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"Combining TPM and RCM"

A recent experience at a large automotive manufacturing facility demonstrates how to combine Total Productive Maintenance, or TPM, and Reliability-Centered Maintenance, or RCM. The combination of these efforts has lead to an improved process for facilitating teamwork between the maintenance and production functions, to improved equipment reliability and uptime, and to lower operating costs. This article describes the process used and the results to date, as well as anticipated plans for the future.

A large automotive parts plant has recently begun the process of introducing a number of methodologies to improve manufacturing performance. Among the tools being applied at this plant is TPM, with a particular focus on operator care and minor PM, or as some people would say, TLC -- Tender Loving Care in the form of actions such as Tightening, Lubricating, and Cleaning. Other tools are also being introduced and applied in an integrated way, including continuous improvement teams, improved cell design, pull systems, process mapping, etc., but the focus of this case history is how TPM was integrated with RCM.

The application of TPM at this plant, and in the author's experience at other plants, has focused most of its attention on operator PM and basic care, operator "condition monitoring", etc. These practices are essential for assuring manufacturing excellence, but used alone are not likely to be sufficient. In this case, a focus on TPM was not considered to give adequate consideration to other, perhaps equally valid or even more advanced methodologies, such as reliability centered maintenance, predictive maintenance, root cause analysis, maintenance planning, etc. This view was confirmed by the maintenance manager for the business, who felt that while TPM was an effective tool for assuring basic care for the equipment, for detecting the on set of failures, and often for preventing failures in the first place, it frequently overlooked other maintenance tools and requirements. This, in turn, often resulted in equipment breakdowns, and in frequent reactive maintenance, not to mention the largest loss -- reduced production capacity. As a result we embarked upon an effort to combine the best of TPM and RCM in order to provide the most effective processes for both maintenance and production. In the process we expected to be able to provide manufacturing excellence -- maximum uptime, minimum unit cost of production, maximum equipment reliability. Each methodology is discussed individually below and then the process for combining them is provided.

Total Productive Maintenance Principles -- TPM

Total Productive Maintenance, or TPM as it is commonly called, is a strategy for improving productivity through improved maintenance and related practices. It has come to be recognized as an excellent tool for improving productivity, capacity, and teamwork within a manufacturing company. However, the cultural environment in which the TPM strategy was developed may be different from the culture in a typical non-US manufacturing plant, and require additional consideration.

TPM was developed in Japan by Seiichi Nakajima[1]. With its Japanese origins, the strategy places a high value on teamwork, consensus building, and continuous improvement; and tends to be more structured in its cultural style -- everyone understands their role and generally acts according to an understood protocol. Teamwork is a highly prized virtue; whereas individualism may be frowned upon. This basic underlying genesis of the Japanese TPM strategy is a significant issue to be understood when applying TPM to a given manufacturing plant. This may be especially true in a US manufacturing plant, since US culture tends to value individualism more, to value people who are good at crisis management, who rise to the occasion, who will take on seeming insurmountable challenges, and prevail. We tend to reward those who respond quickly to crises and solve them. We tend to ignore those who simply "do a good job". They are not particularly visible -- no squeaking, and therefore no grease. This "hero worship" and individualism may be an inherent part of our culture, and may make more difficult the implementation of TPM.

This is not to say that TPM faces overly serious impediments, or is an ineffective tool in non-Japanese manufacturing plants. On the contrary, when an organization’s leadership has made it clear that the success of the organization is more important than the individual, while still recognizing individual contribution, a team oriented corporate culture can develop which transcends the tendency for the individualistic culture, and success is more likely. Many plants world wide have used TPM effectively, and most plants have tremendous need for improved communication and teamwork which could be facilitated using the TPM methodology. Most would be better off with fewer heroes, and more reliable production capacity. Considerable progress have been made through programs and strategies like TPM, but it is still evident that in many plants there still exist strong barriers to communication and teamwork.

