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Experience with Industrial Gas Turbine Overhaul: Field Implementation

Tonye K Jack

Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, 50004, Rivers State, Nigeria

Abstract The process plant maintenance planning engineer for rotating equipment is always saddled with the question: When to Repair, Replace critical or poorly functioning part or implement, complete "tear-down" or equipment overhaul? Gas turbine overhauling is usually a well planned project with the required manning and materials requirements properly put in place. The complete equipment overhaul is inclusive of the "which part(s) to repair?" and "which part(s) to replace?" questions, together with the time and costs implications. The gas turbine overhaul planning engineer must apply the concepts of Value engineering and Value analysis to ensure that the operational economic value, post overhaul, is balanced with immeasurable and defined gains to the equipment owner. In this first paper, one such field experience in answering these questions is recounted.

Keywords Gas Turbine Overhaul; Maintenance of Rotating Equipment; Turbo-machinery Maintenance; Overhaul Planning; Value Engineering; Value Analysis.

Introduction

Based on Operational intervals, the overhaul of a gas turbine is often a very carefully planned, complex maintenance project, where, the planning for the next gas turbine overhaul project begins immediately, following the completion of one overhaul. This is even more the case in fields with several installed gas turbine units for parallel, series or stand-by duty operations. The operations and maintenance costs implications are huge, and if poorly planned, can cause significant revenue losses. Gas Turbines (GT) are designed for field and workshop overhaul. Aspects of the field overhaul may sometimes require specialized workshop repair services. It is thus good practice for the equipment owner's planning engineer to work in close collaboration with the Original Equipment Manufacturer's (OEM) Representative Engineer(s). Costs reduction considerations can spur companies to opt for experienced Contract Maintenance Engineering firms for key hands-on maintenance of certain project tasks requirements. In such instances, the equipment owner is advised to still use the OEM representative as superintendent of the major overhaul project. The key to selection of a good support contract maintenance engineering team is OEM acceptance and certification. This will assure that the risks of loss of warranties are avoided. The primary objective of a gas turbine overhaul project's success should be directed towards a maintenance policy of "Qualitative Functional Performance", which is aimed at achieving near original design or enhanced operational performance of the gas turbine engine, at minimum maintenance cost.

Bloch, Geitner and Jacobson [1] suggest approaches to gas turbine maintenance and overhaul, from one with full OEM maintenance management, to one with full equipment owner participation. Bloch, Geitner and Jacobson [1] in discussing the advantages and disadvantages to any of the approaches, observe that, the reliability of the overhaul project is related to the maintenance policy as defined by the overhaul plan. The planning should be guided by Thomas Edison's exhortation: "If there is a way to do it better …….find it". The overhaul planning is not a rush job. Every step of the planning process should be an engineered thought, guided by in-service operational, preventive and predictive maintenance records. Thus, the experience gained from one overhaul is carried to the next overhaul with cumulative gains to the Company's bottom-line.

Table 1 Time considerations and distribution for: Disassembly, Inspection and Assembly Checklist for Frames 1 & 3 MS model Gas Turbine Overhaul

