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The Integration of Lean and Six Sigma
A powerful improvement strategy for Carbon Plants

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Abstract

Lean Manufacturing and Six Sigma have come to the forefront as models for manufacturing excellence.

- Six Sigma is driven by the strong relationship between reducing process and product variation and increasing business value - as represented by cost, yield, and quality.
- Lean Manufacturing focuses on the elimination of waste to reduce variation, shorten cycle times, accelerate flow and increase customer "value in use."

Although applied to some extent in Carbon Plants, they are not commonly used. The Authors feel there are several reasons:

- Available information focuses on Lean/Six Sigma in discrete manufacturing
- There is little available experience in processes such as anode production.
- Some concepts in Lean/Six Sigma have little relevance to existing Carbon Plants.

These methods require careful integration to deliver full benefits - this is not always done well. Examples will be provided to demonstrate how Lean/Six Sigma can be successfully integrated into a wider framework and used to deliver sustained business value in process industries.

Introduction

Cost and quality pressures will continue to increase in the aluminum industry and as they do, Carbon Plants will be expected to make significant improvements in anode quality while reducing cost. Proven strategies like Lean Production and Six Sigma are directly applicable in Carbon Plant processes to improve quality and reduce cost. "Lean" Production can create business value through its focus on the continual elimination of waste in all forms, reducing the business processes to its core value-adding structure. Six Sigma can create business value through its methods and tools for the elimination or reduction of variation, which if not attended to can create waste and damage quality, resulting in higher costs and damage to business value.

Lean Production

The re-building of post-war Japanese manufacturing provided an opportunity and a catalyst for change. Faced with challenges vastly different from their Western counterparts, Japanese business leaders led the development of new manufacturing practices that aimed to continually reduce the consumption of resources. "Inventors" including Toyoda and Ohno developed a production system now known as the "Toyota Production System." [1] Simply stated, the objective of this system is to minimize the consumption of resources that do not add value to a product through relentless efforts to find and eliminate waste.

Over the years, the principles espoused in the Toyota Production System have been "reinvented" and captured as Lean Production.

- The customer defines VALUE. A lean enterprise thinks more about creating value for its CUSTOMERS than about running machines fast to absorb labor and overhead.
- A clear PROCESS focus to understand the activities, flow paths and connections required to produce a specific product, and to align the process with the needs of the customer.
- CONTINUOUS IMPROVEMENT is necessary to reach your goals. Improvement activities must progress beyond projects into daily work.
- Lean production requires the engagement of all PEOPLE at all levels in the business. Only people make improvements.
- The pursuit of PERFECTION means there are endless opportunities for the systematic elimination of waste. Removing one layer of waste simply exposes the next.

FOCUS ON WASTE

Lean states, "make what the customer needs, when and at the rate the customer needs it." Any more or any less is waste. Eliminating waste starts with an understanding of the forms of waste and for each, the main contributing factors.

- **Overproduction** or producing more than what is needed by the customer or before they need it is the number one sin. It is the result of a "make it when you can mentality" or unpredictable demand. To avoid overproduction, one must produce at the same rate the customer consumes. Examples can include baking anodes at a firing cycle that overproduces or running the anode forming process as hard as you can whenever you can.
- **Excessive Inventory or Work in Process (WIP)** is the visible manifestation of overproduction. It is the material between process steps resulting from unbalanced flow. Unreliable processes and the need to provide a "safety net" can cause this. To reduce inventory, one must stabilize and balance production with demand and eliminate variation in both the rate of demand and the flow of supply.
- **Excessive transportation** is the unnecessary handling and movement of product. It occurs when product flow paths are not well designed or when there are large inventories. To eliminate excessive transportation one must streamline product flow paths and reduce WIP. Excessive transport occurs when baked anodes are produced at a rate faster than required the rodding by room. Stackers lift and move anodes to storage, then return them when needed. Shelf life degradation, handling damage and cost result.
- **Overprocessing waste** occurs when product is processed more than the minimum required, unnecessarily increasing time and resources. To eliminate overprocessing, one must eliminate delays and non-value added steps in the process. When a firing cycle is delayed, overprocessing results in unnecessary heat input and cost.

