VI. METRICS/MEASURES OF PERFORMANCE

Summary

Metrics are essential within the Physical Asset Management process. Beginning with benchmarking, they help management and plant personnel understand the business and mission requirements, identify opportunities to increase effectiveness, and measure performance to objectives. Physical Asset Management links metrics so that improvements in equipment and work effectiveness are connected to the resulting contribution to business and operating objectives. Physical Asset Management metrics begin with business measures such as RONA and ROCE. They include industry benchmarks such as cost per Unit and Replacement Asset Value. Effectiveness metrics cascade through overall, availability, yield, quality and cost measures of performance. Equipment effectiveness and work productivity measures are included in this range.

A. INTRODUCTION

Metrics are an objective means of measuring performance and effectiveness. There is a saying, “You can't manage if you can’t measure.” That leads to, “Unless you are measuring you are only practicing”[10] and “You will achieve what you measure.” Metrics are a two-edged sword. On one hand, metrics are necessary to establish objectives and measure performance. On the other, incorrect or disconnected metrics can mislead and result in unexpected, sub-optimal results.

> *“People don't always use measures to get better, they manipulate measures to look better.” Wrong measures lead to bad decisions.*[160]

Everyone engaged in equipment improvement processes must understand how the business operates and the financial metrics that the business uses to measure results and track improvement. There must be a direct connection from improved equipment performance to overall operational performance (i.e., asset productivity), throughput, quality, and cost—all of which are essential mission/manufacturing objectives. Metrics must demonstrate the value of asset productivity improvements in terms of financial performance. This is the only means of securing the resources needed to implement improvements.[62, 108]

A hierarchy of distinct metrics, all linked to corporate goals, is vital to the success of a corporate program of overall Physical Asset Management. Metrics are necessary to identify competitive opportunities, prioritize resources, and measure the progress and effectiveness of improvement initiatives. Metrics help to better understand the contributors to availability, production output, quality, and cost, as well as what drives plant profitability.[62]

> *A managing system with safety, finance, production, cost, and quality metrics at both management and working levels, and real-time directed feedback, is imperative.*[160]

Metrics and their associated financial results are key links between business and financial executives and personnel engaged in equipment management. They are essential in conveying the corporate value and return gained by improved equipment reliability and overall effectiveness. Metrics also provide the basis for justifying the sustaining investment of personnel and resources required for Physical Asset Management.

A valid comparison of performance measurements requires consistent definitions and rules. For example, is availability reduced when equipment that is spared or otherwise not required removed from service for maintenance? The causes of downtime—market effects (lack of sales/demand), operational considerations (shift to an alternate source for economic reasons), process difficulties, and equipment malfunctions (unreliability)—must be delineated. Failure to properly identify cause will skew availability and reliability values and may lead to incorrect conclusions and prioritization of effort.[47, 62]

Metrics must cascade from high to low levels so that objectives are consistent and activities are connected.

> *Equipment Management metrics must connect directly to corporate/mission objectives and demonstrate the contribution to manufacturing effectiveness. If the corporate goal is to gain greater uptime and/or quality, the metrics must directly relate to the goal. Metrics that aren't related to the goal (e.g., percentage of Preventive Maintenance accomplished as a percentage of overall maintenance) may be counter-productive and lead improvement efforts in the wrong direction.*[42, 108]

Figure 6.1 illustrates the family of linked benchmarks and metrics discussed in the following sections. The differentiation is somewhat arbitrary and the metrics tend to overlap. Flow, linkage and consistency of purpose are of prime importance.

At the top tier, return on equity/assets demonstrates the corporation's ability to create shareholder value. This level must cascade to linked production and asset effectiveness metrics and the elements that compose each. The latter demonstrates the effectiveness of equipment management, measures the contribution to profit and value (production or mission capability), identifies costs (to support the budget process) and verifies the effectiveness of improvement initiatives. Linkage must include the ability to "drill" down from a top tier metric all the way to the lower level metrics for the purpose of identifying the cause of deviations.

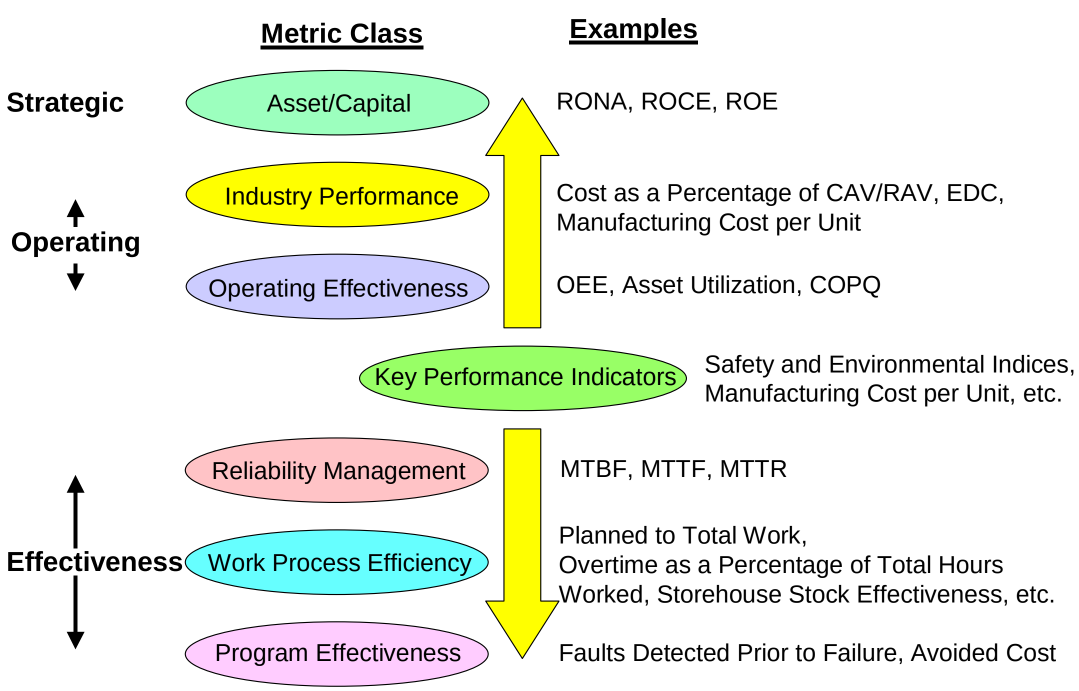

Figure 6.1 Metrics – Overall

Ownership demands answers the question: "How are we doing?" Apart from preschoolers' T-ball, would any competitive endeavor be meaningful without some sort of scoring system? How could effectiveness be measured? What would motivate improvement? Corporations that are immersed in the process of optimized equipment management all report that demand for scoring metrics is essential. Metrics increase interest, ownership, and enthusiasm for the process.

Metrics must be concise. Focusing on too many areas at once may result in information overload and increase the difficulty in directing limited resources to highest value activities.

Metrics are crucial in the strategic planning process for optimizing the application of resources to achieve corporate objectives. Participation by all involved in the equipment management process, especially when setting objectives, is essential to developing the commitment and optimism necessary to achieve the goal. Leaders report that they are often surprised by the ambitious objectives and level of commitment that result from a clear needs statement conveyed to working-level teams chartered to develop action plans.

Management is accountable for implementing an equipment management strategy to meet the corporate/mission objectives. This level includes overall and performance metrics that connect upward to corporate objectives, as well as downward to specific equipment performance, work processes and technical metrics. The lowest tier metrics must identify requirements in areas such as staffing and training requirements.

At the technical level, metrics are used to monitor the performance of specific processes, systems, equipment and components. Used largely by team leaders, engineers, and technicians, these metrics identify opportunities and measure the performance of the ongoing optimization and continuous improvement process.

A valid comparison of metrics within and between corporations requires precise, strictly defined terms. For example, several metrics that are widely used to compare effectiveness within the hydrocarbon processing industry are based on Replacement Asset Value (RAV). When corporations using RAV as a basis are asked for their method of determining this value, major variations are apparent. Mean Time Between Failure (MTBF) is another example. There are many definitions of "failure" that significantly affect the value of MTBF calculated by different companies.

Wherever possible, definitions should conform to industry conventions. Definitions must include the metric itself, all of its components, and the method of calculation. Those who will use the metric and be accountable for results must understand and agree on the definition. Definitions should be printed and readily available to ensure consistency of application.

