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Maintenance Management Concepts in Construction Equipment Curricula

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Any baccalaureate or graduate-level construction program offering a course in construction equipment management should impart instruction about maintenance management procedures and concerns, if the students are to gain the managerial perspectives that they will require upon graduation. Although the content of the instruction may vary, thorough discussions of maintenance management will comprise most of the suggested topics.

Key Words: Construction Equipment, Preventive Maintenance Management, Cost Control

Introduction

An effective construction equipment preventive maintenance program might be characterized as the product of prudence, of the sentiment that "a stitch in time saves nine." Good maintenance programs and the efficient management systems behind them are essential for economically viable and operationally safe construction equipment. Unfortunately, this topic too often seems to draw more yawns than close attention. Perhaps part of the reason for this unwarranted indifference to this vital subject--even among constructors who should know better--is its lack of appropriate coverage in equipment management courses. The authors suggest that six lessons in any three semester-hour baccalaureate or graduate construction equipment management course be devoted to maintenance management procedures and concerns, if the students are to be well prepared for broad construction management responsibilities upon graduation.

Preventive equipment maintenance management implies a coherent and formal program of planned repair, component replacement, and servicing activities and the information management system surrounding them, all of which are implemented by an organization to maximize the availability of equipment for operational tasks. Compared to having no maintenance program at all, the allocable equipment maintenance costs may increase, but the value of improved equipment productivity should be even greater. Maintaining equipment productivity is essential to a firm’s long-term profitability. The program may depend on any of a number of strategies such as operate-to-failure or replace-before-failure, either of which incorporates elements of preventive maintenance to greater or lesser degrees. Whatever the organization concurs is appropriate for the equipment maintenance program--its goals and procedures--should be formally documented, and it should not be open to arbitrary changes or interpretations.

Since the maintenance management program is developed and resourced for maximum productivity and profitability in the long-term, it requires managers to seek continual improvement of the program resources and processes. As they would be for any purposeful organizational program, specific requirements for the program are determined. Managers then devise maintenance activities to satisfy the requirements, after which resources are allocated to match the workload and organized to most efficiently perform the necessary activities, such as equipment repairs and record keeping. Continual program assessment leads to improved performance and efficiency.

Lesson I: Significance of Preventive Equipment Maintenance

The particular project functions and concerns affected by a maintenance program include estimating, scheduling, safety, environment, and cost control. These functions are all interrelated, but the role of effective maintenance should be clarified separately for each to emphasize its significance.

Estimating

One of the main factors that needs to be taken into account in producing a realistic cost and productivity estimate is the production capacity of the equipment in question. This production capacity is in part dependent upon the quality of maintenance associated with the equipment. Therefore it is of extreme importance that the student understand that a machines' lack of maintenance or improper maintenance will adversely affect a contractor's ability to successfully bid on and complete projects within budgeted amounts. After all, making no allowance for variables such as unexpected breakdowns or scheduled idle time for maintenance procedures reduces the value of the estimate to less than the paper it is written on.

Inclusion of a preventive maintenance segment within broader course work, e.g., estimating and equipment usage, will allow the student to assess cost and production history when estimating true productivity and cost figures. The costs associated with increased operating expenditures, downtime, and production rates will become clear and those charges can then be assigned to the appropriate machine. The net result is a truer picture of equipment cost and productivity rates for the individual pieces of equipment.

Scheduling

The scheduling of a construction project is also affected by the absence or inclusion of a project-specific preventive maintenance program. To the beginning student or casual observer a piece of equipment is either working or it is not working. However, the more experienced a practitioner becomes, the more he/she understands that the time required to complete a project is adversely affected by a reduction in hourly production figures. Many factors affect the productivity of a machine, e.g., weather, operator efficiency, differing site conditions, etc. But possibly the most controllable factor is that of machine availability. Therefore, good management periodically schedules equipment downtime for programmed services and inspections, in order to identify and eliminate potentially catastrophic failures.

To this end, the inclusion of preventive maintenance information within the various curricula will allow the student to identify and incorporate into her scheduling talents those factors such as breakdown frequency and severity which would extend the duration of the project. In Figure 1 the components of maintenance time frame have been detailed to a much greater degree than those of the available time frame. This illustrates to students the potential time factor involved in the scheduling of maintenance and its effect upon the project schedule.

