Estimating Maintenance and Productivity Benefits of Motor Decision Policies

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ABSTRACT

Modern motors are very reliable compared to their ancestors, but they are still mechanical devices with a finite life. When they break down, the costs start to add up. These costs sometimes include lost sales, reduced productivity, overtime pay, delayed delivery, and cleanup of spoiled product. A preventive maintenance and motor management plan can largely avoid these costs associated with motor breakdowns altogether.

These costs vary widely between plants, and even within a plant they will vary from one machine to another. To accommodate this broad diversity, a method of estimating the costs associated with motor breakdowns is useful in order to help plant staff establish an appropriate motor policy. A good understanding of these costs is important so that plant staff can quantify them and justify the adoption of preventive maintenance and other proactive strategies in their motor procurement, repair, and maintenance policies.

In a typical scenario, the company requires a separate itemized capital budget in their annual planning cycle, while granting the maintenance department discretionary spending authority on their repair budget. This dysfunctional delegation of purchasing authority does not reduce costs. It actually erodes productivity and increases long-term costs.

Introduction

Many companies are aware of the money they spend buying new motors, and take prudent steps to safeguard this expenditure of company funds. However, few companies understand that the purchase price of the motor is one of the smallest components in the overall cost of owning and operating a motor. Some users, particularly large energy-intensive manufacturing companies, understand that the energy cost is a significant component. However, very few understand that the motor is often the critical fulcrum point where a large amount of inexpensive energy gets leveraged into the high value stream of product leaving the shipping dock. Reasons this cost is not appreciated range from management structures that do not link capital and operating costs, to a simple lack of understanding. We will explore the costs and barriers to implementing a proactive motor decision policy from the perspective of the corporate decision-maker.

Costs of Motor Outages

Modern motors are very reliable compared to their ancestors, but they are still mechanical devices with a finite life. When they break down, the costs start to add up. These costs can result from a number of parameters:

- Idle workers
- Reduced productivity
- Disrupted schedule
- Late delivery, angry customers
- Overtime pay for mechanics blessed with beepers
- Priority shipping charges
- Spoiled product cleanup and disposal
- Damage to driven equipment from seizure

These costs vary widely from plant to plant, and even within a plant, depending on the duty and type of machine. Some real-life examples provide general guidance and suggest estimating rules that can be used by plant staff to begin quantifying these costs to justify the adoption of preventive strategies in their motor procurement and repair policies. Attitudes among plant staff at most facilities that the authors have experience with seem to fall into 4 categories. Maintenance staff at large companies, when asked, typically fall into the first 3 categories with their response, while the fourth response category is largely comprised of smaller plants.

1. We know what the downtime cost is, we track it and we do everything we can to avoid breakdowns and we plan ahead to minimize disruption when it does happen
2. We know that we cannot afford downtime, so we grease the motors to avoid breakdowns.
3. We loose money when machines break down, so we fix them as fast as we can.
4. Motor breakdowns? What motor breakdowns? We have almost two dozen motors in the place and the last time we had a motor break down was years ago.

Identifying Critical Motors

The type of service or duty motors play is a key parameter in the cost equation upon breakdown. For instance, some machines are on solitary duty, meaning there is no redundant machine that can be switched on in the event of a failure. Some machines are key to the process, and some are not. If the machine is key to the process, and on solitary duty, the motor driving it is critical. Critical motors can have a process line or plant wide impact. Because the costs associated with a breakdown of a motor with a plant wide impact are so large, plant staff typically will do everything in their power to avoid this. Examples of these motors might be:

- The 400 hp crane that loads the raw materials in a steel mill.
- Air compressor in a strained system with no backup.

These two systems are quite different with respect to motor reliability. The compressor motor is probably a NEMA standard frame, and you can get a rental air compressor in less than a day, especially if a handshake connection is available to connect the rental. Although it would still be very disruptive, in a compressed air system sometimes you could choose to valve off some air uses so that remaining functional compressors could carry the reduced load, so total plant shutdown is less likely. With the crane motor out, however, the plant stops.

Large one-of-a-kind systems like these come to mind first when considering plant wide impact, but in some plants there may be many motors (even some small) that are critical, for instance:

- Continuous feed rolling mill motors
- Chemical process motor
- Printing press motor

Sometimes the breakdowns of one of these motors can not only trigger a shutdown, but also cause an enormous cleanup headache as the goop solidifies in the lines. Some plants in this situation use IEEE 841 spec motors to ensure the highest reliability possible. One chemical plant in California has adopted a group re-motoring policy. Once every three years upon general shutdown, the critical motors are replaced. The facility reports that this type of group re-motoring virtually eliminates motor breakdowns as a source of downtime. This facility has found that replacing the motors every three years is less expensive than purchasing IEEE 841 motors.