Comparing metrics also requires consistency of mission, overall intensity, location/environment and even age.[(62)] Consider a race car and a passenger car. Even though both may have an internal combustion engine, four wheels and operate on a road, major differences in mission and overall intensity significantly limit the number of metrics that might offer a valid comparison between the two.

Metrics must be understandable, directed to the requirements of users and controllable through work activities by those charged with compliance. At the upper levels of a corporation, asset and capital based metrics, such as Return On Net Assets (RONA), are of greatest importance. At the working levels, RONA holds little meaning and is only marginally controllable. However, improving MTBF (and thereby RONA) by eliminating equipment defects is both meaningful and controllable at the working level. Thus, effective metrics measure results which managers and workers can control and change. And this sense of control, contribution and ownership is vital to the overall optimization and improvement process. Employees at all levels in the organization must understand the metrics for which they are responsible and why those metrics are important.

In addition to sharing a common definition of metrics, companies must ensure the accuracy of measured metrics. Metrics should be measured under consistent conditions within the process. For example, a determination of the average drive time from home to work may or may not include the time required one day a week to fill-up with gasoline. If it did, you might find yourself five minutes early on the days you didn't purchase gasoline and ten minutes late on the day you did. This simple example highlights an important issue that is all too often overlooked. Metrics must represent the process. If the process changes, the performance metrics must change also. In the simplified example, the metric should be made more descriptive of the process; average driving time to work without stops for gasoline, groceries or other errands. From this basis, one could calculate the average time required to fill up with gasoline, get groceries, etc. to arrive at an accurate metric for both the normal process and the exceptions.

There also must be consensus on the exact starting and stopping point in the process. Most frequent airline travelers have experienced this issue. Airline on-time departures are measured on the basis of pushback from the gate compared to scheduled departure. Planes are often pushed back ten feet where they remain for an hour or more due to traffic, weather or other delays. However, by the airline's rules, the flight made an on-schedule departure!

In the industrial world, metrics must be seen as a positive force driving improvements that are beneficial to all. This is an essential step in tracking progress toward the necessary improvements. Otherwise metrics will be manipulated like aircraft pushbacks to ensure that performance, representative or not, is as high as possible.

B. BENCHMARKING

Almost every aspect of business can be improved. Even recognized, world-class competitors understand that companies have limited pockets of excellence. No facility is excellent in every area.(22) Leaders also recognize that tools, techniques, and results from other companies are a vital part of the process. Critical self-examination must occur on an ongoing basis to recognize opportunities for improvement and take full advantage of changing state-of-the-art techniques.

Benchmarks establish an organization's reference objectives. Benchmarking is:

> *A systematic process for measuring "best practice" and comparing the results to corporate performance in order to identify opportunities for improvement and superior performance.(35)*

A realistic benchmarking effort is the first step toward understanding real conditions and recognizing opportunities for improving the effectiveness of an equipment management program.

> *Benchmarking is a means to gain insight into competitive realities and define the objectives and measures of performance needed to initiate positive change and to manage for greatest effectiveness(6).*

In a growing number of cases, enlightened managers understand that equipment management is a key component of business operations and a contributor to—rather than a detractor from—the bottom line. In the long run, top-down, peer and working-level support are all essential for success. Benchmarking provides the insight required to attain organizational buy-in.

The benchmarking process, illustrated in Figure 6.2, has four essential steps:(9, 92)

1. Select a comprehensive set of parameters for comparison
2. Select reliable internal and external sites for comparison, based on performance
3. Compare own parameters with "best-of-best" measures
4. Identify areas of greatest opportunity

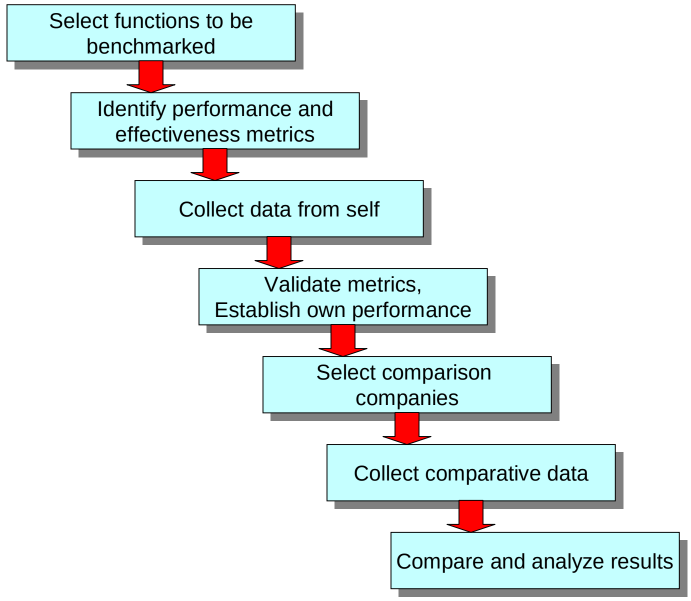

Figure 6.2 General Benchmarking Process[10]

One company elected to benchmark in six areas:[93]

1. Leadership
2. Planning and scheduling
3. Preventive and Condition-Based Maintenance
4. Reliability improvement
5. Spare parts management
6. Contract maintenance management

Power generating companies have traditionally benchmarked in more objective areas, such as:[6]

- RAM, reliability, availability, non-fuel operating and maintenance
- Fuel costs and heat rates
- Capital effectiveness

Successful benchmarking begins with consistent definitions. Activity Based Accounting and a consistent chart of accounts for equipment costs are essential. Data collected should be matched to the data available for comparison. There is often a tendency to want too much data.[6]

Benchmarking methodology must: [6]

- Be plant, process and/or equipment specific
- Consider the reliability of existing data sources
- Be easily understood
- Be repeatable
- Demonstrate cause and effect for the resulting strategy
- Be useful for follow-on monitoring

The comparison to "best practice," often called a Gap analysis (see Chapter VII), leads to a prioritized array of optimizing changes directed to achieving "best practice" levels of effectiveness.[55] A more detailed diagram of the benchmarking process and how benchmarking fits into an overall process of improvement process is illustrated in Figure 6.3.[35]

In a multi-business enterprise there may be a broad variation in performance resulting from factors such as type and intensity of processing. Leaders recognize that all efforts should not necessarily be directed to the largest apparent Gap; profits can be increased in all areas and resources should be allocated accordingly.[160]

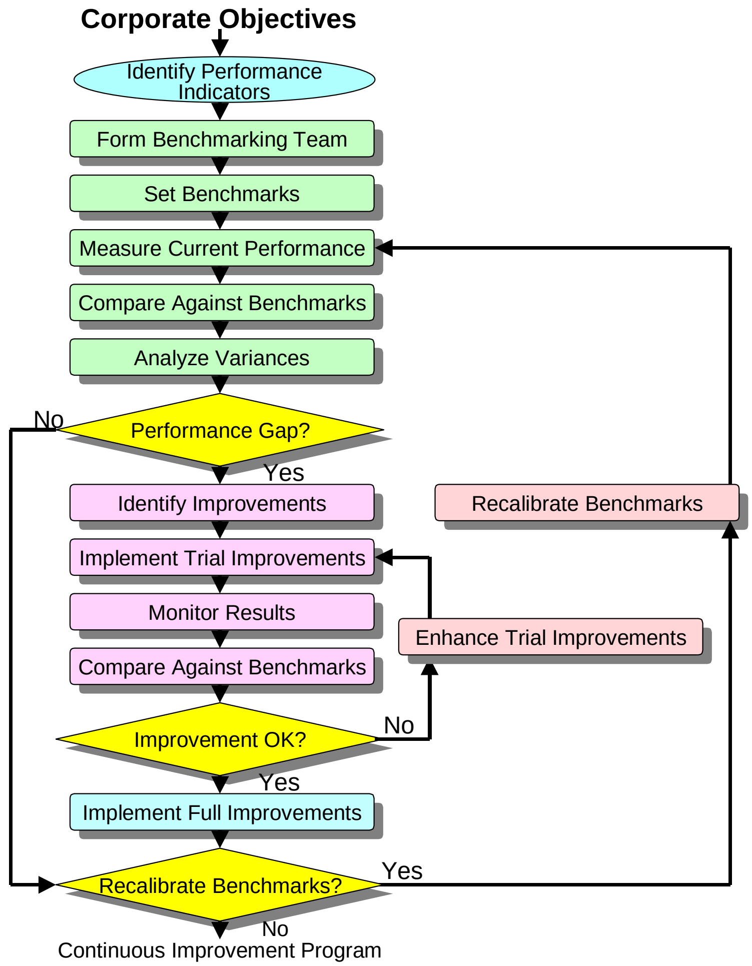

Figure 6.3 Detailed Benchmarking and Improvement Process[35]

Benchmarks are typically in four categories: industry, process, functional and internal.[35] Benchmarks may be obtained from surveys, exchanges with similar organizations or they may represent organizational goals and objectives. In any case, care must be taken to ensure that objective values derived from benchmarks are realistic and attainable. Objectives that are unrealistic will not gain the commitment necessary for success. Leaders report that allowing working-level implementation teams to establish performance objectives typically leads to both ambitious goals and a commitment to their attainment.

