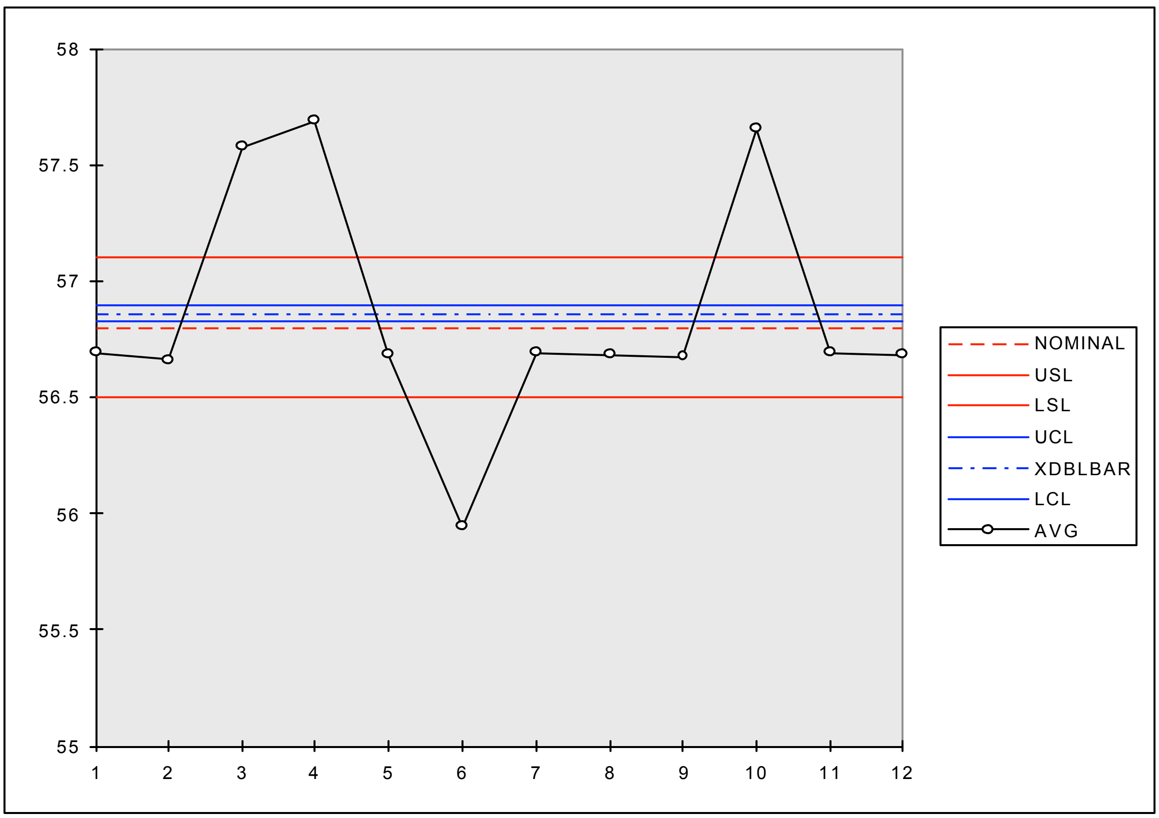
DATE	TIME	INSP.	Part 1	Part #2	Part #3	Part #4	Part #5
7/28	10:00a	J.J.	56.70	56.69	56.69	56.67	56.69
7/28	2:05p	J.J.	56.68	56.63	56.68	56.66	56.67
7/28	4:25p	L.T	57.43	57.65	57.66	57.52	57.63
7/28	9:40p	L.T	57.70	57.79	57.59	57.67	57.69
7/29	1:10a	S.W.	56.68	56.68	56.68	56.68	56.68
7/29	9:30a	P.T	55.96	55.95	55.96	55.92	55.93

7/29	9:40p	J.G	56.70	56.69	56.69	56.67	56.69
8/1	10:30a	J.J	56.68	56.63	56.68	56.66	56.67
8/1	2:30p	J.J	56.66	56.69	56.70	56.66	56.67
8/2	6:25p	L.T	57.66	57.75	57.72	57.62	57.53
8/2	9:00p	J.G	56.70	56.69	56.69	56.67	56.69
8/3	5:00a	S.W	56.68	56.68	56.68	56.68	56.68

If this data were part of a control chart we could understand a great deal about the measurement technique alone by using the chart as a tool such as:

- Measurement frequency is haphazardly followed.
- Different tools, fixtures or techniques are being used by different inspectors.
- S.W. has a propensity for dry-labbing data, which would show up as a zero range.

I have calculated the control limits from the data in the above table. The following control chart shows the control limits in blue and the spec limits in red. With the data presented graphicaly, you can no doubt immediately deduce that you are looking at suspect data.



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Properly used, the charts can tell you a great deal about the process, namely whether or not it is exhibiting a state of statistical process control. This is difficult to determine when molders are loading data into a computer and only looking at it when they get a call from the customer telling them parts are out of specification. For this reason, I recommend that control charts be placed on the floor at the machine, where the people who need to see the data can have access to it. Just to get people started, I usually suggest subgroups of size 4 or 5 on every cavity to be measured at start-up and every 4 hours thereafter. Frequency and the number of cavities to be charted can be altered when the molder has confidence in the measure of control they have over the process.

The control limits on the variable control charts are frequently misinterpreted as being specification limits. It is important to point out to people on the floor that control limits really bear no relevance on what the specification for that dimension is; one hopes that the control limits are well within the specification limits. Anyway, the point is to communicate to people that the control limits are in effect the "voice of the process" and the process itself dictates where the control limits will fall. Anything outside the control limits (or associated trends and runs) should be reacted to, since something has changed. This holds true regardless of the width of the control limits.

When implementing variable charts in a molder, I always get a great deal of feedback as to this topic. People say things like "the point it is only 0.04mm outside the control limit, and we have a spec of +/- 0.1mm, how can we expect our processors to react to that? Another one I often hear is "most of our variation is due to material viscosity changes when we get new lots of material". My favorite though, is "the control limits are too tight!" These are troublesome comments if they come from the management of the operation responsible for implementation of the charts.

More sophisticated molders may make an attempt to tie a decision on whether or not to react to an out of control process to what kind of Cpk it is generating. This is not a prescribed method either, since the focus of implementing SQC and becoming "World Class" should be on continual improvement, not on meeting some arbitrarily set Cpk value. Besides that philosophical issue, it is important to note that the Cpk value only applies to the dimension being measured, not to the entire part and all of its associated critical and functional dimensions. Cpk can be a highly relevant index in tool qualification and aiding in the selection of process control dimensions.

The most difficult factor in the implementation of variable and attribute charts in an injection molding operation is the discipline and documentation of reacting to the chart data. Quality departments can refine their measurement technique, streamline their data collection, and maintain measurement frequencies, but it becomes moot if processors do not respond to the data. All out of control indications on the chart should include written responses for the action taken. The expectation is that root cause will be found and controlled. Somebody needs to audit this process; and I suggest that it should be the managers responsible for the implementation. This would raise the visibility of the program, and also give the managers opportunity to find out for themselves if the prescribed procedures are being followed .

