Challenges of Matching Maintenance Programs to an Aging Rolling Stock Fleet

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Though there are common standards and regulations to dictate maintenance practices for the requirements for safe reliable operation of rolling stock, the methodologies that may be uniquely applied by the agency often do not lead to outcomes of equal performance for the various rolling stock vintages. Consequently, there is a never-ending challenge for agencies to create a balanced management of their rolling stock equipment using progressive maintenance mechanisms, timely execution of intervention processes and employ strategically planned capital investment programs.

The intention of this paper is to present the key elements of the agencies' operational demographics, in terms of service schedule demands, fleet vintages, maintenance facilities (on-site & outsource), support services (i.e. material supply management, reliability engineering). Without direct reference to a specific agency, "real situational" examples will be discussed to demonstrate the impact of these elements in the management of rolling stock equipment.

These non-disclosed examples will reveal hardships associated where agencies have become victimized by utilizing their own standardized convenient processes, which restrict their ability to adjust their programs to match processes to the natural evolution of aging rolling stock equipment. For example, the routine preventive maintenance program can become ineffectual after performing multiple servicing cycles as parts are wearing due to the natural aging process of the equipment. This results in a higher demand for replacement parts in lieu of preforming a service type intervention. Then it is discovered that the required repair material is not available due to the lack of forecasting from a standardized material management system.

The discussion will proceed to identify the "triggers" or indicators for maintenance alterations and identify some solutions and use of "metrics" of rolling stock performance to accommodate the typical lag-in-time of useful data that is necessary for better planning of maintenance activities.

MAINTENANCE PROGRAM LISTINGS

The rail industry has had to come to grips with effectively managing the maintenance costs which are typically 30% of the total life cycle expenditure of their rolling stock fleet. Hence there are numerous common maintenance program concepts, with a variety of strategic ratios of funds and energies applied to these maintenance types that attempt to address meeting the hierarchy of rail operation objectives, namely: railway system safety, passenger comfort, equipment utilization that relates to reliability and availability as well as total operating costs which consider the aspects of equipment appearance, quality and efficiency.

However, when considering that rail transportation has an enduring commitment to being a major component of the societal way of life and in many cases may be the transportation backbone of the economic structure, the maintenance philosophies must continuously accommodate: the integration of refurbishing their equipment with purchasing new or conducting major overhauls, installation of new technologies to compete with other transportation avenues, and deal with the effects of the expansion of services lines and/or payload operation. Recognizing this point, this author has chosen to identify newer and not-so-familiar maintenance program terminologies that the agencies should identify as part of the menu of maintenance philosophies that they could select from, in order to accommodate these inflicted responsibilities of a progressive railroad operation.

The following is this list of maintenance programs outlining their conceptual definitions and identifying their typical characteristics.

Preventative

Is a scheduled routine service activity using periodic time frame groupings that follow recommended practices from original equipment manufacturers (OEM) and/or regulatory organizations. Planned execution of highly standardized activities to accommodate workforce, scheduled utilization of service bays, and employs a consistent parts management process. This program's objective is to prevent failures and sustain equipment life to the required operating performance level.

Corrective

Necessary unscheduled activity, responding to failures during operation, spare parts pool is forecasted to produce an expedient repair turnaround time based on failure analysis predictions and the number of depot service center locations that are to have these on-hand parts available. This is the speedy "in/out" fix it repair shop concept. This exhibits a dependency on having a diverse, multi-skilled work force, use of diagnostic capabilities, and availability of sufficient parts and tooling.

Reliability Centered

Prediction schedule maintenance based on vehicle mileage or operating time frames that use failure analysis or derived metrics of reliability operating statistics, that are typically incorporated with preventative or servicing routine activities. Its premise is to achieve availability targets and repair "just prior" to the time of need. Though the vehicles follow their assigned schedule maintenance dates, the content of maintenance activities performed is specific to the required program design that will ensure high equipment reliability and vehicle availability.

Condition Based

Incorporated into scheduled preventative maintenance programs is a process to review the equipment using criteria that determines the work activities required, i.e. repair, replace, upgrade. The timeline of work or tasks will be dependent on condition of the equipment. There will be cases where a vehicle will have to remain within the service bay longer than scheduled as a result of discovering equipment requiring lengthy repair time and or awaiting additional manpower support. This program will require supported services to maintenance group in providing testing equipment, gauging instruments, and training of workforce to perform the equipment evaluation process.

Scheduled Intervention

Planned activities made to accommodate modification programs or major subsystem overhauls on fleet running equipment. Typically a volume of work is planned, materials are stocked and procured in advance, dedicated non-service work bay areas and task force are assigned. A specified scheduled out-of-service time period is defined for the vehicle unit based on the nature of the work assigned.