TIME						
TOTAL HOURS						
SCHEDULED HOURS (S)						
AVAILABLE (A)			MAINTENANCE (MT)			
OPERATION (OPT)			ONSITE		INHOUSE	
WORKING (WK)	DELAYED (DL)	IDLE (ID)	UNSCHED. (UM)	SCHED. (SM)	UNSCHED. (UM)	SCHED. (SM)
WORKING	FUEL	WEATHER	SERVICE TIME	SERVICE TIME	SERVICE TIME	SERVICE TIME
	OIL	SHIFT CHANGE	WAIT ON PARTS	WAIT ON PARTS	WAIT ON PARTS	WAIT ON PARTS
	FILTERS	NO OPERATOR	WAIT ON MECH.	WAIT ON MECH.	WAIT ON MECH.	WAIT ON MECH.
	WAIT ON EQ'PT	PERSONAL TIME	BREAKS	BREAKS	BREAKS	BREAKS
	MG'MT DELAYS	NOT NEEDED	PERSONAL	PERSONAL	PERSONAL	PERSONAL
	WAIT ON OPER.	BREAKS	DIAGNOSTIC	MODIFICATIONS	ACCIDENTS	MODIFICATIONS
			TEST	DIAGNOSTIC	LOGISTICS	DIAGNOSTIC
				TEST	DIAGNOSTIC	TEST
				INSPECTIONS	TEST	INSPECTIONS

Figure 1. Components of construction equipment scheduled time.

One factor that is not shown is the effect that delayed, improper or non-maintenance has on the hourly production of equipment. The great majority of schedulers and estimators for that matter, use production figures that assume full use of the machine for the duration of the work activity minus the typical job efficiency factors. This assumption of full use does not take into consideration the time needed for scheduled or unscheduled maintenance. Given the severity of operating conditions, scheduled maintenance alone may remove a machine from use 10 percent of the time. This 10 percent reduction in available time increases the duration of the project and the attendant costs.

Safety

A preventive maintenance curriculum must also address the issue of safety. Safety requirements impact system effectiveness, regulatory compliance, and personnel and equipment protection from injury or damage. The instruction should stress that the true professional never compromises safety, since poor procedures lead to higher insurance premiums, recall costs, accident and claim settlements, and legal fees, while reducing productivity and demanding that management spend much time with remedial matters. Students ought to learn that a competent project manager always ensures that all maintenance equipment and facilities comply with applicable design codes (NEC, ASME, API, etc.), construction codes, and government regulations (OSHA 29CFR1926 and 29CFR1910, EPA, etc.). In this way, potential costs associated with production working interruptions are minimized.

The instructor should emphasize procedures that ensure these safety program objectives:

- Safety actions are designed into operational procedures in a timely, cost effective manner.
- Potential hazards are anticipated, identified, evaluated, and eliminated.
- Historical safety data is routinely consulted and applied to ongoing operations.
- Necessary documentation always meets regulatory standards.
- Safety administration and procedures are incorporated into all organizational training.

Environment

Environmental management is related to safety management. Those concerns are everyone's responsibility. But as is true for the safety program, responsibility for the regulatory effectiveness of the program resides with the organization's managers. Delegating the authority for environmental audits and other aspects of the program's management is usually appropriate. Students should be introduced to some administrative aspects of environmental program management, particularly since the exposure can help maintenance managers avoid adjudicated penalties and reduced production time.

Cost Control

Project cost control is obviously affected by accurate estimating, tight scheduling, and minimization of safety and environmental violations, but there is more to it than that. As a capital asset, one of the worst conditions construction equipment can experience is inactivity when it could otherwise accomplish work and produce revenue. When unplanned equipment failures occur, the opportunity to earn is lost, even though ownership and operator labor expenses continue. Any measures that enable the construction organization to avoid lost production opportunities are therefore valuable. As noted before, good equipment maintenance programs allow managers to schedule well in advance any required maintenance periods, presumably when the equipment cannot be scheduled productively on the job. Good programs thus avoid the cost of lost revenues, even as they tend to reduce the average cost to repair or replace the less frequent component failures or potential failures.

Maintenance is a critical link between equipment ownership and operation costs, as Cliff Schexnayder, an Eminent Scholar at the Del E. Webb School of Construction, admonishes. Good maintenance management ensures that hourly operation costs are lower than they would be without an effective program. What is more, the value of well-maintained equipment when salvaged will be higher than it would be with a poor or non-existent program. Higher salvage value leads to lower depreciation costs. Since equipment depreciation for a heavy-highway construction enterprise may be second in annual expense only to management salaries, reducing the cost of depreciation may bolster the firm's bottom line. The nexus between ownership and operation costs further reinforces the significance of equipment maintenance management.

When an equipment manager makes a case for executive management to consider whether or not to implement or enhance a maintenance management program, it is not just the executives who must be convinced. Almost any successful maintenance program involves major portions of the firm or agency. A good program is very much a team effort, so all participants must be convinced of its value. The costs accruing to ineffective programs can perhaps be demonstrated by careful analysis of previous equipment utilization and expense data. One might estimate the costs of lost productivity due to unscheduled "down" time and the expenses of unscheduled repairs. By summing those two costs and comparing them to the cost for planned services or component replacement which would likely have prevented the unexpected breakage, the equipment manager can make a convincing case for a stronger maintenance management program. Students will see that construction equipment maintenance management does indeed have significance for them.