External industry-wide and internal benchmarks are both valuable to assess performance. Each industry has several, generally accepted, overall "world class" benchmarks that are useful for determining comparative performance (e.g., tons of steel production per availability hour and assembly hours per automobile).[108] From there, internal corporate or facility metrics can be established for each component within the overall benchmark to prioritize and drive the improvement process. Figure 6.4 illustrates the decomposition of an industry benchmark into individual system, equipment and component metrics.

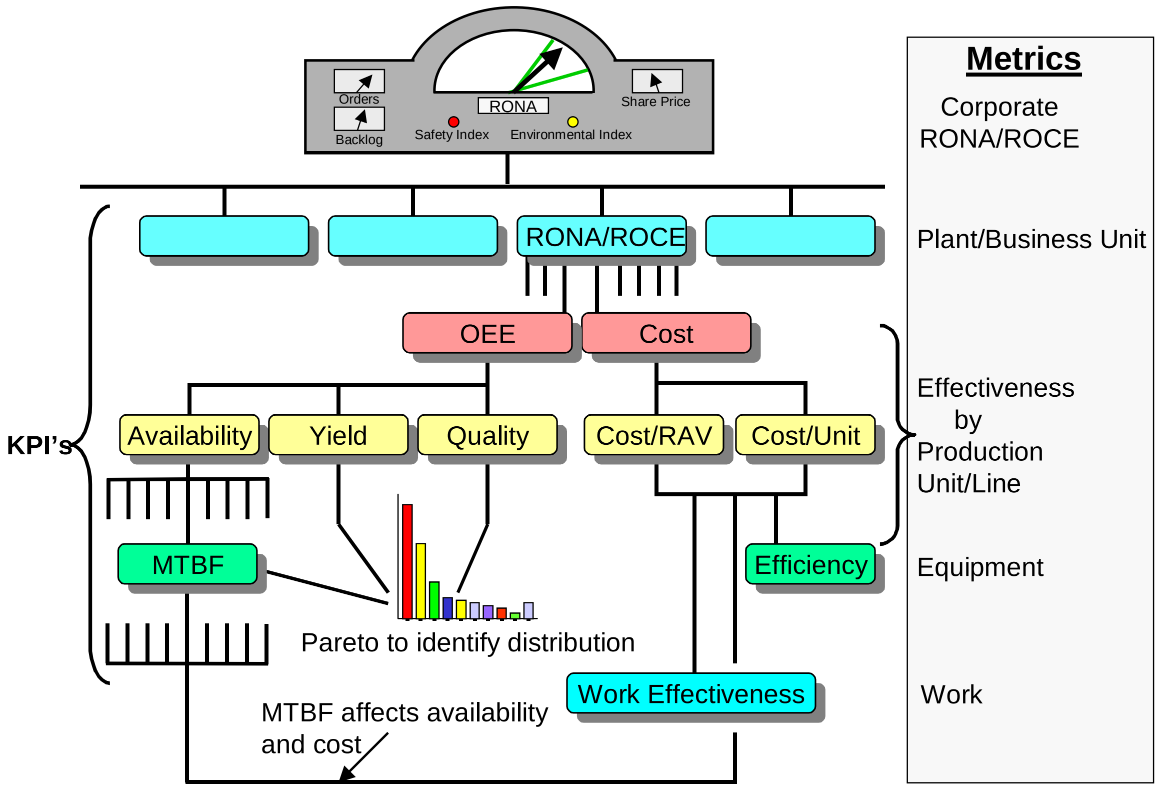

Figure 6.4 Decomposition of a Benchmark

There are several rules of etiquette that must be incorporated into an external benchmarking process. Most important, refrain from requesting anything that your company would be not able or willing to provide. Chances are others will be under the same restrictions. Benchmarking with a non-competitive business avoids many of the problems associated with giving or receiving proprietary information that may be considered trade secrets.

Benchmarks should be used as performance indicators and drivers for continuous improvement and objectives for cost reductions. Some companies risk-adjust opportunities for improvement and then evaluate initiatives to determine which have the highest returns.[160] Benchmarks should not be used as performance goals; this can lead to temporary, short-term fixes that have an adverse long-term impact.[84]

Gaps to benchmark performance must be followed by a comprehensive improvement plan. The plan must include interim metrics and performance indicators.[52] Interim metrics monitor the continuous improvement process, verify progress to a longer-term objective, and indicate changing conditions and/or the need for additional action. Benchmarking is a continuous process.[35]

Benchmarking to improve performance may include non-competing partnerships. A large U.S. Navy maintenance group recognized the need to improve its maintenance response times. It developed a working partnership with a national research laboratory, a major university, a regional utility company and a county department. Over the course of the next year, the effort led to the identification of 21 distinct improvement ideas. Some of those challenged bedrock organizational values, long held work management policies and practices and even existing Federal regulations. All of the participants benefited from the experience. The effort led to the establishment of an informal assistance network that encouraged members to contact one another to resolve other issues. Over the course of time, each member organization excelled at some work practices that it could share with the others. Other such groups will likely have a similar experience.

Learning operating and business requirements and priorities for equipment management may be the most important initial benefit of benchmarking. Once the gaps to best practice have been identified, everyone involved in the equipment management process should begin to explore opportunities and detailed initiatives for improving efficiency and effectiveness.

Efficiency Effectiveness

Repeating an earlier illustration, there is a clear difference between efficiency and effectiveness, Figure 6.5.

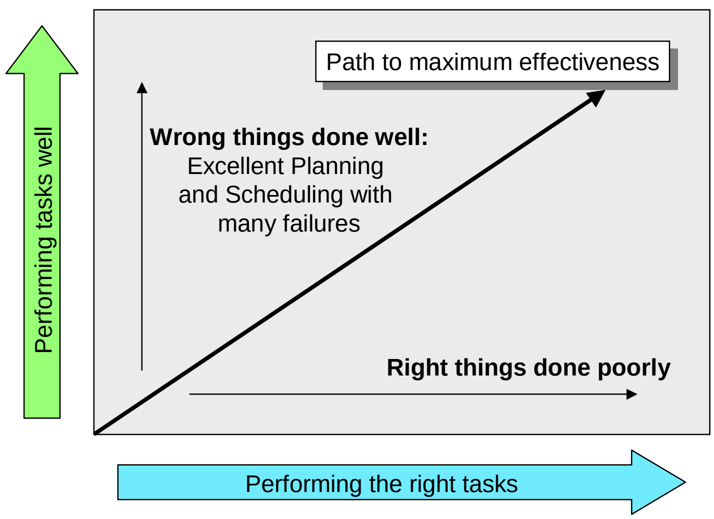

Figure 6.5 Effectiveness is more than Efficiency

Efficiency:

Performing a given task (not necessarily the correct task) well (e.g., budget to actual, PM completion)

Effectiveness:

Performing the correct task efficiently (e.g., safety, availability, quality, output)

- Efficiency is *task* oriented, effectiveness is *results* oriented.
- Efficiency and effectiveness metrics at each level in the performance measurement hierarchy must focus on mission and business results.[160]

Figure 6.6 contains some best practice benchmarks.[35, 160]

