Maintenance Decisions Matter: An Alternative Approach to Stimulating Energy Savings

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ABSTRACT

From an overall business perspective the productivity benefits of improved maintenance, including avoidance of the sometimes huge costs of unplanned plant failure, make it a higher management priority than energy efficiency (Falkner 1999). As a result, industry is much more likely to spend money on maintenance than on energy savings activities. The many strong links between maintenance and energy saving best practice therefore led to the decision by the United Kingdom's (UK) Action Energy programme to start a new initiative promoting maintenance rather than energy saving as the "hook". This paper gives an overview of the many links between maintenance and energy saving, and the outcomes of the UK Maintenance Decisions Matter campaign to date.

Why Maintenance?

Finman & Laitner (2001) analysed 77 published case studies on energy efficiency, from which they identified 6 common non-energy saving benefits:

- Reductions in waste
- Reductions in emissions
- Reductions in maintenance and operating costs
- Improvements in productivity and quality
- Improvements in the working environment
- "Other", such as from saving space, reducing capital expenditure, improved public image, and improved worker morale.

Of the 52 case studies that attempted to put monetary values to these gains, the average payback fell from 4.2 years on energy savings alone, to just 1.9 years when all savings were taken account of. Although the high energy-only payback is distorted by the many case studies demonstrating newer and innovative technologies, the general result remains valid. A further paper, (Laitner et al. 2001) shows the results of ascribing monetary values to the non-energy saving benefits of possible energy saving actions in the US Iron and Steel sector. This showed that for the same payback criteria, taking account of the non-energy benefits doubled the savings that could economically be made. This is equivalent to additional energy savings of 1.9 GJ/ton of steel produced, or 170 PJ (1.6×10^{14} Btu) of potential savings across the whole sector.

Analysis of UK studies also shows that in many cases it was actually these non-energy benefits that were the critical factor behind the decision to consider the project in the first place. This finding was one of the principal reasons behind the idea to try to implement an initiative that, instead of just promoting energy efficiency, would instead use the non-energy saving benefit of maintenance as the primary proposition, knowing that energy saving would follow "through the back door".

Examples of Maintenance Issues Affecting the Implementation of Energy Efficiency Measures

There is much evidence from ongoing energy efficiency work to support the idea that an interest in maintenance is behind the adoption of energy saving practices, with the following selected to show the diversity of ways in which this occurs:

The European Copper Institute's long running UK campaign to encourage greater cable sizing to reduce power losses had shown disappointing results. But when the same measure was expressed as a way of reducing the incidence of plant failure through improving power quality (European Copper Institute 2001), it became their most successful campaign ever, as it was now something of great and immediate interest to lots of companies.

While the economic arguments for higher efficiency motors in the UK is good, it hasn't been convincing enough to see a big change in the market. But both UK work (Action Energy Programme 2000, Action Energy Programme 1998, AEMT/EASA 1996) and the US "Motor Decisions Matter" campaign *(see www.motorsmatter.org)* have found that promoting best practice to take account of what to do when a motor fails is of much more interest. It is therefore much more likely to lead to management attention being given to the running costs of motors and the importance of efficiency (Wroblewski, Elliot and Emerson 2001).

Many consultants have noted that having a site maintenance engineer accompany a consultant during a site energy savings opportunities assessment can give a much deeper insight into the true state of plant operation than anyone else. For example, a compressed air system that always gives enough air at the right pressure and adequate quality would be regarded as "no trouble" by the Production Department, but it's the Maintenance Department staff who will point out the need for more and more compressors or excessive maintenance effort needed to provide this service. More generally, pausing to stop and ask questions of everybody in a plant with an interest in a particular system, in particular any problems that it causes, can also help to identify all sorts of discrepancies in people's understanding of the requirements and performance of systems, and so can give an excellent clue as to energy saving solutions.

One of the key drivers behind the Europump/Hydraulic Institute guide to Life Cycle Costing (LCC) of pumping systems (Europump/Hydraulic Institute 2001), was the realization that energy savings alone were insufficient to make many people improve the design and maintenance of pumping systems. The basis of the Life Cycle Costing guide (Tutterow, McKane & Hovstadius 2001) was that all directly attributable costs over the lifetime of an item of plant, such as purchase, maintenance, energy, spares, disposal etc. should be accounted for when designing a system. The success of this wider approach suggests that thinking beyond just energy saving is more likely to stimulate action. Interestingly, when analysing the impact of the work, it became clear that the rigorous engineering analysis needed to do a proper LCC calculation was too often being ignored either because of pressures of time or simply a lack of skills. We have seen this as a further stimulus to better educate personnel in maintenance and energy and their related costs, since these are usually the biggest unknowns in an LCC calculation.

