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SOME NOTES ON THE ORIGIN OF THE SIX-SIGMA MOVEMENT

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PART ONE – GENESIS

The genesis of Six Sigma can be traced to Motorola in 1979 when executive Art Sundry stood up at a meeting of company officers and proclaimed, 'The real problem at Motorola is that our quality stinks!' (1) Some time later, Bill Smith, an engineer at Motorola's Communications Sector, was studying the correlation between a product's field performance and the variation and rework rate in manufacturing. In 1985, Smith presented a paper that concluded that products produced in processes that had a significant rework rate had higher field failure rates than those produced in processes that had low variation and negligible rework rates.

At about the same time, Dr. Mikel Harry, at Motorola's Government Electronics Group created a detailed and structured approach involving statistical analysis to improve product design and to improve manufacturing performance thereby simultaneously improving the product and reducing costs. This approach developed into what is now known as six sigma.

As this newsletter was researched, several descriptions of six sigma were found. Some of the most common were:

1. In its most literal form in a manufacturing scheme, Six Sigma is the quality standard whose goal is a mere 3.4 defects per million processes.
2. DMAIC is at the very heart of the six sigma process.
3. Six sigma is a drive to achieve near perfection.

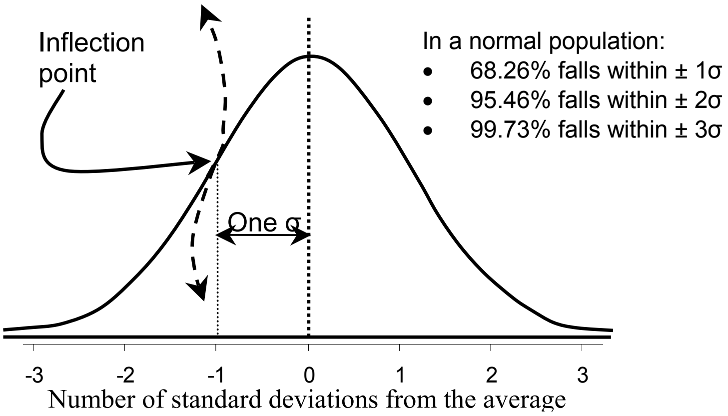
None of these descriptions satisfactorily explains the conceptual core of six sigma, so that is where we will start.

PART TWO – UNDERSTANDING AND REDUCING VARIATION

From Where Does the Term Six Sigma Spring?

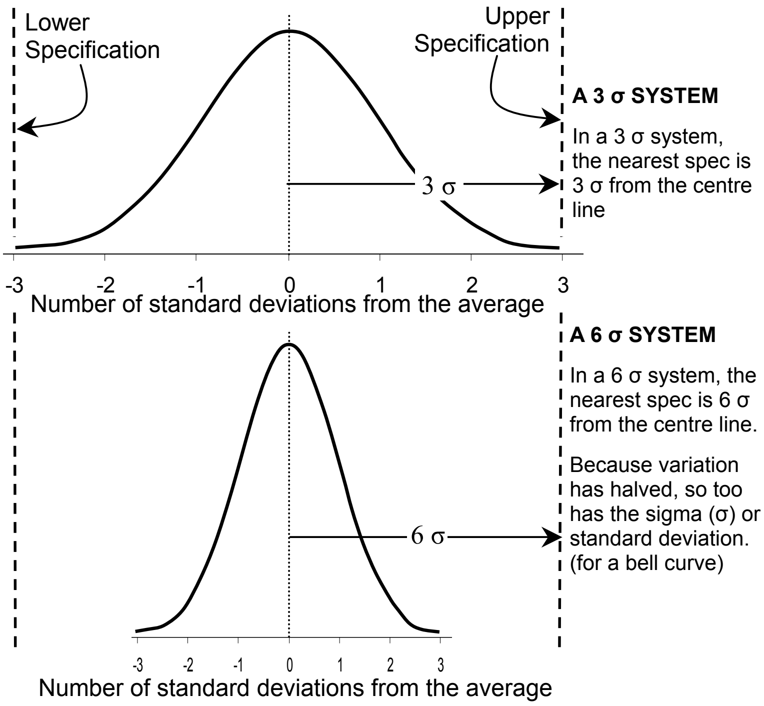
Sigma is the Greek letter σ which represents standard deviation. It can be calculated for any data set. However, when teaching or guiding lay folk, it is best to start with a geometrical description. Note that on either side of the average for a normal or bell shaped distribution, there are in fact two curves. One is concave and the other is convex. If these curves are continued, as shown as dashed lines in Figure 1, there is a point of inflection where the two curves touch. If a line is dropped from this point of inflection to the baseline, the distance between this vertical line and the average is one standard deviation. (2)