In conclusion, my experience has been that companies that truly adopt a preventative SPC based quality philosophy have a relatively easy time implementing control charts. If they grasp the fundamental difference between molding to control limits (with a World Class goal of on target with minimum variation) to molding to specification limits (or goalposts), and the benefits of SPC timeframes for implementation are dramatically shortened. If they are only doing control charting because they have customers that insist on it, or they chart as a marketing tool, the effort takes much longer and is much more difficult. We brought in 3 members from the upper management of every supplier in our base of injection molders to Dr. Wheeler's Understanding SPC at Supplier Day 1995 so they would "get the religion." How well they got it has proven to be variable.

Chapter 6

INVESTIGATING FOR ROOT CAUSE

(Tweaking vs. Thinking)

Root 1. An essential part or element; basic core: *finally got to the root of the problem*.

2. A primary source; origin.

Cause 1. Something that produces and effect, result, or consequence.

An earlier article described the paradigm of convincing technicians that tampering with qualified processes (otherwise known as "tweaking") is almost always the wrong thing to do. We also discussed the fact that the actions of management at most molding operations was consistent with the assertion of quality gurus such as Deming and Juran that management was responsible for the vast majority of quality problems. The leadership in these organizations is responsible because they alone have the authority for systems that are capable of allowing people to produce quality products. In the vein of systems thinking, we talk about preventive vs. appraisal quality philosophies, maintenance, and also root cause analysis, which is the topic of this article.

Selling technicians on the idea that not tweaking processes is a good idea is only part of the equation. You may have succeeded in part by implementing preventative machine maintenance, adequate tool maintenance, decent processing windows, master set-up sheets, variable and attribute control charts, and everything else required to minimize variability. The other half of the battle is giving them another process to use to determine the true root cause of the problem. Also, recognize that technicians will respond to what they are rewarded for: if they are rewarded for just keeping product going out the door, they will continue to process out problems. If they are rewarded for finding root cause and proactively addressing problems, they will strive to change the way they think and operate.

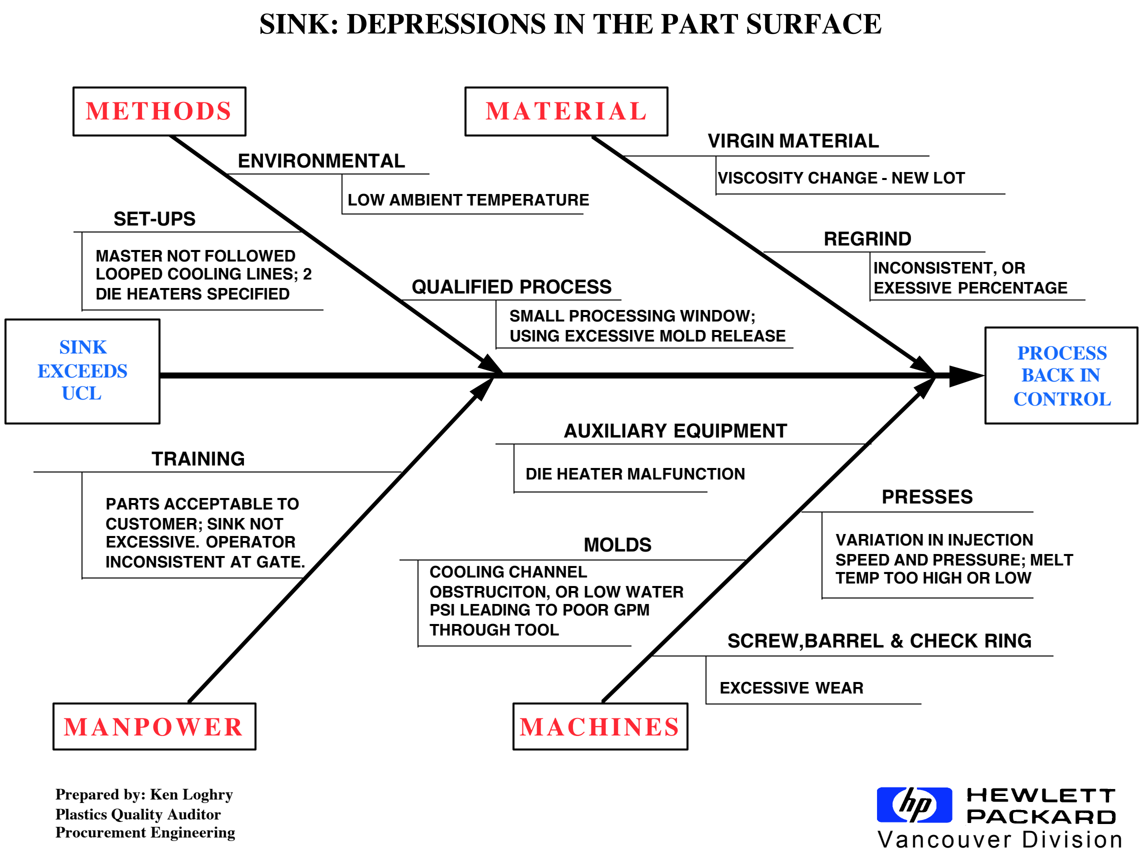
If you tell your technicians that they cannot make changes to a process, what are they going to do if a variable or attribute chart indicates that the process is out-of-control? The realities of a production environment dictate that this will constitute an immediate crisis, since the order is probably already late. The knee-jerk reaction will be to process the problem out, thereby securing the technicians' reputation as a magician.

It requires much more skill and knowledge of the injection molding process to investigate a problem, identify the root cause, and implement a permanent fix instead of turning knobs and adjusting the process until it (temporarily) goes away. The success of this type of approach to problem solving is dependent on the assumption that the following systems and procedures already exist:

- Variable and attribute charts are being properly used to control processes.
- A robust processing window has been established with a controlled master set-up sheet; masters should exist for every tool/press combination.
- Variability arising from poor machine maintenance has been controlled. Machines, auxiliary equipment, screws, barrels, check rings and tools are all in good condition.
- A log exists to record any and all process changes with an explanation for why the change was made.
- The measurement technique provides reliable data.
- A well defined procedure for how out-of-control signals will be dealt with is understood by all personnel.

Training for processing technicians on root cause analysis must be an ongoing commitment; constant follow-up is required to ensure that technicians are doing the right thing. This root cause investigation is based on the fishbone diagrams that Ishakawa developed for cause & effect investigations. We base the investigation on a search for change in one of the 4M's: 1) Manpower, 2) Machines, 3) Methods, and 4) Materials. I have heard variations of these categories to include 5) Mold and 6) Environment, so that it becomes an investigation on 5M's and E. The categories are not nearly as important as an understanding of the philosophy.