Figure 6.6: Best Practice Benchmarks [35]	
Category	**Benchmark**
Yearly Maintenance Costs:	
Total Maintenance Cost / Total Manufacturing Cost	< 10-15%
Maintenance Cost / Replacement Asset Value of the Plant and Equipment	< 3%
Hourly Maintenance Workers as a % of Total	15%
Planned Maintenance:	
Planned Maintenance / Total Maintenance	> 85%
Planned and Scheduled Maintenance as a % of Hours Worked	~ 85-95%
Unplanned Down Time	~ 0%
Reactive Maintenance	< 15%
Run-to-Fail (Emergency + Non-Emergency)	< 10%
Maintenance Overtime:	
Maintenance Overtime / Total Company Overtime	<5%
Monthly Maintenance Rework:	
Work Orders Reworked / Total Work Orders	~ 0%
Inventory Turns:	
Turns Ration of Spare Parts	> 2-3
Training:	
For at least 90% of workers, hrs. / Year	> 80 hrs/yr
Spending on Worker Training (% of Payroll)	~ 4%
Safety Performance:	
OSHA Recordable Injuries per 200,000 labor hours	<2
Housekeeping	~ 96%
Monthly Maintenance Strategies:	
PM: Total Hours PM/Total Maintenance Hours Available	~ 20%
PDM/CBM: Total Hours PDM/Total Maintenance Hours Available	~ 50%
PRM (planned reactive): Total Hours PRM/Total Maintenance Hours Available	~ 20%
REM (reactive, emergency): Total Hours REM/Total Maintenance Hours Available	~ 2%
RNEM (non-emergency): Total Hours RNEM/Total Maintenance Hours Available	~ 8%
Plant Availability:	
Available Time / Maximum Available Time	> 97%
Contractors:	
Contractors Cost / Total Maintenance Cost	35-64%

Benchmarks based on the author's (Kyoumars Bahrami) experience and available literature. Each category benchmark will vary from industry to industry, and with time.

C. USE OF METRICS IN THE IMPROVEMENT PROCESS

Benchmarking leads to objectives. Metrics are the score. There must be accountability for metrics and the status that the metrics represent. Some organizations assign people by name to each metric.[160]

To take full advantage of the benefits of metrics, the metrics should be clearly displayed. Displaying metrics often has an immediate positive effect that encourages everyone to achieve objectives in the functional area being measured.

D. COMMONLY USED METRICS, ADVANTAGES AND LIMITATIONS

Figure 6.1 (presented earlier) illustrates a family of corporate metrics—from asset and capital-based metrics to technical and indirect metrics. Metrics must link to each other and to financial performance of the enterprise at several levels. A proposed financial model illustrating the basis for metric is discussed in Chapter V.

Corporate Asset and Capital Based Metrics

Corporate-level metrics are typically asset or capital based and measure creation of shareholder value. As the top tier, corporate metrics are used to develop and support strategic decisions affecting overall objectives, mission, production, cost, and staffing strategies. Examples include Return On Net Assets (RONA), Return On Capital Employed (ROCE), and Economic Value Added (EVA®). EVA® is a measure of profitability above the cost of capital based on the precept that increasing capital is a measure of increasing shareholder value.

Some companies use a normalized EVA®-type measure called Activity Value or Contribution Margin.

> *One company using Activity Value requires results in excess of 20 percent of sales in good years and no less than zero in bad years.* [50]

Adherence to this objective means that the company's profitability should never fall below the cost of capital. The company measuring Contribution Margin will close plants with negative results that are considered a drain on shareholder value.

Other companies use Return On Equity (ROE) or Return On Assets (ROA) as a governing corporate metric.[160] At least one company using ROE recognized that it must demonstrate a better return on capital than others in equivalent industries in order to attract investment and build shareholder value. This exemplifies the need for EVA®.[160]

Overall Effectiveness Metrics:

> *Asset Utilization, Overall Equipment Effectiveness (OEE), Cost Of Poor Quality (COPQ), Uptime, Operational Readiness, Availability, Cost of Unavailability, and Downtime*

Overall effectiveness metrics are top-level industry measures used to evaluate operating and quality performance. Overall Equipment Effectiveness (OEE) from Total Productive Maintenance (TPM) is a common metric used to measure production effectiveness. OEE is the product of normalized availability (uptime), production throughput (yield) and first-run-quality. OEE is a measure of process and equipment effectiveness when the equipment is scheduled to run. [10, 160] In terms of OEE, "world class" performance is said to be 85 percent or greater for continuous processes and 80 percent or greater for batch processes. When demand exceeds capacity, any reduction in OEE represents lost profit.[112]

One caution with OEE—availability must coincide with operating requirements. This is especially important when requirements to operate are less than 100 percent, such as a peaking power station. Timed Availability, discussed in more detail in Chapter V, requires calculating availability relative to windows of required operation.

Typical North American manufacturing facilities report OEEs near 50 percent. This indicates a "hidden" plant recoverable capacity of at least 35 percent, Figure 6.7. As illustrated in Figure 6.7, the hidden plant includes:

- Downtime
- Process-related rate losses
- Quality and yield losses

A lack of demand may also contribute to the hidden plant.[10]

Downtime can be broken down in a number of ways. One reference suggests dividing total downtime into the following five categories: [112]

1. Process
   - Changeover
   - Set-up and adjustment
2. Logistics
3. Sales
4. Waiting
5. Equipment failure

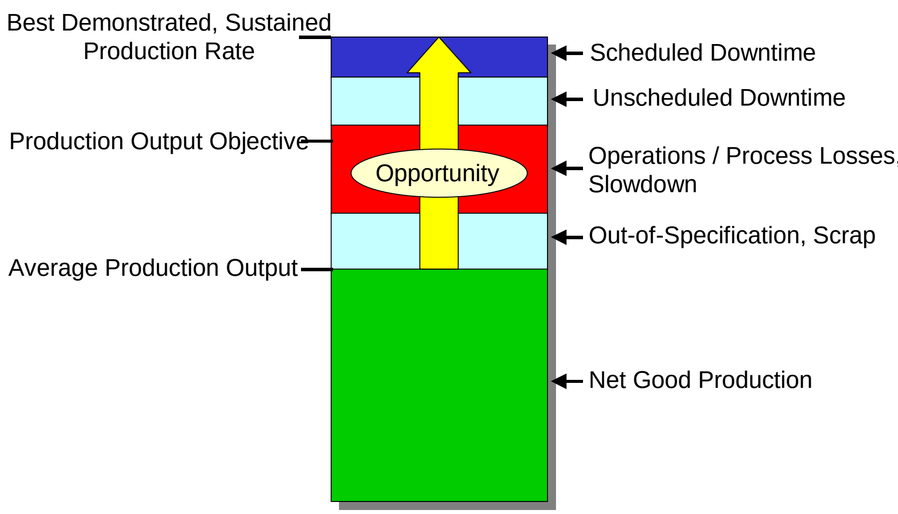

Figure 6.7 Real and Hidden Plants[160]

Some facilities using OEE add cost as a fourth measure of performance:

> *Several companies perform detailed analyses of lost uptime, yield, quality and margins caused by shutdown or slowdown, whether planned or unplanned. The analysis includes frequency of occurrence and consequences. The specific location of the loss in the business process is identified (sales, process [rate and quality], equipment unreliability, or indirects [e.g. support structure, planning, administration, pricing and other variables such as abnormal catalyst deterioration]) along with root cause. Monetary loss depends on specific conditions, plant and product.*[112, 160]

> *One industry-leading company manages to detailed internal metrics within OEE and cost. They do not roll up detailed metrics into an overall measure of OEE. The plant states that understanding and driving details within availability, yield, quality and cost metrics are highly important. However, they believe that an overall OEE calculation offers little added value. It also may be misleading because beneficial changes in one term may mask detrimental changes in another.*[160]

Cost of Poor Quality (COPQ) from Six Sigma includes all quality variations. COPQ is calculated by yield affected (i.e., tons, pounds, etc.), multiplied by price per unit of prime product. One company has established a COPQ objective of less than 10 percent of Cost Of Goods Sold (COGS).[112, 160]

Combined asset utilization, yield and COPQ are similar to OEE.