How often have you heard from operations people- "If only maintenance would fix the equipment right, then we could make more product!", and from maintenance people "If operations wouldn't run the equipment into the ground, and would give the time to do the job right, we could make more product!", or from engineering people "If they'd just operate and maintain the equipment properly, the equipment is designed properly (he thinks) to make more product!", and so on. The truth lies in "the middle", with "the middle" being a condition of teamwork, combined with individual contribution and responsibility, and effective communication. A case history for effecting this "middle" is provided below.

Total Productive Maintenance -- the name itself implies that all maintenance activities must be productive, and that they should yield gains in productivity. Reliability Centered Maintenance -- its name implies that the maintenance function must be focused on assuring reliability in equipment and systems. As we’ll see, RCM also calls for an analysis for determining maintenance needs. Properly combined, the two work well together.

The basic pillars of TPM and some thoughts on their relationship to an RCM strategy are:
1. TPM calls for restoring equipment to a like-new condition. Operators and production staff can contribute substantially to this process. At the same time, according to some

RCM studies, some 67% of equipment failures can occur in the infant mortality mode -- at installation and startup, or shortly thereafter. Good TPM practices will help minimize this through restoration of equipment to like new condition and operator basic care. However, it is often the case that more advanced practices may need to be applied, e.g., a stringent commissioning of the equipment, as well as the process, using condition monitoring tools and standards for methods such as vibration, oil, infrared, analysis instruments and software, to verify this like-new condition. It may also be especially important to understand failure modes and effects in order to take steps in both operations and production to mitigate or eliminate those failure modes. Many will say that TPM calls for application of predictive maintenance, or condition monitoring. However, in the authors’ experience this tends to be quite limited, and more often than not, only involves operator "condition monitoring", e.g., look, touch, feel, etc., certainly good practice, but at times insufficient. Further, condition monitoring as practiced under TPM may not have a strong foundation, such as a failure modes analysis, which drives the specific technology being applied. For example, reasoning such as "it’s a bearing and we do vibration analysis on bearings", without defining whether the failure modes require spectral, overall, shock pulse, etc. techniques, may not an provide adequate analysis method for the machinery in question. Other examples could also be cited, but this should be sufficient to make the point.

2. TPM calls for operator involvement in maintaining equipment. This is a must in a modern manufacturing plant. However, the operator often needs to be able to call upon specialists in more advanced technologies, when a problem starts developing in the machinery. These specialists can use RCM principles such as failure modes and effects analysis, as well as condition monitoring tools such as vibration analysis to help facilitate identifying and prioritizing problems, and getting to their root cause.
3. TPM calls for improving maintenance efficiency and effectiveness. This is also a hallmark of RCM. Many plants make extensive use of preventive maintenance or so-called PM's. However, while inspection and minor PM’s are appropriate, intrusive PM's for equipment overhaul may not be, unless validated by equipment condition review, since according to RCM studies little equipment is truly average. RCM helps determine which PM is most effective, which should be done by operators, which should be done by maintenance, and which deserve attention from design and procurement. PM’s become more effective since they are based on sound analysis, using appropriate methods.
4. TPM calls for training people to improve their job skills. RCM will help in identifying the failure modes which are driven by poorly qualified staff, and hence identify the areas for additional training. In some cases it may actually eliminate the failure mode entirely, thus potentially eliminating the need for training in that area. RCM is highly supportive of TPM, since training needs can be more effectively and specifically identified and performed.
5. TPM calls for equipment management and maintenance prevention. This is inherent in RCM principles by identifying failure modes and avoiding them. Equipment is thus more effectively managed through standards for reliability at purchase (or overhaul), during storage, installation, during operation and maintenance, and in a continuous cycle which feeds the design process for reliability improvement. Maintenance is prevented by doing those things which increase equipment life, and maximizing maintenance intervals; by avoiding unnecessary PM's through condition knowledge; and by constantly being proactive in seeking to improve reliability.
6. TPM calls for the effective use of preventive and predictive maintenance technology. RCM methods will help identify when and how to most effectively use preventive and predictive maintenance through a failure modes analysis to determine the most

appropriate method to detect on set of failure, e.g., using operators as "condition monitors", or using a more traditional approach in predictive tools.

