White Paper

Maintenance Engineering

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Executive Summary

By Karl Kelton and Brent Chertow

The Business Challenge

Despite the benefits of an effective maintenance engineering function, many companies fail to make it a top priority – and suffer the results; unreliable plant and equipment, reduced throughput, poor recoveries, excessive costs, and lost business.

In capital intensive industries, maintenance costs can represent upwards of 30%-50% of total operating costs. And in many executives' minds, maintenance engineering becomes a reluctant part of this cost of doing business. Why do they have this perception? The reality is that, for a variety of reasons, maintenance and operations managers have not demonstrated the real value that maintenance engineering can add - increased throughput, lower working capital requirements, increased labour productivity, improved safety, and lower costs – all measurable on the income statement, balance sheet, and cash flow statements.

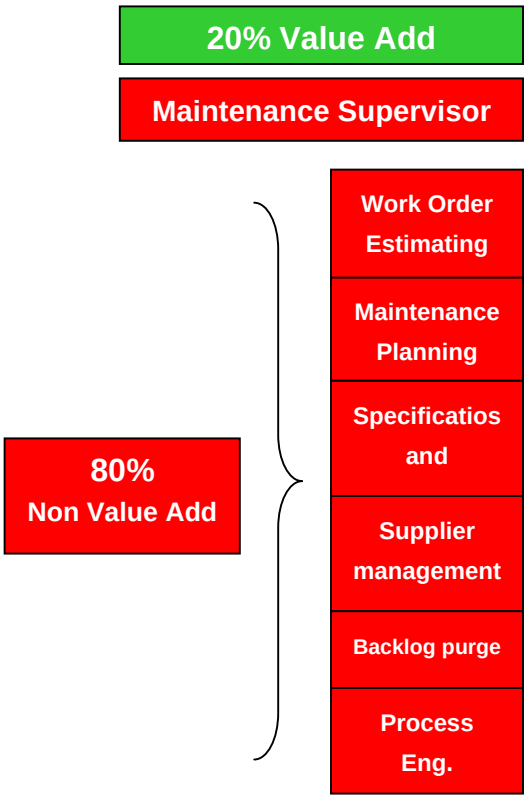
Our Point of View

Maintenance and operations managers need to do a better job in four areas:

1. Develop specific, practical maintenance engineering objectives
2. Define maintenance engineering's role in terms of maintenance strategy development and deployment
3. Actively participate in the development of the consulting skills and capabilities a maintenance engineer should have to deliver long term, sustainable value to the company
4. Implement a performance management process that holds the maintenance engineer accountable for meeting maintenance engineering's objectives built solely around how to constantly improve how maintenance gets done better - better being: higher uptime, higher processing rates, better quality of product, lower cost – all because plant and equipment are running better; at least as they were designed and expected to operate.

Let's dispel a few myths about maintenance engineering's role. In many organizations we have worked with, it is not unusual to see maintenance engineers engaged in the following activities – activities that represent upwards of 80% of their working day:

- Acting as the de facto maintenance supervisor. Too often, the actual maintenance supervisor is pulled into non-productive tasks such as expediting parts, dealing with suppliers, or data entry. Then, when a problem on the shop floor arises, who do the technicians call on?—invariably the maintenance engineer
- Establishing time and material estimates for work orders – typically the job of the maintenance planner
- Purging maintenance work order backlog
- Resolving purchasing and supplier problems
- Planning and scheduling repairs and overhauls for the technicians
- Providing specifications and drawing information to maintenance planners, supervisors and technicians
- Acting as process engineers



All of these activities may be important, even necessary, but they are *not* the responsibility of the maintenance engineer. There is absolutely no leverage over 1:1 to have a Maintenance Engineer wasting his time and ability doing this, albeit, necessary work. The Maintenance Engineer is a leader-manager, teaching and ensuring others to do this as part of his duty to develop and implement maintenance systems to do ever better maintenance.