Investment Based

In order to achieve the highest productive output of a variable aging fleet of equipment of different vintages types that may run on different service environments a railroad operation may be required to look into utilizing an "investment based" maintenance program.

This requires a more integrated outlook of capital equipment procurement plans to the life usage of the rolling stock to be maintained, considerations of service utilization factors, cost value analysis of investment for extending/salvaging core components will be factored into the planning of maintenance activities. This is an intermediary step to the life cycle of the rolling stock that can factor into the decisions of retirement or refurbishment of the aging rolling stock equipment. The critical long life equipment components are weighed in terms of investment required to salvaging and maintaining them to fulfill and/or exceed their design life requirements.

For example, it may be a cost benefit solution to plan for an interior refurbishment and major truck overhaul knowing that the stainless carbody structure exhibits potential for additional 8-10 years of operating service before strip down repair. Note, other sub-system considerations can also come into play as these cost scenarios analysis are being evaluated. Reinforcing that this investment based maintenance program is a long range outlook that is specifically designed to the 'existing' behavior of the fleet equipment and forecasted investment outlook available to the railroad operation.

At first glance, the aforementioned maintenance methodologies appear quite familiar and these are applied by most agencies and operating railroad authorities in some version or combination during the life cycle management of their rolling stock equipment. The issue is determining whether the effectiveness of these maintenance work programs and their resulting outputs is achieving the planned objectives of their operating railroad.

Note, that each version of these programs serves a limited function within managing the life cycle of the rolling stock equipment, and neglecting to apply any one of these programs will lead to a recognizable void, usually resulting in a cost impact or service performance deficiency. This awareness to these issues affecting their rolling stock typically comes too late in time to react effectively to combat these detrimental effects on their railroad operation.

Consider a scenario, and the impact of an unpredicted accelerated failure of electronic power supply devices due to the fact there is no required service intervention, and are to be replaced only upon failure. A condition of an accelerated rate of failures occurs as a result of the power supplies having experienced a harsher heat environment due to it being contained in a non-ventilated electrical locker location and as this device rapidly ages causing it to have a shorten service life, they now begin to fail collectively. This high unscheduled demand of power supplies has depleted the corrective maintenance pool stock from the OEM supplier, which by the nature of its design requires a repair/replace time of 6 months, and/ or a new design for a replacement to be performed since some of the contained parts within these power supply units are obsolete. This situation results in a high capital, revenue producing vehicle to be out-of-service till the authority can "rob" the 'good suspect to fail' part from a vehicle that is currently scheduled for overhaul. This in turn means the overhaul vehicle will remain inactive till it can acquire its' replacement.

This 'real' situation may signify a familiar type experience to many operations that have suffered a similar situational hardship, yet this can be remedied by only a few known agencies, that will be discussed later in this paper. To be fair, latent defects of design as the previous example portrayed cannot be easily identified or can be preventatively managed, but it is a point that again speaks to this author's suggestion we must acquire the timely communication of the rolling stock health to then react to minimize fleet crippling effects.

The intentions and maintenance program designs are good and typically effective but can suffer from the following constraints' and/or interferences that are attributed to the isolation of departmental roles within their organization, and/or the nature of work place trends that can have an impact on their program designs.

LIMITATIONS, CONSTRAINTS AND CHALLENGES

As previously stated no singular maintenance program can be selected to accommodate the needs of the rolling stock equipment. If we examine the limitations and benefits of each maintenance program design, and identify the key components that make them effective for their purpose, we can later develop a "balance" program of maintenance activities to service the requirements within the period of the current status of rolling stock equipment. Ultimately, we are seeking to provide a plan of control in a non-controlled and continuous 'morphing' environment whether it be the aging conditions of the rail vehicle itself, the ever-changing operational demands, evolutionary changes of the working culture, accelerating incidences of obsolescence due to rapid technology advancements and external social-economic financial influences affecting the agency's transportation servicing role.

It can be seen from reviewing these influences described below that the principle message of this paper is to have an adaptive approach to maintenance program implementation. By recognizing what are these constraints and challenges, there can be solutions created to have a pre-planned directed maintenance plan in order to break away from being a response lagging type organization that must react to the necessity of putting out fires, where in fact these fires can be predicted!

The following will discuss a list of typically known unmanageable influences.

Capital Investment, Funding and Financial Planning

Rail transportation especially if it is passenger oriented is dependent on external support funding from federal, state, provincial and municipalities. These funds may be obtained through any combination of lobbying, budget applications and timely intervention with the political flavor of the day. History has shown no consistency in funding other than it has peaks and valleys, and is also affected by the economic climate. This insecurity in capital funding strongly influences the ability to implement an *investment based maintenance* plan since it is difficult to place a risky bet based on a non-committed date to when funds will be available for new vehicle acquisition or refurbishment programs.