Figure 1
The Normal Curve (and a Geometric Representation of Sigma)



Imagine parts are being made for a medical devices assembly operation in the pharmaceutical industry. As the parts are manufactured, the critical variables are measured and these data are plotted to make frequency distributions. For the purpose of illustration, assume that the distributions created only just fit into the customer's specifications, as illustrated in Figure 2. If the process were improved so that the degree of variation for this particular variable was halved, the specifications would now be six sigma from the centre line. The specifications remain unchanged, as does the distance between the centreline and the specifications. However, because the degree of variation in the data has been halved, so too has the standard deviation. This is only true of bell-shaped distributions, but the relationship expressed is adequate for illustrative purposes here.

Figure 2:2
Three and Six Sigma Systems Compared
(Assuming Stability)



This, then, is the origin of the term six sigma. [3] In a six sigma system, every part and every processing step shows variation such that the nearest specification is six sigma away. If the distribution is correctly centred and bell shaped, it must display no more than half the variation allowed by the specifications to be a six sigma system. Nevertheless, many people are inclined to ask why one would bother to reduce variation so far below the specified requirements.

Early Six Sigma Companies

Most of the original six-sigma companies were assemblers. They assembled parts made sometimes by external suppliers, sometimes by internal suppliers, and sometimes by a mixture of both. Motor vehicles, cell phones and other electronic items are a few well-publicised examples. It was from this environment that the six-sigma movement initially arose, although it has much wider application. Three of the firms that put the six sigma approach in the spotlight were Motorola, Allied Signal, and GE.

Genesis -The Motorola Experience

By the early to mid eighties, Motorola had sold off elements that once were the core of their business, such as television and Hi-Fi manufacturing. Many of the businesses Motorola sold off were purchased by Japanese companies, who made the operations they purchased more profitable with little or no capital expenditure. It was at about this time that Art Sundry made his pronouncement. Some people in Motorola started to look for answers. A few of the Motorola people did a study of all the best companies they could access. They found that the best performing operations (in terms of quality, productivity, warranty repair rates and customer service levels) were performing at a level about which they dared not dream. For most of the Motorola folk, improved quality meant higher cost and yet the excellent companies they studied provided good quality at low costs. A closer inspection revealed that the outstanding companies they studied were all six sigma operations. [(3)] Initially, this flattened them. It seemed to make no sense. Why go to all that trouble and expense? Why not be satisfied with meeting the specifications?

The Awakening at Motorola

Bill Smith figured out the crux of the issue. It was a mix of variation and complexity. He and other engineers were able to demonstrate mathematically that to get both great quality and great productivity was impossible if every part/assembly/component/raw material was delivered to the next step in the process with three sigma quality. They went to their cell phone assembly process and counted the number of base components. They counted not assemblies, but every piece of wire, every transistor, every contact and switch, every soldered joint. Then they counted the number of processing steps. These counts were combined to arrive at what was called the number of 'events' required to make a cell phone. Here an event is defined as every opportunity for something to go wrong, or every opportunity for a defect to occur. The count for a cell phone was about five thousand events. Imagine how many events there are in the assembly of a car or an aeroplane. The complexity becomes staggering. [(3)]

It was observed that the crème de la crème plants had a very high 'first pass yield', that is, a high proportion of finished products that were right (met all specifications), on time, first time (no rework or similar fiddling). This made engineering and economic sense. Also, their data suggested a strong correlation between high first pass yield and low field failure and warranty repair rates. Some Motorola folk wondered how they could achieve first pass yield figures over 95% when their combined rework and reject rates were far greater.

What they then did was to create a model, assuming statistical stability in each and every component and event (a highly unlikely scenario with five thousand events) where the variability in every event was three sigma (specifications three sigma from process mean). The model was a simple factorial. By definition, a three sigma event produces 99.73% inside specs, assuming normality. The model showed that after about only one thousand events the first pass yield fell to zero. At that level of variation, all event supervisors or managers could claim that they were doing their job; that their three-sigma processes were producing out-of-spec components/assembly etc. at a rate of only 0.27%. However, even if every component maker and every assembly step had three-sigma variation, the first pass yield was going to be very poor, unless there were very few events. Table 3 shows how the first pass yield fell as the number of events rose in a three system. Three sigma systems worked when manufacturers made muskets and wagon wheels. It even worked reasonably well for early machines. As Dr. Deming was fond of saying, we no longer live in that world. Note the enormous increase in yield for a six sigma system.