A recent experience involved the so-called Maintenance Engineer who repeatedly spent considerable time responding to phone calls from technicians asking him the amount of wrench tightening torque required for a variety of special flange bolts around the plant. Each time the Maintenance Engineer would go to his handbook, look up the torque required and relay the information to each technician, one of 20 in a crew - a 1 to 1 leverage situation. The Maintenance Engineer would have been 20 times more effective and efficient if he bought each technician in the crew a copy of his handbook and taught them how to use it. Better yet, have the torquing information available electronically in the work order system for all equipment in the plant. That would be 20 to 1 leveraging and a much better employment of the Maintenance Engineer's time and ability.

Executive Summary Conclusion

If your maintenance engineering function is not adding measurable financial value to your bottom line, get it to do so, or replace it with one that can, and will.

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Introduction

In an earlier article entitled “Capacity Assurance: Maintenance Can Mean Competitive Advantage”, we described how the path to capacity assurance begins with a change in operating philosophy and culminates in an unwavering adherence to the execution details. In this article, we extend the discussion and focus on the value that maintenance engineering should be delivering to the organization.

First, we describe what we believe the major objectives of the maintenance engineering function should be. Second, we share with you what we believe a maintenance engineer should do, with practical, real-world examples. We conclude with a review of the consulting capabilities and skills a maintenance engineer should have to deliver long term, sustainable value to the company.

1. Objectives of Maintenance Engineering

The maintenance engineer’s primary goal should be to continually identify opportunities of significant value to their organization. These opportunities should relate to:

- Improvements in the specific asset environment (physical plant and equipment)
- Improvements in resource utilization (people, materials, services and EAM systems)
- Improvements to the maintenance management processes – including the decision support and management systems

In short, to constantly improve the way maintenance gets done so that plant and equipment are more reliable, produce at better quality or higher quantity, and that costs less to maintain. If they’re not doing that, then get them to or get rid of them. An organization gets absolutely no leverage from having a mechanical engineer on board, calling him/her a maintenance engineer, and burying them fighting mechanical equipment failure “fires”, one off’s, playing with the “toys”. A waste of time, money and talent!

2. Role of Maintenance Engineering

What is the role of the maintenance engineer? In our opinion, a maintenance engineer is responsible for the following:

1. Defining the organization's Capacity Assurance objectives
2. Developing the improvement plan(s) to achieve these objectives
3. Identifying the resources and skill sets required to execute the plan(s)
4. Developing and supporting the implementation of effective Maintenance Management Systems. This includes the Enterprise Asset Management (EAM) system and the Decision Support systems – including the Maintenance Master Schedule
5. Monitoring the progress of the plan(s)
6. Ensuring the improvement(s) deliver the expected financial and operational benefits
7. Supporting the optimization of maintenance costs. Maintenance engineers should be involved in budgeting the annual **prescribed** downtime and how that downtime will be spent on maintenance activities.
8. Providing advice and counsel on the design of new installations.
9. To lead the Organization, doing whatever it takes, to continually improve the way maintenance gets done, often in step change fashion "in the beginning".

3. Consulting Capabilities

A principle we promote is the idea that the maintenance engineering function act as the company's on site, in-house fulltime maintenance management consulting group. This group should be made up of legitimate maintenance engineers who know how to develop and improve the effectiveness of the maintenance function.

The question then becomes "what specific maintenance consulting skills and capabilities should maintenance engineers learn and practice?"

We have developed an index of skills and capabilities that has proven to be effective in organizations where maintenance represents a significant cost of doing business.

1. **"Learning to See"**

How many times have you heard the expression "Ill believe it when I see it?" One of the major hurdles in effecting maintenance performance improvement is getting people to overcome their own biases and perceptions about how work gets done and how resources are productively consumed. One way to find out is to spend time in the workplace observing, and documenting - in detail - how work is performed. Learning to see is not easy. It requires tact. It means explaining that you are there to observe how maintenance processes and activities are planned and executed, including the day to day problems that technicians face – that you are not there to evaluate them personally. It requires that the right questions get asked, and understanding that the first answer supplied often requires a number of subsequent questions to be asked before the root cause of a particular issue is identified. Conducting effective observations takes practice. Our advice? "Learn to see" early and often.