Lesson II: Equipment Management Responsibilities and Analysis

Equipment Manager

The person most critical to viable maintenance management is the equipment manager. In deliberately structured organizations, supervision of all equipment dispatching, maintenance operations, and repair versus replace decisions are among his or her responsibilities. The equipment manager should report to the chief operating officer or the vice-president for construction, in order that he may have adequate authority to work with construction project and operations managers, his internal customers. With this line of authority, occasional operation-maintenance scheduling disagreements between the parties can be resolved at the lowest possible level of supervision. The equipment manager needs the full support of upper management in order to best serve the organization. Certainly, the organization’s equipment is purchased to provide project operational productivity, and good equipment managers never lose sight of that purpose. But both those who maintain and those who use construction equipment must learn how people and systems in the organization synergistically contribute to productivity.

Staffing

Recruiting qualified maintenance personnel can be difficult. At a minimum, hiring standards for mechanics should include that they have formal technical education in a field relating closely to the equipment they will service. They should understand the preventive maintenance process, in general--the methods, materials, and tools, as well as the relationships among maintenance-related activities of the typical construction equipment organization.

Training

All personnel who have any role in attaining high standards of equipment maintenance must be well-trained. Increasingly complex construction equipment demands more professional skill from labor. If mechanics lack equipment item-specific training, then their "repairs" may be ineffectual or, what is worse, may lead to yet more expensive premature failures. Likewise, equipment operators must understand how to obtain maximum efficiency and safety from their equipment, and this requires more deliberate instruction than the "learn as you go" approach sometimes relied upon. No matter where they obtain their knowledge, skills, and abilities (KSA)--whether from union locals, equipment dealers, or their employers--operators must prevent unnecessary, improper wear on their assigned equipment. Excessive speed or load weight on hauler bearings, for example, may drastically reduce equipment economic life and elevate ownership and operation costs far beyond any added revenues earned by applying higher speeds to the job.

Numerous human resources studies have demonstrated that good training programs lead to less personnel turbulence and higher morale. The costs avoided thereby are significant, and such cost savings are additive with expenses reduced or eliminated through the better maintenance programs which, in turn, also result from effective training. Thorough training of maintenance personnel substitutes for highly formalized procedural rules. Besides encouraging a greater sense of employee responsibility from job enlargement and enrichment, better-trained mechanics and foremen provide greater tasking flexibility and staffing depth for the organization. More employee skills equals more value to the agency or firm.

Teamwork and Partnership

Operational and maintenance managers together share some required KSA. It makes good sense for them to share maintenance management training, to enhance their teamwork through better understanding of each other’s concerns and resources. The authors’ experiences with maintenance management programs have been that the "us-them" mentality between project and maintenance managers must be eradicated before significant maintenance improvements result. For that matter, some instruction combining both management and labor may be appropriate. All organization members holding equipment-related positions need to know what the new maintenance technologies are capable of doing. But the best technological and systemic enhancements available yield minimal returns when the people involved are not motivated to work in a spirit of partnership. This mutually supportive philosophy is essential to building a strong, ongoing maintenance training program. Ideally, students will carry this attitude with them as they work into construction management positions.

Program Requirements Analysis

Critical to the development of an appropriate equipment maintenance plan is the company’s or agency’s scheme of field operation and the details of the construction projects. If the project scope, duration, and location make it appropriate, managers will probably seek specific maintenance assets to be exclusively assigned to the project for its duration. If the support package is adequate in capability, the responsiveness of the project-specific maintenance effort will surpass what it might when resources are provided only on a job order by job order basis. This may be very costly, however, if there are periods of minimal maintenance work at the project when completion of job orders is delayed elsewhere. If project-specific maintenance resourcing is unaffordable, then contact maintenance teams which travel, e.g., with wreckers and tool trucks, among the organization’s job sites can often be advantageous. They might be able to satisfy a job order on site, saving the expense of evacuating equipment back to the main shop for repair. While not as immediately responsive as project-specific service and repair teams, they may afford an optimal compromise between reduced non-available time and low maintenance cost-per-hour.

Students should note that the maintenance organizational structure devised by management and its level of resourcing should be supportive of field maintenance requirements. One may organize a team for project-specific service and repair support over an extended duration, but with what effect on other projects' maintenance requirements? If an analysis makes management conclude that routinely employing contact maintenance teams will best contain costs, then a team-based structure might be implied for the main shop.