Asset Utilization:

> *Percentage of time a plant is in operation at Maximum Demonstrated Production Rate, perfect quality and defined yield.*

There also must be some method to measure delivery reliability, especially when the production output is part of a JIT supply chain.[112]

Industry Performance Metrics

Industry performance metrics provide a basis for determining comparative effectiveness. Industry metrics include:

- Cost as a percentage of Current /Replacement Asset Value (CAV/RAV) – commonly used in the petrochemical industry.
  - Most companies operate at 4 percent or greater. "World class" performance is approximately 2 percent. Some companies claim less than 2 percent. Process intensity also affects what should be an optimum sustainable value of cost per RAV.
  - One company computes costs per RAV for every production unit, rather than calculating costs per unit output.[160] Another company, reporting about 1½ percent above the "world class" value, states that the gap represents $32 million annually in lost profits.[10]
  - A downward trend in cost per RAV without corresponding increases in equipment effectiveness metrics probably indicates assets are being consumed.[92] Reducing defects is the only way to gain a sustainable reduction in cost per RAV.[160]
- Cost and other measures as a percentage of Equivalent Distillation Capacity (EDC) – Solomon Associates maintains EDC benchmarks that are universally used in the oil refining industry.
- EFOR (Effective Forced Outage Rate) – determined from an EPRI calculation and used in the power generating industry
  - EFOR: the probability of experiencing either a forced outage or forced de-rating when called upon to deliver load.
- Output – (tons) per availability hour is used in the steel industry
- Production cost and/or labor hours per unit production – (ton, pound, Mw, barrel, automobile, etc.) is widely used across industry.

Inconsistent definitions and methods of calculation often add uncertainty to metric comparisons between companies. Values such as RAV may be defined and calculated differently by different companies. Their use is much more effective for tracking performance within a single company where the calculation is consistent.[160]

> *A financial indicator such as Costs as a percent of Replacement Asset Value might be a meaningful corporate management metric; however, it is unlikely to inspire individual employees. Specific objectives combined with micro metrics such as maintenance costs for generic equipment, e.g., motors, pumps, compressors and parts are understandable to employees and within their ability to impact.*[41, 108]

Life cycle profit (return on an asset) is a better way to evaluate asset performance than life cycle cost. Establishing metrics based on life cycle profit will reinforce the necessary cultural change from a cost-centered mentality to the more constructive profit-centered mentality.[160]

Equipment Management Metrics:

> *Mean Time Between Failure (MTBF), Mean Time To Failure (MTTF), Mean Time To Repair (MTTR)*

Equipment management metrics are used to assess reliability and maintainability and identify problems. But are reliability and maintainability the best standards for measuring equipment effectiveness? If so, reliability must be related to performance and profitability. How is this accomplished if required availability is significantly less than 100 percent and/or there are system redundancies?

Many companies are realizing that a large investment in improving component reliability does not necessarily translate into a measurable increase in overall function or system reliability. For example, reliability improvements to two parallel pumps may have little overall effect. However, reliability improvements to their automatic start switches may have major effects. Reliability investments must be focused on prioritized improvements that have a direct impact on system availability.

Figure 6.8 illustrates the relationship between Mean Time Between Failure (MTBF), Mean Time Between Repair (MTBR) and Mean Time To Repair (MTTR).

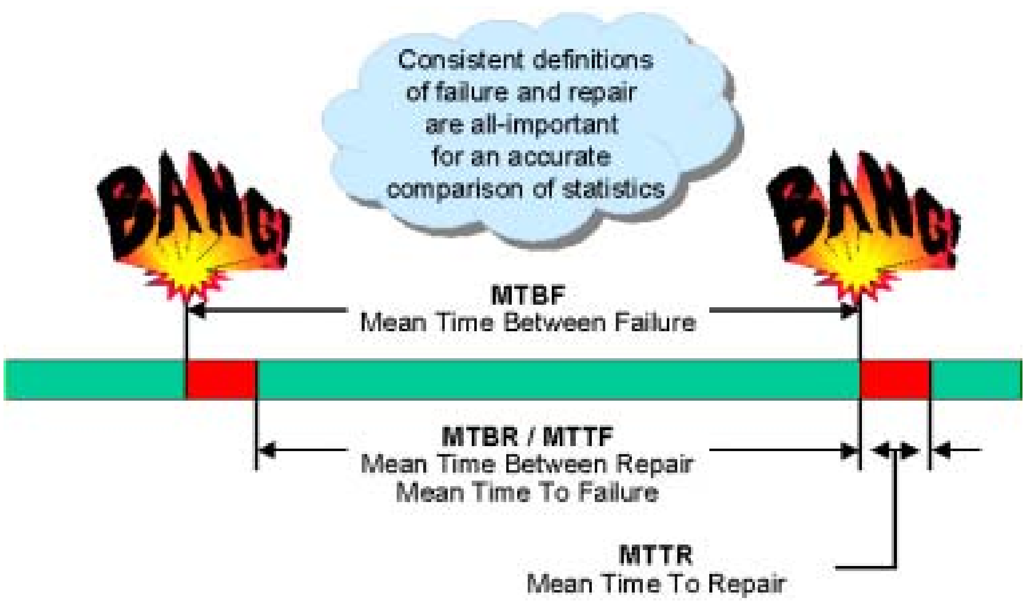

Figure 6.8 Relationship between MTBF, MTTR, and MTBR

Some observations:

- MTBR is MTBF minus MTTR and thus, is a better measure of reliability (poor maintainability results in a longer MTBR and therefore extends MTBF for a given MTBR)
- MTTR is a measure of maintainability (i.e., how fast repairs can be completed)
- When MTTR is relatively small in proportion to MTBF, MTBF and MTBR are essentially equal.
- Accurate MTBF/MTBR by equipment and component (model number) is necessary to be able to identify common failures spread across a population of equipment. If MTBF/MTBR is low, the cause, whether a few bad actors or an institutional problem such as poor alignment or balancing, must be detectable from the data.
- MTBF and MTBR are plotted for similar equipment to locate process, environmental and installation variations that may change failure characteristics.(160)
- Equipment MTBF/MTBR may lose some usefulness as a result of the staggered life of components and the effect of external influences—corrosive or abrasive environment, harsh loading conditions, contaminated fluids (lubricant and hydraulic oil), misalignment, and unbalance—on component lifetime.(160)

Organizations must take care in selecting maintenance effectiveness measures. Too often maintenance effectiveness is judged on time to repair, rather the more effective MTBR/MTBF.(112)

Loss Margin is a better measure of effectiveness than either EFOR or MTBF. Neither EFOR nor MTBF identify the ability to operate when required. Loss Margin focuses on the correct objectives.(8)

In the process and petrochemical industries, “world class” MTBF/MTBR for pumping equipment is reported to be approximately seven years. As stated earlier, numbers for “world class” performance must be used with some caution because of the varying service, environment and definitions of “failure” and “repair.” Some organizations reserve the term “failure” and “repair” for events that affect production. Events that have no effect on production are not classified as failures and, hence, are not considered as “repairs.” In other cases, problems that require intrusive disassembly are “failures.” Under these definitions, a bearing, seal or coupling that requires replacement is classified as a “failure” and the corrective action a “repair.” Likewise, degraded performance that necessitates overhaul would be classified as a “failure.” Lubrication and adjusting packing and belt tension would not be classified as “failures.”

One company that uses this system does not classify a worn, frayed or broken drive belt as a “failure,” or its replacement as a “repair.” There are numerous other examples in a gray area that could be classified either way. Perhaps the best solution is to decide what information is required from the standpoint of reliability analysis (a case can be made that drive belt failures fit this criteria), define those as “failures” and designate the corrective action as “repairs.”

Determining how “hidden” or impending failures, identified and corrected during maintenance conducted for another purpose, are counted is often difficult. As maintenance and overhaul intervals are extended, these issues assume greater importance.