You can put together your own fishbone diagrams that break down the major categories for each potential out-of-control situation. These include: dimensions outside the control limits on XbarR charts, as well as for each attribute (e.g., flash, shorts, splay, warp, contamination). Here is a sample of a fishbone diagram I prepared for sink:



When sink is encountered in most molding operations, what usually happens is that the technician immediately goes about processing it out. This can be accomplished in many ways, but the typical knee-jerk reaction (tweaking instead of thinking) is to increase any or all of the following parameters: injection pressure or velocity, pack pressure, or the shot size. Other ideas may be to change the transfer position, increase the heat profile on the barrel, or to increase the steel temperature.

Whatever the actual combination, the technician will continue to turn knobs until the problem goes away. Experience has shown that the technician on the next shift often encounters flash or parts that exceed specification as a result of those changes . He then immediately goes about processing that problem out; those process changes may then eventually cause sink once again or short shots for the next technician, who is called to fight that fire. This vicious cycle repeats itself countless times, when the root cause may have been excessive wear on the check ring, a material lot change, or a die heater that is malfunctioning.

Extrapolate this scenario across every process in your plant, and it is no wonder that technicians are often thin fellows with thinning hair who always have a harried look on their face. The root cause of their appearance is that they are running their tail ends off with their hair on fire trying to deal with all of these problems each and every day. The table on the following page includes more examples of this “tweaking vs. thinking” concept. It is not meant to be a definitive list, but rather an illustration of the idea.

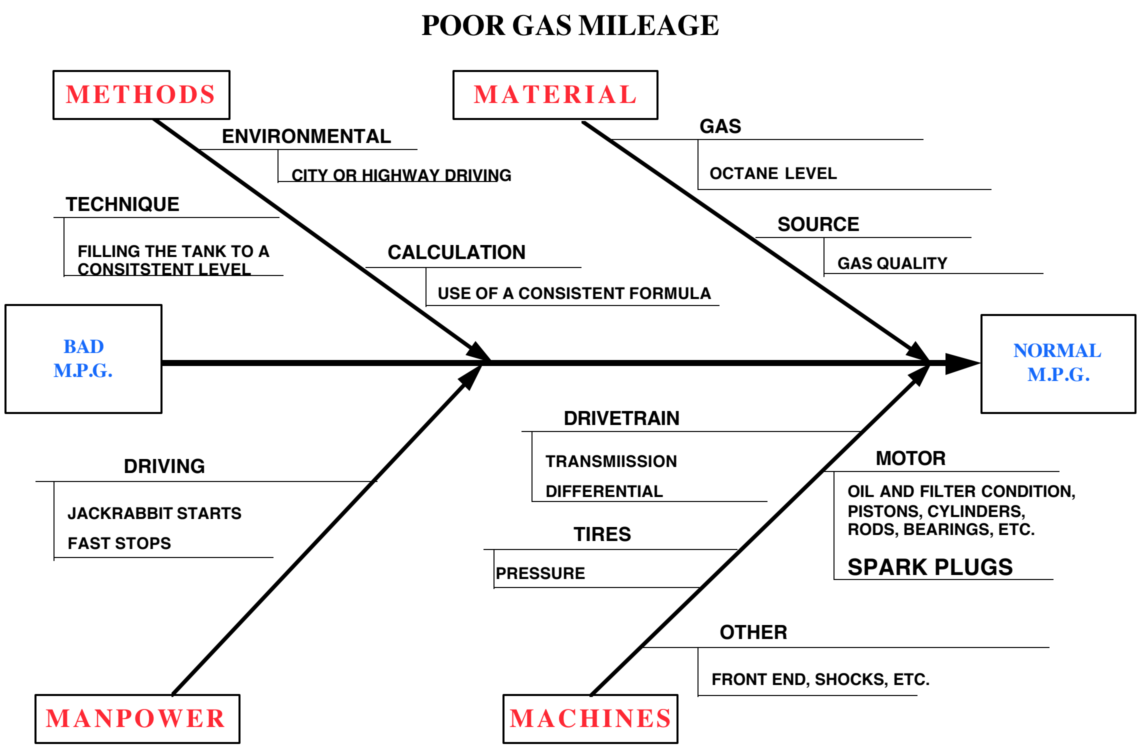
ADJUSTING QUALIFIED PROCESSES AS OPPOSED TO CONDUCTING 4M'S ROOT CAUSE ANALYSIS FOR OUT OF CONTROL SQC CHARTS

PROBLEM	TWEAKING RESPONSE	ACTUAL ROOT CAUSE
SMALL DIMENSION	• Turn up injection pressure • Increase shot size.	• Blown heater band, material processed too cold. • Material lot change.
BURNS	• Decrease velocity • Change staging	• Plugged vent • Material is too hot; heater band out of calibration.
SPLAY	• Reduce injection velocity Increase injection pressure	• Drier turned off/broken. • Hopper got too low before filling.
WARP	• Adjust the heat profile • Turn die heaters up or down.	• Broken die heater/plugged filter. • Water channel plugged in tool. • Melt temperature too low.
DROOL	• Turn down nozzle heats • Switch to variac	• Wrong nozzle • Set-up sheet not followed; nozzle hot
FLASH	• Decrease injection pressure. • Change staging • Reduce shot size	• Too much regrind • Plugged vents. • Tool damaged by falling sprues/runners
CONTAMINATION	• Turn back pressure down. • Increase plasticate time	• Bad lot of virgin material • Contaminated regrind; uncovered sprues and runners, or operator is regrinding contaminated parts.
LARGE DIMENSION	• Turn down injection pressure. • Decrease shot size.	• Part loaded in fixture incorrectly • Parts not cooled sufficiently.
SHORT SHOT	• Crank up injection pressure • Increase shot size • Increase melt temperature.	• Normal; attribute chart in control • Machine too small (shot size) • Screw and barrel wear
BLACK SPECKS	• Turn down heat profile • Turn down back pressure • Reduce injection velocity	• Dirty screw and barrel. • Contaminated regrind. • Too many fines in regrind.
BRITTLENESS	• Turn up die heater	• Material too cold; heater band failure. • Too much regrind.
STICKING	• Spray mold release frequently. • Reduce shot size • Decrease injection pressure	• Polish mold surfaces • Sprue bushing and nozzle misaligned. • Sprue bushing needs polished.
DEGRADATION	• Reduce melt temperature	• Heater band thermocouple broken • Too many fines in regrind.
COLD SLUGS	• Increase nozzle temperature	• Incorrect nozzle used.
WELD LINES/ WEAK KNIT LINES	• Increase melt temperature • Increase injection pressure	• Lost cushion • Die heater running cold, or has a plugged filter.
SINK	• Increase injection pressure • Increase melt temperature • Increase injection velocity	• Failed heater band • Check ring wear. • Screw and barrel wear.

Can this philosophy of investigating for root cause be mutually exclusive of the systems and procedures that were earlier described as essential to making it work? Of course it could, to some extent. The question you need to ask yourself is whether or not it would be effective, or if it would stick long-term without a total commitment to a preventative quality philosophy.