Contracted Out-Sourcing

Heretofore, this paper tacitly implies that the firm or agency will perform its own maintenance. Students should learn, however, that maintenance can be out-sourced, whereby any or all required effort can be obtained through contract, perhaps with an equipment dealer. Reduction of fixed costs such as those incurred by maintenance shops allows organizations to be more flexible and better able to react to changing competitive environments. On the other hand, organizations with well-established and efficient internal maintenance capability may find out-sourcing to be a poor alternative. The competitive differentiation that a good shop provides can contribute to winning work and enhancing profit margins.

Those organizations that do not already have shops of their own may want to avoid the significant start-up costs of building internal service and repair capability. Even though the contracted maintenance cost-per-hour may be higher than that for a well-run shop of its own, a company may opt for out-sourcing with its known costs, since it removes an element of risk from the project cost equation. Some companies may find that contracting nearby for scheduled services while repairing unscheduled failures themselves is the lowest-cost alternative. In that case, retaining some degree of maintenance response in the organization and not becoming fully dependent on outsiders mitigates some risk. Analyses involved in making decisions such as these may be complex, but they are essential for cost-optimization and competitiveness. Future construction managers should appreciate the sorts of alternatives from which they may one day select.

Lesson III: Maintenance Strategy and Techniques

Preventive maintenance procedures are established by the organization to best meet project operational demands, and one may even track their origin to the competitive strategy of the firm. The operate-to-failure (OTF) strategy, simplest to implement, demands that manufacturer-specified services be performed. Students should recognize that no equipment organization can remain profitable even in the short-term if minimal preventive maintenance activities--lubrication, fluid and filter replacement, and pressure and alignment adjustments--are not timely accomplished. Besides those procedures, nothing is done in OTF to determine the maintenance condition of the equipment, until the item cannot produce as it ought due to component failure.

At the other extreme, a fixed-time maintenance (FTM) strategy causes equipment components to be replaced at rigorously specified times, established on a statistical basis developed from design and historical data. One of two replace-before-failure strategies, FTM may cause parts to be "swapped out" although they are nowhere near failure. Unneeded downtime and component replacement may lead to equipment operation costs not much reduced from those of OTF. The optimal approach would seem to lie between FTM and OTF. A condition-based maintenance (CBM) strategy seeks to proactively replace components before they fail, like FTM. However, the components are replaced only when there is clear indication that they are near failure. This stretches their lives and reduces operation costs below FTM levels. The increased maintenance expenses of CBM above those of OTF are justified by the non-availability costs avoided by scheduling maintenance when the equipment is not required on the job. Although total maintenance expenses may escalate with the CBM strategy, the equipment operating cost per hour drops. Essential for CBM to be effective is a predictive capability.

Predictive Maintenance

The primary predictive maintenance procedure which many construction equipment maintenance organizations deem sufficiently reliable for integration into their preventive maintenance programs is oil analysis. The sample is at least analyzed to determine when the lubricant might need to be changed due to breakdown. While this knowledge allows managers to eliminate expenses from premature replacement of oil and filters, the greatest value of oil analysis may come from ferrographic or spectrographic analysis of the contaminants in the oil. These permit laboratory personnel to measure the wear on the component, and ferrographic comparisons may reveal the reason for the wear. This affords a meaningful predictive capability. In the years ahead, today’s students will certainly see even better predictive maintenance capabilities routinely imbedded in equipment they manage. Extensive component and system condition warning systems, including on-board computerized vibration analysis, will become commonplace and afford very accurate estimates of time to component failure.

The benefits of maintenance prediction are not always obvious to organizational "beancounters." The costs averted from breakdowns that never happened (probably because more resources are devoted to maintenance activities) often go unrecognized. This leads to doubts about the elevated level of resources allocated to predictive maintenance of equipment. So as budgets get tighter, maintenance shops may be the first elements of the organization to suffer cutbacks. By the time the longer-term effects of such cutbacks are manifest, productivity and profitability may be reduced. Overcoming inertia to get the program back to a more proactive stance is then difficult. Students should appreciate that such longer-term perspectives are necessary for profitability.

Some Recommended Techniques

No matter the maintenance strategy an organization applies, daily pre- and post-operative checks of the equipment should be routine. This activity is often a critical interface between operation and maintenance. Equipment manufacturers provide complete inspection checklists. Managers should provide such lists and related documentation to any equipment personnel who have need of them. Especially in the case of more proactive maintenance management strategies, frequent cleaning of the entire item is necessary to thoroughly inspect for damage and incipient failures.

Proper painting adds to equipment value by protecting surfaces from corrosion. Thorough cleaning and proper painting also lead to pride of operation and enhance the public image of the firm or agency, and it is good for morale. Component or system deficiencies--especially if they involve safety--and imminent failures must be repaired before operating the equipment again. Lesser shortcomings may often be deferred until the next scheduled maintenance period. Effective operators know their equipment well enough that they can often tell, by its behavior, if it has or soon will have a mechanical problem. This bolsters the argument that equipment should have an assigned operator and maybe an assistant, who except for emergencies, should be the only persons permitted to drive or operate their assigned items. This may not always be an achievable arrangement, but students should appreciate the benefits of assigning the same operator to designated equipment, if possible.