It is useful to look at motors by what they drive, how that equipment relates to overall plant operation, and how a failure impacts other operations. These scenarios are presented Tables 1 and 2. The direct and incidental costs may or may not apply depending on the specific situation. Table 1 is a qualitative discussion of the costs for three broad categories of motor breakdown situations: plant critical machines, production line critical machines, and non-critical machines. Within those three are specific scenarios for substitute motors, such as on-site spare, local shop stock, regional warehouse stock, and not in stock - repair.

One trend visible through Tables 1 and 2 is that overtime pay and installation labor are about the same for all facilities that operate 24/7 (this is more a function of the size and weight of the motor). For the 24/7 operations, overtime pay is assumed to be for the mechanics that get called in the middle of the night. For 5-day operations, the overtime is for the operators who come in on Saturday or work an extra second shift to catch up on lost production time caused by downtime. The clean-up cost is highly specific and varies from plant to plant and process to process. But if there is a clean-up cost, it would be incurred in any breakdown situation covered in the table, except the case of the redundant machine or the intermittent duty machine.

As an example, we evaluate some actual systems in the same way, and apply what we learn to improving the cost model. For instance, if we choose to tally the costs for a printing press, we would get one outcome, and get a completely different outcome if we evaluated a critical plant-wide system with no backup, like a strained compressed air system.

Table 1. Typical Motor Outage Impact for Plants Operating Continuously (24/7)

	Less product	Labor to install	Overtime pay	Priority shipping	Clean-up
Plant Critical machines					
Spare motor on site	few hours	few hours	few hours	unlikely	possible
Local shop 1-3 hour emergency delivery	4-8 hours	few hours	few hours	possible	possible
Regional distribution center 1 day delivery	1-1/2 days	few hours	few hours	possible	possible
Not in stock, 2 day emergency repair	2-1/2 days	few hours	few hours	probably	possible
Line Critical Machines					
Spare motor on site	few hours	few hours	few hours	unlikely	possible
Local shop 1-3 hour emergency delivery	4-8 hours	few hours	few hours	possible	possible
Regional distribution center 1 day delivery	1-1/2 days	few hours	few days	possible	possible
Not in stock, 2 day emergency repair	2-1/2 days	few hours	few days	probably	possible
Non Critical (redundant)					
Any source within a day or two	No	few hours	no	no	unlikely
Non Critical (intermittent)					
Any source within a day or two	No	few hours	perhaps	probably not	unlikely

Table 2. Typical Motor Outage Impacts for Plants Operating 1-3 shifts, 5-6 day week

	Less product	Labor to install	Overtime pay	Priority shipping	Clean-up
Plant Critical machines					
Spare motor on site	no	few hours	few hours	unlikely	possible
Local shop 1-3 hour emergency delivery	no	few hours	few hours	possible	possible
Regional distribution center 1 day delivery	possible	few hours	few days	possible	possible
Not in stock, 2 day emergency repair	possible	few hours	few days	possible	possible
Line Critical Machines					
Spare motor on site	no	few hours	few hours	unlikely	possible
Local shop 1-3 hour emergency delivery	no	few hours	few hours	possible	possible
Regional distribution center 1 day delivery	possible	few hours	few days	possible	possible
Not in stock, 2 day emergency repair	possible	few hours	few days	possible	possible
Non Critical (redundant)					
Any source w/in 2 days is usually fine	no	few hours	no	no	unlikely
Non Critical (intermittent)					
Any source within a day or two	no	few hours	possibly	unlikely	unlikely

Quantifying Less product

The type of service or duty that the motor plays is a key parameter in the cost equation. For instance, some machines are on solitary duty, meaning there is no redundant machine that can be switched on when it fails. If the machine is key to the process, and on solitary duty, the motor driving it is critical. Critical motors can have a plant wide impact or a process line impact. Examples might be the crane that loads the raw materials in a steel mill, or a motor in a steel rolling mill.