Some companies measure and track Mean Time Between Events (MTBE), where an event is any departure from normal operation that costs more than a specified amount of money. Two companies require a full RCFA on individual equipment when the cumulative cost of repairs over a 12-month period exceeds $10,000.(160)

Key Performance Indicators (KPIs)

Key Performance Indicators are widely used within industry to measure specific parameters across all the classes of metrics. KPIs are often used to measure short-term progress to objectives. One company selects KPIs to measure progress to objectives.[160] Examples of KPIs include:[10, 21, 108]

- Safety and environmental indices
- Percent plant utilization
- Availability/uptime
- Units/availability hour
- Manufacturing cost/unit (ton, pound, bbl., Mw, automobile, etc.)
- Yield loss
- Percent unplanned production losses
- Cost Of Poor Quality (COPQ)
- Customer complaints
- Maintenance management indices (i.e., bearings and seals used or number of unexpected failures)
- Condition monitoring/CBM program effectiveness (i.e., percentage fault detection or average vibration level)

A leading oil company has 21 categories of equipment each with KPIs linked to MTBR.[160] Another leading company in the petrochemical industry measures detailed KPIs for each processing unit, including electrical power, thermal energy, and air consumption per unit output. About 80 percent of the performance indicators are based on metered values; the remainder are largely allocated between production units on a fixed formula.[160]

One paper listed the following KPIs for a "world class organizations": [17]

- Percentage planned work: 90 percent
- Schedule compliance: 70 percent
- Work order discipline: > 90 percent
- Process availability: 95 + percent
- OEE: > 80 percent
- Maintenance cost as a percentage of total sales: < 3 percent

Work Process Productivity Measures

Work process productivity measures are used to assess effectiveness in terms of task accuracy, adherence to schedule, completion, and other factors. They measure how resources, primarily labor, are deployed to meet production goals. The measures identify opportunities for improvement and define staffing, budget, and training requirements.

Measures in use, such as maintenance costs divided by net asset value, have significant weaknesses. In this case, the measure fails to consider the age of the facility and operating intensity, both of which have a strong influence on maintenance costs. Second, with the numerator being the only variable in the equations, only cost reduction can have a positive impact. Earlier chapters have warned of the dangers of short-term cost reductions at the cost of long-term quality and operational effectiveness. Such practices contradict the value or profit center mentality that is the core principle of Physical Asset Management.

Some practitioners suggest a measure of the proportion of scheduled to total maintenance. However, it should be recognized that a high percentage of scheduled to total maintenance has no meaning if the scheduled tasks are unnecessary or improperly performed.

The productivity measures explained herein are based on planned maintenance, defined for this purpose as:

> *Maintenance scheduled in advance of commencement by a specified lead-time (planning interval) that is typically one week.*

Some facilities require a two-week lead-time to qualify as planned maintenance. The goal in measuring productivity based on planned maintenance is to optimize planning accuracy.

Typical productivity measures include:(10, 43, 84)

- Cost per unit production
- Total hours worked
- Work scheduled as a percentage of work accomplished—percentage of labor hours expended on scheduled work. *Daily schedule compliance is the most important measure in work management.*(19)
- Preventive and Condition-Based Maintenance as a percentage of total maintenance. *Preventive Maintenance completion percentage means very little if the work is unnecessary or lacks value. Effectiveness is more important than adherence to a program. A facility cautions about the use of this metric—it may result in flooding the system with worthless Preventive Maintenance tasks.(160)*
- Unexpected failures
- Emergency work required. *One facility has established an objective of reducing unplanned or break-in work (defined as work scheduled during the same week as accomplished) to less than 10 percent of the total. Another combines emergency (accomplish immediately) and class 1 (accomplish within 24 hours) work.* (160)
- Percentage of candidate equipment covered by an optimized maintenance plan
- Planned completion rate (tasks completed within a specified time from schedule). *One facility reports 65 percent of Preventive Maintenance Tasks are completed on-time (within one week of schedule) and cites a 95 percent total completion rate. Preventive Maintenance completion is tracked by trades. A large corporation in the hydrocarbon industry that has a four-week rolling maintenance plan is achieving 70 percent compliance with the four-week plan and 90 percent compliance with the one-week plan. Another facility performs a monthly Pareto analysis of the cause of break-in (unplanned) work.*(160)
- Overtime work as a percentage total hours worked
- Planning accuracy – actual time expended as a percentage of planned time. *Only a few facilities measure planning accuracy, although studies show that those who do are 40 to 60 percent more productive.*(82)
- Work backlog – *by trades*

- Labor Utilization (i.e., wrench time). *Fifty to sixty percent is considered world class.*[160] *It should be noted that a profit centered focus includes time expended on tasks such as RCFA in Labor Utilization.*
- Percentage of labor and material cost. *The ratio is roughly 50 – 50 in the industrialized world shifting to as much as 70% parts to 30% labor in Asia and the Middle East. One facility uses the ratio of maintenance labor to material to measure labor effectiveness. They state that as maintenance becomes more proactive, the labor percentage should increase.* [160]
- Percentage improvement in MTBF/MTBR
- Life cycle extension
- Rework – the percentage of work that has to be repeated within a given time indicating faults or errors in the original work
- Storehouse stock effectiveness (i.e., service level) – percentage of time parts are available when required
- Inventory value as a percentage of RAV. *The Society of Maintenance and Reliability Professionals (SMRP) reports that 1 percent is a best practice benchmark.*
- Inventory Quality Ratio (IQR): ratio of active MRO parts inventory to total inventory.[81] *In Japan, stores disbursements as a percentage of total maintenance material appears in two distinct regions. Plants with a percentage above 50 percent are managing stores through Western-style storerooms. A cluster of Japanese sites with ratios of less than 20 percent are using dependable local suppliers in a just-in-time (JIT) environment.*[92]
- MRO parts inventory turns. *A facility expressed reservations that when inventory turns are used as a critical metric, all stock is lumped together. Slow movers may be hidden.*[81]

Material turnover rates in Japan are reportedly stratified into two distinct regions. Companies who manage their own inventories have turnover rates exceeding 4. Companies who have established close relationships with local JIT suppliers maintain slow-turning critical spares at a turnover of less than 0.6.[92] It is important to recognize that outsourcing or employing consignment spares will reduce inventory and also reduce storeroom turns.

A large manufacturer reports combined production and MRO inventory is approaching 21 turns with an objective of 85 turns. (Eighty-five turns represents approximately three days of material and WIP on hand.) To meet 85 turns, MRO inventory must be addressed.[160]

Work Productivity Metrics must be consistent with and reinforce overall optimizing actions. For example, enlightened practitioners of Equipment Management encourage RCFA, view repairs as opportunities to eliminate defects, and consider the process as essential to improving equipment effectiveness. The conventional definition of Labor Utilization as wrench time excludes RCFA and is contrary to encouraging proactive failure avoidance measures. As stated, the better solution is to count time expended performing RCFA in Labor Utilization.

Increasing inventory turns via a reduction in slow moving spares, combined with a general reduction in the number and quantity of stocked parts, should be approached with caution. Attempting to comply with both metrics may result in scrapping vital, long-lead insurance spares.

Spider charts, illustrated in Figure 6.9, are frequently used to compare the performance of multiple Work Process Metrics with benchmark objectives. A spider chart can provide a useful display of Balanced Scorecard results, as described in Chapter IV.

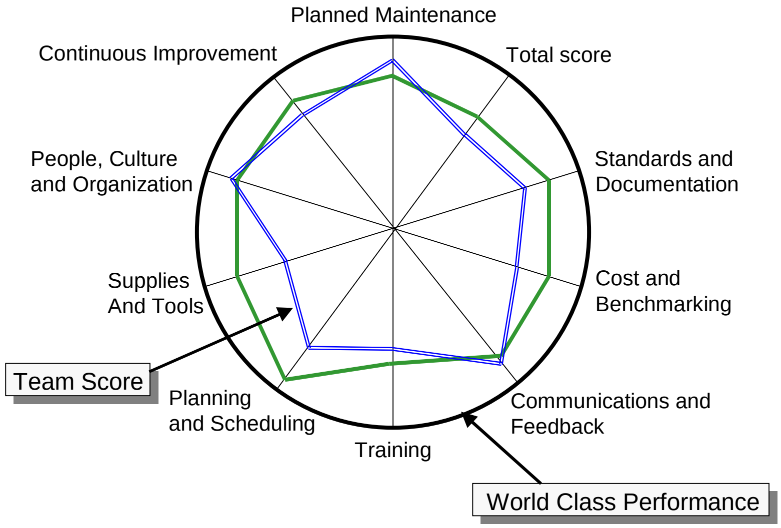

Figure 6.9 Spider Chart

One large manufacturer evaluates performance on a spider chart in the following nine areas, as well as providing an overall assessment:(160)

1. Planned maintenance
2. Continuous improvement
3. People, organization and culture
4. Supplies and tools
5. Planning
6. Training
7. Communication
8. Costs and benchmarking
9. Standards and documentation

The evaluation process begins when questions are submitted to work teams. The teams prepare written answers that are evaluated by other teams, who then conduct a four-hour verbal review. The score in each area and the overall are plotted along with benchmark objectives on the spider chart, shown in Figure 6.9, to identify gaps and gain potential. Comments and the spider chart are combined into a feedback document that includes a written evaluation and suggestions for improvement. The latter are focused on success—not criticism. The team evaluated has the option to apply improvement initiatives in areas other than metrics with the greatest gap on the spider chart and the team is accountable for results. Gaining the optimum mix of effort requires effort.(47,108).