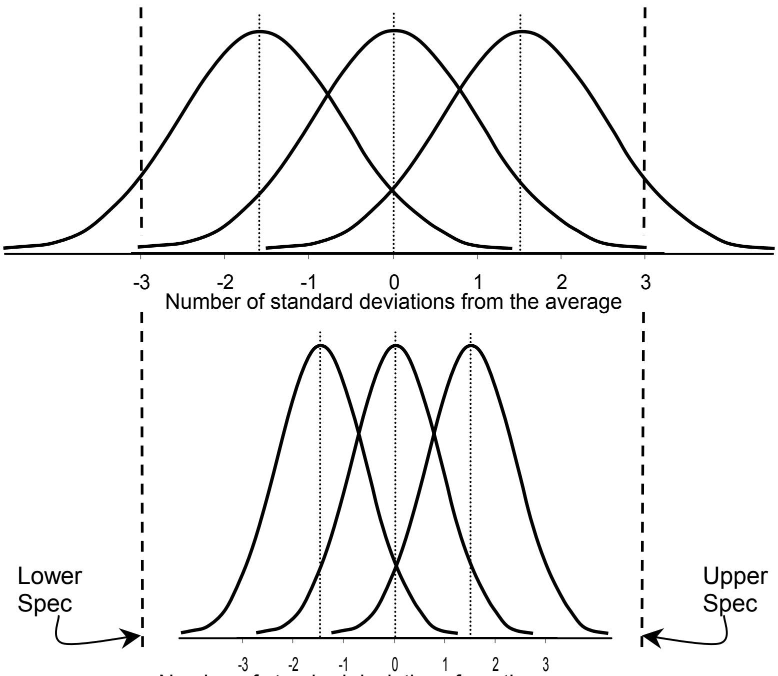
One can enter any multiple of sigma for each event to try and mimic a certain process. Most of Motorola's processes were operating at about four sigma. The factorial model was not a good fit for Motorola's factories. Some processes had even worse first pass yield than the model predicted. This was expected, at least in part, because perfect stability was impossible. Incoming raw material will show lot-to-lot variation. Temperature will vary. Lab analysts and operators will grow tired and make mistakes. Machines will drift out of adjustment. Tool steel will dull. Bearings will wear and vibrate. Refractory will erode. And all these things will happen, at least to some degree, in even the best managed plant. This is why most plants operate at four sigma levels of quality, to provide a buffer against these issues. Bill Smith went one step further with the observation that long term variation was impacted significantly by shocks to the process that knocked the process average off target, often my as much as 1.5 sigma.

Table 3
First Pass Yield for Three and Six σ Systems Compared
(Assuming Stability)

NUMBER OF EVENTS	THREE σ SYSTEM	SIX σ SYSTEM
1	99.73	99.99
10	97.33	99.99
20	94.74	99.99
40	89.75	99.99
60	85.03	99.99
80	80.54	99.99
100	76.31	99.99
200	58.23	99.99
400	33.91	99.99
700	15.06	99.99
1,000	6.70	99.99
3,000	0	99.99
10,000	0	99.99

Motorola reworked the model. Keeping the range for each event unchanged, the inevitable variation was simulated by allowing the process mean for each event to drift back and forth by 1.5 sigma as seen in Figure 4.

Figure 4
Three and Six Sigma Systems Drifting ± 1.5 σ Compared



Here a model is being discussed. It is worth recalling that whilst all models are wrong, some are useful [(4)]. This one is useful, but it is wrong. No factory behaves exactly like these models. Nevertheless, when the Motorola people rechecked their own data and that from the Japanese electronics and car manufacturers, it was found that the model was a reasonable fit. In particular, the best of the best plants all had a first pass yield that fitted the six-sigma model in Table 5 quite well. With every event at six sigma, even if the event mean is allowed to drift by ± 1.5 sigma, first pass yield will be about 96% after ten thousand events, as noted in Table 5.