Activity Number	Activity Description	Duration (in Days)
D1	Check Operating Data	4
D2	Shut Down Unit	4
D3	Disassemble Package	7
D4	Remove Combustion Chamber Cover	0.5
D5	Disassemble Coupling	1
D6	Pull-out Chamber Liner	0.5
D7	Check Alignment	1
D8	Disassemble Combustion Chamber/Diffuser Casing	1
D9	Disassemble Exhaust Housing	0.5
D10	Remove First Stage Seal Rings	0.5
D11	Disassemble Exhaust Plenum with Low Pressure Rotor and Mount on Stand	4
D12	Remove Transition Piece	0.5
D13	Remove Low Pressure Rotor from Plenum	0.5
D14	Remove Labyrinth Seals	0.5
D15	Disassemble Axial Compressor Upper Half Casing	1
D16	Remove Variable Nozzle Upper Casing	0.33
D17	Remove Bearings	0.33
D18	Remove Upper Half of First Stage Nozzle	0.33
D19	Check Rotor, Stator Blade Clearances	0.5
D20	Remove Axial Compressor Rotor and Place on Stand	0.33
I1	Inspect Bearings	1
I2	Combustion Liner Check for Crack(s), Corrosion, and Erosion	0.5
I3	Steam Wash Rotor and use Dye Penetrant for Crack Test	0.5
I4	Steam wash Low Pressure Rotor and Check Turbine Wheel for Crack(s)	0.5
I5	First Stage Nozzle Check for Crack	0.5
A1	Reinstall Lower Half Bearings and Seals	0.25
A2	Refit Liner Housing	0.5
A3	Reinstall First Stage Nozzle	0.25
A4	Reinstall Axial Compressor	0.33
A5	Reinstall Seals and Bearings on Low Pressure Rotor	0.25
A6	Reinstall Low Pressure Rotor in Exhaust Plenum	2
A7	Refit Liner	0.5
A8	Refit Liner Cover	0.25
A9	Refit Spark Plugs, Gas Ducts	0.25
A10	Reinstall Axial Compressor Blades	0.33
A11	Reinstall Upper Seal Halves	0.5
A12	Check Axial Compressor Blade Clearance	0.5
A13	Reinstall Seal Rings	0.5
A14	Reinstall Transition Piece	1
A15	Reinstall Combustion Chamber/Diffuser Casing	0.5
A16	Reinstall Variable Nozzle Upper Casing	0.5
A17	Reinstall Exhaust with Low Pressure Rotor	3
A18	Reinstall Exhaust Housing	2
A19	Align Machine	2
A20	Repackage Unit and Connect all pipes	6
A21	Start-up	4

Source: Jack, [13]

Phases in the Gas Turbine Overhaul Project

The hands-on-implementation requirements of the Overhaul project are made up of the disassembly, inspection, and assembly or reassembly phases. The inspection phase is crucial during the disassembly and assembly phases to ensure that critical parts' clearances, tolerances and machinery alignments are as directed in OEM manual guides for efficient GT running operations. Preceding the critical parts inspection phase is cleaning involving steam wash and degreasing [2]. More Modern units have online cleaning (also called "fired washing") facility [3].

These hands-on-implementation phases can be identified in the Activity Description Table 1, by notations: disassembly - D, inspection – I, and assembly or reassembly – A.

Preceding the field implementation of D, I, and A, activities is the actual planning for, manning, tooling requirements and possible replacement spares or repairable parts.

Calendar Controlled Activities by Tasks

The D, I, and A phases of the overhaul project implementation are defined by assigned tasks on an activity table by calendar events in days' unit as shown in Table 1. The estimated measured durations are based on experience at a customer gas compression facility with eight gas turbine installations - three for power generation, and five for gas compression service. These time estimates, can act as a guide for planning engineers and maintenance managers, and the actual focus should be on minimizing the total time for the overhaul project. Delays in overhaul project completion can arise when a needed spare is not available in the store or has not been delivered by the supplier. Therefore, before the shut-down for the overhaul, allowance should be made for such cases. However, when the overhaul is spurred by a sudden breakdown, additional cost effects for materials, labour and downtime must be provided for, in the forced shut-down overhaul planning.

Tools and Spares Planning

Safe use of proper tools in the disassembly, inspection and assembly of a gas turbine are important. Such tooling will include, well equipped tool boxes, mobile lifting equipment. Certain tasks will require special tools such as measuring devices, hydraulic torque and puller devices, rotor-stand amongst others. Good machining service (in-house, or outsource) is recommended.

For a well planned gas turbine overhaul, proper estimates can be made for anticipated replacement parts during pre-unit shutdown planning periods. The difficulty often arises when the overhaul project is prompted from a sudden breakdown as for example which might arise without warning from a failed oil pump which delivers oil to the journal bearings. Such dry runs can cause friction assisted seizure of the shaft journal, and cause ripple failure effects to other parts. In these unscheduled cases, the minimum spares requirement may not be sufficient to meet up with overhaul requirement. In a proper Gas Turbine shut-down for overhaul project, the likely repairable parts are, Combustion Liners, First Stage Nozzle, Axial Compressor Inboard and Outboard Bearings [4, 5].