A petrochemical company uses a spider chart to evaluate performance in more general terms: Focused Empowerment, Compliance to Balanced Scorecard, Asset Management, and Maintenance Prevention.(160) Another company tracks linked metrics on a combination plot (e.g., Preventive and Condition-Based Maintenance completion and downtime). As Preventive and Condition-Based Maintenance are applied more effectively, an increase in completion should result in a corresponding decrease in downtime. If the cause/effect does not trend as anticipated, an effort is initiated to learn why.(160)

Leading Indicators

Leading indicators are task specific metrics that respond more quickly than results metrics. Leading indicators are selected to anticipate progress toward long-term objectives that may not change quickly in response to effort. As one example, employee training should result in improvement. Thus employee training is considered a leading indicator. Initiating a program of precision shaft alignment may require years to affect overall reliability measures such as, MTBF, MTBR. In this case a leading indicator might be grouped MTBFs or MTBRs for equipment subjected to the reliability improvement initiatives. Leading measures are also an early indication where added improvements might be necessary.

Examples of leading indicators that are in use for equipment management include: [160]

- Schedule compliance
- MTBF/MTBR on specific equipment with improvements implemented
- Percentage Preventive and Condition-based Maintenance, percentage overdue
- Overtime hours worked
- Emergency work required
- Warehouse stock turn, planning accuracy
- Percent failures subjected to RCFA (measure of proactive to reactive failures)
- Hours of training per employee

The overlap with other categories is also apparent with this list.

To demonstrate contribution and progress, leading indicators must connect through overall effectiveness measures to functional and enterprise financial objectives.[160]

Technical Metrics

Technical metrics are used to measure the effectiveness of equipment management programs and systems at the facility, unit, or equipment level. These metrics demonstrate the technical results of programs such as vibration monitoring, fluid (lubricating oil) analysis, and thermography as the first step in linking their contribution to corporate and facility results. Technical metrics capture, in objective terms, results that can be trended over time to track progress toward program objectives and demonstrate improvement (e.g., percentage of predictive monitoring performed within one week of schedule).

Technical objectives allow program owners and managers to determine contribution and identify areas where improvements are required to increase effectiveness. Examples of technical-level metrics applied to typical facility programs include:

- Percentage of facility/unit equipment monitored with predictive technology
- Facility average overall vibration levels – *several organizations report a direct link between reduced vibration levels and reduced maintenance costs, see Figure 4.7.*
- Number of early warning alerts or alarms by unit or condition survey
- Number of second warning danger alarms by unit or condition survey
- Number of faults detected for each technology in use (e.g., fluid analysis, electric current analysis, thermography, and steam trap surveys)
- Number of undetected failures for each technology in use
- Percentage false alarms

Indirect Metrics

Indirect metrics are used to measure the impact of an equipment management program on organizational imperatives such as safety and environmental incidents.

> *One company reports that 50 percent of all environmental incidents are caused by equipment failure.*[160]

Indirect metrics demonstrate the value of equipment management to those managers who are accountable for vital areas such as safety and environmental compliance. These indirect metrics provide another means for demonstrating the value of an equipment management program to influential decision makers who have little to no awareness of such programs. Some examples of indirect maintenance metrics are:

- Safety and environment incidents
- Environmental savings achieved through waste reductions
- Energy savings attributed to equipment management

E. AVOIDED COST

An assessment of the contribution of a predictive or proactive equipment management program should include the issue of avoided cost. Avoided cost is defined as the differential between the actual repair cost and the cost of repair had the equipment and/or system proceeded to failure, plus the estimated cost of downtime related to an unscheduled failure. In other words, it compares what actually happened to what most likely would have happened if the problem went undetected.[21]

Policies regarding credits for avoided cost vary by company. One company disallows avoided cost credits if the impending failure likely would have been recognized during operator rounds and would not have adversely affected operation/production. Some companies use an average cost of failure, taking into consideration the cost and probability of a failure causing added damage (e.g., a bearing failure that results in housing, shaft and/or rotor damages). Others avoid the challenge by not allowing avoided cost estimates in the calculation of program value.

A detailed procedure for calculating Avoided Cost is found in reference 91.

F. APPLICATION OF METRICS

Significant thought must go into the process of selecting metrics to support the equipment management program. The value of meaningful metrics cannot be overstated—the impact of metrics that are inaccurate or inapplicable cannot be understated. One must first identify the goals and objectives of the organization. Metrics must connect to organizational objectives; therefore, the selection criteria must establish the path from corporate financial results down through overall, equipment and program effectiveness. The contribution at each stage must be understood and linked. Fundamental issues such as safety and environmental protection must also be identified so that the appropriate metrics will be selected.

All key processes within the overall effort should have one or more metrics to indicate goal compliance and progress. In each case, the process owners and implementers must be involved in selecting metrics, as well as objectives and time to gain compliance. This first vital step toward ownership is the basis for data collection and the means to embed a continuous improvement culture.

Organizational capabilities to collect and report metrics must be considered. The cost of obtaining data for metrics and the relative value the metrics add to the overall program must be calculated. Some companies have one or more people dedicated to the task of accumulating and reporting metric information. As information systems improve, automatic, real-time processes will supersede manual “batch” methods. The Equipment Management process is directed toward adding value. Metric selection and reporting must be consistent with that principle.

There are several rules to follow applying metrics:

- Good metrics focus activities on maximum benefits and value added
- Poor metrics lead away from optimum activities, often to unintended results
- Whenever possible, metrics should be positive, rather than negative (e.g., measure first-run quality, not rework)
- Prevent conflicting metrics, as exemplified by the stock reduction conundrum mentioned earlier
- Always examine complementary metrics together (i.e., there isn’t much benefit in directing efforts to increase yield if quality is significantly below objective)
- Non-compliance with a metric should be followed by efforts to identify cause, full cost, and other effects of non-compliance. Many organizations use Pareto analyses for this purpose.
- Metrics must be used and kept current. Metrics that are not regularly used should be eliminated.

G. Benefits

Benefits that should be associated with metrics to identify the real worth of an Overall Physical Asset Management program include:

- Increased availability and decreased downtime with real numbers to document improvements – monitor availability and convert the increase to product value
- Increased product quality – with quality value calculated in terms of quality premium compared to COPQ losses (e.g., rejects, returns, discounted sales, and quality penalties)
- Increased throughput – demonstrated increases in product value gained from reduced slow time and other equipment delays
- Reduction in maintenance costs – labor hours, parts, and consumable savings realized by minimizing failures and unnecessary PMs, improving labor effectiveness
- Reduction in breakdown costs – identification of “saves” and a reduction in average repair costs for a typical failure compared to repair costs prior to the Physical Asset Management process when operated to failure
- Increase in energy efficiency – calculated energy costs for production before and during the improvement process
- Reduction in spares parts inventory – current value of freed capital resulting from reduced usage and better planning

H. Measurement Process

The following paragraphs outline a metric selection and measurement process that objectively identifies real conditions within the Physical Asset Management process. The establishment and collection of metrics must be clearly related to the organization’s business conditions, mission, and objectives and must identify opportunities for improvement. Objectivity and honesty are fundamental, but often neglected, aspects of this process. Everyone is familiar with some type of large-scale effort that was undertaken to prove or disprove what was already “known.”

Like many important business decisions, the keys to a realistic equipment management measurement program are clearly stated objectives, understanding, consultation with all affected parties, and effective planning and training for all personnel, from shop floor employees to the Board Chairman or equivalent in military and service organizations.. The needs and concerns of each group should be recognized and accommodated in the design of the measurement process. This will help ensure that nothing important is overlooked and will gain more cooperation and support when the equipment management measurement process is installed.

The top metric should be whatever the corporation/facility uses to measure financial performance. For many this will be RONA. At the next lower level, many organizations use some variation on OEE (availability, production throughput and first-run quality) plus cost. Improvements required at this level to meet the top tier objective should be determined. A financial model of the type contained in Chapter V is useful in performing the analysis. The analysis should lead directly to the selection of key equipment management metric, work process metrics, and technical metrics for each of the second tier categories illustrated in Figure 6.1.