Lesson IV: Maintenance Organizational Structure and Facilities

The organizational aspects of maintenance programs require that company resources be combined to fulfill specific performance objectives as efficiently as possible. These resources involve groups of individuals of varying expertise blended into an organizational structure to accomplish a variety of functions. Among other determinants, the structures vary with the broad goals and objectives of the organization; the specific functions to be performed; the resources available for maintenance; and the working relationships of the maintenance participants.

The successful implementation of total preventive maintenance (TPM) requires both an understanding of system-level requirements and organizational interaction. To appreciate this, students must be introduced to organizational responsibilities that may not be discussed in some construction curricula. Human resource concepts such as position management and personnel training demand attention. Effective maintenance organizations are deliberately planned and staffed. Inevitable changes in equipment design, its operating environment, and maintenance techniques and resources mean that structures which prove efficient today may nevertheless demand a new configuration tomorrow.

Equipment Organizational Grouping and Structure

Students should become acquainted with organization structural models to better appreciate how formalized working relationships can enhance productivity. Three basic structural groupings are commonly denoted as *functional*, *product*, and *matrix*. A functional construction organization groups individuals with the same general types of expertise and job requirements. All equipment-related functions, including that maintenance, are placed under the direction of an equipment manager in one division or department of the construction organization. Equipment is dispatched to projects as needed, is returned when not actively used, and the equipment manager maintains control of all items. A smaller firm performing local work might find this arrangement to be most efficient. Within the maintenance section itself, the structure would be described as being *simple*. If the firm's or agency's equipment requirements expand, then the equipment department or division will expand and maybe sectionalize internally on a functional basis.

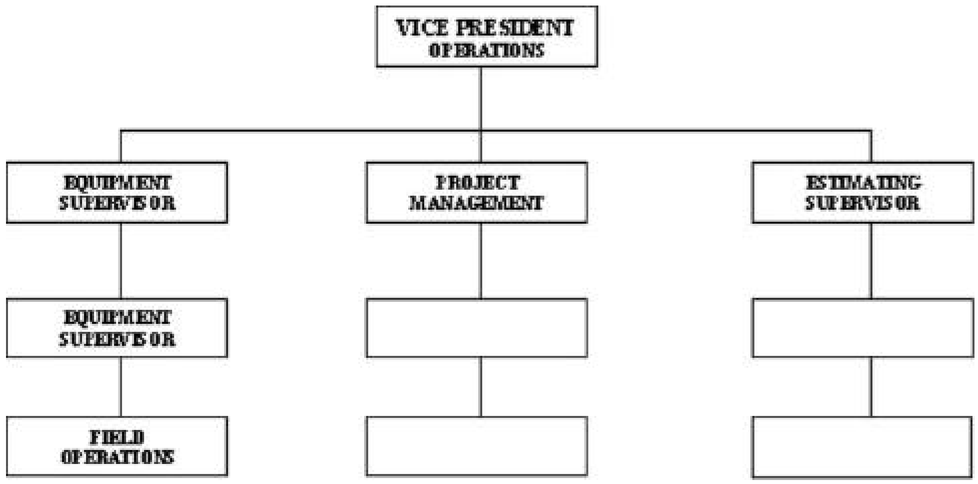

Figure 2. Function-Grouped construction organization.

As companies grow and expand into new areas of technical expertise and specialize in products or geographic regions, a divisionalized structure may evolve. Divisions are analogous to smaller and comparatively autonomous specialized firms subordinate to the main company. A company might restrict itself to excavation and concrete projects, establishing separate divisions for each product. Another possibility could be two geographically differentiated divisions, both doing excavation and concrete, but in different regions. Company equipment could be divided appropriately between the divisions, and each division would establish independent internal mechanisms to manage the equipment and maintenance, perhaps entrusting it to divisional equipment managers. The preventive maintenance procedures employed by the divisions may differ to better match their respective productivity needs, so details of their respective maintenance organizational structures may not be the same either.