Table 1. The Link Between Energy and Maintenance Savings

	Practice	Result
Motors	Rewinding	A good quality rewind will reduce efficiency by only 0.5 – 2.0%
	Lubrication	Over-lubrication can cause premature bearing failure and efficiency loss of up to 1%
	Shaft Alignment	Incorrect shaft alignment costs about $8/kW per degree of misalignment
	Belt adjustment	Belt drive efficiency deteriorates by 10-15% without regular adjustment
Compressed Air Systems	Fixing leaks	Typically reduces costs by 15-20% if controls are adjusted to accommodate the reduced volume required. Network zoning, removal of redundant spurs, and maintenance of connector & cylinder seals all reduce leakage
	Condensate drain traps	Electronic condensate drain traps are much more reliable, wasting less air than mechanical or manual traps
	Servicing	Regular servicing maintains performance and efficiency
Pumping Systems	Impeller maintenance	Maintaining impellers and coating pumps maintains efficiency. Pump condition monitoring equipment identifies the proper timing for pump refurbishment
	Speed control	Variable speed control reduces wear on the pump, bearings, and seals
	Adjustable speed drives (ASDs)	ASDs can alleviate water hammer and its effects, and can prevent cavitation in certain circumstances
	Valves	Jammed non-return valves waste lots of energy in parallel pumping systems
	Fixing leaks	Reduces water consumption as well as reducing energy consumption
Fan Systems	Filter cleaning	Dirty filters produce unnecessary pressure drop
	Duct cleaning	Dirty ducts create excessive friction, producing unnecessary pressure drop
	Blade maintenance	Worn and dirty fan blades reduce efficiency
	Dampers	Worn or inoperable dampers increase energy consumption
Steam Systems	Boiler maintenance	A poorly maintained boiler loses 5-10% efficiency
	Oxygen control systems & ASDs on combustion air fans	Reduces the need to regularly monitor and adjust burner controls, thus saving fuel, reducing emissions, and reducing fan power consumption
	Fixing leaks	Leaks and faulty steam traps waste energy
	Pipe insulation	Maintaining the integrity of pipe insulation minimizes steam heat loss

Finally, Table 1 lists for five key items of industrial plant some of the common actions that have both a maintenance and energy saving benefit. The amount of overlap shows that there are many practical maintenance actions that have a direct energy saving benefit, and so help to justify the promotion of maintenance as a way of also saving energy.

The Costs of Failure

The cost of maintenance failure explains why there is so much management interest in the subject, and a readiness to spend money to improve plant performance. As an example, Table 2 below shows the typical costs of an unplanned stoppage in a selection of industries.

Table 2. The Costs of Unplanned Equipment Outages

Industry	Typical financial loss per stoppage
Computer centre	$825,000 (Euros 750,000) per event
Financial trading	$6,600,000 (Euros 6,000,000) per hour
Glass industry	$275,000 (Euros 250,000) per event
Semiconductor production	$4,180,000 (Euros 3,800,000) per event
Steel works	$386,000 (Euros 350,000) per event
Telecommunications	$33,000 (Euros 30,000) per minute

Source: European Copper Institute 2001

In addition to these costs, feedback from UK Maintenance seminars finds that management is increasingly concerned with maintaining equipment properly in order to comply with health and safety regulations, where the costs of a successful prosecution are a big deterrent to poor practice. Poor quality or late delivery of products resulting from equipment failure can jeopardize future business, and so also came across as being a major additional concern.

Table 3. The Energy Costs of Plant Failure

Effect of unplanned breakdown	Related energy cost
Temporary reduction of output during breakdowns	Core or background energy needed to maintain essential services is spread across less output, and so the specific energy consumption rises.
Start up losses	A lot of energy is lost during the warm up time of high temperature processes
Alternative methods for re-gaining production used	Less efficient methods of production may be used, perhaps using older equipment or involving additional transport costs
Loss of product during warm up time	Some processes have to produce scrapped product while they are "warming up".
Energy used in part processing the product is lost	Much energy may have been expended in getting a product to near the end of a production process, and this energy will be wasted.
Disposal of damaged product	There may be energy costs involved n the physical disposal of scrap product.
Emergency repairs made to re-start plant ASAP	Maintenance staff will do what ever is quickest to get the plant running, with speed taking priority over getting the optimum quality repair or looking for the most efficient spare part or replacement kit.
Rework costs	Additional energy used in re-working spoiled product.
Time lost for less urgent work	Time that could have been spent on energy saving work is lost