Plant Wide Impact

In a continuous feed rolling mill, if one motor goes down, the whole line stops. Motors on a continuous process line like a chemical plant or a paper mill may be in a similar situation. To evaluate the breakdown costs, first look at the value of the product produced. For instance, if the plant produced $36 million last year, and operated 360 days, then the lost revenue from loosing one day of operation is $100,000. Because every plant has a different annual production figure and market demand, the daily losses will be different for each plant. If this daily rate is not known it can usually be approximated for the purpose of this type of analysis. Whether the daily losses are $100,000, or $50,000 makes little impact in the decision to buy a $5-10k spare motor, if having that motor on site means an outage of 2 hours vs. 2 days. In this case the purchase of the spare motor is like an insurance policy against prolonged plant outage. In fact, insurance companies that insure plants against prolonged outages look at things like spares and predictive and preventative maintenance plans when they do their evaluation of rates and when they decide whether they will underwrite the facility (Schlindwein 2001).

Process Line Impact

For motors that do not affect the entire plant, but affect one process line the analysis of downtime costs is similar. For instance, if a large printing plant has 20 magazine presses, and their total annual volume is $120 million, then the losses can be approximated as $120 million/20 presses /360 days = $17,000 per day. In the case of presses hourly losses are harder to quantify because there is already a percentage of time taken for setup and teardown. To avoid this, daily figures are used or when calculating the hourly loss, the productive hours are used as the denominator. For instance, the press does $17,000 per day in revenue, but only actually runs for 18 hours per day because of setup, teardown, and cleaning. One way to approximate this would be to take 17,000 divided by 18 = $950 per hour, not $700 per hour. Given the size of the motors (small) on the presses, the investment in spare motors once again is quite small compared to the downtime costs. In this case a 5 or 10 hp motor might cost $500 or $1000, which is small compared to $17k per day of lost revenue.

Calculating Lost Profits

Converting the lost revenue into lost profits is a bit more problematic, because the profitability and the things that affect profitability are different in every plant. For instance, consider the press above. When the press is down, the company stops accruing some costs, while others continue to add up.

- Labor: The crew is there whether the press is running or not. Four operators at a loaded rate of $35 per hour each is about $140 per hour.
- Paper: When the press is down, the paper stops. There is some waste associated with a breakdown, but it is brief.
- Capital (debt maintenance) and facilities costs: these continue to accrue
- Energy: When the press shuts down the electricity, heat, and compressed air demands drop significantly.

When attempting to calculate lost profit, it may be tempting to simply use an estimation of the profit margin times the revenue loss, but this will not yield an accurate estimate in most cases, because the profit margin itself is dependent upon the amount of uptime. Let's assume that the printing business has a 10% profit margin. Taking 10% of $17,000 = $1700, would not necessarily be a good way to estimate the lost profit from one day of shutdown, because 90% (of the costs) are mostly still present (except the paper and the energy). These costs without a corresponding revenue stream create a debt that brings down future profits.

Considerations For Small Plants

In small facilities, the motor population is smaller, and the environment is different in a few key ways. Because of these differences, the maintenance manager of a small plant is more likely to say that motor breakdowns do not effect production. A small plant may have 24 or 36 motors, the largest of which is maybe the air compressor at 100 hp. If the average life of a motor is 10-15 years, then the motors in these small plants, which are often much drier and cooler, probably last even longer than average. Also, small facilities are much more likely to have 5 day a week operating schedule, and not have every machine or line fully scheduled, so sometimes they can juggle production to other machines or make up some lost time by having a Saturday shift. Hence, they may not actually loose revenue upon breakdown the way a continuous process would. Their costs are still higher (idle workers, then overtime), but they have not lost revenue.

Cost Example

In Table 3, we attempt to quantify some of the costs. Since the information in Table 3 is closely guarded information for nearly all plants, the data presented is not actual plant data. For the plant wide scenario, we have chosen to present numbers for a small manufacturing plant that does $36 million in sales per year and has 5 planned shutdown days. Thus, a day of lost revenue for this plant is $36 million divided by 360, or $100,000 per day. Table 3 numbers are based on a small motor that would take 2 hours to uninstall and install the on-site spare. Delivery times are added on to this for the various sub-optimal stocking situations. For the process critical motors, we have assumed that a large printing plant with 20 presses generates $120 million per year in revenue. $120 million divided by 20 divided by 360 days is $17,000 per day per press.

It will be no surprise to plant staff that the revenue loss costs in Table 3 grow enormous with the passage of time.