- **Waiting is** the delay that is incurred by people when processes and people are not properly aligned. For example, t meet a production quota, maintenance is kept waiting to get access to the equipment. Weekly shutdowns that do not run to plan can cause production crews to wait.
- **Unnecessary motion** occurs when work processes are poorly designed. It results in wasted time and effort. To eliminate unnecessary motion, layout, methods and workplace organization must be improved. For example, the waste involved with people "hunting" tools and equipment in a workshop that is poorly set up or maintained.
- **Making defective product** is waste. Defective product not only includes scrap, but also product with inconsistent properties over time. To avoid defective product, one must improve process control, planned maintenance or product / process design to reduce variation. Green or Baked anode scrap or continued use of damaged rods are typical examples.

Analysis of the Toyota Production System" [2] has shown that rigid specification of processes and outcomes is the very thing that produces flexibility, creativity and continual improvement. When a process is properly specified, it sets out a hypothesis that reflects the current best understanding of the process and what is required. This hypothesis can be described as; "if the critical inputs and parameters of a process are identified, specified and controlled, then the output will satisfy the customer's requirements." Timing (to prevent overproduction) and quality (to create value in use) are specified to align with the customer's requirements.

Systems for daily process management are implemented to control the "inputs" and built-in tests are created to check the outcomes (timing and quality). Response plans are pre-specified to help people working in the process address problems at the closest point in time and location to the source of the problem. Problems can then be identified and addressed quickly and effectively.

Three different gaps can be identified in the course of daily work. Closing these gaps leads to continual improvement. [3]

- Stability Gap - sporadic and random problems (special causes) are identified and removed
- Capability Gap - chronic problems that prevent either quality or timing from being met (common cause) are analyzed and process changes are implemented (six sigma is a powerful method for this work)
- Knowledge Gap – the outcomes of the process are not satisfied but the inputs and parameters do not indicate a problem – other factors, not yet identified are involved.

The Lean efforts of many organizations over the past 10 years have attacked individual instances of waste through event-based methods like "kaizen events." For many organizations, the results were unsatisfactory with only pockets of localized improvement, unable to withstand the test of time. Too many organizations confused the tools and methods with the design of the systems that make them so powerful.

Six Sigma

The concepts underlying six sigma deal with the fact that process and product variation is known to be a strong factor affecting manufacturing lead times, costs, yields, product quality, and ultimately customer satisfaction. [4] A crucial part of Six Sigma work is to define and measure variation to discover its causes and to develop operational means to control and reduce the variation.

Six Sigma methods are heavily based on the use of statistical methods and:

- An explicit and measurable alignment with the creation of business value
- A project based approach that follows a structured problem solving method
- Development of highly trained improvement specialists

<u>Measurable Alignment with the Creation of Business Value</u>

One of the most important features of Six Sigma lies in the idea of system alignment. Processes are viewed from a process flow perspective (as opposed to functional), defining how inputs and process parameters affect process outputs. This understanding is expressed as: $Y \sim f(x)$ [5]

- The outcomes that create value are expressed as the "Y's."
- The inputs and process parameters that influence the outcomes (Y's) are expressed as the "X's." (Figure 1)

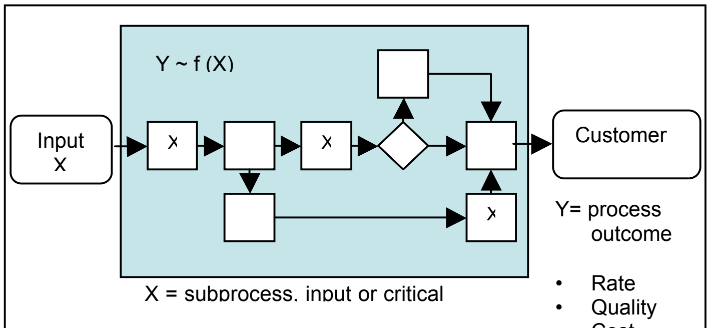

Figure 1: Y = f (x)

Improvement is driven by "identify the X's that are the most important and improve them, this will improve Y, which in turn, will create value for our customer and the business." Six Sigma tools and methods are applied to advance this understanding.