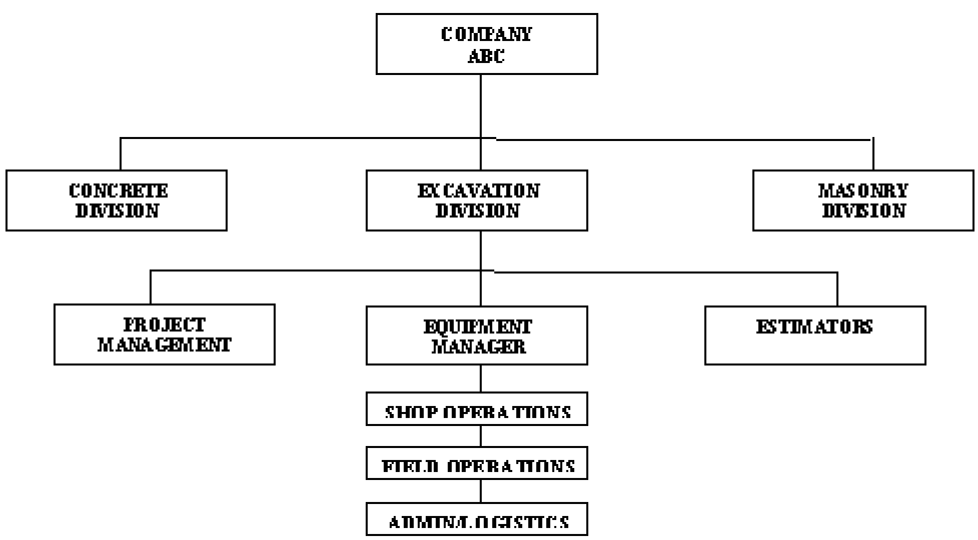

Figure 3. Product-Grouped construction organization.

The matrix organizational structure combines functional and product organizational strengths while reducing their weaknesses. Matrix structure typically requires personnel to respond to two authorities, their functional supervisors and their project managers. Some employees may be assigned to multiple projects simultaneously. Depending on the degree of autonomy that a project manager must command in order to perform effectively, not only the productive equipment, but also some maintenance assets, may be designated for his exclusive use. This scheme would probably prove necessary when a company secures a project far away from its normal area of operations. The structure demands more professionalism and teamwork from members than do simple or divisionalized structures. If the employees of an organization have had little autonomy and seldom established effective informal working relationships, then evolving to this sort of structure may engender more trouble than it is worth. Many public and private sector entities have employed this scheme with varying degrees of success within the past decade, however.

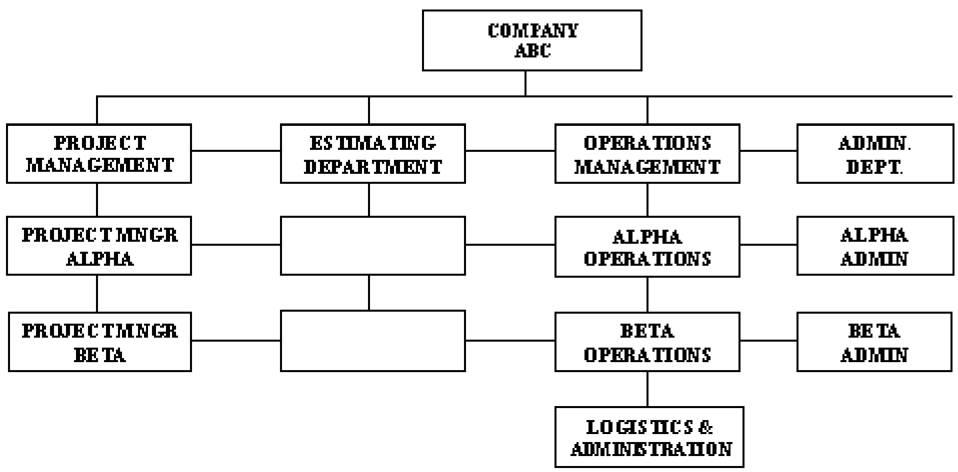

Figure 4. Matrix-Structured construction organization.

No matter the particular structure imposed, someone must know that he or she is directly responsible for monitoring and controlling the equipment and its maintenance. The manager must have immediate access to the resources needed to effect necessary maintenance activities.

Facility Design

From the organization structure and subsequent characteristics, the required maintenance facilities can be determined. The increasing complexity and size of equipment demands larger and better designed maintenance buildings to enhance productivity. Construction program graduates may become involved with decisions to extend or rebuild existing maintenance facilities. They should be made aware of parameters that control such designs.

Four factors most control the design of the maintenance area: floor area, workshop bay height, workshop bay width, and layout. The total floor area required must include all equipment workshop bays, gangways, storage areas for such items as tool rooms and repair parts stores, and offices. Identifying the requirement for the latter three types of areas is a relatively simple proposition, but determining the workshop bay area is more tedious. Three methods may be employed to perform the more complicated calculation: scaling dimensions to meet the equipment fleet's biggest machine; providing bays for the number of mechanics employed; applying a repair time-area formula.

$$\text{Total Maintenance Bay Area} = \sum [(N\ T\ A) \div (50 \text{ weeks/year})]$$

where N = total number of equipment items of one type and size
T = average time (weeks) each type-size is in shop each year
A = bay area required for each type-size

Project requirements may compel the equipment manager to perform many repairs with on-site maintenance contact teams. If it is logical to expect that condition to continue, then the formula T factor for each type-size will remain small, and the total bay area will be less. This reduces the organization's investment and operational expenses for fixed facilities, to compensate for contact team expenses.