This unpredictable funding cycle and often late arrival of funds has created a tendency to extend the service life of rolling stock equipment. Consequently, the component of *investment based maintenance* planning must be factored in. Meaning, a target of service life must be established, a determination of retirement or refurbishment must be made. These decisions will influence what investment in major subsystem components are to be made, questions of intermediary upgrades are to be asked and implemented in a *scheduled intervention* program.

Challenges managing the vehicle's different subsystems' equipment service life have to be addressed so they sustain their performance life throughout the predicted end of the life of the vehicle. This can impact organizations that utilize *corrective* or *reliability based maintenance* programs in that if equipment is left unattended these repair based activities will increase whereas the best suited format of managing varying service life components is to use a combination of *condition-based* and *scheduled intervention maintenance* processes. This suggests opportunities to apply condition base criteria processes by selecting high cost equipment items that are suspect for future reliability failures; these can be identified and evaluated during the *preventative maintenance* program cycle which will result in only replacing those high cost items based on their condition criteria.

To cite some examples, this could be applied to door operating mechanisms or air compressors. For other items that have different staging of required overhaul periods, they can be set up in groups having similar common time frames (i.e. propulsion contactor units, communication LED display signs) to be replaced with new, or have an intervention of a mini-overhaul from a scheduled plan .

The vision presented is to perform the work in a shift or two, on multiple systems and possibly employ the services of OEM field crews for this life extension capability, not unlike exercising a mini modification program.

Resource Availability

The following list of items display some of the real situational experiences that should be familiar to those who have had to manage any rail equipment operation. These are constraints that challenge every rail operation authority in some period of the rolling stock life existence.

Plant: Issues arise in terms of there being sufficient service bays, and if they are properly equipped with necessary tools, jigs, lifts, cranes, etc. It may be questioned if the service bays accommodate the equipment of today versus when they were built 30 years prior to handle the older vehicle equipment. For example, the newer vehicles are utilizing roof-mounted drop-in modular designed LRU (Line Replaceable Unit) HVAC units that now require a mezzanine area equipped with a crane lift for HVAC servicing and replacement exchange.

These plant requirements have to be factored in the acquisition of capital required for upgrading the plant facilities to accommodate the servicing requirements of new equipment technologies. In addition, this will translate to attention required for staff training and tooling.

The result of a maintenance facility having a limited number of service bays relative to the number of trains required to be serviced, also creates shorter timeframe allotments in which the vehicles can occupy that limited resource location i.e. one shift per train/loco/vehicle, thereby creating restrictions on long term required work activities. In addition, often this precious time can be eroded by inefficiencies in hostelling the train from the yard to the shop.

Operating Budget: Due to the consistent battle of the budget, maintenance funds can be wrongly cut by reducing needed manpower due to the perception of an idle workforce who may be waiting for their train to arrive, again a negative outcome due the inefficiencies of train to shop movements. Needless to say, the balancing of budgeted funds for maintenance programs, to produce meeting the ‘metrics’ requirements of operation, namely, availability to meet service demands, to generate ridership revenue is what drives the funding allocation to implement the solutions to combat the interfering constraints.

Another key issue that affects the management of rolling stock is that operation funding versus capital investment funds typically come from different sources and are not necessarily integrated to a coordinated operational plan. By this, it is suggested that the influence on one area acquiring funding can negatively influence another area, if the funding does not transcend to the total operation. To emphasize this point, consider the case where capital funding is not coordinated to match the installation of a new line extension or to acquire new vehicles, with the funding required to expand the existing maintenance facility thereby creating a fleet servicing resource issue. This lack of on-time capital spent to expand facilities leads to all rolling stock new and existing being compromised in their maintenance programs execution.

Parts Availability: The necessary parts for which every maintenance program type is being implemented may not have arrived at the right time and location. Materials management is confronted with supplier deliveries that work only to committed forecasts, their long delivery times and their ‘just-in time’ manufacturing process. Hence if the requirement of the part from the shop floor does not fall in the time frame of the expected planned demand and is not properly communicated to the material management group, will result in a vehicle waiting for its replacement part. Regardless, the train will either leave for required service with uncompleted maintenance tasks or remain parked out-of-service till the part has arrived; this then creates a vehicle availability issue and potentially creates a service bay or yard storage limitation.

Remaining on this point, but diverting to a significant trend change in modern passenger type vehicle design configurations is the departure from older two-car married pair designs to producing four, five or six car consists of unit trains. Hence from the non-availability of a necessary part, the impact of train availability for revenue service is significantly greater, as the multiple healthy units permanently attached to their designated train sets are dormant due to one unhealthy repair required unit.

This multiple car train unit trend has also produced issues requiring redesign of maintenance shops to accommodate the longer consist lengths. This results in a loss of flexibility and ability to maximize the shop utilization to perform different service needs as was previously applied to the older version of individual cars or married-paired vehicles.