Table 3. Cost Examples for Motor Failures

	Less product	Labor to install	Overtime pay	Priority shipping	Clean-up
Plant Critical machines					
Spare motor on site	$8,000	$300	$150	< $100	$0-$5,000
Local shop 1-3 hour emergency delivery	$16,000	$300	$150	< $100	$0-$5,000
Regional distribution center 1 day delivery	$100,000	$300	$150	< $500	$0-$5,000
Not in stock, 2 day emergency repair	$200,000	$300	$150	< $1000	$0-$5,000
Line Critical Machines					
Spare motor on site	$2,000	$200	$100	< $100	$0-$5,000
Local shop 1-3 hour emergency delivery	$4,000	$200	$100	< $100	$0-$5,000
Regional distribution center 1 day delivery	$17,000	$200	$100	< $200	$0-$5,000
Not in stock, 2 day emergency repair	$34,000	$200	$100	< $500	$0-$5,000
Non Critical (redundant)					
Any source w/in 2 days is usually fine	$0	$200	$100	< $100	$0-$5,000
Non Critical (intermittent)					
Any source within a day or two	$0	$200	$100	< $500	$0-$5,000

On-Site Backup vs. No On-Site Backup and Motor Type Considerations

The type of motor is not included in Tables 1 and 2 above. This is because the actual type of motor has less to do with the costs than whether a spare motor is in stock. In facilities that do not have a sophisticated maintenance or spare parts inventory, when a breakdown occurs, they are caught unprepared. Through their inaction, they have decided to not be prepared for motor breakdowns when they happen. The fact that the local motor shop can rescue them is independent of that decision to not be prepared. Although it is economically inviable to have a backup of every motor, plants cannot afford to not have a backup for critical motors, particularly unique critical motors. For instance, the steel mill crane motor where the rotor moves in and out along the axis of the shaft to engage and disengage the brake is one to keep a spare (Schlindwein 2001). Some industry estimates suggest that 50% of all motors enter the market through the OEM channel with unique options (such as special axial thrust bearings) (Whalen 2000).

Critical Machines vs. Redundant or Intermittent Duty Machines

The large downtime losses in Table 1 and 2 are why plant designers build in redundancy whenever they can. This converts a critical machine to a non-critical machine, and greatly increases plant reliability. Most companies understand this, but there are some systems where redundancy is not possible. In these situations, the on-site spare is the next best option.

Vanilla Motors vs. Unique Motors or *What Is Unique?*

Another difference between large industry and small industry is the staff perspective on two minor, yet key definitions. "Do you have any big motors?" is a question that almost always gets a response of "yes" from small plant staff. The other issue is what constitutes a unique motor. Here again, small industry may have a different perspective. To some small company maintenance staffs, if it's not 1800 or 3600 rpm, ODP or TEFC, in their minds it is unique. Since large, specialized motors tend to be rewound and repaired, a fuzzy or broad definition of "large" and "specialized" greatly impacts the likelihood that the motor will be repaired. Since repaired motors are more likely to break down than new motors, these definitions will affect productivity.

One Example of a Proactive Approach Applied to Motor Management

According to Jon Schlindwein, Electrical manager at Charter Steel, Saukville, WI, preventative and predictive maintenance (PM) are the single most important factors to keeping a large plant with hundreds of critical motors running smoothly. Charter has a regular PM program that includes detailed greasing and oiling instructions for every motor and gearbox in the plant. On Monday morning, the maintenance crew gets a print out that shows which machines are to be lubricated, what type of lubricant to use, how much grease to use, and proper procedure for purging the old grease. Schlindwein thinks that setting that program up was one of the most important contributions to maintaining high productivity. In addition, Charter has a predictive maintenance scan done on all critical motors once a month to identify suspect bearings and other potential problems. In addition to doing all he can to avoid breakdowns Jon keeps an exact duplicate backup for all critical motors (which is most of them). This way, when the motor goes down, even in the middle of the night, an exact duplicate replacement is immediately available. Previously, if the failed motor was a 40 hp Siemens, and mechanics found a 40 hp Baldor motor in stock, they would call him at 2:00 AM to get permission to substitute the Baldor for the Siemens. This approach has yielded tremendous benefits for Charter Steel. They are dependent on over 100 critical motors, but in the past 5 years they have had only two unplanned outages due to motor breakdowns.

Elements of a Proactive Approach to Motor Management

In order to minimize the number of breakdowns, it is important to adopt a proactive strategy. A reactive strategy will work in a plant with all new equipment, but it will be a recipe for failure in the long run.