Dean Jacobson in Bloch et al., [1], states that the reconditioning costs for these repairable parts can be compared to 30 % - 60 % of the cost of a new part, with improved new repair technologies increasing confidence of equipment owners in using more of this alternative in their gas turbine overhaul economic value analysis decisions. All other spares are usually replaced anew.

The Overhaul Team

The overhaul team is usually made up of mechanical, electrical, instrument specialists and a support labour gang. The team leader should ideally be multi-disciplined. However, the team leader is to act as coordinator of the project, and so can also be from any of the specialties listed, preferably one with a supervisory experience. Castillo [6] uses the title of "Prime Project Manager" for such a team leader on whose shoulder lies the control and eventual successful completion of the overhaul project *on time*. For cost effectiveness, it is common practice that overhaul crew is engaged on daily personnel costs contract. Some equipment owners have also been known to assign some in-house maintenance staff as support crew. In some country government supported companies these in-house support staff are sometimes placed to understudy the experts with a view to replacing them. A balance must always be made to ensure that the risks of loss of warranty are mitigated, when improperly trained personnel are assigned certain responsibilities.

Maintenance Value Engineering, Value Analysis and "Maintenance Value Added"

The value types of major interests in a gas turbine overhaul project are, *cost* and *use* value. The *esteem* value is nil. But, because of the critical nature of the gas turbine, it will be bad practice to use second hand parts. However, in a typical developing country with sometimes resource limitations and corporate challenges bothering on political interference, experience has shown that, it is not unusual for faulty stand-by units to be cannibalised to keep one unit running. Thus, the *exchange value* of some spares can vary. From a life-cycle cost consideration, such spare parts exchange values can be estimated based on the Dean Jacobson [1] reconditioning guideline earlier stated. Can maintenance plan centred on exchange value of some spares or whole equipment be related to the "Maintenance Float" approach? The concept of "Maintenance Float" as discussed by Levine [7] may be a good guide in such exchange value considerations for multiple Series or Parallel systems with standby units. However, considering the initial and operating costs of ownership, care must be exercised in applying the concept of "Maintenance Float" to the maintenance management of industrial gas turbines. In "Maintenance Float", an extra equipment is made available as support to keep another equipment continuously in operation [7]. Levine [7] defines the support equipment used, as a "revolving fund" of extra equipment, whereby equipment that has failed is replaced by a unit from the float, and the old unit repaired and returned to the float. An equation to determine the amount of float required from an equipment population is provided by Levine [7].The unique feature of replacement and concurrent repair of the "Maintenance Float" approach of [7], makes it an interesting alternate operational economic value proposition, though exceedingly difficult to apply to industrial gas turbine projects. However, a once extremely resource challenged chemical plant with two gas turbine driven generators units (Turbo-generators) for its power needs, resorted to using one broken down unit as the source of spares just to provide pre-rescue degrees of intermittent operations. Other resource challenged operations with out-of-date technology engines, with the potential difficulty in sourcing for needed spares, may also be applying this ingenious variant approach to the Maintenance Float concept. Bloch et al. [1] in discussing the need to develop a maintenance policy for reliable gas turbine operations, notes that some equipment owners in other to address the spares needs for critical operations, have been known to purchase entire gas turbine engines as spares.

Telsang [8] and Wikipedia [9], define Value by the relationship of eq. (1):

$$Value \uparrow = \frac{Performance \rightarrow}{Cost \downarrow} \quad (1)$$

This relationship is adapted, and modified for application to maintenance overhaul projects.