I have prepared a fishbone diagram that lists many of the potential root causes for injection molding related problems. I suggest that suppliers use it as a training tool, because the vision for any operation should be that technicians in processing positions should understand the impact of all sources of variability on the process. Deming called this profound knowledge; without a true understanding of the process, it is impossible to thoroughly minimize variability

Most of the learning comes from the preparation of the diagram. If you want your technicians to develop the knowledge of the process , conduct training meetings so that they can put one together. Start with a fishbone for a relatively simple problem not related to molding, so they understand the concept. I often use poor gas mileage, and help walk people through the filling in of the buckets under the major headings. Here is a swag at the variables that can contribute to poor gas mileage:



For the sake of argument, suppose that the root cause investigation revealed that the spark plugs had crud all over them. The natural inclination of most people, had they even reached this stage, would be to assume that they had fixed the problem by either cleaning or replacing the spark plugs. But does this fix properly address root cause? I would argue that there is a reason for the crud on the spark plugs, so the investigation must proceed farther, perhaps resulting in a root cause of bad valves or valve adjustment.

The point here is that you must continually ask the question "why" until you arrive at the true cause. I don't recall where I heard it, but a good example of the concept follows:

A circuit breaker blows on a motor that immediately puts production down in a run that the customer had told you was essential they get on time. Maintenance is called, and they monkey around for a while and finally replace the circuit breaker after they have to work late to run up town to get a replacement. Problem solved. They are heroes.

But wait! The new Operations Manager is well-schooled in SQC techniques. He evaluates the down time and figures out it cost the company $1,500 in lost revenue, based on the opportunity cost of the machine capacity, overtime for the maintenance man, paying an operator to basically do nothing, and all of the paperwork that was filled out. In addition, he knows he may lose the account because the customer's order is going to be late. He actually has the gall to ask ***why*** the circuit breaker went out in the first place.

The maintenance man tells him it must have been a solar flare or something.

Not good enough, says the manager, find out ***why*** it blew.

The maintenance man comes back after investigating the problem, and tells the manager that it turns out that the reason the circuit breaker blew was that the motor overloaded. He suggests getting a new motor.

Why did the motor overload?

Because it was drawing too many amps. I told you we need a new motor.

Why was it drawing too many amps?

Because the shaft was not turning smoothly.

Why was the shaft not turning smoothly?

Because grease had pushed through the seals and the shaft was dry.

Why had grease pushed through the seals?

Because the seals should really have been replaced 2 years ago.

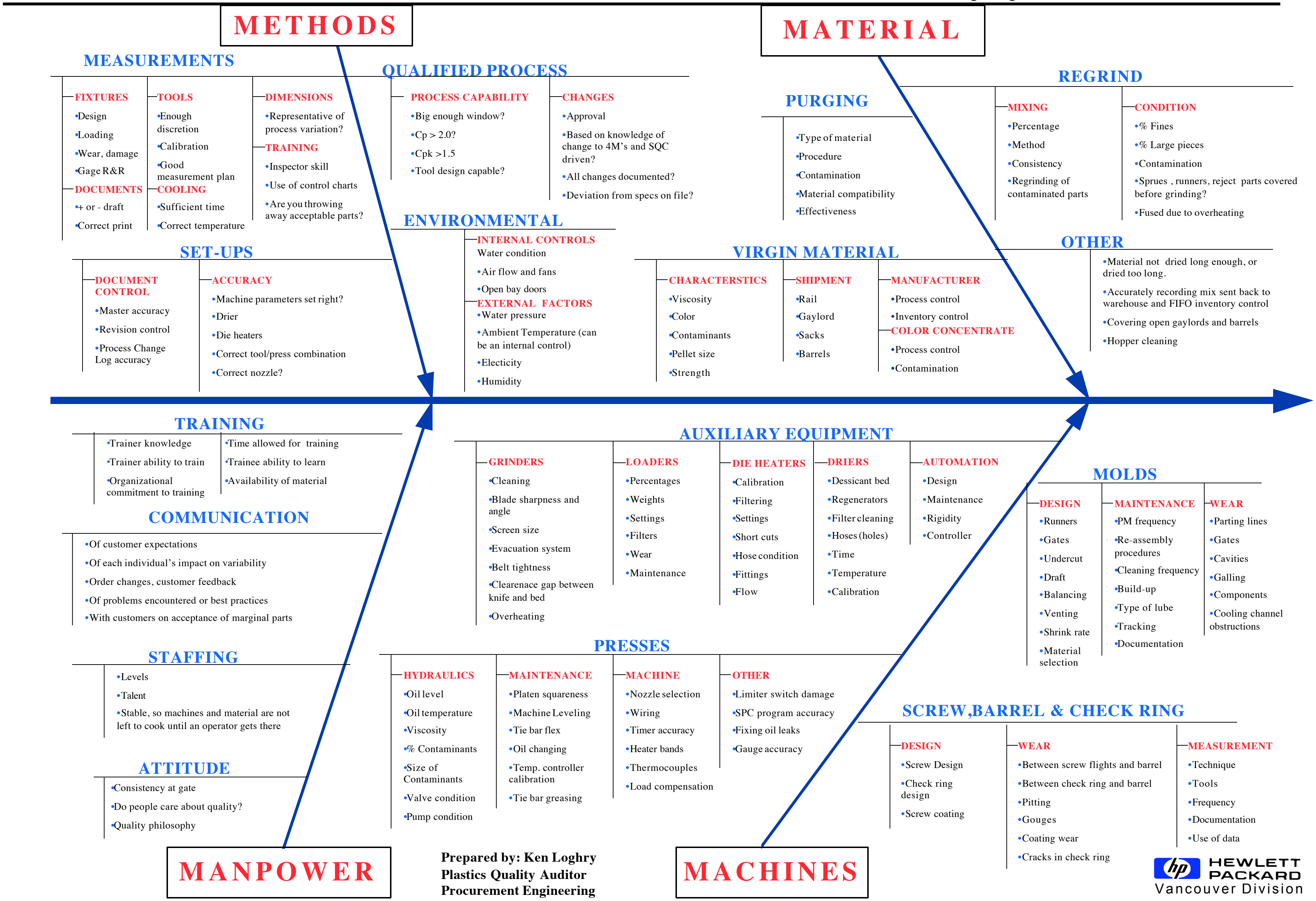
Why weren't the seals replaced 2 years ago?

Because we don't have a PM schedule on this piece of equipment.

Oh.

So you see in this example that the root cause of the downtime was not because the circuit breaker had the audacity to blow, but because the variability from the motor was not controlled to the manufacturer's suggested periodic maintenance schedule. To take that scenario a step further, you could ask the maintenance man what he suspected would happen if we did not immediately put the motor on a PM schedule. No doubt he would say that the circuit breaker would eventually blow again. The situation had probably repeated itself in many situations many times throughout the plant over the years, but the maintenance man always looked like the hero, because he got production going again. This is not a knock on maintenance; there may not have been adequate staffing of the position to do anything but be the hero and fix broken stuff. My opinion is that maintenance people in most molding operations are on what I call a variable maintenance schedule, having earlier defined this as being the next broken thing fixed is whatever broken equipment is needed worst. The point is that his job would be a lot less stressful if he were preventing disaster from happening instead of reacting to it.