Overall Equipment Effectiveness

The measure most commonly used by management to assess the performance of a plant compared to the ideal is that of "Overall Equipment Effectiveness" (OEE), and so it is interesting to see how energy efficiency relates to the parameters measured by this. OEE takes account of all the direct costs of poor plant performance, and is usually defined as:

OEE =	Availability	(Breakdown losses	+	Set up and adjustment losses)
	x Performance Rate	(Idling	+	Minor stoppage losses)
	x Quality rate	(Rework losses	+	Start up losses)

If the bracketed maintenance costs look familiar, it is because they also represent common sources of energy loss. These hidden energy costs can be substantial, and these and other sources of energy losses due to plant failure are described in more detail in table 3.

Table 4 gives a simple breakdown of the causes of plant breakdown, and the remedies to eliminate the causes. Again, the direct energy efficiency benefits of better maintenance in the top 85% of causes are apparent.

Table 4. How Plant Breakdowns Can Be Eliminated

Percentage of breakdowns / stoppages	How they can be eliminated
> 40%	Refurbishment and hence restoration of equipment to its standard conditions
> 20%	Application of daily asset care checks and best practice routines of operation
> 25%	By application of regular and relevant condition monitoring and planned maintenance
> 15%	By designing out physical weaknesses in the equipment

Source: Petrie, Sandie 2003

How Maintenance Best Practice Can Help Overcome Non-Economic Barriers to Energy Efficiency

So far it is just the clear links between energy efficiency and maintenance that have been shown. But in addition to the commonality of technical measures, there are other aspects of maintenance best practice that help to overcome some of the common non-economic barriers to energy saving projects being implemented:

Gaining the Support of Others Who Might Benefit from a Project

Talking to other staff, such as maintenance and production personnel who are also familiar with the item of plant, is a very good way of identifying other benefits. But in addition, by making them feel involved and being able to identify what is in it for them personally, they are more likely to support the proposal.

Integrating Energy Saving Actions with Planned Maintenance Shutdowns

On equipment that runs for weeks or months between scheduled stoppages, the cost in lost production means that shutting down plant to fit and commission energy saving equipment can only be done if planned ahead as part of a schedules shutdown.

Integrating Regular Maintenance and Energy Saving Databases

A list of all key equipment should be at the heart of a maintenance management programme, and is an excellent basis for an energy management programme.

Integrating Routine Maintenance and Energy Savings Checks

Routine checks on equipment such as checking for leaks, monitoring temperatures/pressures etc. are core elements of both maintenance and energy saving campaigns. The implication is that the person doing these should be aware of both reasons for undertaking them, and where appropriate modify the details of the work to maximise all energy saving and maintenance benefits.

Reviewing Site Service Demands

Expansion or contraction of plant output can quickly lead to a mismatch between the provision of site services and the actual demand, and is a common cause of inefficiency. A better match minimises the costs of maintenance both through better use of existing plant, and through the avoided costs of maintenance on plant to supply capacity that is no longer needed. The periodic re-appraisal of what site services are actually needed should therefore be part of maintenance and energy saving best practice.

Design for Maintenance

Designing equipment so that it can be easily maintained, or not need maintaining at all, can reduce energy consumption.

A Way of Working

An organization that has a right approach towards maintenance, both by having a maintenance management system that works, and by having the right employee attitude, is in a much better position to implement a successful energy saving campaign.

Better Maintenance Is Free

Analysis of case studies from the 2002 UK Maintech conference (Maintech 2002) shows that in all five of the detailed examples cited, in addition to reaping the benefits of better maintenance, overall maintenance costs actually went down. This is because the additional expenditure on better monitoring and preventative maintenance was more than compensated for by the reduction in expensive "fire-fighting" maintenance. With so many companies looking to further squeeze maintenance budgets, the idea that you can do better with less expenditure is a very attractive promotional idea. The overall operational benefits from these studies are summarised below:

- Lever Faberge increased production capacity by $2.4 million/year (£1.5 million) via an increase of OEE of 110%, while reducing maintenance costs by 31%.
- Blue Circle Cement reduced breakdowns by 67% and saved almost 20% on their maintenance budget.
- British Aerospace increased OEE on machinery from 26% to 65%, improved quality by 10%, reduced downtime by 10% and halved spares costs in another area.
- Imperial Chemical Industries (ICI) reduced maintenance expenditure by 20% while increasing throughput leading to a reduction of maintenance costs/tonne of product of 30%.
- Unilever achieved a 30% improvement in productivity whilst reducing maintenance costs by 30% and also substantially reducing defects.