2. Developing an Effective Maintenance Organization Structure

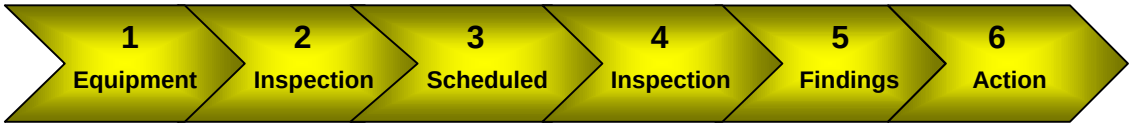
"We're on a Lean journey, how should we be organized?" "We've re-engineered our business processes and built process villages, but our maintenance costs are still too high" "We've moved from a centralized model to a decentralized model to a matrix organization, but production and maintenance still aren't working together effectively" Do these questions sound familiar? Too often, senior management becomes pre-occupied with designing a functional structure, then worrying about who they're going to fill the boxes with. Our experience tells us that ultimately, all organizations remain, or become organized vertically, by department, (maintenance, procurement, production, sales, etc.) They always will be because that is the best way to create and store knowledge, and the most practical way to channel careers. In defining the appropriate maintenance organization and structure, the first question management should ask is "what is our business strategy and plan, and how can maintenance support it?" The next question is "who are the right maintenance people to help us meet our business objectives?" Jim Collins, in his book "Good to Great" said: "People are not your most important asset. The *right* people are". If Maintenance Engineering's mandate is to effect step change improvement in maintenance performance, then here are some initiatives to define who those *right* people should be and how to get them involved in step change improvement:

- Define maintenance (capacity assurance) objectives in the context of the overall company's business objectives. The key here is to ensure that the people in Sales and Marketing, Product Development, Finance, Human Resources, Engineering, Maintenance and Production are aligned and working to a common set of objectives. Link maintenance objectives to rest of the hierarchy of objectives. Make it easy to understand and assess for everyone that matters.
- Define the maintenance accountabilities for each person that has a stake in maintenance performance improvement. Get them to "own" those accountabilities. If they refuse, they cannot deliver on the organization's expectations.
- Support the development and implementation of maintenance training programs – technical programs as well as management development programs. You would be surprised how many "non-maintenance" management people have a key role to play in how effective and efficient maintenance is delivered in their organization and they do not know it until accountabilities are designed for those positions regarding maintenance.
- Define the maintenance functional support requirements e.g. Sourcing specialist for Maintenance, Repair and Operating (MRO) supplies, stores and warehousing support, VMI support, inspection process specialists
- Develop project management requirements for major maintenance related work events e.g. annual shutdowns. This includes determining who will be responsible for managing and controlling the shutdown, and naming equipment team leaders responsible for making sure the work is executed to specification on time and budget.
- Define who will screen and prioritize maintenance work orders
- Ultimately, organizational success lies in the day to day support structures built around cooperation to get the work done. Simplicity is key.

3. Managing the Inspection Process

Effective maintenance organizations employ rigorous, disciplined inspection processes. From a systems perspective, maintenance engineering needs to support the build-out and implementation of the following processes and systems.

Figure 3. 1



1. **Equipment**
   - Identify the equipment or part that needs to be inspected
   - Repeat the process for every piece of equipment that needs to be inspected

2. **Inspection Required**
   - Define the type of inspection to be performed e.g. visual, sample analysis, x-ray, dye penetrant testing, thickness, wear loss, thermographic analysis

3. **Scheduled When**
   - Refine/update inspection schedules during PM routines
   - Determine when during the overall shutdown inspections will be done
   - Define which inspections are on the shutdown critical path

4. **Inspection Done By**
   - Determine who will be accountable for the inspection process
   - Establish who will actually do the inspections
   - Designate someone to summarize and report out the findings

5. **Findings**
   - Document the root causes of corrosion and failures
   - Determine whether capital can be deferred
   - Agree on the repairs that can wait until the next shutdown
   - Determine what equipment should be overhauled or replaced