A shop ceiling height of 16 to 18 feet is adequate for most equipment owned by small- to medium-sized construction organizations. Maintenance personnel working on equipment in excess of that height should plan to service and repair the items in an open-air facility. The width of the workshop must allow for the angling of the bays and their length. A bay in most shops should be 35 to 45 feet wide. If the length of the work area is excessive, then the contractor should consider "stacking" the bays with a walkway between them. The layout of the area should take into consideration the number of craft specializations and their repair tool requirements, proximity and security of any tool rooms and repair parts stores, ample number and capacity of electrical outlets, and safety and environmental security needs. The work area design requires flexibility to be reconfigured to accommodate inevitable changes in equipment design. Of course, other architectural criteria for efficient industrial operations remain valid. Attention to detail in the facility design stage costs little compared to unnecessary facility overhead expenses.

Lessons V and VI: Maintenance Evaluation and Control

Statistical Measures

If maintenance organizational structure, facilities, and other resources are tailored to the maintenance strategy and procedures that best serve job site productivity, the entire maintenance operation will probably be effective. Among the most critical measures by which to gauge maintenance organizational effectiveness are the mean time to repair (MTTR) or the speed of repair, the mean time between failures (MTBF) or the frequency of repair, and the maintenance ratio (MR). These can be determined for equipment components and systems, for an equipment item, and for entire categories of equipment.

$$\text{MTTR} = \text{Unscheduled Maintenance Hours} \div \text{Number of Failures} \leq 6 \text{ Hours/Failure}$$

It includes the time to evacuate to shop or to bring a contact team to the item, to get a mechanic, to inspect equipment and find the failure, to obtain repair parts, to make the repair, and to operationally test the repair. Repair should normally be performed in well under one day. Poor quality which results in redo work is anathema to quick equipment return to production and low maintenance costs.

$$\text{MTBF} = \text{Operating Hours} \div \text{Number of Failures} \geq 100 \text{ Hours/Failure}$$

This is a function of equipment design, intensity and skill of operation, and accurate and timely maintenance. As a rule of thumb, if items are properly repaired, they should operate at least 100 hours before failing for some other reason.

$$\text{MR} = \text{Maintenance Hours} \div \text{Operating Hours} \leq 0.25$$

Good maintenance systems should result in at least four hours of operation per hour of maintenance.

$$\text{Availability} = \text{Available Hours} \div \text{Scheduled Hours} \geq 90\%$$

Naturally, 90 percent is a rule of thumb which may vary with such factors as equipment age and type and with intensity and type of application. Rules of thumb require care in application, but they afford students points of reference for evaluating equipment maintenance programs.

Information Systems

Only by measuring and recording maintenance program data can managers determine their effectiveness. Manual maintenance management data systems--some of them rather primitive and reflective of the minimal maintenance techniques formerly in vogue--have existed for generations. Nowadays, automated information management systems facilitate compilation and analysis of equipment-related data. The automated systems often capture the same information as the traditional manual systems, but they afford more efficient data sharing and manipulation. They make it easier to record expenditures by equipment component or system, e.g., structural frame, power train, engine, or hydraulics. Whether the system is designed by the organization itself utilizing generic spreadsheet or database software or purchased from vendors offering commercially available programs, it must provide the sort of information managers require to make critical equipment maintenance-related decisions.

For Equipment Item:

operator name(s); purchase price; depreciation; salvage value; job orders applied; historical ownership and operation costs; historical utilization and non-available time; current location; current availability status; next programmed maintenance; results of most recent diagnostic activity; currently deferred maintenance shortcomings.

For Equipment Category:

mobilization costs; utilization estimates; cost estimates; MTTR; MTBF; projects worked.

On Job Orders:

mechanic name(s); dates and times maintenance begun and completed; parts and components used; labor by craft, versus standard time; maintenance delays.
Estimating, accounting, and maintenance databases should share data.
This implies flexible units of time: hours, days, etc.

Figure 5. Useful equipment and maintenance information system data

Organizational structures and leadership philosophies naturally play a role in determining what information will be made available to whom. As wise managers move their organizations to greater employee empowerment, the architecture of the information management system that they purchase or devise should be adaptable to the new internal working relationships and expectations. For example, allowing a mechanic to readily query the recorded data associated not only with the particular item on which he is working, but also with consolidated data pertaining to the equipment category, may enable him to detect component failure trends no one else sees. The level of data detail should be structured not only for current application, but also for possible future analysis. Compiling meaningful data demands management's close attention, and other system users or potential users should contribute to the system needs analysis, too. What sort of data will be included and how much of it are not small matters, since data entry adds up to consequential labor costs, and insufficient data can impede well-informed decisions. Devoting adequate time to devising a worthwhile architecture usually pays big dividends in the long run. Upon implementation a properly constructed and readily accessible database demands some control, since "garbage in equals garbage out."