The fishbone chart on the following page should help drive home the concept that a much higher level of operational discipline needs to be practiced in most molding operations. The fact that the chart is so detailed (and still incomplete) also gives insight into why molding has long been considered "black magic." If your processors can get to the stage where they understand how all of the sources of variability impact the final product, they have essentially turned an art into a science.



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Chapter 7

Cp and Cpk

(The voice of the process, and the voice of the customer)

<u>Capability</u> 1. The quality or condition of being capable; ability. 2. Potential ability. **<u>Targeting</u>** 1. To aim at or for. 2) To establish as a target or goal.

Like yourselves, I have been through numerous classes on SPC where everybody was expected to memorize formulas, figure out the limits for an XbarR chart, and in the process of doing so, get totally confused calculating Cp and Cpk. Let's ask a reality-based question here. How many of the participants in those classes ever use what they learned about Cp and Cpk, or really understood it in the first place? I don't have any statistics to support it, but my guess is it would be a very small percentage. The point of this article is not to bore you with the statistical calculations for Cp and Cpk, but rather to illustrate the concepts and their importance to molding operations.

I developed the perception that few people understand Cp and Cpk through working with individuals at all levels in molding operations who have been through the classes and know the math, but the instruction was not focused on why the concepts are important. It would be easy to look up the formulas if people understood why they should concern themselves with the numbers at all. Hopefully, this article will help in regard to the latter. I am not going to extrapolate ppm (parts per million) defects data from the process capability indexes for several reasons: 1) because the indexes only apply to the dimensions that were measured to form the data, 2) people develop a false sense of security if Cpk values are high and thus do not want to respond to processes exhibiting a lack of control that have historically run a high Cpk, 3) because focusing on a Cpk number (such as 1.33 or 1.5) as a *goal* runs contradictory to the concept of continual improvement, and 4) ppm data should be generated from actual part performance, not hypothetical models.

My experience has been that people who really know a great deal about this topic do not necessarily run their processes in control, and are often using the index (and their knowledge of it) as a marketing tool. I recently read an article in the July 1995 issue of Plastics Technology where two quality people were arguing whether a Cpk of 2.0 means that 3.4 defects per million are expected, or if it really means that 2 parts per *billion* is the expected defect rate when taken to the 6 sigma magnitude. To take the discussion a step further, some quality professionals focus on the relationship between Cpk and fraction nonconforming. A Cpk of 1.0 is expected to have a fraction nonconforming of 0.13%, while a Cpk of 0.80 is expected to have a fraction nonconforming of 0.82%. Furthermore, a Cpk of 0.6 is expected to have a fraction nonconforming of 3.59%. As you can see, the two have a nonlinear relationship. While this is a great discussion, end-users of plastic parts are typically more concerned with what they are actually getting as opposed to what the Cpk data says they should expect. Another consideration is that Cpk numbers are generated for individual dimensions and disregard attribute related defective product; the molder may be manufacturing dimensionally sound parts, but with warp, flash, splay, contamination, or other cosmetic defects. A more simple estimate of fraction nonconforming can be found by dividing the total number nonconforming found by the total number examined.

Cp - Process Capability Cp is a number generated from part measurements that tells us what the process is capable of producing. Thus, it is the “voice of the process”, since the process is telling us what it can do. Cp can be thought of as the ratio between what the process can do and how wide the specification is. A Cp of 1.0 indicates that the process capability is equal to the tolerance range (or that the 3 sigma control limits are the same width as the specification limits); this is often referred to as a capable process. If the middle of the distribution of part measurements were equal to the nominal specification for that dimension, 99.73% of the parts would be within specification. That is a big "if" though. The distribution of parts could actually fall completely outside of the specification range, and still have a Cp of 1.0. If that is the situation, then (at a minimum) we need to target that distribution of parts better, which in molding usually involves moving steel. We will cover targeting later when we talk about Cpk. If part measurements yield a Cp of 2.0, the process is telling us it is capable of producing parts in one-half of the specification range, or that the width of the specification is twice as wide as our distribution of parts. The only way to improve Cp is to reduce variability.

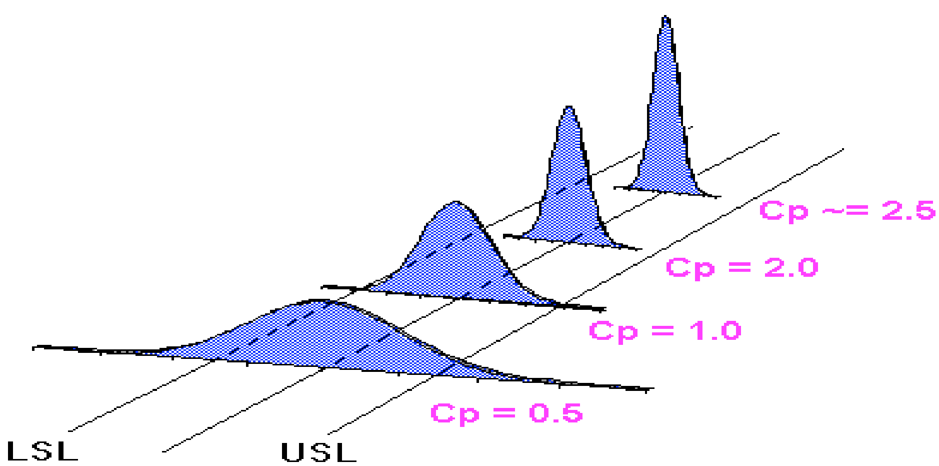
Why should technicians, inspectors, or management for that matter concern themselves with this number? For self-defense, if for no other reason. A frequently seen occurrence on production floors is where the Cp is less than 1.0, say a Cp of 0.8. What this indicates is that no matter what the technician does, all of the parts from that process (or less than 99.73%) cannot be molded in specification, even if the distribution is perfectly centered.

What eventually happens is that parts on the trailing edges of the part distribution get measured, and the inspector tells the technician that parts are bad. The technician turns knobs this way or that until the next measurement yields good parts. Bear in mind several things about that scenario:

- The distribution of parts did not get tighter.
- The distribution is just as wide but may be targeted in a worse spot.
- Bad parts are still being molded.
- Based on the number of parts measured and the frequency, more bad parts may not show up for quite some time. When it is, the fire drill will repeat itself.

- The customer is either calling and complaining all of the time or adding to their cost by doing incoming inspection.
- The technician would have been better off to have done nothing.