6. **Action(s) Required**
   - Findings form the basis for defining >80% of the scope for a maintenance shutdown, or 50% of the scope for routine maintenance outside of a shutdown
   - Specify and document actions required
   - Define who will take the necessary action
   - Determine who will be responsible for monitoring the expected outcomes and benefits

To be clear here, the inspection process is critical to maintenance and it is the Maintenance Engineer's role to ensure its proper design and implementation. It is because of a great inspection

process that the maintenance technicians know before a piece of equipment or plant is handed over to them, what the job task is – no surprises. “No exploratory surgery”. The surgeon already knows what he is going to do to the patient before the operation because of all the inspections and diagnostics conducted beforehand. That’s professional and that’s what’s expected. Those doing proper maintenance without a great inspection process are “flying blind”. They’re going to be very unprepared, frequently surprised and end up doing a very costly job.

Table 3.2 illustrates various inspection tools available

Inspection Tools	
Temperature	Thickness Test
Pressure	Thermography
Viscosity	Calibration
Sample and Analysis (contamination, pH)	Dye Penetration and Ultraviolet light
X-Ray	Microscopy
Ultrasound	Metallography
Vibration	Audiometric
Visual	Current draw

4. Master Scheduling

Earlier, we stated that the maintenance engineer is responsible for the development and implementation of maintenance decision support systems, including the Maintenance Master Schedule. Generally understood to be a manufacturing and production tool, master scheduling is simply the act of matching and balancing the volume of work to be performed to the required resources – people, time, and materials. In the context of maintenance, it means coordinating the amount of planned, unplanned, and shutdown work orders with the resources available to the company to optimally schedule and execute the work.

Table 4.1 illustrates the elements required to develop a Maintenance Master Schedule

Maintenance Master Schedule Elements			
Element	**Purpose**	**Data Source**	**Reporting Frequency**
Production Volume Forecast	Input as to when equipment can be made available for maintenance, with the exception of major planned shutdowns	1.Business Plan 2. Production Plan	Monthly and Annually
Maintenance Budget	$ allocated for both routine and shutdown work	1. Maintenance Dir. 2. Maintenance Eng.	Monthly and Annually
Work Order Volumes • **PM/Inspections** • **Planned W.O.s** • **Unplanned W.O.s** • **Emergency W.O.s** • **Shutdown W.O.s**	Defines the volume of planned, unplanned, and shutdown activity for the year. Expressed in both #'s of work orders and total hours by craft for each work order category	1. Maintenance Dir. 2. Maintenance Eng. 3. Enterprise Asset Management (EAM) system	1. Monthly and Annually 2. Reviewed weekly and re-prioritized as necessary
Estimating Guidelines	Used to establish the work-to-time relationships for all scheduled work orders	1. Maintenance planner 2. Maintenance Sup'r 3. EAM system	Reviewed annually
Productivity Objective	% productivity expected in order to complete all the work on time and on budget, at the specified quality. Sensitive to current skill levels.	1. Work orders 2. Maintenance Sup'r.	Set Quarterly
Resources	Establishes # of people required by craft. To complete the work. Includes supervisors, planners and subcontractors	1. Maintenance planner 2. Maintenance engineer	Weekly and Monthly
Equipment and Materials	Defines non-labour resources based on scheduled work orders and shutdown plan	1. Maintenance planner 2. Shutdown manager 3. EAM system	1. Monthly 2. Based on shut down plan

The Maintenance Master Scheduling process is perpetually managed to ensure balance of plant and equipment stability, reliability, *and* responsiveness of the maintenance organization. If continuous improvement is a critical maintenance goal, we felt it might be useful to provide a Maintenance Master Schedule Performance Checklist .