Reliability Centered Maintenance Principles -- RCM

The primary objective of RCM is to preserve system function, as opposed to equipment function. That is to imply that if the system function can continue even after failure of a piece of equipment, then preserving this equipment may not be necessary, or run to failure may be acceptable. The methodology itself can be summarized as follows[2],[3],[4]:

1. Identify your systems, their boundaries, and their functions.
2. Identify the failure modes which can result in any loss of system function.
3. Prioritize the functional needs using a criticality analysis.
4. Select the applicable PM tasks, or other actions, which preserve system function.

In doing the analysis, equipment histories are needed, and teamwork is also necessary in order to gather the appropriate information for applying the above steps. However, not having equipment histories in a database should not negate the ability to do an RCM analysis. As is demonstrated below, equipment histories can be found in the minds of the operators and technicians. More over, operators can help detect the onset of failure, and in take action to avoid these failures. Like TPM, RCM describes maintenance in four categories: preventive, predictive, failure finding, and run to failure. At times the difference between these can be elusive.

RCM analysis as traditionally practiced can require lots of paperwork -- it’s very systematic and can be document intensive. It has been shown to be very successful in a number of industries, but particularly in airlines and nuclear industries which have an inherent requirement for high reliability, and a very low tolerance for the risk of functional failure.

The system selection criteria typically includes a Pareto analysis of those systems which have a large impact on capacity, high maintenance costs, frequent failures and/or corrective maintenance, large impact on safety or the environment. Within a system, components, failure modes, failure causes, and failure effects are systematically defined at the local, system, and plant levels. In turn, this information is used to establish PM requirements. Typical failure mode descriptors might be words such as: worn, bent, dirty, binding, burned, cut, corroded, cracked, delaminated, jammed, melted, pitted, punctured, loose, twisted, etc.

RCM is a good, disciplined methodology in that it documents processes, focuses effort on function, facilitates PM optimization (don’t do what you don’t need to do to prevent failures -- you may introduce more than you eliminate), facilitates teamwork, facilitates equipment histories and the use of a computerized maintenance management system. There are however some potential RCM pitfalls. Most of these are addressed by the better practitioners, but let’s discuss them for completeness. For example, it implies that if back up equipment exists that run to failure is acceptable, since it has no effect on system function. However, this could be risky in that run to failure may result in ancillary damage; or the back up, if not cared for, may not operate, or operate long; or it may reinforce a historical culture of run to fail, and reactive maintenance, which typically costs much more.

More over, its traditional or historical focus may tend to be primarily PM activities, versus a more proactive, integrated approach, which includes the effects of product mix, production practices, procurement practices, installation practices, commissioning practices, stores practices, etc. The more advanced application by most current practitioners does include these effects, and caution should be exercised to assure that these issues are included.

The primary objective of RCM is to preserve system function. It calls for a systematic process for definition of system boundaries and functions; for the analysis of failure modes which result in loss of function, and putting in place those tasks which preserve system function. It can be an excellent part of an overall maintenance and manufacturing strategy.

Combining TPM & RCM

At the automotive plant, the first step was to bring together a cross functional team of people to review a critical production line with the goal of identifying those failure which were resulting in a loss of function -- production line capacity. This team of people were generally production supervisors, operators, maintenance supervisors, engineers, mechanics, technicians, electricians, etc. -- people who knew the production process and the equipment. We also, as necessary, brought in support staff such as purchasing and stores people to help in defining and eliminating failures.

From the outset, however, we defined a *functional failure* in the system (the production line) as **anything** which resulted in *loss of production output*, or resulted in incurring *extraordinary costs*. That is to say, we did not restrict a functional failure to the equipment, but rather defined a functional failure very broadly. We also looked at the frequency of these failures and their effects, principally their financial effect as measured by the value of lost uptime or extra costs.