When possible, benchmarks should be identified for each of the metrics selected. If possible, the benchmark values should be based on industry standards or organizational past experience. If such data are not available, they can often be developed by contacting professional societies such as the Society of Maintenance and Reliability Professionals (SMRP), visiting reliability-oriented web sites, or consulting the numerous texts available on the subject. Fellow practitioners will typically offer advice regarding what benchmark values they use for variables such as MTBF. If all of these resources fail to provide representative metrics internal objectives can be generated from current values. Any value chosen must fulfill the top-tier objective.

When all parties agree on what needs to be measured and how the metrics are defined, the next step is to set up training and get started. Whether establishing a Physical Asset Management process for the first time, modifying an existing process with new definitions or a more precise focus, sufficient time must be allocated to gather information, identify and prioritize improvement initiatives. Gather sufficient information to determine historical values for all metrics. Compare historical values to benchmarks in a Gap calculation (as described in Chapter VII). The Gap calculation identifies opportunities for improvement and provides direction for prioritization and implementation. This process is detailed in Chapters VII and VIII.

An improvement process of the type detailed in Chapters VII and VIII must be paralleled by a measurement process that tracks results metrics against objectives to ensure progress. When the results measurement process is initiated, management must decide how often data should be collected and by whom and how frequently the data should be reviewed. Technicians involved on a daily basis and managers directly responsible for the process should monitor results at least weekly and no less frequently than monthly.

In a typical measurement process, most information should be considered suspect for the first two or three reporting cycles. This is typically the amount of time required for everyone to understand what is being measured, to gain measurement accuracy, and to reasonably ascertain that the data are being reported correctly. Definition fine-tuning to gain consistency, minor process refinements and additional training may be required. Thereafter, the real data collection begins. For the next year, performance data should be collected and analyzed without further corrections, improvements, or fine-tuning of the measurement process. A stable system is necessary to obtain value from the data. If problems or shortcomings are noted in the measurement process, they should be held for incorporation after the first annual review.

A word of caution: This process requires significant effort. There is always a natural tendency to identify a large number of key factors for measurement and tracking. Experience indicates that the number of factors analyzed in each area should be limited to six or so. More and the effort is in danger of losing focus.

Persons directly involved with a specific process may want to track more equipment metrics. This should add to an understanding of processes and problems, identify more areas of potential improvement, and provide background information to clarify the metrics being reviewed by operating and financial managers.

The greater the number of factors that are being tracked, the more difficult the results analysis. Confusion may arise if several related metrics appear inconsistent. Selecting indicators at several stages in a key process for identifying indicators from several different equipment management processes helps avoid potential confusion.

Interim objective performance levels should be established for metrics such as MTBF, to ensure progress toward the long-term goal. (This process was depicted in Figure 6.4 and described earlier in this section.)

When measuring values such as MTBF, equipment both below and above the average are of interest. “Bad actors,” equipment with chronic problems requiring attention and correction are found below the average – the further below the greater the opportunity. Equipment significantly above average longevity should be also evaluated to learn if reasons for superior performance can be replicated on other similar equipment. To assure focus and concentration of efforts on highest value opportunities, control limits can be used to divide equipment into reasonable “below average,” “average” and above average categories as shown in Figure 6.10.

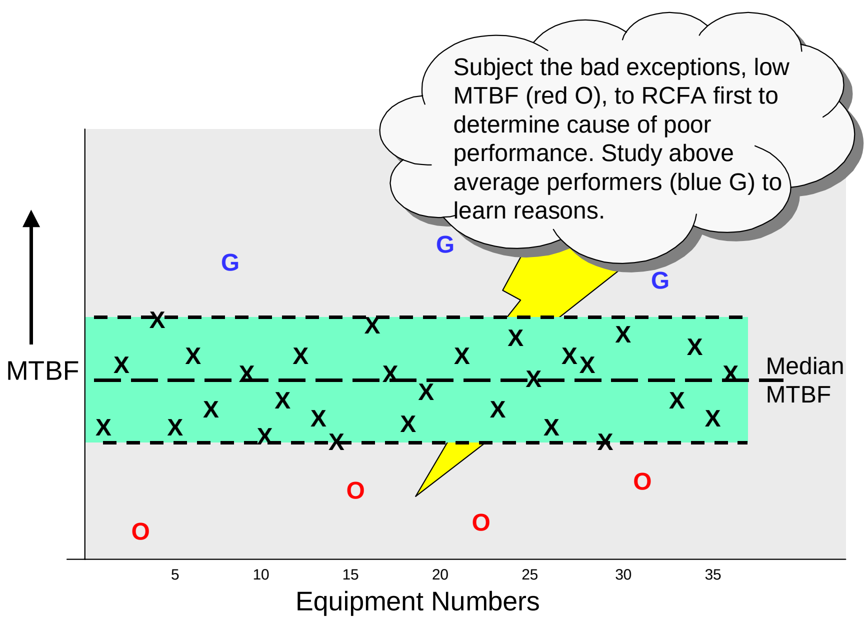

Figure 6.10 Control Band

A limit graph similar to Figure 6.10 readily identifies equipment that are significantly better and worse than normal (e.g., equipment with MTBF’s significantly greater or less than the average).

Most companies use either plus or minus two standard deviations (which covers 67 percent of all possible occurrences) or plus or minus three standard deviations (which includes 95 percent of all possible occurrences).

Most set boundaries at the three standard deviation, 95 percent level. This results in 5% of the total population both above and below the limit. Limiting the outlyers to 10% of the total population provides good prioritization for in-depth RCFA or other analyses to determine why the specific case deviated. For the initial year, efforts should be focused on improving the most egregious low performers. When the reasons for distribution within the control limits is better understood, initiatives can be developed to improve the median. A clustered distribution around a low median may indicate the presence of a common problem, such as improper bearing installation, poor lubrication, misalignment, or unbalance. A large scattering in the data typically indicates numerous localized problems.

Some organizations that are well along in this process consolidate the type and number of failures on similar equipment in a Pareto analysis, as shown in Figure 6.11. A Pareto graph is an excellent method for identifying primary detractors from objective performance by number and cost.

At some point a year or more after the formal measurement period commenced, changes may need to be implemented. The necessity for changes may result from revised objectives and a corresponding change in prioritization. Changes may also originate from recognition of improvements needed in the measurement process to identify conditions more specifically. Most often, defect distribution along the median is examined to identify cluster defects as previously mentioned. Control boundaries also may be reduced slowly to identify more departures for prioritized study. With the cause and distribution of defects better understood, the improvement process can begin to address broader problems.

The process must continue tracking all equipment effectiveness indicators. As familiarity with the processes increases, corrective action will become easier and the contribution of equipment management to the effectiveness and profitability of the overall organization will become clearer. This is an essential step toward maintaining executive endorsement and funding.

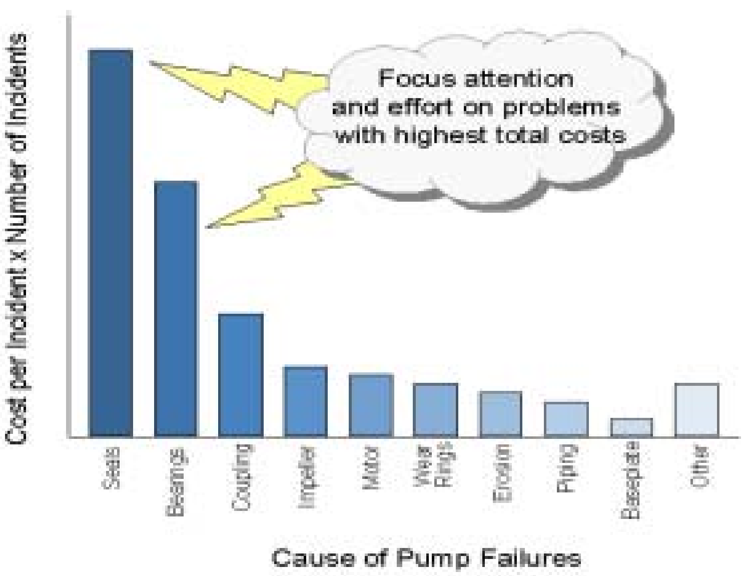

Figure 6.11 Pareto Chart