The key question is, how to keep the gain function ratio relationship between the "maintenance value gained (or added)", qualitative equipment functional performance, and overhaul cost, nearly equal-to or greater-than one in line with:

$$Ma\text{int}\,enanceValu\,eAdded\,(MVA) \uparrow = \frac{\text{Qualitative - Functional - Performance (QFP)} \rightarrow}{\text{Overhaul Cost (OC)} \downarrow} \geq 1 \quad (1a)$$

That is, ensuring same level of, or exceeding customer needs in gas turbine in-operation performance, post-overhaul, from a reduced cost of the overhaul project due to the increased maintenance value added.

The Arrow directions indicate: ↑ = Increase; → = Unchanged or Stable; ↓ = Decrease.

In instances, when there is a request from a customer to enhance performance of an existing gas turbine unit with a new technology update as in cases of retrofit of certain new parts or functional engine control systems, additional costs may be incurred, and the following maintenance value added relationship may apply:

$$Maint\,enanceValu\,eAdded\,(MVA)\uparrow = \frac{\text{Qualitative - Functional - Performance (QFP)}\uparrow}{\text{Overhaul Cost (OC)}\uparrow} \quad (2)$$

The European Value Management Regulatory Standard, EN12973 provides this guide, Quote: "…that value may be improved by increasing the satisfaction of needs, even if the resources used in doing so increases, provided that the satisfaction of need increases more than the increase in the use of the resources." [10]

Thus, the overhaul planner may need to plan for an optimum maintenance, and balance costs between the two cost bands of eq. (1a) and eq. (2). In which case, a reduced cost model enhanced post-overhaul operational performance in line with the relationship of eq. (3) will apply:

$$Maint\,enanceValu\,eAdded\,(MVA)\uparrow = \frac{\text{Qualitative - Functional - Performance (QFP)}\uparrow}{\text{Overhaul Cost (OC)}\downarrow} \quad (3)$$

The planner may however be tempted to want to gain from both a technology update of certain parts for enhanced performance, at the same reduced cost model of eq. (1a), in line with eq. (4):

$$Maint\,enanceValu\,eAdded\,(MVA)\uparrow = \frac{\text{Qualitative - Functional - Performance (QFP)}\uparrow}{\text{Overhaul Cost (OC)}\rightarrow} \quad (4)$$

Care must be exercised in reasoning along these lines, in order to avoid the risks of cost cutting measures that may lead to reusing parts which altogether should be replaced, or the use of poorly trained and uncertified personnel. The OEM warranties would also be greatly affected in such instances.

An attempted definition for "Maintenance Value Added" patterned after the defined general objectives of the Value Analysis (VA) Standard EN 12973 of [10], and the Value Management Certification Board of the Association of German Engineers (VDI) of [11] is:

"The gains by way of lowest cost and/or functional improvement through organized method(s) of providing required repairs and replacements on time of functional components of an equipment to achieve overall enhanced equipment performance. "

Also, a shorter attempted definition is:

"Maintenance value added" is: "the gains from an organized method of providing and achieving required functional equipment components repairs and replacements on time at the lowest overall cost."

As argued by Maxgrip [12], maintenance being always viewed as a cost element by industrial managers, and since savings are always possible to be made from most costs elements, the added values will justify maintenance activities.

Functions Centred Value Analysis Process Planning

The industrial gas turbine is used as a driver of the gas compressor or the alternator. From a value engineering point of view, the primary (basic) function when used as a driver of a gas compressor is to *deliver gas*; and the secondary function is to *drive compressor*. When the gas turbine is used as driver of an alternator, the primary function is to *provide power*, or *provide light*, and the secondary function is to *drive alternator*. The successful accomplishment of the gas turbine overhaul project objectives will thus be focused around ensuring that these primary functions are fulfilled. Useful Value Analysis methods listed by Telsang [8] are adapted and modified for application to the gas turbine overhauling project, and will involve in order of planning precedence:

LIST - the GT components tasks and parts
PLAN – Specific tasks requirements
ARRANGE – tasks into form
TIME and RETIME – focus on tasks times with end goal of not exceeding the total time
ESTABLISH – Priorities and cost of basic parts and service charges
SUBMIT – a definite plan of action to plant management
MAKE – presentation to management
OBTAIN – Management Approval to proposed overhaul plan
SECURE – approval for implementation
APPOINT or SELECT – Experienced and trained team
FIX – assigned responsibility for implementation
EXPEDITE - Implementation
REVIEW – maintenance strategies or methods to be followed
RESOLVE – difficulties encountered during implementation
PREPARE – post overhaul project reports with remarks and observations
AUDIT – cost savings and compare with original expectations
EVALUATE (and TEST) – the effectiveness
RECOMMEND – changes and corrective actions
AUTHORISE – change recommendations for next overhaul.
A Value Analysis Flow Diagram is shown in figure 1.
The value engineering approach must be rules systematic with trade-offs, and allowance made for limitations in eventual outcomes. Allowance in the planning precedence list should be made for feedback, as shown in the value analysis flow diagram. The intermingling of the, information, orientation, and implementation, follow-up, and recommendation, value analysis phases can be identified in the precedence list, allowing for the feedback. The freedom to REVIEW and control planned strategies is key to success.
Thus, the key performance measure to be determined by the gas turbine overhaul planner is to pay attention to the GT overhaul decision review loops in the GT Overhaul Value Analysis Flow Diagram of Fig. (1), for effective use of time, materials and men, so that, the Maintenance-to-Cost Plan (MTCP) aligns with the gas turbine overhaul objectives, bearing in mind that, as noted in EN12973 [10]: “Value, is not absolute, but relative”.

The Rules Guided System Approach to Trade-offs
The system approach will require that the following rules be followed:
Rule 1: Use and Source standard parts from the OEM, unless Rule 2 applies
Rule 2: Use parts costing less that provides the same measure of functional performance and warranty
Rule 3: Use Remanufacturing/Reconditioning Services provided by the OEM, unless Rule 4 applies
Rule 4: Use alternative OEM certified Workshop facility offering competitive costs and logistics advantage
Rule 5: Use OEM overhaul team, unless Rule 6 applies
Rule 6: Use trained and OEM certified overhaul service contractors costing less
These system checks will of course depend on the maintenance approach adopted by the equipment owner’s Company.

Scheduling Procedure and Data collection
Jack [13] used the critical path network diagram method (CPM) with activities-on-arc for the activities analysis of the gas turbine overhaul project. The CPM while useful may appear a bit unwieldy in trying to apply the Fulkerson numbering. The “**Maintenance DisIA**” method is suggested. It is a structured freeform, time, parts used and cost check implementation, value analysis network to assist maintenance managers and planning engineers.