Initially we focused on the first production step, say step A, but once we finished with identifying all the major functional failures in step A, we looked downstream and asked questions: Are failures in step B causing any failures in step A?"; are failures in utilities causing any failures in step A?; are any failures in purchasing or personnel causing failures in step A?; and so on. We walked through each step in the production line looking for areas where actions (or failures to act) were resulting in production losses or major costs (functional failures). We also made sure that all the support functions were encouraged to communicate with the team regarding how the team could help the support functions more effectively perform their job through better communication.
A point worth mentioning is that this may be an imprecise process, bordering on controlled chaos, and given the inability to accurately measure the losses, we’re often only "guess-timating" at the value of those losses. However, these estimates are made by those who should be in a position to know best, and can be validated later. Perhaps more importantly, an additional benefit is that we have our staff working as a team to understand each other’s issues, and using this information to focus on common goals -- improving process and equipment reliability, reducing costs, improving uptime, and in the final analysis improving the company’s financial performance.

For example, we found that:

1. Raw material quality was a contributor to functional failures, e.g., lost uptime, lost quality, poor process yields, etc. Operations and maintenance have little control to correct this problem, but, they can advise others of the need to correct it.
2. Gearbox failures were a contributor to mechanical failures. There’s generally little that an operator can do to detect a gear box failure with the typical operator PM, if the gear box was poorly installed or specified.
3. Operator inexperience and lack of training was also concluded as a significant contributor to production losses. The problems resulting from their inexperience was often logged as maintenance downtime. For example, on one machine it was initially felt that electrical problems were the major source of maintenance problems. However, on review, it turned out that electricians (under a work order) were coming to the machines to train inexperienced operators in machine functions and operation.
4. Production planning was driven by a sales force which had inadequate concern as to its impact on production, and the inherent "functional failures" which occur when equipment is required to make frequent changeovers. While their decisions may be right strategically, it almost always requires a more comprehensive review, and better integration of the marketing and manufacturing strategies.
5. Spare parts were frequently not available, or of poor suitability or quality. Purchasing was driven to keep inventory low, without sufficient consideration as to the impact of a lack of spares on production. Better specifications and understanding of maintenance needs were required, and low bid should not be the only criteria.
6. Inherent design features (or lack thereof) made maintenance a difficult and time consuming effort, e.g., insufficient pull and lay down space, etc. Lowest installed cost was the principal criteria for capital projects, versus a more proactive lowest life cycle cost.
7. Poor power quality was resulting in potential electronic problems, and was believed to be causing reduced electrical equipment life. Power quality hadn’t been considered by the engineers as a factor in equipment and process reliability.
8. Lubrication requirements had been delegated to the operators without adequate training and procedures.
9. Mechanics were in need of training on critical equipment and/or precision mechanical skills. A few needed a review course on the equipment itself, and in bearing handling and installation.
10. And last, and perhaps most importantly from an equipment reliability standpoint, precision alignment of the machine tools was sorely lacking and if implemented should dramatically improve machinery reliability, and hence reduce system failures.

Beyond the general findings above about functional failures in the system, we also found that three separate sets of production equipment, were key to improving the overall system (production line) function. Functional failures in this equipment was resulting in the bottlenecking of the production line. It varied from day to day as to which equipment in the production process was the "bottleneck", depending on what equipment was down. Therefore all three steps and equipment were put through an RCM analysis to develop the next level of detail.

At this next level, a method was established for assessing the criticality of the equipment by creating a scoring system associated with problem 1) severity, 2) frequency, and 3) detectability. This is shown in Table 1.

Table 1. Criticality Ranking M

	Severity		Estimated	Problem
Rating	Who	Repair Time	*Frequency*	*Detectability*

1	Operator	n/a	Quarterly	Operator, little inspection required
2	Maintenance	< 1 shift	Monthly	Operator, w/considerable inspection
3	Maintenance	> 1shift	Weekly	Operator normally unable to detect

The score for a given problem was the multiple of the three factors, Severity x Frequency x Detectability. If a given problem was given a score of more than 4 by the group, then it was considered one which required additional attention. Scores of less than 4 were considered to be those which operators could routinely handle, and/or were of lesser consequence. For example, suppose a functional failure was detectable by the operator, e.g., broken drill bit. Further, suppose it was occurring daily, and could be repaired in one shift. Then it would received a score of 1x2x3, or a fairly serious problem. Very few problems occurred weekly, and required more than one shift to correct, and were not detectable by an operator. Finally, this scoring system could obviously be further refined to provide greater definition on a given system or set of problems. Readers are encouraged to develop their own models which adequately address their particular situation; or to use models already existing in their organizations for product or process FMEA's.

