Six Sigma Keys to Lean Maintenance

How the Y = f(x) thought process can lead the way to lean maintenance reliability

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Too many times in lean manufacturing and other lean environments, 10-40 year old equipment is redeployed, moved, and organized into lean cells without adequate concern or attention to maintenance reliability. In a lean cell, unscheduled equipment downtime usually costs 10-20 times what the same equipment downtime costs in a traditional batch processing or functional department.

For example, before lean, CNC machine tool downtime may have been \$250–\$750 per hr for a single 3-5 axis machine or robot. Now, automakers who have well-configured lean manufacturing plants cite machine tool or robot downtime costs of \$2500-\$5000 per hr unless the robot misses painting a car. Then the factory is backed up and downtime cost jumps to \$3350 per min.

As a maintenance engineer for John Deere Co. in the 1970s, this writer was highly motivated by downtime figures of \$250-\$750 per hr—motivated to find ways to avoid, reduce, or eliminate downtime wherever possible. How much more motivating is lean maintenance reliability today?

Six Sigma for increased uptime

The answer to increased reliability and uptime of computers, telecom equipment, machine tools, automation controls, hydraulic systems, electronics, etc., used in lean manufacturing and other lean environments can be derived from Six Sigma's Y = f(x) and DMAIC. That is as long as the wrong (apparent) path is not followed, as explained below.

Before Six Sigma, analysis began by gathering "cause," "effect," and "result" information on each maintenance downtime situation. For example:

Cause—Bad CAU2 circuit board
Effect—X-Y axis cutting egg shapes rather than circles
Result—Scrap parts, downtime

Log books with this format were placed at each machine. Each machine maintenance situation was detailed by the electrician or mechanic as soon as the machine was repaired and the cause was known and corrected.

Soon the analysis database looked something like Table 1.

As this history table of malfunctions and failures is examined, there is little commonality in cause but great commonality in result. Even the effect is often similar from dissimilar causes.

Six Sigma improvement methods would express these malfunctions and failures in terms of Y = f(x) where Y is the malfunction, error, or defect which results from a function of x. Using this approach, three possibilities are apparent:

- Y as the effect and (x) as the cause
- Y as the result and (x) as the effect
- Y as the result and (x) as the cause

It seemed important to focus on the third approach using the result (Y) and

TABLE 1. MAINTENANCE HISTORY OF MALFUNCTIONS AND FAILURES

Cause	Effect	Result
CAU2 board	Egg shaped cuts	Scrap, downtime
Bad memory board	Part ID growing	Rework, downtime
Axis drive board	Axis oscillation	Scrap, downtime
Spindle CMD board	RPM swings	Rework, downtime
Servo valve	Y run to limit	Downtime
Bad solenoid	No coolant	Downtime
Hydraulic pump	No chuck gripping	Scrap, downtime
Hydraulic 3W valve	Turret unclamping	Broken tool holder
SCR failed	Z axis runaway	Downtime
CMD board	No X movement	Downtime
FE-2A board	Only rapid travel	Broken tool, scrap, downtime
Z-PWM drive	A axis not stopping	Scrap, downtime
Bad limit switch	X axis crash	Rework, downtime
Bad encoder	Positioning errors	Scrap, rework, downtime
Loose FB connector	Y axis run-away	Rework, downtime
Cap. on Y FB board	No Z axis movement	Scrap, downtime

TABLE 2. MAINTENANCE HISTORY WITH STRESSES IDENTIFIED

	Effect	Result
Heat Caused		
CAU2 board	Egg shaped cuts	Scrap, downtime
Bad memory board	Part ID growing	Rework, downtime
Axis drive board	Axis oscillation	Scrap, downtime
Spindle CMD board	RPM swings	Rework, downtime
Contamination Caused		
Servo valve	Y run to limit	Downtime
Bad solenoid	No coolant	Downtime
Hydraulic pump	No chuck gripping	Scrap, downtime
Hydraulic 3W valve	Turret unclamping	Broken tool holder
Surges Caused		
SCR failed	Z axis runaway	Downtime
CMD board	No X movement	Downtime
FE-2A board	Only rapid travel	Broken tool, scrap, downtime
Z-PWM drive	A axis not stopping	Scrap, downtime
Vibration Caused		
Bad limit switch	X axis crash	Rework, downtime
Bad encoder	Positioning errors	Scrap, rework, downtime
Loose FB connector	Y axis run-away	Rework, downtime
Cap. on Y FB board	No Z axis movement	Scrap, downtime

the cause (x) to try and reduce Y (downtime, scrap, and rework). More recent years of experience also show that eliminating or reducing Y also results in increased precision, repeatability, and yield for semiconductor and nanotechnology fabrication and other process industries.

The problem is there does not seem to be much commonality in the cause (x) factors as is expected by Six Sigma methodology. This would normally suggest the need for a more elaborate, expensive, and time-consuming predictive maintenance program. With enough tracking, mean time between failure (MTBF) should be able to be calculated and a prediction made as to when these devices and components are about to fail so they can be replaced before they fail.

Identify stresses

At John Deere, this was the apparent path when a single downtime situation, caused by a failed axis drive board, shocked this writer into a huge paradigm shift. It was written into the log book:

Cause—Bad axis drive board
Effect—X axis oscillation
Result—Scrap, downtime

But the simple observation was made, "No wonder the board failed, it's too hot in that cabinet!". There was a "cause of the cause." It was instantly clear that heat stress was causing much of the higher downtime experienced every summer with this vintage of CNC lathe and the stress for each downtime situation in our log books should have been identified:

Heat—Caused—Bad axis drive board
Effect—X axis oscillation
Result—Scrap, downtime

And what are the other stresses that cause electronic, hydraulic, and automation equipment downtime? In this instance the (x) factor was heat. Y (scrap and downtime) was happening as a function of (x), heat.

What are the other basic stresses that cause these seemingly random malfunctions, failures, and downtime? That very day, brainstorming identified these stresses: heat; vibration; dirt buildup; oxidation; corrosion; power surges, lightning storm transients, etc.; and hydraulic contamination.

The first efforts to eliminate heat by adding a cabinet air conditioner proved so effective that the focus moved completely away from predictive maintenance to stress elimination to prolong rather than predict MTBF. Eliminating a stress or hardening equipment against stress resulted in such an increase in MTBF that there was little sense in predicting failure when we were still finding ways to prevent the failure, prolong reliability, and increase uptime.

Now our maintenance history table looked like Table 2.

In Six Sigma terms, (x) had been identified. Of course not all seven (x) factors are present and active on any given computer, machine, or piece of equipment. But, in the 25 years since that discovery, I have not been able to add to that list of basic stresses. Sometimes there are other key issues, such as poor design, operator abuse, or inadequate component ratings, but even these can frequently be endured and downtime avoided by eliminating the related stress.

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Eliminate stresses

Now the question is what are the most cost-effective ways to eliminate these stresses. Or, how can equipment be protected against the unavoidable presence of these stresses? Possibly the most effective way to make sure these questions get answered and acted upon is to use Six Sigma and its DMAIC model:

- Define the problem
- Measure the problem
- Analyze how the problem can be eliminated
- Implement the solution, and
- Control the solution to ensure it continues and is improved if practical (kaizen).

At John Deere's Dubuque Works, 2 years of analyzing and implementing solutions resulted in cutting unscheduled maintenance downtime by 50-60 percent.

Future articles will discuss these seven chronic stresses to keep production moving with lean reliability.

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