Time: Time by nature is a limited constant under any scenario. Efficient use of time is the key issue and has intertwined in the effects of the other limitations or constraints some of which have already been discussed.

From a maintenance perspective, recent rolling stock design requirements have earnestly addressed the issue of time and associated efficiency by demanding equipment having shorter repair times, by packaging components in modular Line Replaceable Unit (LRU) designs to promote quick LRU component exchange on the train, and the exchanged faulty LRU repair is performed in the "back shop". Design improvements are made to extend the service intervention periods, materials are selected to be more resilient to handle environmental elements (i.e. climate, passenger, technical stresses), to increase their wear rates and to extend their replacement/overhaul periods. By the way, this LRU process is well suited for the implementation of providing quick turnaround times and shorter front shop service bay utilization times for *scheduled intervention* and *condition-based maintenance programs* as well.

The ability for LRU components to be exchanged in the service pit, (the NASCAR /Indy Race Car concept) does influence the materials management process as they become dependent on the size of the LRU, larger LRU parts may require use of different material handling mechanisms like fork lifts, or drop tables, or the need to increase the size of staging areas for the healthy replacement units. Then there is the need to transport the failed unit to its assigned support shop location that may or may not exist within the same service shop facility. Also these support shop areas will have their own parts stocking areas and the material management process must be equipped to handle the logistics and control of parts that are in multiple locations, or are in motion and in different conditions of repair (bad order, to be repaired, under investigation, return to inventory, evaluated for scrap, send to OEM, etc.).

What has been witnessed, as railroads agencies are becoming more familiar with the LRU exchange process for *corrective maintenance* is that a practical and pragmatic approach is being considered not to replace a large faulty LRU item (i.e. air compressor or propulsion inverter) by replacing the much smaller failed sub-component - Lowest Line Replaceable Unit "LLRU" i.e. (a failed pressure switch or welded worn contactor) while it remains on the car.

The trade-off of advantages may include:

- Reducing the risk of failure to other healthy components caused during the exchange of a large bulky LRU (e.g. pin damage while removing cable connectors),
- It may employ less technical and material management manpower,
- Less time taken for the repair,
- Diagnosis of the cause of the fault versus the symptom, and
- Eliminates the need to test the whole LRU, instead the functional test of the repaired component is performed on the vehicle versus the test bench thereby using the vehicle's powered subsystems to validate the equipment functions correctly.

The counter argument for LRU replacement verses repairing the failed sub-component in 'situ' is the element of ensuring quality and standardization of work which becomes dependent on the trade skills and abilities of the on-vehicle repair person.

New vehicle designs also incorporate the use of new communication technologies to enhance failure reporting, and are equipped with on-board diagnostic features that transmit fault information to the vehicle operator and/or wirelessly to the awaiting facilities to assist with *corrective maintenance* activities. These on-board vehicle mechanisms provide opportunities to perform the troubleshooting diagnosis, determine and acquire the necessary parts and tools, assign the appropriate service bay, issue the work-orders, all done in-advance of the train completing its service route and entering the maintenance facility. This ensures efficient use of the assigned plant service bay, and minimizes the out-of-service time of a valuable revenue generating vehicle.

Additionally, the recording of the event can be immediately and automatically input into the reliability data base, omitting the common issue of time delay between acquiring statistics and recognizing equipment failure trends which are needed *for reliability based maintenance* planning processes.

Technical Support: Dependent to maintenance philosophies or programs selection is the agency's structure for technical support services to accompany the management of the operation and maintenance of rolling stock equipment. Technical support service is in fact a critical link between the operating and maintenance groups in terms of understanding the relationship between each other from an issue resolution perspective. By that, the service operation can impact the outcome of the equipment behavior in terms of failures, wear rates and level of performance, likewise, the equipment condition impacts the operation in terms of its' availability for service, passenger comfort and overall safe operation.

Depending on where the technical support is provided, or who is responsible and has ownership of an issue, or how they are networked and what departments are involved within the rail operation, (namely: engineering, maintenance facility, workforce/ operator training, suppliers, track and systems groups) will determine the role and contributed value these groups will employ on managing the equipment borne issues and their resolution.

Technical support is a necessary resource to implementing *condition-based maintenance* activities, in order to provide the criteria information for evaluating the status of equipment functional life and performance requirements. This is an 'engineering' type function to produce the criteria standards typically exercised prior to implementing the maintenance work schedule. Dependent on the skill set level of the shop floor service personnel, on-site technical support may also be required to perform troubleshooting functions in the *corrective maintenance* environment. Likewise, if a *reliability base maintenance* program exists then technical support will be required to take a 'back office' approach to analyzing the reliability data. From their root cause failure analysis, the technical services groups will provide proposals of remedies and/or equipment modifications that will likely affect various *scheduled preventative maintenance* procedures /actions as well as result in planned work to the equipment under *scheduled intervention maintenance* programs

Workforce Skills: The skill of the workforce is a key influential critical aspect of fleet management and is the most significant ingredient in maintenance practice changes. Though many railroads still foster the avenues of apprenticeship and in-house training for service skills development, the content has been significantly altered as well as their focus from technical information and more towards procedural understanding and workplace safety. There is no argument that all of these training components are necessary for a productive and healthy workforce.