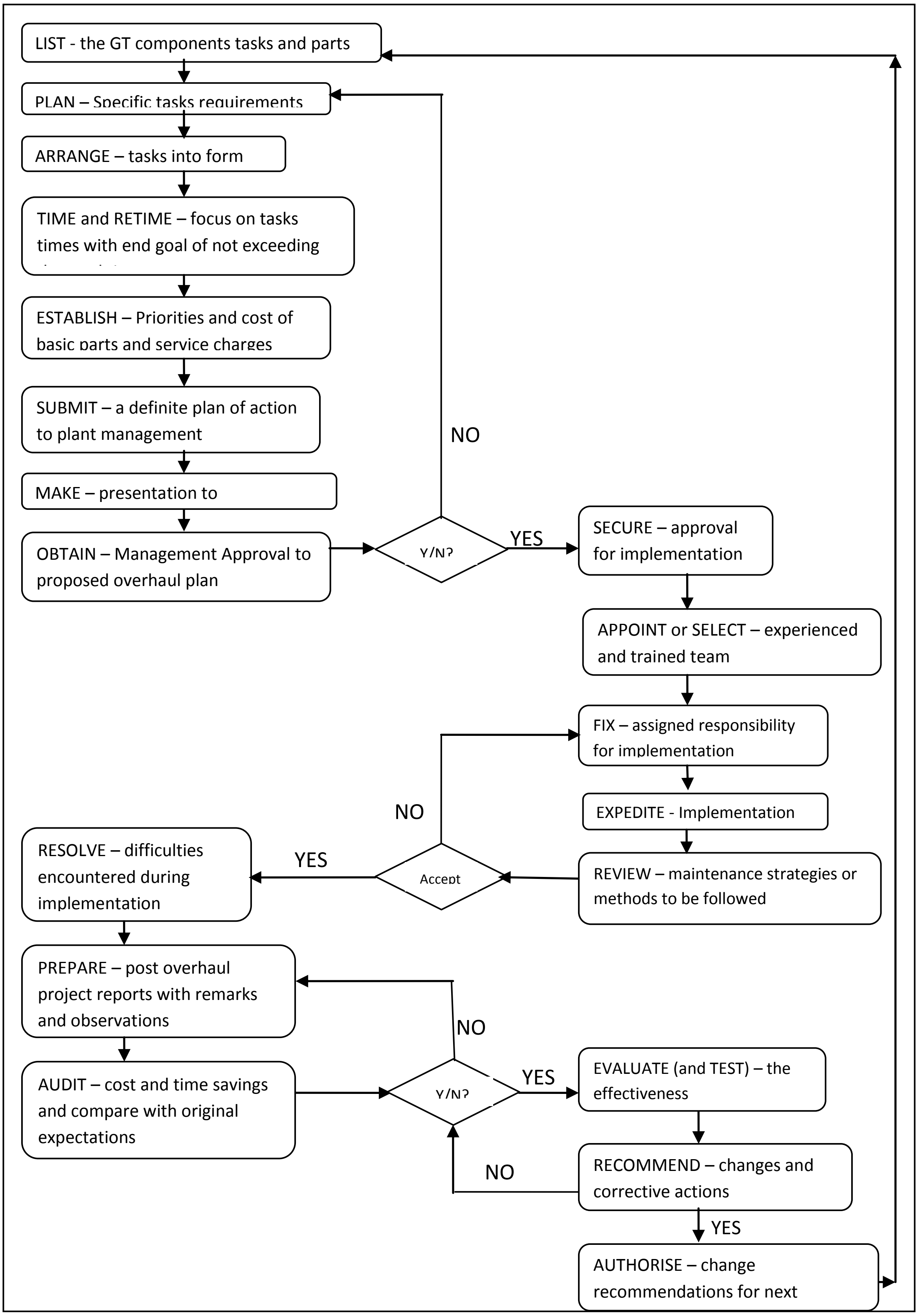

Figure 1 *Gas Turbine Overhaul Value Analysis Flow Diagram*

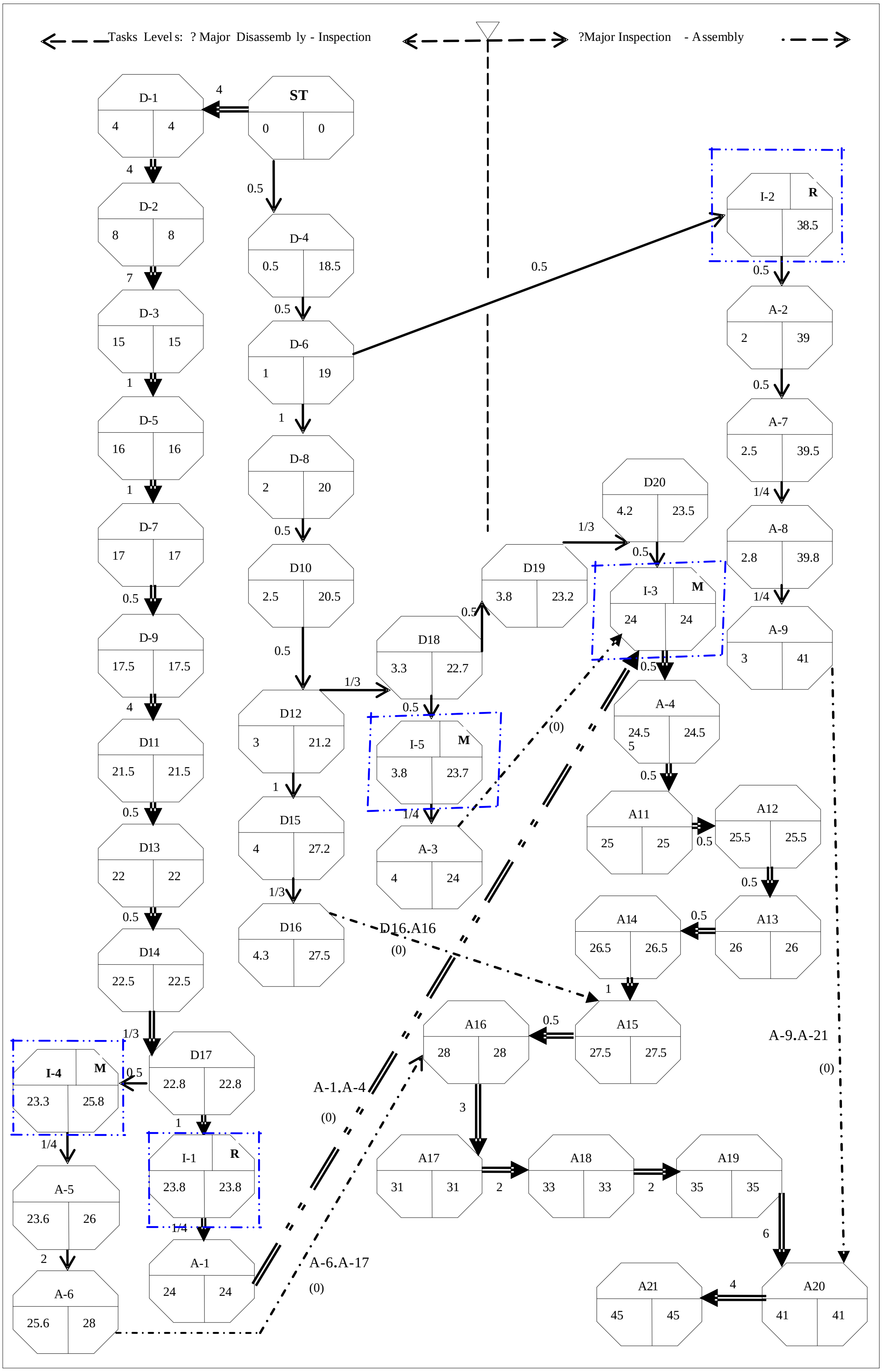

*Figure 2: Maintenance **DiSIA** Network Diagram*

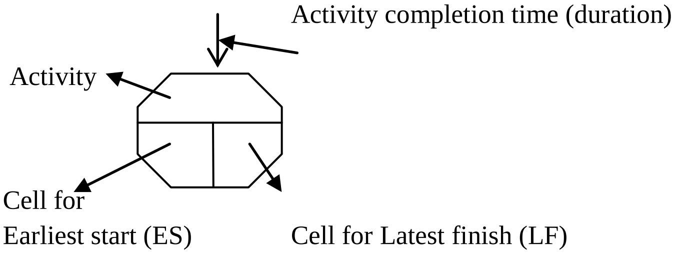

Figure 3 *Typical disassembly and assembly activity-event node*

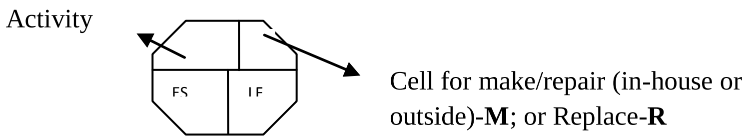

Figure 4 *Typical inspection activity-event node*

The "Maintenance DisIA Network Diagram"

Van Handel, Castillo, and Mueller [14] used the Gantt chart planning approach for a major turbo-machinery overhaul project in Moerdijk. The Gantt chart is very popular for applications in major projects of significant magnitude. However, it has limitations in the inability to properly indicate details of activities progress, and which activity or activities are dependent on, or overlapping others [15].