Students should learn that the compiled data is often applied to many significant management decision processes, so it must be complete and accurate. Whether manual or automated, the job order is almost always the primary means of monitoring and controlling what is done for service or repair, by whom, and at what cost in labor and materials. In most cases, the documentation for maintenance job orders is manually gathered on the shop floor. Key shop administrators should be specifically trained to review the manual documentation before entering the information into the computerized database. Some fields of an automated database may be linked to yet other management and financial information systems, for such compilations as the equipment expense ledgers or the repair parts store inventory.

Operators should be kept informed of such things as minor equipment shortcomings which they have noted and which have been deferred for repair until the next scheduled maintenance period. Operators must be tied into the flow of information, if their sense of ownership is to be cultivated as it should be. Construction site foremen and field engineers must realize how important their daily or weekly production reports are to the accuracy of the system data. Equipment operation-maintenance team cohesion and mutual ownership improve with information flow and integration of this nature. Future managers thus see how to effect meaningful systemic improvements for minimal cost by adjusting information processes.

Cost Accounting

The equipment cost accounting system, which includes the ledger for equipment maintenance expenses, serves two primary functions: (1) to collect the data for internal rental rate calculations, and (2) to control costs against project and general overhead budgets. As a result, among other characteristics, the accounting system must be able to summarize labor and materials costs by specific equipment item (e.g., D-8 bulldozer #4, serial #999) or by general item type (e.g., all large bulldozers), as well as by costs allocable to specific projects.

Repair or Replace

One of the equipment manager's most critical duties is determining whether to repair or replace a piece of construction equipment. Since contractors seek profit maximization, productivity enhancements built into new equipment might cause a manager to procure the new and the dispose of the old. This may occur even if maintenance is managed efficiently and the productivity of the old equipment is relatively high while its operation costs are comparatively low. Maintenance management and its effect play a significant role in the eventual decision, since the remaining value of the currently owned equipment derives from how it has been operated and the effectiveness of maintenance. Critical to the decision is good information by which to evaluate the likely future performance of the old item. This is yet another justification for a thorough equipment information management system.

Repair Parts

The maintenance organization must establish procedures for supplying repair parts and components to fix equipment. The procedures will derive from the maintenance flexibility and response the various jobs demand and the order-ship time, i.e., the time lag between a part being ordered by a mechanic and the part being delivered for installation. There are few equipment repair delays as frustrating as long waits for repair parts, so shops have strong motivation to provide for rapid delivery of a wide assortment of repair parts. The overhead associated with properly storing many repair parts can be costly, however, so managers must determine optimal levels of repair parts stockage, if management decides to supply parts by internal stores. Besides the order-ship time, demand history--which parts were needed and how frequently--determines what and how many repair parts should be stocked. Also important to that determination are the equipment manufacturers' recommendations, the maintenance strategy, and risk to the project costs if the components fail and cannot be quickly replaced.

Future maintenance managers must learn to be cautious of mechanics hoarding parts that they believe will be difficult to obtain quickly. If the parts are needed often and not readily available, then stockage procedures are not synchronized with demand history, and the repair parts store must correct its historical data or revise its inventory model to begin stocking the parts. Mechanics' caches of repair parts often grow when the internal parts store seeks to reduce costs by making demand stockage criteria more stringent. Ironically, what begins as an effort to reduce costs may not accomplish its purpose, as it delays job order completion. Students should see that all of the factors affecting stockage levels must be weighed to ensure proper results.

Conclusion

Expanding the above material and the ideas it provokes into five or six lectures of a construction equipment course will provide future construction managers with detailed managerial perspectives not always developed in construction curricula. Many articles in recent years have reiterated noticeable trends or repeated the possible merits of broad concepts to create certain competitive advantages in the construction industry, but they usually lack specifics that can be readily grasped and applied. These equipment maintenance management concepts are more specific, offering a direct opportunity for profitability enhancement. Students who gain such exposure are of immediate value on the job site or in the office to their future employers.

The authors invite collaboration with other construction equipment management faculty to elaborate upon these lesson ideas with a view to jointly publishing detailed, integrated construction equipment maintenance management lesson plans. They might be offered for the asking to any Associated Schools of Construction institutions who would care to employ them. No doubt other concepts besides those of this paper would merit inclusion. The increasing legitimacy of construction program and individual constructor certification processes implies that the body of knowledge pertaining to subjects of this nature should become more standardized. Lesson plans and course syllabi, which include the KSA that academic and industry consensus indicates are necessary for competent construction managers, will contribute to greater construction productivity and professionalism.

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