However as a result of recent higher priorities on quality assurance, combined with the integration of LRU replacement concept, and the unionized workforce requirements for establishing equal opportunity for job bidding based on seniority, and redefining task and roles of trades within the agency's maintenance work plans, there is less technical skills competency expectation and usage performed by service personnel. (A statement that may be counter-argued by some organizations, but still a point this author wishes to identify for discussion based on experiential observation.)

Today's rail maintenance workplace environment is typically structured and the service person is classified under a broader work category. The service person now must be trained to be multi-dimensional in knowledge for servicing more vehicle systems equipment, whether they encompass electrical, mechanical, pneumatic/hydraulic or micro-processing devices; hence the "generalist" concept is being fostered.

Taking advantage of technology, the vehicles have various on-board diagnostics and equipment health monitoring devices, that now affects the service person' s diagnostic process by incorporating a Portable Test Unit (PTU) device, which is a lab-top computer that can be connected as a remote onboard diagnosis machine on various subsystem control systems to identify the component parts to be replaced. The operation of the PTU is expected to be utilized by service personnel member trained and equipped to independently diagnose and service the failed equipment as instructed by the PTU software logic.

However, the reality is that there is limited number of these expensive and fragile PTU devices, and since the service person now has a larger scope of equipment responsibilities, still working within a restricted time frame may or may not be able to perform all the necessary diagnosis and troubleshooting functions. Consequently they will either defer that analysis to be done by an on-site technical support person, or make their best guess and exchange the suspect part.

This creates a "trial and error" methodology environment, resulting in a stack of suspect parts needed to be sent to the remote repair shop for either validation or repair, because the workplace mandate is based-on a quality assurance and safe practices philosophy which will not permit any suspect device (though potentially good) once removed from the vehicle to be returned to the vehicle or stock until it has been validated by the remote repair facility exercise.

To summarize, many *scheduled* and/or *corrective maintenance* programs are designed to streamline the workforce to have a more common category of skills and the management thereof (in terms, of unionized labor relations). This is to provide benefits of "one-man-do-all", and make use of enhanced on-board diagnostic technology, to enforce quality control actions and material cost control benefits.

However, the reality of execution of the process within this philosophical structure has resulted in making natural alterations to accommodate the required equipment servicing activities. The result is maintenance shops adjusting and modifying the process so that service personnel are becoming reclassified as "parts changers", thereby deflecting the responsibility of diagnostics to a software program within the subsystem control units, and breaking the chain of communication and knowledge of failed components history that could be used to remedy subsequent failures.

To be noted, the embedded diagnostic software programs can only look at "input to output" relationships of their equipment, based on the on-board monitoring sensors installed on the equipment. They cannot take into account the environmental influences which affect the performance of their equipment, namely, climatic, physics type stresses, passenger, operator or maintainer actions, as well as the chain reaction of events associated with integration of other systems. This type of analysis can only be done by a remote observer/analyst who can view the issues from an external global perspective beyond the equipment boundaries.

As an aside, should the PTU information, maintenance record activities and records of equipment health monitoring information be collated and evaluated by a technical analyst, the use of these new technology diagnostic type mechanisms are valuable tools in creating and/or implementation of a *condition-based maintenance* program. Hence, this information can create standards and/or metrics for determining what actions are to be taken on the component at the time of scheduled maintenance activities. This requires that the service person must be well equipped with information, tooling, time for repair and replacement material to respond to the actions requested. Or at a minimum this work must be identified on a task list to be performed at the next schedule interval, where time, manpower and material resources can be made available, or be deferred to be acted on in a *schedule intervention maintenance* type program.

Reflecting on the "old days" the word "technician" or "mechanic" or "electrician" or "millwright" was a role and function that a service person had to exercise, meaning they were regarded as the person who performed the troubleshooting diagnosis, implemented the "correction", validated the equipment as functional, and "signed-off" to release this the vehicle for service. This formatted created a hierarchy of system and equipment specialists amongst the ranks. There was the "go-to guy" who for example was the specialist for brakes, and one for the propulsion equipment and one for HVAC or doors, etc.