Checklist

- Accountability for maintaining the Master Schedule is clear. The importance of maintenance master scheduling is reflected in the organization *and* reporting relationship of the master scheduling function.
- The maintenance engineer participates in the maintenance planning process.
- The maintenance planner responds to feedback that identifies master schedule issues impacting material and/or capacity availability.
- The maintenance engineer initiates the problem resolution process.
- Equipment histories are maintained by the maintenance planner.
- A written master schedule policy is followed to monitor stability, reliability, and responsiveness; goals are established and measured.
- The maintenance master schedule is “firmed up” over a sufficient horizon to ensure stability of operations. Guidelines for this firmed horizon include:
- Cumulative material lead time
- Lead time to planned resource availability (including contractors)
- Lead time to clear agreed backlog
- Master schedule changes within the “firm zone” (closest time fence) are managed; they are authorized by the maintenance director, measured, and reviewed for cause.
- Policy governs the use of safety stock to increase responsiveness and compensate for inconsistent supply and/or demand variations.
- All levels of master scheduled items are identified and master scheduled. This is particularly critical for major planned shutdowns.
- The master schedule is defined in weekly/monthly periods
- The structure of the Equipment Master List supports the maintenance master scheduling/forecasting process.
- A materials kitting or kanban approach is coordinated with the master schedule to schedule work orders to completion.
- A weekly master scheduling communications meeting exists and is attended by production, procurement, and maintenance.
- Output (completed work orders) is measured in terms of cost, productivity, and quality. Weekly and monthly performance are compared to planned performance targets; reasons for variance are highlighted with appropriate analysis and potential resolution.

The final element associated with Maintenance Master Scheduling deals with ongoing education. Just as the modern manufacturer understands that the road to success is paved with continuous improvements, maintenance engineers who appreciate the benefits of maintenance master scheduling, understand that knowledge and operational competence are critical. A best-in-class maintenance master scheduling company maintains an ongoing education program that continues

to develop more master scheduling organizational expertise. It is the maintenance engineer's responsibility to support the development of this expertise.

5. Project Management

The discipline of project management includes providing the tools and techniques that enable the project team (not just the project manager) to organize their work to meet the constraints of scope, time, cost, performance, and risk. In the context of maintenance, the maintenance engineer has a responsibility to ensure these tools and techniques are a) developed, b) in place, and c) effectively deployed. The tools and techniques need to be developed and executed according to the nine knowledge areas in project management:

- Project Integration Management
- Project Scope Management
- Project Time Management
- Project Cost Management
- Project Quality Management
- Project Human Resource Management
- Project Communications Management
- Project Risk Management
- Project Procurement Management.

Our intent is not to describe each of these concepts and principles. They can be referenced through the Project Management Institute (PMI) or the Project Management Body of Knowledge (PMBOK). Rather, it is to provide the Maintenance Engineer with a model to assess Maintenance project management capabilities. Based on the assessment results, he can then work with maintenance to upgrade these capabilities.

Figure 5.1 Maintenance Project Management Maturity Level Model

	Level 1	Level 2	Level 3	Level 4	Level 5
	Non Existent	**Initial**	**Repeatable**	**Managed**	**Optimized**
Process	Project Management Office (PMO) processes are not defined or deployed	Core PMO processes are defined and deployed for key programs. Processes focus on bringing visibility to scope and objectives and monitoring status of ongoing programs.	Initial definition and deployment of all PMO processes. Formal and consistent project management processes aligned with industry standards (PMI). Management of project life cycle.	Processes fully deployed throughout organization. Consistency of practices enables knowledge sharing and rotation of resources across programs / projects.	Processes continually improved to integrate leading practices. Alternative procedures adapted to Plants or Program types / size. Consistency with IT, MandA and other business PMOs.
Roles	Job descriptions not defined (tacit information only). No personnel dedicated to formulating.	Program manager role introduced. Training available and resources responsible for core project management processes.	Permanent staff accountable for program planning and ongoing PMO and Program management. Formal training on Program and Project management processes for all Program / Project managers.	Dedicated centralized or virtual PMO team. Succession and career planning in place. Training adapted and delivered to all program / project stakeholders.	Continuous education and training provided to Core and Extended teams. 360˚ performance evaluation conducted for PMO, Program and Project leaders.
Tools and Technology	No tools or technology supporting PM processes.	Toolkit is identified and selected. First version of Excel and PowerPoint based tools and templates.	Second or third generation of Excel or PowerPoint-based tools and templates, integrating feedback from users. Toolkit is deployed and used across Maintenance organization.	Integrated enterprise wide Program / Project management toolkit. Only large initiatives managed using the advanced functionality of the toolkit. Use of a rolling master plan for continuous planning.	Integrated enterprise wide portfolio management toolkit. All programs / projects managed using approved tools and methodology. Integration with HR and Financial management tools.
Performance Measures	No performance measure exists. No benchmark information considered for programs/ projects.	Program / Project scorecard with basic indicators (budget, schedule, scope). Basic business cases with a single financial target (EVA, ROI, etc.). Business case is never updated and benefits are not tracked.	PM scorecard with leading indicators (risk, change readiness, earned value, etc.). Scorecard used for all Programs / Projects. Business case is updated and some benefits are tracked.	Impact on Strategic Business KPIs is identified and tracked. Financial benefits are tracked. Performance measures of past projects used in estimation of new projects.	Program / Project indicators are changed to monitor and address new issues. Maintenance Program/ Project scorecard integrated with business scorecard. Performance measures tied to compensation.