<u>A structured method for project based problem-solving</u>

At the heart of Six Sigma is a systematic method for analyzing and improving business processes called DMAIC, providing a "project management" pathway:

1) Define the problem or opportunity
2) Measure the process
3) Analyze the process
4) Improve the process
5) Control the process

<u>Development of highly trained improvement specialists</u>

Six Sigma emphasizes the need for highly trained specialists to teach tools and methods and guide projects. Each specialist is expected to return in excess of $250000 per year in net savings.

Six Sigma has proven to be a powerful method for projects but can encounter problems when transitioning from the project stage to embedding the results in daily operations. Although the concept of "control" is identified, Six Sigma does not always deliver the process stability required in operations such as Carbon Plants. This stability is a prerequisite to effective project based improvements. Further, the Six Sigma focus on team-based "projects" can cause variation in daily process activities to be overlooked causing the "overburden" (waste resulting from the fundamentals not being right) in daily activity to remain heavy. This "overburden" often makes the implementation of project results difficult or temporary. The active engagement of the workforce in improvement of their daily work can be lost.

Lean and Six Sigma in Daily Process Management
Individually, Lean and Six Sigma provide effective tools and methods for business process improvement. The attention to Lean and Six Sigma across industries is widespread. In the view of the Authors, what separates the "few" from the "many" is the integration of the principles of Lean and Six Sigma into the design of systems for daily process management. [6]

- Daily work (as opposed to projects) is aligned with the creation of business value and reflected in measures.
- Everyone at every level (as opposed to specialists or teams) is engaged every day in problem solving and improvement.
- Rigorous scientific methods are used to solve problems in daily operations as close as possible in time and location to the source (as opposed to large, complex problems).
- Processes are highly specified with built-in tests to signal problems early in the process, before they escalate and damage value (at the customer).
- Daily work is conducted as a "running experiment" (as opposed to one-off experimentation) enabling processes to be tested and continually refined and improved.
- Leaders (as opposed to specialists) are teachers and coaches.

Daily process management systems are designed to drive the relentless identification and elimination of variation and waste.

BUILDING "DAILY" PROCESS MANAGEMENT
Processes can and do drift, we can be slow to respond and are not always sure when/where the problem is or whether it is real. This can lead to the customer being the first to know things have "gone astray." We need to manage processes in a smarter way, in real time, in the course of daily work. The integration of Six Sigma and Lean Production principles provide the framework and tools for the development of a Daily Process Management system that identifies optimum operation targets and quickly triggers action in the process when there is a move from this point. Waste is highlighted (because of its impact on speed or flow) and variation is detected early so actions can be taken quickly before important process outcomes are adversely affected.

Development of the daily process management system follows a simple yet rigorous method.

Specify value from the customer perspective

STEP 1
Identify and specify what value looks like to the Customer. To align supplier and customer in this manner we define:

- What is the customer demand rate?
- How does the suppliers' product create "value in use" for the customer?

Define supplier requirements to meet customer value expectations

STEP 2
Specify the supplier process rate and quality requirements

- What is the required output rate to avoid overproduction and the waste that flows from it - inventory, excessive transport, losses and product damage…?
- What are the quality requirements that will create "value in use" for the customer assuring no value damage occurs in downstream processes?

Define measures and built-in tests

STEP 3
Measure rate and quality at the supplier-customer interface and define built in tests - set up systems to make it daily work.

- Measures with "built-in tests" signal when action is required - close in time and location to the source of the problem. Problems can be identified and action taken in a timely manner to avoid and reduce damage to customer value.

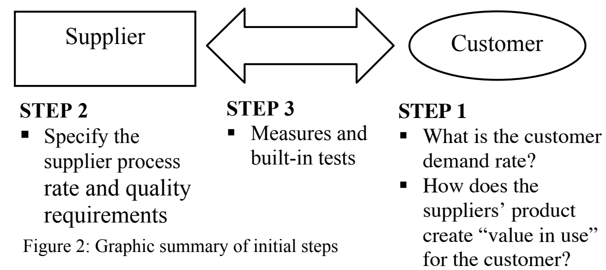

Figure 2: Graphic summary of initial steps

- Blue loop action or countermeasures are designed to "protect the customer" - not resolve the root cause of the problem
- Black loop action or root cause actions are designed to analyze the problem, investigate causes and implement solutions that prevent the problem from reoccurring.