It has been observed, by this author, in a number of maintenance operations, probably developed out of necessity, a creation of a 'disguised' culture to the "old days" of shops having created the "go-to person". To validate this comment, you simply just have to ask the shop superintendent or shift foremen who they send out on the missions of challenging maintenance issues, or how they create the partner work teams. The principle applied here is: "water seeks its' own level", meaning that getting the job done is performed to an unwritten standard, based on the reality of aforementioned limitations. The "go-to person" is a natural model to the normal distribution of workforce skills and productivity, in which the workforce maneuvers the systems to suit and match their capabilities and/or interests. (Note; to management the control of a productive work force is an additional challenge as a result of job security protection, unionized leveling principles and social benefit regulations that must be addressed in the implementation of maintenance programs).

All these aforementioned constraints or challenges produces ebbs and flows of balance and periods of unbalance in terms of managing the fleet related to the lifecycle of equipment performance changes in a "non-changing" departmentalized maintenance environment. Here is the "challenge" of managing an aging fleet! It is the need to recognize when actions and processes are required to be changed in a timely manner in order to minimize the effects of equipment performance deterioration, and create the ability to maintain the balance of service performance objectives.

TRIGGERS FOR MAINTENANCE ALTERATIONS

Depending on the maintenance plan philosophy selected it will be relevant to identify indicators or triggers which will be useful in designing their program processes. However, as initially stated the premise of this paper is to consider applying a maintenance program that responds to the how the equipment 'speaks' to us as it goes through the aging process of its' vehicle service life.

Realistically, we cannot ignore the departmentalization and processes of standardization of maintenance practices due to regulatory or OEM requirements, for safety and quality assurances and protection against potential negligence litigation matters. However, neglecting to read the signs of equipment health is a prescription for experiencing large volumes of failure that can cripple a fleet, affect service availability and produce dramatic high cost reactions that are ill planned and executed strictly for the remedy required. Note, it does not have to be a high cost component but a simple low cost device that is needed for the operation of a valued function device, i.e. consider the impact of a rash of obsolete micro-switch failures contained in the operator's master controller or a series of a cracked suspension brackets considered critical to safe truck operation.

By monitoring and recording equipment behavior, there will be data to determine if required analysis is to be performed as a means to thwarting such events. Note, there is a common process applied by most agency operations and rolling stock suppliers that employ the FRACAS (Failure Reporting, Analysis, Corrective Action

System) methodology to record and track the visibility of component failures that induce operational degradation. To gain the value of monitoring programs such as FRACAS requires a set of unbiased "eyes" applying a scientific approach to determine cause/effect relationships, a "set of legs" to walk freely in the environment to observe and collect data, understand the issues of limitations or status of what the other interacting departments are experiencing, then use an authoritative "voice" to be heard when a recommendation for action is announced and presented with options of alternatives that demonstrate consequences, costs, benefits. It can then be seen this requires a specialist, with competent knowledge of the operation and/or of the equipment and someone that can be dedicated to resolve cost absorbing problems. This suggests being handled by the technical support group.

The recommendation for our rail environment is to capitalize acquiring information from the multiple units of rolling stock to establish an understanding of the trends and equipment behavior to then forecast and plan remedies in advance of potential catastrophic events.

Understandably, we will always be challenged by budgets and resources to do "what we can afford", but the question to be answered is: "what can't we afford?" Hence, acceptance of actions will be based on consequence, investment and most importantly the time of planned implementation.

Experience has shown that collectively there is more than enough information from all the transit agencies and railroad operators, contractors and suppliers to input statistics of equipment behavior. Hence the application of reliability statistics as contractual terms in vehicle acquisition programs. There can be some deception of these figures in that identical equipment on one property does not behave identically to that on another property or service environment, so the reliance of a common reliability statistic is mute for specific use but can be used as a statistical guideline for equipment behavior. Meaning that, an agency can determine if their equipment behavior is of the norm or increasingly becoming a cause for concern.

A passenger railroad company reviewed the reliability statistics of their brake equipment to discover that the failure rates were not impacted by performing the regulated 3 year periodic overhaul requirement that was outsourced to the OEM supplier. Though the OEM had been successful at providing a 100% reliable overhauled product it was determined that there were failures occurring attributed to the change-out process within components exchanged as part of the overhaul requirement, e.g. missing a gasket to cause leakage, component damage in handling or a similar component incorrectly applied to the vehicle, etc. This observation became the "trigger" or indicator for the operating authority to challenge their scheduled overhaul maintenance process and revamp its processes

Additionally, the railroad company sought to extend the overhaul period and conducted a carefully control test program which analyzed the condition of the internal components which were typically replaced by the OEM supplier to determine what was the "real" life of these internal components to then possibly support a longer overhaul requirement period. The results of this study supported extending the overhaul period for many of the brake component to five (5) years from the standard three (3) year requirement. (Aside, the Federal Railroad Administration (FRA) is currently reviewing the time extensions to brake equipment COTS (Clean, Oil, Test and Stamp) requirements as requested by various North American rail transit agencies.)