Given a maintenance engineer's responsibility is to strive to develop Level 5 Maintenance Project Management expertise, we advocate the following:

At Level 5, a maintenance organization's project management methodology operates routinely, and projects meet schedule, cost, technical and quality requirements. Roles and responsibilities

in the maintenance organization are well understood. Accordingly, this maturity level is characterized, and focuses on, continuous improvement. The emphasis at this level is on preventative, not just, corrective actions. Common causes of project problems are documented and tracked so that preventive actions can be taken.

The maintenance engineer focuses on the processes by which project management is practiced, ensuring that any common causes of problems are prioritized and systematically eliminated. The maintenance engineer strives to improve its project management processes and refine them to meet new business challenges. For example, maintenance regularly participates, in and is active in, benchmarking forums as a way to generate ideas for improvement and to refine its metrics. It also works to refine and expand knowledge-based systems for decision models.

At Level 5, Project Management excellence is organized according to six objectives, all of which focus on continuous process improvement.

Objective 1: Continuous project management process improvement is established and maintained

Objective 2: Appropriate new technologies for project management are planned for and transferred in to normal practice throughout the maintenance organization.

Objective 3: Projects selected are aligned with strategic business objectives.

Objective 4: Maintenance engineering develops a strategic plan for long-term development of the competencies and workforce needed for maintenance project management.

Objective 5: Maintenance has developed a structured approach to project team performance incentives that rewards both individual and team accomplishments

Objective 6: Participation in improving personal competencies in project management is organization-wide.

Finally, here are *7 Key Performance Measures of Project Management Excellence*:

1. % of projects completed on time
2. % of projects completed on budget
3. % of planned benefits vs. actually realized
4. % of modifications/enhancements requiring business case update
5. Maintenance engineering rework cost/Total project cost
6. Customer satisfactions survey score
7. Number of technologies transferred (knowledge and capabilities)

6. Cost Management

Earlier, we stated senior management often views the maintenance engineering function as a cost depleting, unfortunate necessity. This view stems in part from the lack of disciplined, maintenance cost management processes. If maintenance engineers want to dispel this view, they need to become proficient in the following cost management processes:

- Cost estimating
- Financial justification and Trade-off analyses
- Budgeting and control

Cost Estimating. Equipment and materials, time and manpower. Multiple techniques are available for activity-duration estimating. These include: a) Monte Carlo to calculate multiple durations with different sets of assumptions, b) PERT to calculate project duration, c) Analogous estimating if there is limited information available about the project, and d) expert judgement guided by historical information.

For major projects, lifecycle cost analyses are prepared to estimate costs and risks associated with critical decisions. Lifecycle cost models are used for projects at their inception as well as for projects in progress.

> Note 1: Actual productivity data should be used as a basis for resource estimating.