Table 5
First Pass Yield for Three and Six σ Systems Compared
(Assuming a Drift in Mean of ± 1.5 σ)

NUMBER OF EVENTS	THREE σ SYSTEM	SIX σ SYSTEM
1	99.32	99.99
10	50.08	99.99
20	25.08	99.99
40	6.29	99.99
80	0.40	99.97
100	0.10	99.97
200	0	99.93
400	0	99.86
700	0	99.76
1,000	0	99.66
3,000	0	98.99
10,000	0	96.66

The above data show how some Japanese operations achieved such seemingly impossible productivity and quality figures simultaneously. What Motorola discovered was that the greater the complexity, or number of events, the greater was the impact of variation. They had to either reduce the number of events or greatly reduce variation, or some combination of both. This is not news for people with an Operations Research background. It's what Little's Law predicts.

Wernher von Braun, architect of the United States space program, recorded the complexity problem much earlier. He noted that if a large number of components must function for a system to accomplish its objective, the probability of system success diminishes rapidly as the number of components increases unless the reliability of each is essentially perfect.

Stirrings at Ford

Another group that made a similar discovery in the early eighties was Ford. They realised that the transmission plant that was to make Ford's first USA front-wheel-drive automatic gearboxes could not make enough gearboxes for the predicted production rates. Ford had recently acquired a sizeable proportion of Mazda, so they asked Mazda to make identical gearboxes and to ship them to the USA. Mazda did this, and it delivered the gearboxes to the US, freight paid, for less that they could be shipped out of the US based Ford plant.

Not long after launch the dealers and the warranty people at Ford noticed significant differences in performance. The Mazda boxes were quieter, smoother and had a much reduced warranty repair rate when compared to the US manufactured units. Ford tore down a sample of US boxes and discovered that for the critical components they were running at about four sigma. They were well pleased. It looked an impressive result.

Then they tore down some Mazda units. In at least one case they needed to buy a new instrument for the inspector, because the one she already had could not adequately detect variation between the parts. The components were manufactured so that the variation, piece-to-piece was at about six sigma. This staggered them. Again, it made no sense. Who would do that; and why?

They went back to Mazda and soon found some of the answers. It surprised many to discover that the Japanese had learned about variability reduction from Americans such as Dr. Deming and Dr. Juran. Also, Mazda had determined that assembly costs were a very large element of the total cost of a gearbox. So, they put a lot of effort into the manufacturing of components. As one Ford executive said, the specifications disappeared 'over the horizon'. The outcome was brilliant first pass yield. Just as importantly, the parts, 'practically fell together' and assembly time as well as labour used for assembly plummeted. Simultaneously, work-in-progress fell as did cycle time. It must, in accordance with Little's Law. The manufactured cost of the components in Mazda was actually higher than it was in the USA, but the much-reduced assembly costs meant a unit that was not only superior, but also which cost less to make overall. The reduced warranty repair rate was an additional bonus, as was the improved customer satisfaction level. [(5)]

Most manufacturers and assemblers in USA, Australia and Europe are doomed before they start. The most common style of management forces every manager at every step in the process to try to reduce costs within a given department or other organisational component. It can be extraordinarily difficult to get department managers in the first few steps of a process to increase their costs by one million per annum so that downstream managers can reduce their costs by two or more million per annum. Instead of objectives for, and management of, the entire production process, every step in the process has individual budget targets, and people are held accountable for them. There is a better way, and our Japanese cousins learned it a long time ago from Americans such as Deming and Juran. Six sigma uses the same process based approach.

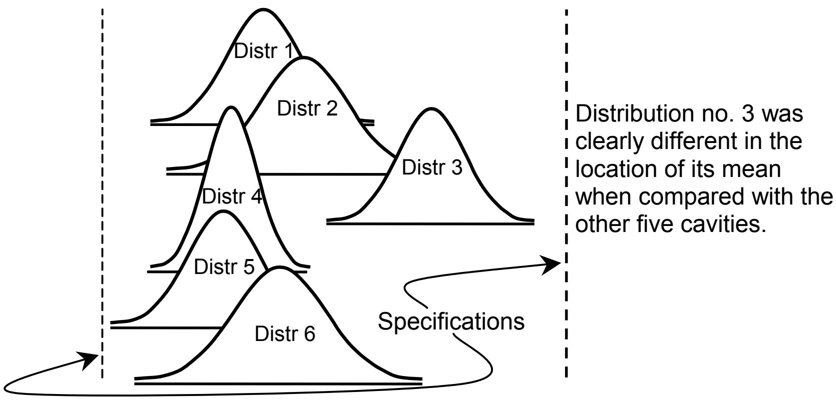
Mazda chose to manage the entire process and to manage total cost. In this case, this required higher cost components so that significant savings could be harvested from the assembly process.