Molding to specifications allows this situation to repeat itself time and again. If an XbarR chart were being utilized, the first clue that this was a no-win situation would have been that the control limits were wider than the specification limits. The whole philosophy of a preventative SPC quality philosophy is on continual improvement; on continually striving to make the process more capable. The following graphic was prepared by Valerie Wildman, an Engineer in the Design Margin Team at the Vancouver Division. It illustrates the idea of Cp and continual improvement as well as any I have seen:



Improving Cp, or the capability of the process, is a management responsibility. Reacting to out-of-control signals on control charts is a local responsibility which should be investigated and remedied by production personnel. As stated earlier, there is only one way to improve Cp, and that is to reduce the amount of variability present in the process. Sources of variability remain largely discussed but rarely acted upon: preventative maintenance, material control, establishing and documenting robust processing windows, tool balancing, adequate training programs, and adequate staffing are just a few.

<u>Cpk - Process Targeting</u>

Cpk is a the number that is generated when comparing the width and position of the distribution of parts ("voice of the process") with where the customer tells us he wants them to be through providing specifications ("voice of the customer"). A good working definition of what Cpk indicates is the amount of "elbow room" the process has in relation to the specifications.

Take the earlier example of a process that produces a Cp of 1.0 and the distribution is perfectly centered. In this scenario, the width and position of the parts fall exactly where the customer has told us he wants them to be, through the print specifications (provided they have not added a Cpk expectation of >1.0). The other example involved the same Cp of 1.0, but the distribution was completely outside the specification. In this scenario, the Cpk calculation will generate a negative integer (such as -2.0). A negative number is also generated if the mean of the distribution is outside the spec., but part of the distribution is still within spec. (-0.5 for example). The only remaining scenario for a given Cp is one in which it the distribution is targeted such that a portion of the parts are outside the specification. This will generate a Cpk of less than 1.

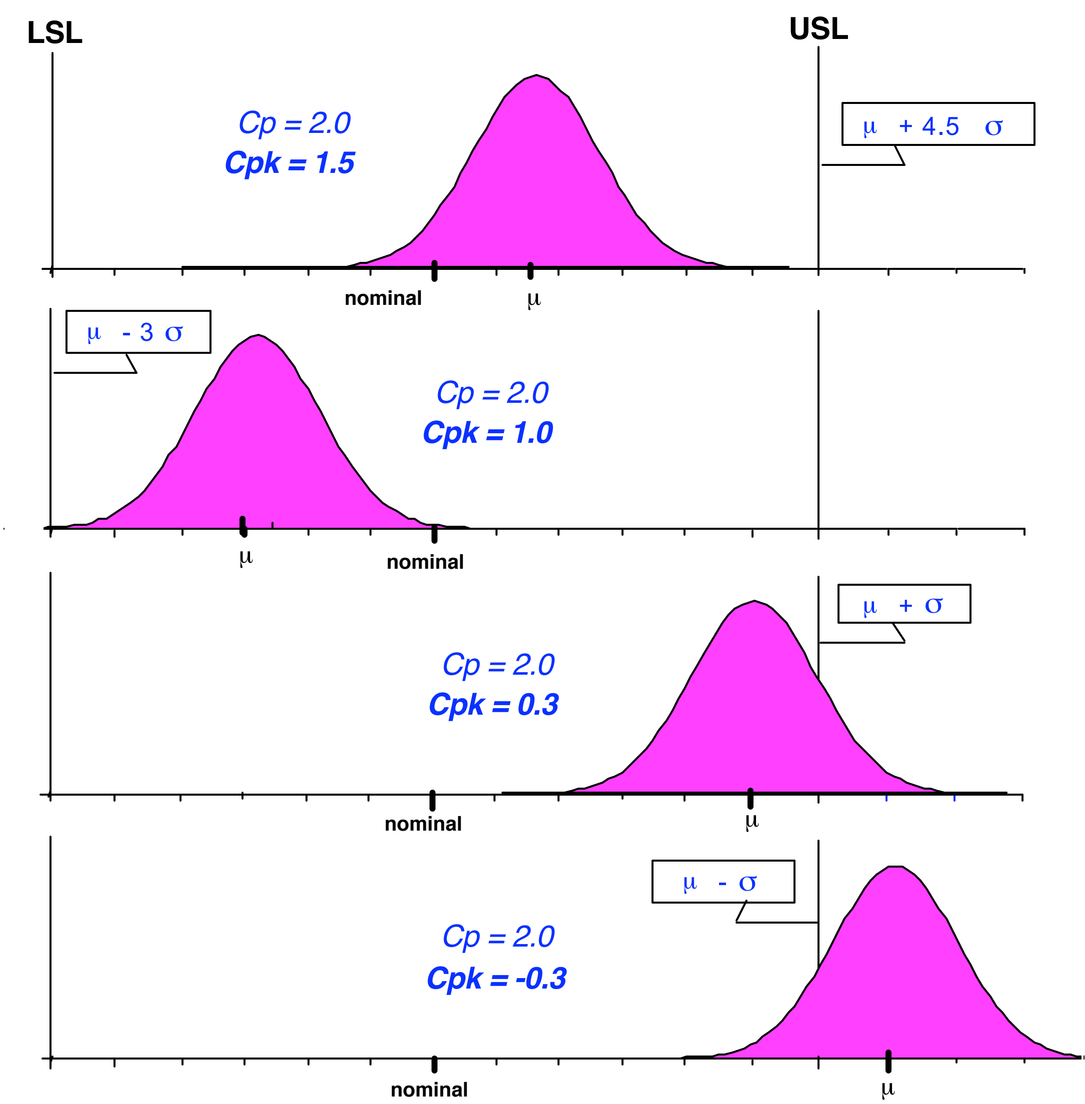
There are only a few ways to improve a Cpk number:

- Improve the process capability (Cp) by reducing variability.
- Change the specification. Don't laugh, customers may do it if you provide them with data indicating that you have a high capability index, and the parts function properly.
- Alter steel to target the distribution where the customer wants it to be.

The three most important things to remember for all parties involved are: 1) that for Cp and Cpk indexes, the higher the number is the better 2) Cp and Cpk have an direct relationship; if you increase Cp, Cpk will increase also, and 3) Cp and Cpk numbers *only apply to the dimension being measured* , every dimension will have a unique number. Dr. Don Wheeler also defines "World Class" quality as being on target with minimum variance; continually tightening the part distribution around the nominal specification for the dimension is the goal.

An additional consideration when analyzing Cp and Cpk indexes is how much confidence one should put in the number generated. Basically, the larger the sample size submitted for measurement the more confidence one can place in the number generated, provided the measurements are accurate. This topic is covered in depth in Design Margin Notes Volume 2.1, January 1995; they are available from the Design Margin Group.

The following graphic was also prepared by Valerie Wildman and illustrates the idea of Cpk as well as any I have seen by moving the same Cp around in relation to the specification:



In conclusion, visibility of process capability indexes should be a key concern to molding operations. Ensuring that the Cp and Cpk indexes indicate that you have a robust process with sufficient elbow room for all critical and functional parameters is critical before the tool goes into high volume production.