As a final step in enhancing the brake reliability, the railroad company repositioned its brake equipment change-out philosophy based on failure detected via periodic test inspections that had enhanced test protocol instructions. This would then identify a weak or worn component that should be replaced just prior to committing an 'on-the-road' service failure.

Here we see that this progressive railroad operation responding to the reliability information to gain detail knowledge of the characteristics of equipment.

They had altered their maintenance program from a *scheduled intervention* type process (standard 3 year overhaul) to a *condition-based maintenance* program. This produced a benefit of reducing the overhaul costs due to the 5 year period extension; reliability was increased due to less intervention with healthy components, as well as experiencing a reduction of in-service failures and an increase in safety values because of implementing a more stringent inspection program.

From a technical perspective, determining equipment operating health or evaluating its position in its life cycle is done through periodic inspections and functional tests. These tests must be pertinent to performance expectations, the tests themselves may be more detailed in terms of requiring measurements to be taken and /or evaluated against "Go/ No Go" criteria.

Observations of wear and the location of wear, recognizing influences of environment, measuring the rate of wearing components, this type of information is valuable in determining if the equipment can sustain its design life as predicted or if the wear characteristics create a new prediction and is cause for concern to develop a planned action of intervention.

To cite an example, consider ground brushes found wearing at an accelerated rate, which was determined via measurements taken as prescribed in the periodic *scheduled maintenance* program. Some ground brushes had worn beyond their ability to make contact before their scheduled change-out, which was determined in a much later equipment investigation study to be the cause of electrical pitting damage on gear teeth.

Analysis was performed on the ground brush resulting in change of material to increase wear life. In addition a change to the ground brush spring mechanism was made to ensure contact for electrical grounding, which was needed due to the harsher than normal vibration environment experienced by the truck suspension system.

Fortunately, electrical pitting on gear units was determined not to be detrimental to the life and performance of the gear, but the associated bearings found exhibiting electrical pitting damage made them suspect to possibly cause catastrophic failure. Hence a decision of what actions may have to be made on implementing a cost adding gear unit inspection program was weighed against the risk of a high cost replacement of a gear unit assembly resulting from an undetectable bearing failure.

This example typifies one of many situations that each railroad operation and fleet management program is confronted with time to time. There are generally no alternatives but to react, re-engineer solutions, to make pragmatic decisions conditioned on risk versus cost and set-up resources for implementation that must be integrated into the normal day-to-day operation to ensure the minimal disruption to revenue servicing demands.

Another ‘trigger’ for altering a maintenance program relates to incorporating the planned acquisition of new vehicles or overhauling the existing fleeting into the maintenance program plans and or processes.

The concept is to create or adapt the maintenance practices to be a seamless transition for managing the new vehicles (equipped with newer technologies) into the operation and existing and/or newly designed maintenance facilities thereby keeping the high cost capital vehicle in service and ready for service at all times. Basically, it is planning for “transition”. The aging fleet must endure coordination of the timeline of these new and reconditioned fleets.

Decisions will have to be made regarding what equipment can be salvaged from the ‘old’ fleet or will the retired fleet be suitable for resale. If a revitalization or major overhaul program is decided for the aging fleet a determination of the scope of work must be done on major subsystem components based on if they have or will be upgraded on their overhaul cycle, or if they will be retired as obsolete and replaced.

There have been cases observed, where new technology has been made to equipment during the life of the vehicle, (e.g. conversion of air dryers from single purging canister type to regenerative twin tower desiccant type, married-pair mechanical couplers exchanged for semi-permanent link bars, DC chopper control propulsion systems changed to AC propulsion IGBTs units. etc.) Regardless, if these changes and/or upgrades may have occurred independently or at a planned end of life vehicle rehabilitation program, they now need to be assessed for salvage depending on whether they are well maintained and at what period they are in their life cycle, and also how many years of high reliable performance they will be able to contribute in the new refurbished vehicle.

Dependent on the agency relationships and their organizational structures, capital investments and facility management are to be factored in the coordination and integration of new or overhauled fleet programs with the operation sectors of a railroad authority. There are either invisible barriers or missed opportunities to share valued information based from operational experiences that can condition the planning and acquisition of rolling stock equipment to be more efficient in the areas of maintenance activities.

Cases exist where maintenance or operation input is asked late in the stages of a new vehicle acquisition program, i.e. during the design review process versus upfront in the specification development phase. This usually results in unresolved maintenance issues which can escalate the total cost of vehicle ownership. Obviously, the best approach is to involve all the stakeholders in these programs, and from this the stakeholders can condition their processes to produce an integrated plan where each department player can optimize their operation in managing the acquired fleet of equipment.