Further Illustration – Vial Capping Issues

At a parenterals plant where vials are filled with a liquid drug, issues with failed caps had plagued the line for some time. A statistical study revealed that the vials, all of which were manufactured in a single six cavity die, met specification easily, as seen in Figure 6. However, when the data were stratified by cavity it became apparent that cavity 3 was different from the remainder. Vials from this cavity were responsible for nearly all the failed caps. All vials met specifications, but this is not a six sigma system. In fact, none of the cavities taken in isolation is a six sigma system.

Understanding and reducing variation lies at the heart of the six sigma concept. This imperative can be traced back in time at least as far as the industrial revolution. In the first half and middle of the last century great minds such as Dr. Shewhart, Dr. Deming Dr. Juran and Dr. Taguchi established the critical role that understanding and reducing variation played in improving quality, productivity and competitive position. Six sigma has an excellent ancestry.

Figure 2:6
Distributions for Vial Necks



What the six sigma concept did very well was to explain how some Japanese companies could lay claim to defective rates expressed as three to six parts per million. To those western managers and technical people who were hard pressed to achieve defective rates of less than five to ten percent, the claimed Japanese outcomes seemed light years away from their current reality. In many cases, the Japanese figures simply were not believed because the improvement needed to reach these levels of performance in most western companies seemed several orders of magnitude away from their existing situation. However, the six sigma approach gave many something at which they believed they could realistically aim. If a business was currently operating at a quality level of about four sigma, which was where the Motorola studies showed most western manufacturers to be, it was not too difficult to accept the task of reducing variation at each event by about one third. This would make them a six sigma business, and the seemingly impossible defective rates being claimed by the Japanese would be achieved in the west.

> **‘Statistical thinking will one day be as necessary for efficient citizenship as the ability to read and write.’**
>
> **H. G. Wells**
> **1925**

At Motorola, the variability objective set for every manager was expressed in terms of the first pass yield that would be achieved if every event achieved a level of variation they described as six sigma. This is sometimes referred to as the ‘shotgun’ approach, because it was a task for every person in the business. Motorola then added what we might describe as a ‘sniper rifle’ approach, where advanced statistical techniques were used to identify and target those variables that gave the greatest leverage, which introduces part three.

PART THREE – GAINING GREATEST LEVERAGE

Limits of Technology

Manufacturing people everywhere know that sometimes no matter how much effort is expended, the limits of existing technology can prevent further variation reduction. It can be difficult, expensive or impossible to achieve six sigma levels of variation for some events in the process. One example came from the early Motorola experiences. One component they struggled with was a crystal used in the manufacture of a cell phone. Crystals are not manufactured, they are grown, and there was significant variation from crystal to crystal. Initially, Motorola had been laser trimming these crystals to achieve the desired uniformity in outcomes. The approach worked, but it was very expensive. Using some sophisticated multi-variable statistical analyses, the Motorola people discovered that if two of the other variables involved could be held to extremely tight tolerances, that the interaction between these variables and the crystals was such that the crystal could be allowed to vary significantly without loss of performance. Instead of reducing the variation in the crystals, they discovered a much cheaper way to achieve the desired outcomes. [3]

This was the 'sniper approach' element of the six sigma approach developed at Motorola. It involves projects using advanced statistical methods that help to locate those variables that, if addressed, give the greatest leverage in the drive towards improving processes and products. There are many sophisticated statistical methods that one can use during the conduct of such projects, but these are the preserve of highly trained people, and they are beyond the scope of this newsletter. Instead, an overview of some of the principles associated with Little's Law will be provided.

Lessons from Little's Law

Little's Law states that output volume is a function of cycle time, which in turn is a function of variation. [6] If variation in the flow of material/parts through the process is successfully reduced, volume output will rise providing work in progress remains constant. The Dice Experiment illustrates this law in action. However, in the Dice Experiment, every event has the same capability and the same stable variation in terms of volume throughput. Any manufacturer knows that real factories look quite different. Some events are more critical than others. However, Little's Law offers some insights we can use that are generally very helpful.