Chapter 8

PILOT PROGRAMS

(Starting Small To Ensure Success)

Pilot: - serving as a...trial apparatus or operation.

Once a molder has bought into SQC as being the tool with which they want to control their processes, the next step is to get the applications out of the textbooks and onto the shop floor. In most operations, a full-scale implementation of variable and attribute control charts and process control documentation would guarantee failure because the scope of such a project would be too large.

The alternative to this is the Pilot Program concept, where SQC tools and techniques are implemented on a small scale to allow a focused effort and time to fit the process to an individual molders environment. Once the correct procedures are continually practiced and the necessary degree of operational discipline has been achieved on this small scale project, more processes are added in the next phase. This gradual implementation continues until the techniques are being practiced plant-wide and a preventative strategy becomes part of the organizational culture.

When I work with a supplier on developing a Pilot Program, I let them choose the parts that they want to participate in the pilot. I suggest that they pick processes which are probably going to be successful and not a "problem child" type of process, where the problems are such that they will preclude the learning and practicing that you want to take place in a pilot program. The idea is to get people used to using the tools and to provide a "win" in the minds of the people who are going to have to do the work.

A pilot program should be designed so that all production elements relative to part quality are controlled before the part processes are monitored with control charts. These elements include:

- **Optimizing the process and generating a permanent master set-up sheet**. This master set-up sheet should satisfy the following criteria:
    - It should be typed, so people can't change it all of the time.
    - It should be approved by a central source, such as a Process Engineer.
    - It must include every machine parameter, including the clamp half.
    - It should include a revision block, so that when the process is permanently changed, people can look back into the reason why.
- **Optimizing the measurement process**. Inspectors will be expected to notify processors when they have an out-of-control process, so it is critical that they provide measurement data with high integrity. The molder should conduct Gage R&R studies on the measurement technique for all parts on the pilot, and conduct training as necessary.
- **Developing a master run sheet for each tool/press combination**. Tools run differently in every machine; they cannot be scheduled by press range.
- **Developing a process for responding to out of control points**. This includes writing down the response on the control chart in a timely manner.
- **Communicating when process changes are allowed**. Changes should occur only in response to SQC data.
- **Establishing a process change log**. It should include, the date, time, technician, the problem, the root cause and any process changes that occurred.
- **Resolving tool maintenance and record keeping issues**. Tools must be maintained to a prescribed frequency and tracked by the number of shots.

- **The scheduling of tool maintenance**. Scheduling needs to know when the tool is going to need to be taken out for a TD&C or modification *before* it is needed and before it happens.
- **Placing presses and auxiliary equipment on periodic maintenance schedules**. Very few molders maintain their equipment properly.
- **Deciding upon control chart formats, sample size, frequency, control limits**. This is a bigger deal than it would seem. For variable control charts, I suggest sampling 4 parts every 4 hours and using Shewhart's control limit formulas. Limits can be drawn for as few as 2 subgroups, but most people use at least 10 subgroups and then recalculate after 25 subgroups. For attribute charts that are on operator assisted processes, use np charts with the standard calculations based on past machine yields (if you don't have yields data, use your quoted yields until you can accurately calculate the control limits).
- **Implementing manual variable and attribute charts on the shop floor at the machine**. They need to be out where people can see them, not buried in the computer back in the Q.C. lab.
- **Establishing criteria for the recalculation of control limits**. Control limits should not be recalculated unless a change in the 4M's (man, machine, method, or material) can be identified. I have seen many computer programs that recalculate the control limits every time data is input.
- **Identifying the dimension(s) that were to be used for controlling the process**. The dimension(s) chosen should be representative of other dimensions and provide a "voice of the process". It serves no useful purpose to chart dimensions that do not change.
- **Measuring the screw, barrel and check ring for comparison to specification and to establish a baseline for understanding the impact of wear on part-to-part variability**. It is important that wear characteristics be understood and predicted. The first step is to make sure that the gap between the screw and the barrel (and also the checkring and the barrel) is within specification.
- **Establishing an internal auditing process and schedule**. Management should be highly visible during these audits; the ideal is to have management conduct the audit and subsequent follow-up.

A technique that has proven to be quite successful is to develop a Pilot Program team. The best ones I have seen were made up of experienced processors, inspectors and operators from all shifts who *volunteered* to be part of the team. It is very helpful if these individuals have also had exposure to SPC in the past; it could be argued that SPC experience should be a prerequisite. The formation of such a team allows for a concentrated flow of information to key individuals, instead of trying to communicate to an entire plant.

Once the pilot program is dubbed a success, plans need to be put in place for incremental steps to full-scale implementation. It is difficult for a molder to put such a timeline together until they have been through a pilot, because so much is learned about a molders' capabilities through the course of the implementation. Training often turns out to be of paramount importance before the effort can be expanded. Machine maintenance needs to be scheduled. Screws, barrels, and checkrings usually need to be purchased. The true cost of old, worn-out machines and auxiliary equipment is better understood, and molders often put plans in place to upgrade much of their equipment. The pilot helps to clarify the path to achieving the vision of becoming a World Class operation.

Chapter 9

ISO - NOT A PANACEA

A great deal has been written of late in quality and plastics trade publications regarding the benefits of ISO certification. It is not clear whether the folks who are writing these articles also happen to be ISO consultants, but the tone of most of the articles indicates that ISO certification is something that your company cannot live without. The articles imply that your customers want you to get ISO certified and that the certification process will cure many of the problems in your company. While ISO certification is extremely desirable from the standpoint of a demonstration of operational discipline, accurate documentation and following written procedures, it is not a cure-all for everything ailing your company. Poor performance in on-time delivery, quality, yields, process engineering control, project management, and profitability will not magically be improved when you get certified.

As the Plastics Quality Auditor for a large user of injection molded parts, I have the opportunity to take a comprehensive look at our suppliers' systems during on-site audits. At its best, ISO has proven beneficial at exposing and improving poor documentation and training, instilling discipline in updating procedures and driving companies toward adhering to them, and galvanizing companies toward achieving a worthwhile goal. In the worst cases, ISO certification has ensured that a system that does not work well or meet customer needs has been thoroughly documented and is followed to a "T". Discussions with individuals associated with implementing ISO in industries outside the plastics commodity have strengthened this perception. ISO certification basically involves 3 steps: 1) say what you do, 2) do what you say, and 3) constantly check to make sure that step 2 matches step 1.

The aforementioned worst-case scenario is very unfortunate for companies that invest a great deal in the certification process. Certification can take years to achieve and cost tens of thousands of dollars. If the molder had unrealistic expectations about what the ISO certification process was going to do for them, it can be demoralizing.

From my perspective, there have been two major problems with the ISO process:

1. ISO consultants typically know very little about how an injection molder operates. Little thought is given to how well the system works; the goal is to document it and make sure everyone does it the same way every time.
2. Companies who pursue ISO certification from a marketing perspective instead of as an opportunity for continual improvement. Current customers are impressed with one of their suppliers attaining ISO certification.. They stay impressed until a manufacturer with superior quality, similar capabilities, and more competitive pricing attracts their attention.