1. **Establish a carefully planned preventive maintenance policy for all motors.** This should include greasing and oiling instructions specific for the machine based on the manufacturers recommendations. At a minimum it should include frequency of greasing, type of grease and quantity of grease, in addition to effective procedures for purging old grease.

2. **Establish purchase policy.** OEMs buy motors based on two criteria, price and warranty. If the user does not ask for a premium-efficiency NEMA frame motor, chances are one will not come with the machine, especially if it was manufactured off-shore. Some specialized machines only come with metric motors, and this cannot be avoided. Metric motors are now catalog items in the US, so replacements and spare parts are less of a problem than they were 5 years ago. Unfortunately, some machines' motors come with sealed bearings as well as grease fittings, or some other goofy arrangement like a grease fitting, but no drain plug. A purchase specification can avoid this nonsense, and reduce downtime by making sure that the maintenance policy can be effectively carried out. For users who are serious about maintaining their motors, it is beneficial to have the drain fittings and purge lines accessible.

3. **Establish repair/replace policy.** A good repair policy has two levels. First, the 50,000 foot overall approach that outlines which motors should be repaired and which ones replaced. Usually this is set as some size threshold. Above the repair threshold size, motors are considered for repair. Before making the final determination, certain tests are done to evaluate the condition of the motor, and certain procedures should be followed as suggested in EASA publication 16. (EASA, 1992) If the repair cost is less than 60% (some facilities use 50%), the motor is repaired.

A second level of a good repair/replace policy looks individually at all critical motors. Motors that have already been repaired once or are very old and inefficient should be tagged "Do Not Repair" or marked with a yellow dot or some other prominent marking the plant staff understands. General-purpose motors below the repair threshold should also be tagged with a yellow dot (Nadel 1994). Then, the supply chain should be examined to see how soon these motors can be delivered. If delivery time is unacceptably long, stock a spare motor. If the motor is critical, consider stocking it even if it is a common size, or negotiate with the dealer to keep one reserved in stock. Of course, even if the motor will be repaired, it may be beneficial to have a spare.

The costs of proactive approaches can include:

- Shift from repair to replace
- More money spent on new motors
- Effort to catalog or inventory motors and learn MotorMaster
- Effort to identify replacement parts or replacement motors
- Preventive maintenance costs
- Predictive maintenance costs

Barriers to Implementing a Proactive Motor Management Approach

The lack of appreciation of the costs, existing management structures, and a simple lack of understanding all represent barriers in implementing a proactive motor decision policy. As can be concluded from the previous discussion of costs, this is a complex topic that does not lead to a ready appreciation. However, elements of the corporate structure contribute to this.

Corporate Management Structure

In most facilities motor decisions are divided among different departments. For example:

- Many maintenance departments have discretionary spending authority on their repair budget, but are restricted on capital expenditure. Thus, they can repair a motor, but may not be authorized to purchase new motor.
- On the other hand, plant management in consultation with corporate management frequently makes capital decisions. Capital budget decisions are frequently made independently from the operating decisions.
- Utility costs are frequently paid from a different budget than capital and maintenance, so savings are not credited against the capital or maintenance expenses.
- Many of the cost impacts are born by the production division, so they may not be directly evident to the maintenance department. In turn, production is not aware of the decision process in maintenance.

In a typical scenario, the company requires a separate itemized capital budget in their annual planning cycle. Motors may or may not receive priority for funding when decision-makers are faced with urgent capital requests from other departments. Corporate decision-makers must intervene since this split means that maintenance staff usually does not have the unilateral authority to implement the most logical and cost-effective motor policy. However, so long as decision-makers do not understand the benefits and that intervention is necessary, they will continue in their belief that maintenance "is handling the motors".

Lack of Staff Time

Over the last two decades, we have seen plant staffs reduced to cut operating costs. While this has contributed to impressive increases in productivity, staffs have less time to tend to preventive actions. They frequently take an attitude of "don't fix it if it ain't broke." This change is manifest in such trends as a reported decline in over-lubrication failure in motors, mirrored by a corresponding increase in under-lubrication failures (Nadel et al. 2001). It is important to note that this in general is not due to laziness, but rather to over commitment, a trended noted in other sectors of the economy as well. The focus is on managing the crisis a hand, and often no time is left for preventing future crises.

Summary and Conclusions

Downtime costs can be quite large for critical motors, but these costs can be minimized or in some cases virtually eliminated with the judicious application of proactive motor policy principles. Vigorous preventive and predictive maintenance combined with sound motor purchase and repair policies can greatly increase reliability and uptime.

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