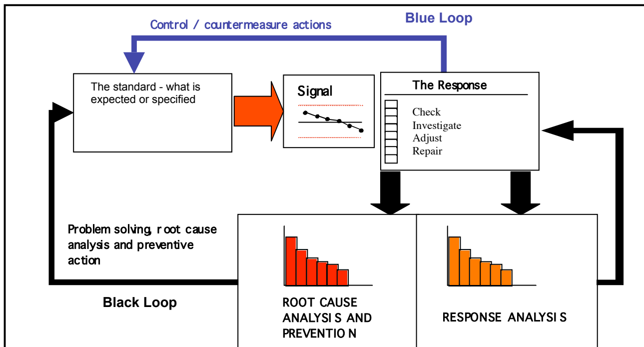

Figure 3: Blue loop and black loop

Drill down in the process and align systems for daily process management with critical process

STEP 4
Map the process to align the process at the operational level with rate and quality requirements. Subordinate supplier-customer interfaces are identified within the value context.

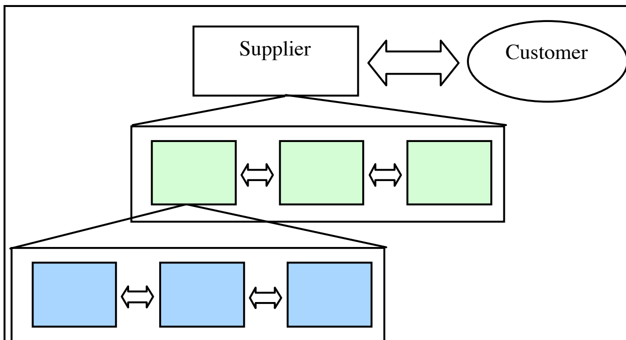

Figure 4: Drill down for alignment

Repeat the process – at the next level down

Return to step 1 to 4 and repeat the analysis, specify and establish measures at the supplier-customer interfaces.

What is the result?

On first glance this may appear to make what is simple, complex. Rather, it takes what is known and builds rigor in the application of this knowledge in daily work. Further, it creates systems that test that understanding every cycle. By specifying all supplier-customer interfaces, we define process outcomes (at every level) as hypotheses ($Y \sim f(x)$). Every outcome is defined and specified as well as critical inputs and parameters (the "X's).

In the course of daily operations, we test these "theories," (e.g. have we got the specifications correct?) Built-in tests tell us immediately when outcomes are not met.

When work is designed in this manner, we can put the energy and knowledge of all people to work. First, to identify the variation and waste that causes failures in process outcomes and then, to specify clear accountabilities and responses to:

- Protect the customer (countermeasures)
- Prevent a recurrence (root cause analysis)
- Manage the process at the lowest possible level – where problems are smaller and less complex, and where actions can be taken to prevent the problem from escalating and damaging business value.

This rigorous and disciplined approach to daily process management in Carbon Plants can help us meet future quality and cost challenges.

BUILDING DAILY PROCESS MANAGEMENT – A GREEN MILL EXAMPLE

<u>**STEP 1**</u> Specify what **VALUE** looks like to the **Potrooms**

Demand Rate

Average Potroom demand is 500 anodes per day determined from:

- Normal set cycle
- Early change rate (burn offs, air burn, cracking…)
- New pot starts

The Takt time = (1440 minutes per day) / (500 anodes per day)
= <u>1 anode every 173 seconds</u>

Quality (Value in Use)

A critical value in use characteristic of anodes is the rate of carbon consumption. This makes a direct contribution to business value:

- Carbon costs (net carbon)
- Metal purity (exposed stubs)
- Anode life (anode demand)

<u>**STEP 2**</u> Specify **Carbon Rate and Quality** to meet **Potroom** requirements

Factoring back into the anode manufacturing process, allowing for scrap, schedule differences and downtime; determine the rate at which the anode vibroformer must produce to meet this takt time.