One finding of this review process was that a considerable amount of equipment really needed a complete overhaul. That is, it needed to be restored to "like new" condition (a TPM principle), but it was found using RCM methods as we looked at the failure modes and effects associated with the system which defeated function. This equipment subsequently went through a "resurrection" phase wherein a team of people -- operators, electrician, electronic technicians, mechanics, and engineers thoroughly examined the equipment and determined the key requirements for an overhaul, including the key steps for verifying that the overhaul had been successful. Less intensive, but equally valuable, (and summarizing) we found the following model to be effective:

Table 2 Ranking of Equipment Action

Component/				Failure			
Process	Function	Mode	Effect	Cause	Prevention	Detection	Rating Action SxFxD

This model was then used to analyze the equipment and assign a criticality rating which then dictated the priority of action required for resolution of the problems being experienced.

See Table 3 and 4 for specific examples of results of this analysis.

Some additional benefits

Further, as we went through this analysis, we began to determine where to best apply certain technologies. For example, precision alignment of the machine tools turned out to be of critical importance throughout the plant, since in the view of the staff, much of the production losses were a result of failures caused by poor alignment. Further, it was also determined that if poor alignment were causing extraordinary downtime and costs, in the short term we could use vibration analysis (a so-called predictive technology) to confirm proper alignment and to anticipate problems and be prepared to respond to them in a planned, organized way. In the long term, the engineers had to look for more constructive solutions by improving the basic design (a more proactive approach), and to incorporate into the purchasing standards requirements for better alignment fixtures and capability. Further, we considered how best to prioritize our production and maintenance planning efforts, anticipating where resources were best applied. What also came from the analysis was that we were doing preventive maintenance to little effect -- either over-doing it on some equipment and achieving little uptime improvement, or under-doing it on other equipment and experiencing unplanned equipment downtime. In this manner we began to optimize our PM practices. We could go on, but the point is that if you don’t understand where the major opportunities are, then it is much more difficult to apply the appropriate technologies and methods to improve your performance in a rational way. Using a TPM/RCM approach we found these opportunities more quickly. Finally, as a consequence, the new ‘model’ for behavior among the staff is now changing to "fixed forever" as opposed to "forever fixing".

We also found that it was critical to our success to begin to develop better equipment histories, to plan and schedule maintenance, to be far more proactive in eliminating defects from the operation, regardless whether they were rooted in process, equipment, or people issues. This was all done with a view of not seeking to place blame, but seeking to eliminate defects. All problems were viewed as opportunities for improvement, not searches for the guilty. Using this approach, it was much easier to develop a sense of teamwork for problem resolution.

Table 3. Sample of Three Hole Drill Analysis

Function: Drill three holes in a part a given diameter, depth and cycle time

Functional failures:	1) Poor cycle time	2) Broken drill
Effect:	Reduced production rates	Stopped production
Rating	1	3
Frequency:	Weekly	Daily
Cause:	Dull drill bits	Misalignment (after RCA Analysis) Tool and fixture design
Rating	3	3+
Detection:	Increased cycle times	Machine stops
Rating	1	1
Prevention:	Better drill bit material	Alignment of tools Improved installation and operation

In this example, the severity code of the broken drill bit is 9+, when added to other issues such as quantity of downtime, bottlenecking, etc., this became a critical problem throughout the plant, and was addressed as rapidly as possible, using root cause failure analysis and putting in place practices to eliminate the problem.