Reciting the previously mentioned example (the “non-available” electrical power supply) where significant yet small cost components can hold a multi-million dollar vehicle or trainset hostage to be out-of-service for an extended period of time; this is the nightmare that has to be addressed by transit agencies.

There are agencies that require the OEM suppliers and contractors to accept service contracts that are designed to assure availability of replacement components or expedient repair/replacement of such components whose condition of functional performance are not ‘conditioned’ inspected by the agency’s *preventative scheduled maintenance* cycles. This luxury of service does typically come at a cost, where the price of repair or parts availability is at a higher premium due to the cost of the OEM contractor taking on of the responsibilities for maintaining stock, material storage and having a specialized repair team within their standard production facility. But this price premium is viewed as acceptable by the agency because it is a better price to pay in lieu of the high cost impact of the loss of availability of a revenue producing vehicle.

Typical for railroad operations that have a large number of rolling stock vehicles, is that they will set-up their own electronic or pneumatic type repair shops to address localized repair. These shops must in fact be set-up with engineering and technologist support personnel, equipped with sophisticated Bench Test Equipment (BTE), have component redesign capabilities, a competent material management process that has a broader stocking level of lower level components and means to deliver components expeditiously to the awaiting vehicle. This approach also requires a significant commitment of investment for the benefit that the railroad operations is less dependent on outside OEM suppliers and can self-manage their fleet to effectively react to situations of non-forecasted technical mayhem in order to maintain high equipment availability.

A recommended practice to determine requirements for maintenance alteration is to create periodic investigations in order to understand the operation impact and its relationship of the equipment performance. Such investigations are rarely performed and yet, there are likely no cases where a railroad operation has remained stagnant in their operation from the inception of acquiring their newly specification designed rolling stock vehicle throughout thirty (30) plus years of operational service.

Such investigations or studies could be assigned when operational changes are being considered; test or analysis could be performed on key equipment components to determine if additional “stresses” will be applied that may or may not have been factored into the original equipment design specifications.

Reflecting on situations, such as a speed operation change, trains operating on dedicated routes which may experience high percentages of crush loading conditions, extending the time of a regular schedule service activity, or experiencing seasonal environmental conditions causing poor track adhesion conditions all of these situations would likely create dramatic stress induced effects on truck suspension, carbody interiors, propulsion/braking equipment and their subsystems interface relationships.

An independent team, call them “equipment performance auditors”, equipped with an evaluation plan could observe equipment behavior via diagnostic information. They could speak to the person(s) that interface with the equipment under review to then acquire their day-to-day experience testimonials, review schedule times, costs, materials and energy records employed by maintenance centers. From this information they could then perform their analysis to then challenge the suitability of the design to meet the operational and environmental conditions.

In the opinion of this author, this process if performed periodically will provide the knowledge which will help rationalize actions needed to address maintenance activity changes to meet the primary objectives of a railroad operation. Namely; cost effective management of their rolling stock equipment, to maintain the highest regard for safe operation, reliable revenue producing service and maximize the use of the available capital assets.

SUMMARY HIGHLIGHTS

Clearly the “challenges” to managing rolling stock equipment at various stages of their life cycle (new or at the end of life) are “real” and familiar to railway operating agencies.

It is recognized that several limitations and constraints, *capital funding, resource availability of plant, parts, operating budgets, time, support services and workforce skills* will play into the direction of maintenance activities and will impact the effectiveness in meeting the operating objectives of service demands, vehicle/trainset availability and control of costs.

There are many examples that demonstrate the benefits of new vehicle technologies (e.g. *extensive diagnostic capabilities),* implementation of the LRU parts exchange concept, a changing work force culture (from ‘technically competent’ specialists’ to ‘parts changing’ generalists), together with improvements in material management and technical support services. These actually become some of the features that drive the need for adjusting maintenance program processes. In addition, trends of agencies to employ OEM service type contracts versus a more independent self-reliant set-up of localized repair centers can be shown to have their benefits in terms of efficiencies and costs.

“Triggers” for justifying maintenance alterations were found to be difficult to categorize or define in terms of metrics. Reliability investigations and use of FRACAS methodologies are examples of metrics used to understanding equipment behavior but cannot be solely applied to developing maintenance planned activities due to time lag from failure to data entries and must incorporate purposeful analysis using an un-biased cross sectional investigative approach involving all departments of influence.

As this paper describes, there is no “status quo” for any agency, or for any rolling stock vehicle types (new, aging, or refurbished) to effectively manage their valued revenue producing equipment. There is a continual need to employ a “Kaizening*” process that confronts and combats the challenges of common constraints, in order to create “adaptive” and “balanced” maintenance programs, that are justifiably well planned and timely executed.

*'Kaizen' is a Japanese manufacturing process that employs continuous improvement strategies to maintain efficiencies in terms of minimizing material handling, maximizing manpower utilization, and reducing plant floor space, scrap rate and inventory.