Rate calculations to align with demand are shown in Table 1.

	Green Mill	Baking	Rodding Room
Schedule	2 shifts x 5 day	3 shifts x 7 days	2 shifts x 7 days
Overall Effectiveness	85%	98%	90%
Losses	4 % scrap	3 % scrap	
Production cycle	1 anode formed every 65 sec	Firing cycle every 26 hours	1 anode cast every 104 sec

Table 1: Aligning rate with demand

Quality is determined through value in use – from customer input we targeted the rate of carbon consumption and early anode change frequency because of their direct impact on business value. Mapping back through the anode manufacturing process we identify Baked Apparent Density (BAD) as a critical anode characteristic linked to consumption. Continuing to map this deeper into the process we then identify Green Apparent Density (GAD) as critical to BAD.

This alignment of process outcomes within the anode manufacturing process with the customer value requirements is shown in Figure 5.

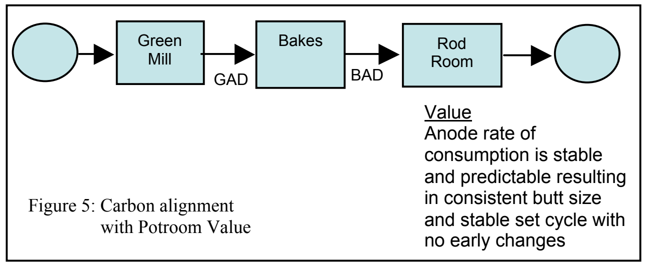

Figure 5: Carbon alignment with Potroom Value

<u>**STEP 3**</u> Establish how rate and quality will be measured at the supplier-customer interface and define built-in tests - set up systems to make it part of daily work.

Potroom measures

- Daily consumption is monitored to ensure that demand is level and predictable. Significant changes that require attention are signaled against pre-specified action limits.
- The rate of anode consumption is monitored through measures such as butt weights or exposed stubs. Significant changes that require attention are signaled against pre-specified action limits.

Carbon measures

- BAD is measured but not used to track performance because of the limited sampling and long turnaround time for results.
- GAD is measured for every anode– tracked on a run chart and response actions signaled against specified limits
- Anode forming rate is tracked on an hourly basis – recording the number of anodes produced. The target cycle rate is 55 per hour (65 seconds per anode) – if the rate goes outside specified limits, action is taken to recover the flow.

<u>**STEP 4**</u> Through the use of process mapping; drill down into the process to align the process at the operational level with the rate and quality requirements (Figure 6).

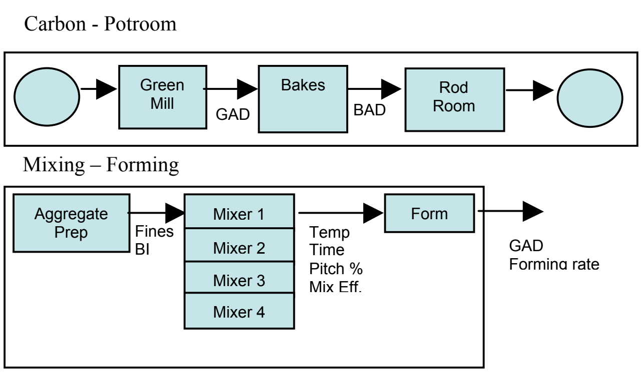

Figure 6: "Map" down from Carbon-Potroom to Mixing-Forming

NOTE: This supplier-customer relationship is between each mixer and the former – NOT – mixing and forming. This is an essential point arising from the principles of the Toyota Production System. In the view of the authors, mixing is often managed as a "black box," opening the door for wide variation in materials, mixer conditions and inputs, which is in direct conflict with the principle of specification and standardization. As a "black box," the mixing process can operate in an "ad hoc" fashion doing "whatever is needed" to deliver material to forming. Specifying each mixer establishes a standard for how each mixer must operate to satisfy the "customer requirements" 100% of the time in the most cost effective manner. Variation in GAD or RATE can be traced back to individual mixers and acted upon quickly and effectively.