Both the Motorola models and the Dice Experiment show that leverage is gained by working upstream in the process; by working on the inputs and the first few events. If variation is reduced there, there will be a flow on effect through the remainder of the process. Nonetheless, in most factories that is not where the improvement efforts are focussed. Any process has what we might call the 'transformational event'. This is the event or step in the process where the alchemic transformation takes place. In the service elements of our businesses, 'transformation' might be the movement of a product in the distribution system.

Too often, the most talented people in a business can be found intensely studying the transformational event when the root causes of most problems are to be found earlier in the process. A good rule of thumb is that for all the issues we see at the transformational event, 50 – 80% of the root causes of these problems will be found earlier in the process, up to and including set-up of the transformational event. Many of those that are not solved by addressing the early events have their causal relationships exposed after the variation in the early events has been conquered, and they become easier targets. Statistical methods are available to find those variables that offer the greatest leverage. Another approach is to start every project by focussing on the inputs and the early steps of the process. Both approaches have their merits. They both work. This is not an either/or situation. Rather it is one more properly characterised as an 'and' situation.

There are many quite simple tools and techniques that we can use in project work to isolate key variables. The various fishbone or Ishikawa diagrams, flow diagrams, frequency distributions, Pareto charts, and simple two variable correlations are some examples. There is a place for sophisticated statistical techniques, but equally there is a place for the simpler approaches that everyone can master. A search for the key variables that provides greatest leverage need not always involve heavy-duty statistics.

Summary

The 'sniper rifle' element of the Motorola six sigma approach involves locating and addressing those variables that, if successfully addressed, give the greatest leverage. Sometimes simple tools will do the job. Sometimes sophisticated statistical modelling and/or tools are called for. Because of the size limitations of this newsletter, the more advanced techniques cannot be addressed here. Nonetheless, if readers are aware that some very powerful statistical tools are available, and know to whom to turn when their use is called for, advancement can be made.

PART FOUR
SOME STRUCTURAL ELEMENTS OF SIX SIGMA

A Business Strategy

Six sigma is not only a quality initiative. It is a business strategy. [1] Unless the approach is part of the mental models of senior management, and is being driven by them, it will sub-optimise at best and fail at worst. Six sigma brings a focus onto the cost of quality. In the highly regulated industries such as the food, aeronautical and pharmaceutical industries, the cost of compliance needs to be added to this. The irony with the high compliance costs in these industries is that the cost of preventing deviations is often small when compared with the cost of raising and clearing them.

Some management aspects central to a successful six sigma approach are:

1. Senior managers must not only be the leaders of six sigma, but also they must be seen to be the leaders. Visibility and credibility are essential. 'Follow me' is an approach that works. 'I'm right behind you', is one that seldom does.
2. Every manager must be held accountable to achieve six sigma levels of variability, particularly process owners. This requires the improvement of processes until short term variation occupies only half of the allowable specification range. There are other approaches of calculating six sigma levels of performance for processes devoid of formal specifications. [1]
3. Process owners must be accountable for the entire process for any given product or service, not just a department or similar element.
4. Management must provide education and training for everyone in the organisation. The level of education and training will vary depending on the role each individual plays, but everyone needs a basic understanding so they are able to participate.
5. Resources, and in particular trained full time improvement project leaders, must be allocated to business units to drive the improvement strategies.
6. Information systems need to be developed to track progress. This is not an additional system; it is a revamp of the core information system. For key items, monthly variance reporting should be replaced with control charts so managers can differentiate between random variation and signals in the data.

Any organisational psychologist will explain that most people need structure in their working lives. Not all, but most. Many of the companies who stumbled with their initial attempts to introduce Deming's approach/Kaizen/TQM (etc) discovered that part of the problem was that they had failed to put into place structures that provided guidance and cultural guideposts as well as some of the 'how to'. Whilst it is certainly possible to create a snarl of counter productive bureaucracy, in companies such as Motorola and GE, six sigma did demonstrate how these structures could be helpful.

A widely misunderstood part of six sigma structures concerns leaders and black belts. Black belts are widely thought to be what Dr. Harry calls 'tool masters', or people skilled in the use of sophisticated statistical methods. Dr. Harry writes that leaders and black belts should be idea mongers rather than tool masters. [7] In this spirit is this newsletter written. The ideas or concepts should drive the structures and tools, rather than the reverse.