Table 4. Sample TPM/RCM Results

Other problems identified which were fairly common are described below, including the operator and/or maintenance action required:

	Detection	Prevention	Action
Bearing failures	Noisy Vib. Analysis	Improved installation, specs, operation	Maintenance training, care, tools, commissioning
Quill damaged Visual	Noisy	Operator cleaning, Improved lubrication	Improved installation Operator PM
Part concentricity	Quality control Visual	Operator inspection Improved design	Routine inspection Frequent replacement
Leaky hydraulics	Visual Pressure gage	Operator tightening Better design	Operator tightening Improved installation

Improved Design

Notice that a combination of operations and maintenance, as well as design and purchasing actions were often required in order to truly address the problems. TPM and RCM principles were routinely applied, but often extended beyond this to get better application of existing methods, such as root cause analysis, and better tools, such as alignment fixtures and tools.

Summary

The first step in combining TPM and RCM is to perform a streamlined RCM analysis of a given production line as the system. A functional failure of the "system" is defined as anything which causes loss of production capacity, or results in extraordinary costs. It is focused on failure modes, frequencies and effects, and is extended to identify those failure modes which would be readily detected and prevented by proper operator action, as well as detailing those failure modes and effects which require more advanced methodology and techniques such as predictive maintenance, better specifications, better repair and overhaul practices, better installation procedures etc., so as to avoid the defects from being introduced in the first place. The next step is to apply TPM principles related to restoring equipment to like new condition, having operators provide basic care (TLC) in tightening, lubricating and cleaning, and applying more effectively preventive and predictive techniques. Operators represent the best in basic care and condition monitoring, but very often they need the support of more sophisticated problem detection and problem solving techniques. These are facilitated by integration of TPM and RCM methods.

Results

Process. The results thus far have been very encouraging. The cross-functional teams have identified areas wherein operators through their actions can avoid, minimize, or detect developing failures early on such that maintenance requirements are minimized and such that equipment and process reliability are improved. Moreover, more effective application of maintenance resources is now being applied in order to assure that they are involved in those areas which truly require strong mechanical, electrical, or other expertise in getting to the more serious and difficult issues and problems. The application of these principles is in fact much the same as we behave with our cars, that is we as operators of our cars do routine monitoring, observation, and detect developing problems long before they become serious. As we detect problems developing, we make changes in the way we operate, and/or we have a discussion with a mechanic. As necessary we bring our car into the mechanic describing the symptoms for a more in-depth diagnosis and resolution of the problem using their superior skills. Similarly, we as operators of our cars can preclude failures and extend equipment life by applying basic care such as routine filter and oil changes which don't require much mechanical expertise, leaving the mechanic to do the more serious and complex jobs, such as replacing the rings, seals, transmission, etc.

Equipment. The machines to which the methodology has been applied has been very encouraging. For example, before this method was applied to one bottleneck production area it was common that 6 out of 16 machines would be unavailable for production, with only one of those typically being down for planned maintenance. After the process was applied, 15 of 16 machines are now routinely available, with one machine still typically down for planned maintenance. This represents an increase of 50% in equipment availability. In another area maintenance was routinely called in for unplanned downtime. After application of this method, production staff were trained in routine operational practices which essentially eliminated the need for emergency repairs and for maintenance to "come to the rescue". This eliminated many unnecessary work orders, improving equipment availability, and reducing costs. The methodology continues to be applied in the plant with continuing improvement.

In closing, it must be said that methodologies such as TPM, RCM, TQM, RCFA, etc. all work when consistently applied. However, as a practical matter, each methodology appears to have its focus or strength. For example, TPM tends to focus on maintenance prevention and operator care. RCM focuses on failure modes and assuring system function. Both are good methodologies. Both work. However, in this instance, we've found that combining the two actually led to a better process and to improvements in teamwork and cooperation at the production level, leading to improved performance and output, and lower operating costs.

References:

1. Total Productive Maintenance, Seiichi Nakajima, Productivity Press, Portland, OR, 1993.
2. Reliability Centered Maintenance, United Airlines, F.S. Nowlan, NTIS Document No. AD/A066 579, December, 1978.
3. Reliability Centered Maintenance, A.M. Smith, McGraw Hill, New York, NY, 1993.
4. Reliability Centered Maintenance, J. Mourbray, Butterworth-Heinemann Ltd, Oxford, England, 1991.

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