The Activity Description Table 1 shows "what-comes-out-of"-"komzOutof" or "GozOutof"; and, "what-goes-into-what" – *GozInto* [16].

The graphical or diagrammatic representation is referred to in this paper as, the "***Maintenance*** **DisIA"** Network. The mnemonic, **"DisIA"**, is coined from: ***Dis***assembly-Dis; ***I***nspection –I; and ***A***ssembly=A).

The ***Maintenance*** **DisIA"** is an activities-on-node Network diagram method; uses the essentials of the Critical Path Method (CPM), Arrow or Line diagram Method, the GozInto or Explosion Network [16], and the freeform method for effective maintainability of the "Technique for Evaluation and Analysis of Maintainability" diagram or simply, "TEAM diagram", developed by the Martin Company for the random access and correlation for extended performance (RACEP) SK600 project [17].

The ***Maintenance*** **DisIA** network diagram allows for, component parts that will require or have undergone repair or replacement to be indicated, enabling cost review checks or audits to be easily conducted. Further modifications can be made for personnel allocation, particularly along the critical path. The time analyses are treated as in the normal CPM method.

Maintenance DisIA Network Diagram Symbols

ST = pre-Shutdown State, ready for Disassembly Start – field Implementation stage.

Node type for Disassembly and Assembly activities is shown in Figure 3. Node type for Inspection activities is shown in Figure 4.

The node type for the Inspection tasks can in some cases be applied to Disassembly phase tasks, since visual and other non-destructive inspection tasks are ongoing activities at every stage of the overhaul project. This is necessary, if in the event an internal or external part not anticipated for repair or replacement is discovered to have become a major cost element. Since the overhaul activities Network diagram is handy for field engineers to use for the project on site, field notes and add-on modifications can be made to the overhaul network diagram when new cost elements or time adjustments need to be made. Such possible add-ons can be encircled as shown by the blue coloured dots for the items inspected and noted for repair or replacement in the Maintenance DisIA network diagram. The team leader can also add personnel allocation at corners of the node. Maintenance Managers and Planning Engineers can then use such allocations for a slack chart and manning table [15].

Example slack chart for this project is given in [18]. Experience acquired through proper value AUDIT checks can be carried over to the next overhaul activity to avoid delays, and get cumulative maintenance value gains in subsequent overhaul projects. Quality AUDIT checks should be in conformity with plan specifications and materials requirements [19].

Tasks along the critical path, indicated in double lines, may require more manning requirements and attention should be paid to these.

Conclusion and Discussion

Maintenance Planners, Managers, and Gas Turbine Overhaul Engineers, will need to work with the activities descriptive list, and "Maintenance DisIA" network diagram which uses the Alphanumeric Activity Numbers on node. The method, however, can be extended with the "Technique for Evaluation and Analysis of Maintainability" (TEAM) of [17] approach which uses actual Activity description at every node with the mean time to repair (MTTR) indicated for every Activity as applied in this paper, but, without the total time tracking for the project as applied in fig. (2). Some CPM and other Network diagram practitioners also recommend, making allowance for such short description of each activity in an enlarged node to avoid problems with logic [20]. A focus on ensuring that the initial planning estimated total time for the overhaul project is reduced can result in some savings in manning costs for outside contractors. And, for equipment owners with several gas turbine units installed, such savings and experience gained are transferred to the next Gas Turbine Overhaul Project (GTOP). In all, the primary objective of the gas turbine overhauling project is to give to the equipment owner improved optimal performance during operation, post-overhaul. The EVALUATE or TEST value check, will provide a window of opportunity to fulfill the major objectives of the gas turbine overhaul project: - equipment owner's enhanced confidence of in-operation mechanical and aero-thermal performance of critical parameters matched to expectations of increased gas power with efficient fuel consumption, maximized equipment availability, and anticipated long life in time between overhauls (TBO) [21]; and the fulfillment of the primary functions of *providing power*, or *delivering gas*.

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