Some of the salient structural elements introduced as part of the Motorola six sigma approach include:

1. Removal of options to participating.
2. Allocation of substantial resources.
3. A project-by project approach similar to the one about which Dr. Juran wrote so passionately.
4. Accountability and a demand for results measured in terms of both reduced variation and financial outcomes.

Optional? One of the very clear features of Motorola's approach was the removal of options to effectively participating in their six sigma initiative. This was part of their 'shotgun' approach. Everyone was expected to participate. During his early seminars Dr. Harry was fond of telling stories about managers and executives who failed to fully participate, and of the 'significant emotional event' with a VP that invariably followed. [3] A favourite story comes from the CEO of an Australian company introducing a quality initiative in the eighties. He would tell the old story about the production of his favourite breakfast, bacon and eggs. The two animals involved, he'd explain, were a chicken and a pig. The chicken was involved in the production of his breakfast, but the pig was committed. He would then explain that the approach he was driving only worked for pigs, and that chicken managers were not welcome in his business. It is a useful analogy. Six sigma only works for pigs.

Resources. Another element that tended to be missing from many other improvement approaches was the allocation of significant resources. The green and black belts may seem corny to some, but even those not enamoured of the terminology would mostly applaud the allocation of resources to help managers conduct improvement projects. A course or seminar on the subject followed by an exhortation to sally forth and 'do six sigma' is not sufficient training and guidance for most managers. In his book, 'Out of the Crisis', Deming lays out a structure that could easily be mistaken for the approach developed at Motorola.[8] These similar approaches have stood the test of time. Unfortunately, in the words of the bard, they seem to be more honoured in the breach than in the observance.

Project-by-Project. Those familiar with Dr. Juran's work will recall that he was adamant that no other approach would work. (Initially, Juran and Deming seemed to differ on this subject to some extent. It is a position on which both softened a little later in life.) I see no need for the project-by-project approach and the more general cultural and 'shotgun' approaches to be mutually exclusive. May not both be used? Must this be an 'either-or' argument, or might it be a suitable place for an 'and' approach? Motorola certainly opted to pursue both approaches simultaneously.

Accountability. Another element of the Motorola method was their approach to accountability. The company made it clear that it believed that conquering variation would lead to improved financial and customer service outcomes. To this end the accountability model was altered so that a prime measure of a manager's success was their ability to improve products, services and processes in six sigma terms, that is, to reduce variation and to show demonstrable improvements in business results. At his early seminars, Dr. Harry would produce a slide showing a distribution in the crosshairs of a telescopic riflescope. 'You've got to shoot the tails of ***all*** your distributions', he would say, followed by, '…and managers must be held accountable to reduce variation to six sigma levels.' Problems and costs in manufacturing that could be traced to design or facility construction were transfer priced back to the design and construction departments. This fundamentally changed the perspective of many managers. So too did the demand that financial people be involved in the planning and execution of major projects so that high value improvements were targeted and improvements could be better quantified.

CONCLUSION

The concept called six sigma was born in Motorola in the 1980's, but it has a long and proud tradition that reaches back to the 1920's. It brings some interesting new ways to explain why reducing variation is a business imperative as well as structure and a sound array of tools and process improvement methods. Sadly, in some consulting firms and businesses the six sigma concept seems to have grown from its original roots a tangled thicket of paperwork, administrivia, and management ritual. Structure is not a bad thing, but too much structure and bureaucracy will choke even the best of ideas. As Dr. Harry noted, ideas and concepts are more important than tools or structures. If the tools and structures become more important than the core ideas, the ideas can be smothered.

Six sigma is a tried, tested and proven approach. It lacks much of the management theory found in Dr. Deming's theory of profound knowledge, but some companies have reported outstanding results. Nonetheless, some consultants have modified the original approach to such an extent that it is barely recognisable. Elements that are difficult to teach or to sell are omitted. Branches cut from exotic species are grafted onto the rootstock. Sometimes this robs the organism of its vitality. In many cases, the approach is burdened with so much bureaucracy that it has become a ticket punching exercise. No good idea is proof to such tampering. It was noted in the past with the work of men like Deming, Ohno, and Juran, and with approaches such as re-engineering and supplier partnering. It seems criminal when an approach with the enormous potential of six sigma becomes hamstrung with bureaucratic nonsense, but it can happen unless leaders are eternally vigilant.

However, if readers are aware of the original concepts they can defend themselves against misinformation. The clue is in the name, six sigma. It is, or should be, a statistical approach; its foundation is reducing variation and managing systems. Does that sound familiar?

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