The point of this article is not to dissuade molders from pursuing ISO certification; far from it. The potential benefits from going through the process outweigh any downside. It is important to spend time putting together a realistic set of expectations of what ISO certification can do for you and also recognize its limitations. It is a perception in the industry that ISO certification will become a requirement to do business with some companies, much in the same manner that UL certification, quality systems, and tooling repair capabilities may be minimum requirements for many firms.

In the July, 1995 issue of Injection Molding magazine, Carl Kirkland wrote of the paper Russel J. Nichols presented at ANTEC, entitled *Keeping Up With ISO 9000: How The 1995*

Revision Affects You. In it, he described changes to the 20 requirements of the 1987 ISO 9000 standards. Those changes include:

- **Quality system**: a quality manual is now required.
- **Process control**: control of process parameters and product characteristics is now required, as is maintenance of process control equipment.
- **Corrective action**: Title change from "Corrective Action" to "Corrective and Preventative Action" with additional focus on preventative action techniques.

These changes attempt to address many of the limitations of ISO certification, and are consistent with our expectations of injection molders. Exactly how effective an ISO auditor is going to be at auditing the effectiveness of quality systems and process control procedures in a wide variety of industries remains to be seen, but the changes are definitely a step in the right direction.

In conclusion, the fact that the ISO process is so exhaustive points to a huge opportunity for injection molders, or any other commodity for that matter. In addition to going through the process of defining and documenting systems, the company should determine whether each system meets the needs of their customers and if the system is as streamlined and efficient as possible. The certification is an excellent opportunity to improve your operation, as opposed to taking inefficient or redundant systems and casting them in concrete. Finding an ISO consultant who knows the industry or involving your customers in analyzing the systems could help a great deal in offering different perspectives on what the ideal system would look like since it is always difficult to "see the forest from the trees".

Chapter 10

BEYOND SQC: MOVING TO SPC

SQC (Statistical Quality Control): process control based on after-the-fact part inspections to ensure part quality.

SPC (Statistical Process Control): in-process control utilizing actual real-time machine parameters and/or cavity pressure curves (with an understanding of how those elements impact part geometry) to ensure part quality, with a goal of a closed-loop system.

Few molders can differentiate SQC from SPC, but they all understand that they want SPC once you tell them the difference. The reason for this is that they have an excellent understanding of what the benefits are to them of not having to do part measurements and preparing control charts. The problem with getting there is that they need to learn to walk before they can run. I have seen operations with full-blown process monitoring equipment that have absolutely no idea about what they are looking at (provided they look) except for gross abnormalities.

There are 10 levels of Statistical Process Control. The first 3 are all dependent on part measurement (SQC), and are where the main learning curve takes place. The next 4 utilize a mix of SQC and SPC, where out-of-control processes are investigated through the use of an SPC system such as Shotscope, Plantstar, or NPE. The last 3 steps involve the transition away from taking in-process part measurements.

It seems intuitive that a molder who is not capable of monitoring processes with a functioning SQC system would not be capable of doing any better with an SPC system. Apparently, few of the molders who buy the equipment feel the same way, because they make the same mistakes with an SPC system once they have it installed. The mistakes are relatively easy to spot: failure to react to the data, incorrectly calculated control limits, and lack of visibility of the data to the people who need it are just a few. SPC systems are a great sales tool though, and customers perceive that molders who have invested so heavily in such a “quality” system must therefore make good parts.

In-process monitoring systems have been around for a long time. Interest in them waned for many years after molders figured out that they were not a “silver bullet” that was going to solve all of their problems and give them all of the answers. The biggest problem with SPC systems, both then and now, has been in the area of compatibility between the SPC system and the injection molding machine. Most SPC system manufacturers will say they can hook their machine up to virtually any molding machine. What they do not tell you is how long it will take, how much it will cost, or if the data will have any integrity. These systems have gained in popularity in recent years as molders become more sophisticated and customers raise their expectations. While such systems may be capable of eventually taking a molder to a true SPC environment, many molders are again finding that the systems are only as good as the people who use the data.

Their are many potential pitfalls to monitoring part quality solely with SPC systems. The biggest one is the failure to do any correlation between machine parameters and part geometry. Some systems monitor upwards of twenty machine parameters. Most will signal operators when a parameter goes outside the established control limits. The tendency of most processors is to widen the control limits so the system does not alarm out all of the time. They do this since many of the machine parameters being monitored have varying degrees of significance on how the part actually turns out. The net effect is usually that the limits around the machine parameter setpoints become so wide that it will only alarm when something catastrophic happens, in which case the part would be probably be short, flashed or warped anyway. Calibration of such systems is also a common problem; processors often do not believe what the data tells them from past experience.

Cavity pressure transducers are also getting a great deal of attention. There is a steep learning curve that must be scaled in order to first hook-up the system, then understand what the pressure curves indicate, and finally use the data to establish the optimum process. The pressure curves essentially give engineers and processors a window to see what is happening inside of the tool, which is the missing element in the in-process monitoring systems such as Shotscope. A great deal of debate has occurred in applications that allow for the use of two transducers over where to control the process and where to monitor the process, either with the transducer at the gate or at the end-of-fill.

Also unresolved is the use of the pressure curve data to monitor part quality. Once the optimum process is established, I have heard various arguments for how the curve should be monitored: an area around the peak (fill, pack, or hold) pressure, or the total area under the curve, or variations of both. Conducting a DOE to determine where the limits are placed around the area of the curve that is selected for monitoring will be essential to correlate the value to part geometry.

An idea that many trade publications seem to be preoccupied with is the concept of having a robot pick a part that was molded with an out-of-control parameter and drop it in the grinder. Proponents of this idea advocate throwing out parts that do not meet some arbitrary process index goal, say a Cpk of 2.0. This makes very little sense to me; if you have high process capability, why throw out parts that may in fact have dimensions outside of the control limits but are within specification? One of the huge benefits of molding to control limits is that if the process goes out of control, you (hopefully) will still be well within the specification limits and have time to investigate for root cause. Throwing out any parts that fall outside a Cpk number amounts to implementing tighter specifications.

The translations between the brand of transducer you select and the brand of machine in which you are going to run the tool can be a major obstacle to successfully using the technology. In-process monitoring systems often claim that their systems come supplied with jacks that you just have to plug the transducer leads into and you are off and running. Manufacturers that are capable of providing both are rare; caveat emptor.

In conclusion, I hope that it has become clear that molders who have not successfully implemented SQC should not be expected to be able to go out and purchase an expensive process monitoring system and immediately become a World Class molder. These systems, and cavity pressure transducers, are tools that can help them attain that goal, but there are still no “silver bullets” for molders. Developing an injection molding operation into a World Class operation is a journey fraught with huge obstacles at virtually every step of the way. The benefit to the molder in their competitive positioning and costs, and to the customer in the quality consistency of the end product are well worth the investment.