Financial justification and Trade-off analysis. Required for all major repairs, modifications, "replace in kind" or new technology. For each, the maintenance engineer needs to ensure that a justification is prepared that provides the basis for evaluating future selection trade-offs. Trade-offs include, but are not limited to:

- Safety
- Profitability potential e.g. throughput, unit cost reduction, yield
- Risk e.g. environmental, regulatory, business interruption
- Capital requirements
- Resource availability
- Schedule
- Ease of implementation
- Payback and ROI
- Operating necessity

Financial justification methods include NPV and Differential Cash flow Analyses against multiple alternative solutions/opportunities. Maintenance engineers need to understand the time value of money. And, they need to evaluate alternatives in the context of operating capital implications and cost.

> Note 2: All modifications should be subject to a rigorous gate keeping and financial analyses process.

Budgeting and Control. The maintenance engineer must be involved in the preparation of a cost management plan for all major repairs, modifications, "replace in kind" or new technology. The cost management plan is the basis for performing budget and cost control management activities. It includes the assignment of roles and responsibilities for budget and control activities.

Cost control elements typically include:

- Monitoring cost performance to detect budget variances
- Ensuring that changes are recorded in the cost baseline
- Preventing incorrect or unauthorized changes to the cost baseline
- Informing appropriate stakeholders of authorized changes

Note 3: The maintenance engineer needs to ensure that management and contingency reserves are established for major projects.

- Management reserve is for risks that are unknown and unknowable to the project stakeholders
- Contingency reserve is for risks that have been identified in advance of their occurrence, and that can be budgeted on an individual-risk basis
- Management reserves and contingency reserves constitute the project's risk budget

7. Maintenance parts and services procurement

Nothing is more frustrating to a maintenance technician than to expect readiness of parts, tools and contractors, and find out they're not. If key performance in Procurement processes is: the "right" parts (and service) in the "right" place, at the "right" time, in the "right" quantity, at the "right" cost, then what is maintenance engineering's role in this process? We submit the following:

- Identify critical parts and equipment/services
- Identify the appropriate usage, quantities, and re-order levels
- Assess the overall cost structure of the parts and service procurement process
- Assist in contract negotiations – select the best "key" suppliers
- Ensure quality and specification requirements are set and met – approve modifications
- Establish a flagging/exceptions system on key parts and services to ensure procurement effectiveness

Work order screening and prioritization. Together with maintenance supervisors, planners, and production foremen, the maintenance engineer needs to meets daily to accept, reject and prioritize accepted work orders. Maintenance engineering establishes a set of decision making criteria to help maintenance and production decide "yes" or "no" to accept the work orders and put them in priority.

Train Technicians and Operators. Best-in-class organizations understand that promoting operators and technicians into front-line management roles on the basis of their technical skills is not sufficient. Foremen, supervisors, and managers need strong organizational skills, problem solving skills, as well as several of the so-called "softer" skills e.g. communication, conflict resolution, negotiation, to drive performance improvement *and* foster a culture of continuous improvement. In many respects, maintenance engineers are uniquely positioned to facilitate the development of these skills in technicians and operators. They work with maintenance and production on a daily basis. They're involved in operations and capital budgeting. They participate in procurement decisions affecting the plant. They're familiar with inspection processes and get involved in plant decisions that may affect product quality. And, as mentioned earlier, they are responsible for designing and implementing the appropriate maintenance cost management processes and systems. Here's a sample of some of the programs maintenance engineers can train technicians and operators on:

- Train technicians how to anticipate problems before they occur including how to use Failure mode, effect and criticality analysis (FMECA), Mean time between failure data (MTBF), Mean time to repair data (MTTR), Inspection data, and lifecycle cost data.
- Train technicians on how to "Learn to See" - to identify the root cause of problems and problem resolution options.
- Train Technicians on how to trouble-shoot.
- Train operators on equipment limitations and how to operate the equipment effectively.
- Train operators and technicians on how to hand off equipment for maintenance, and then restart as efficiently as possible.
- Train both groups on Six Sigma and Lean manufacturing techniques e.g.
    - SPC
    - SMED
    - Pareto analyses
    - 5S
    - Supplier relationship management (SRM)

Conclusion

Maintenance engineering isn't glamorous. But smart, capital-intensive organizations are transforming their maintenance and maintenance engineering functions into strategic, value-adding processes – value that's hitting the bottom line. And that's something that senior management *can* get excited about.

White Paper Index