REPEAT – next level – STEP 1

STEP 1 Specify what value looks like to the **Forming Process**

Using **Six Sigma** terminology

- Forming Rate ~ f (mixing time, number of mixers in service)
- GAD ~ f (mixing temperature, mixing efficiency, pitch %, fines Blaine index)

STEP 2 Specify **Mixer Rate and Quality** to meet Former Requirements

Each mixer must be capable of:

Pitch %	Set at a process specific target*
Mix temperature	165C
Mixing time	65 minutes per batch
Mixing efficiency	Visual inspection – no evidence of particles not wet by pitch
Mixers in service	6

Setting Targets

- Pitch % is set to an optimum, typically a function of raw material and pitch quality characteristics, aggregate particle size and mixing conditions.
- The optimum targets for mix temperature, pitch % and fines Blaine Index can be evaluated experimentally based on their impact on GAD, i.e., through the application of **Six Sigma**. Optimizing the process following the DMAIC method and using experimental design is the most efficient way to develop your understanding of the process.
- No experiment is required for mixing time or number of mixers – it is calculated from historical analysis of the time required to make target temperature (165C) which determines the number of mixers in service (6) required to create uninterrupted flow of material to the former.

STEP 3 Establish measures for rate and quality at the mixer - former interface and define built-in tests - set up systems to make it part of daily work.

Every mixer cycle is measured as follows:

- Time to reach target temperature
- Discharge temperature
- GAD of anodes produced from that mixer

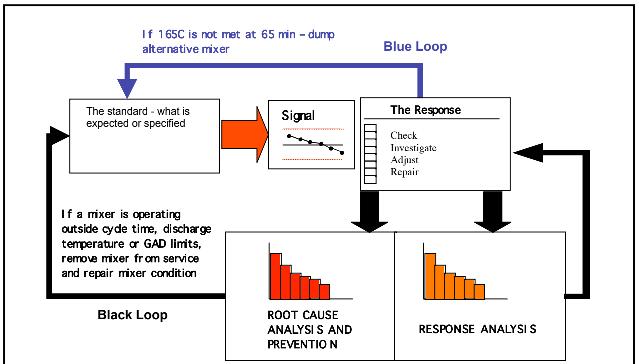

Figure 7: Blue Loop / Black Loop Control at a mixer

Set up systems to make it part of daily work. (Figure 7)

- Blue loop – If we hit the time set point, but the temperature is not on target, we use "flexibility" to protect flow to the former (the customer) and dump a different mixer.
- Black loop – On a weekly basis, examine box and whisker plots for mixing time, mixing temperature and GAD to determine if the mixers are still operating in an acceptable range – let the performance of the mixer determine when it comes out of service for maintenance (Figure 8).

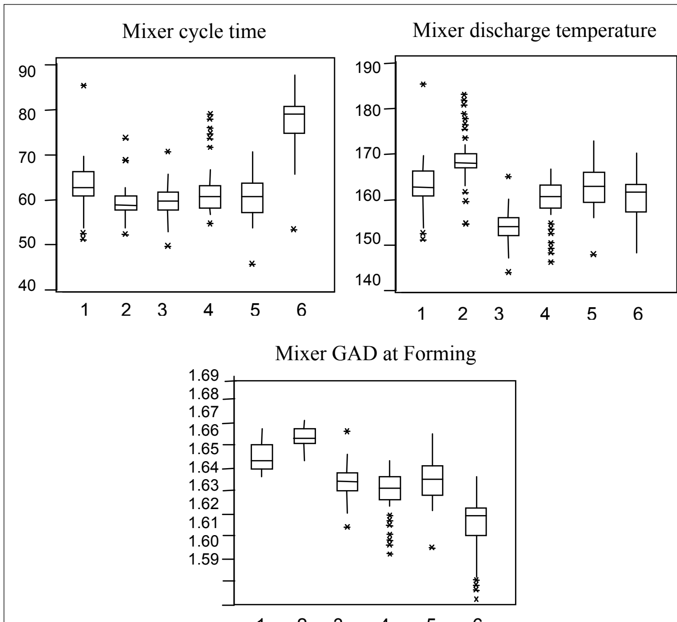

Figure 8 Weekly analysis of mixing time, mixer discharge temperature and the resulting GAD identifies mixers that need service

An important note on "buffers." *Mixers wear over time and the maintenance of mixers is critical. To protect flow to the customer, spare mixers ready to go into service are needed. The number of mixers in this "buffer" is determined by "time between failure" (not meeting time and/or temperature) and the "time to repair." This approach "pulls" mixers into service when needed as opposed to a fixed "annual schedule."*

STEP 4 Use process mapping to align mixing time and temperature – what factors drive the process ability to satisfy these outcomes 100% of the time?

Once targets are established for mix temperature and degree of mixing, further experimentation is required to determine the critical process variables that contribute to these outcomes.

- Mix temperature ~ f (flow rate of Heat Transfer Fluid (HTF), condition of heat transfer surfaces, control actions, mixer condition…)
- Mixing efficiency ~ f (wear of the mixer blade and lining, mixer energy input, temperature, Blaine Index (BI) of fines fraction, degree of pitch/coke interaction…)
- Pitch % ~ f (Pitch (QI), coke (porosity) properties, BI of fines, mixing temperature…)
- Mixing time ~ f (HTF temperature, heat transfer effectiveness, mixing efficiency…)

Having identified the critical process parameters at the operational level to maintain proper specifications for mixing temperature and time, mixing efficiency and pitch %. Two actions follow:

1. Build systems to monitor and control each of these contributing factors, e.g.:
- How will we control flow rate of HTF? A visual system inspected daily?
- Mixer condition will be monitored as described previously using weekly box and whisker plots.
- Fines fraction Blaine index is a new supplier customer interface and we repeat this 4-step process to specify, measure and control.
- The same approach can be used to set up the supplier-customer interface between the Coke and pitch suppliers with the Carbon Plant customer.

2. Develop response plans that guide investigative actions when the process fails to satisfy the specified outcomes:
   - Equipment parameters
   - Flow rates
   - Control actions
   - Operating practices

The Daily Process Management System at Work

The design of this system for daily management provides:

- Tighter feedback loops
- Quicker response to problems at the operational level that prevent small problems from escalating into larger problems and increasing the damage to business value
- Y ~ f (x) and response plans guide rapid, effective problem solving (problems are smaller and less complex)
- Specification of process and outcomes enables us to "test" the process every cycle driving continual improvement.

Alignment and Specification	The creation of value at the Carbon – Potroom level has been cascaded down to the operational level and systems built to monitor and sustain alignment.
Built-in Tests	Measures or checks monitor the process at every level to signal when the process has failed to meet specified outcomes triggering immediate action
Problems identified and solved, close to the source	Monitoring individual mixer performance every cycle enables us to respond quickly when one mixer starts to perform "unacceptably" with respect to time/temperature/GAD
Countermeasures	When the process does not meet time and temperature, we use our flexibility and dump "out of sequence" to protect flow to the customer (a pre-specified action)
Prevention	Our ability to trace variation back to individual mixers enables us to target and time removing mixers from service to perform needed maintenance to meet specified standards

Lean and Six Sigma Principles in Daily Process Management

Lean and Six Sigma are built on two basic principles:

- Variation is the enemy – standardization in the form of rigid specification is fundamental
- Waste is the enemy – it must be identified and eliminated to reduce the process to its core value adding steps

Both provide a way of thinking and a set of methods and tools that are essential in today's world of rapid, continual improvement. But to maximize the benefits from these improvement strategies, they must find their way into the design of systems for daily work.

- Processes are specified in terms of outcomes and the inputs and parameters that contribute to those outcomes.
- Measures and built-in tests are implemented to signal process "failures" quickly and early
- Actions in response to these signals are specified – blue loop or countermeasure actions (accountability of operators and supervisors) as well as black loop or root cause analysis leading to corrective actions (accountability of the level of management "one level up."
- This continual improvement cycle is built-in to daily work, and is complemented by projects as necessary; people at every level are engaged every day in the process of improvement and in a manner consistent with their role.

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