In addition, there is one Action Energy independently monitored case study that gives both OEE and the related energy savings – *Cutting Energy Losses Through Effective Maintenance (Totally Productive Operations*) (Action Energy Programme 1997). This is at a UK site manufacturing polypropylene packaging that in 1992 instigated a new maintenance programme, which by 1995 had led to an improvement in OEE from 59% to a target of 81%. In addition, these maintenance actions gave a 16% improvement in plant energy/ton of product.

Use of Condition Monitoring to Minimize Unplanned Failures

Having made the case for better maintenance, how should a company go about improving its maintenance practices? As with improving energy saving practice, the first activities should be to assess or benchmark the current approach to maintenance, and then to devise and win management and operative commitment to a company maintenance policy, *(Action Energy Programme 2003).* The next step is to identify what is the right level of monitoring (if any) on items of plant to be included within the maintenance programme, and what techniques to do this are most appropriate.

Condition Monitoring is, as its name implies, a group of techniques for monitoring the condition of equipment so as to take action before there is an unexpected failure. There are many high tech solutions available, but a lot can be understood by experienced personnel just by looking, listening, feeling for vibrations, and smell. The following four families of powerful techniques are those most commonly used in industry, with wider use of these being an important objective of the UK Maintenance programme.

1. **Thermographic analysis.** This is the use of infra-red sensitive cameras to check for heat-related problems, many of which are directly related to energy efficiency, such as:

- Poor insulation on steam or refrigeration pipes
- Losses from building fabric
- Losses from ovens or cold stores
- Imminent bearing or seal failure
- Over-loaded electrical systems.

On all but the largest sites an experienced thermographic surveyor can in just one day produce an automatically generated computer report incorporating color photos of the heat loss on the above and other equipment. This is an excellent way for a site to rapidly identify problem equipment, and to later verify that remedial action has been successful. Some companies are now even stipulating that a thermographic survey is undertaken as part of plant acceptance procedures.

2. **Oil Analysis.** This is the microscopic analysis of oil to check for breakdown of the oil molecules or contamination with water or other external substances, ensuring that it is replaced before its lubricating performance is reduced so much that the equipment is damaged. It can also be used to identify particles that have worn from the machinery it is protecting, hence giving advanced warning before serious failure.
3. **Vibration analysis.** This detects patterns of vibration is rotating machinery, and by comparison of the frequencies with those of the different rotating elements, it can identify which elements in a drive train are causing a problem.
4. **Motor current signature analysis.** By examining the current signature of an electric motor, a detailed diagnosis of its condition can be made, giving time to decide what action to take rather than suffer an unexpected failure.

Development of the Action Energy Maintenance Campaign

The Action Energy maintenance initiative started with the simple objective of persuading companies to improve their maintenance practices. But analysis of the feedback from the first six Maintenance Decisions Matter events shows that actually the reasons for interest in the programme are more complex than this, and so we have now split the audience in to four distinct audience segments. For each of these segments, the publications that are either written or planned are shown in italics, with the variety of content and styles reflecting the big range in audience needs and interests. This segmentation is now also being used as the basis for other promotional elements such as articles and events, and it is hoped will enable us to both attract more people to the campaign, and to better address their needs.

1. **Maintenance managers** who are looking for ways to do more effective maintenance, with often decreasing budgets. They are most interested in the strategic maintenance topics, such as the selection and implementation of maintenance philosophies, and are always interested in case studies to find out the real effect of implementing different schemes. We found that many were turned off by the rigid "all or nothing" approaches that are sold by some consultants, and were instead interested to hear that you don't have to follow any one particular philosophy and/or spend lots of money on a Computerised Maintenance Management System (CMMS).
   A short glossy leaflet "Maintenance Decisions Matter – a guide for executives" (Action Energy Programme 2003), gives senior management an insight in to the costs

of poor maintenance and the many benefits of improved maintenance. This includes a short self-audit tool and an overview of the most common maintenance systems used in the UK.

2. **Front line maintenance workers** who are every day having to cope with the impact of maintenance failures, and who are interested in tactical maintenance issues. They are most interested in finding out about the range of equipment and techniques for preventative maintenance, and also about deciding what equipment needs attention and when.

A series of technical guides on condition monitoring techniques and how you select them. These compliment the existing Good Practice Guides that already contain much useful information relating to the maintenance of particular items of plant. In order to assist companies in benchmarking their maintenance performance, there is a maintenance self-audit tool, from which it is also hoped to develop an interactive internet version.

3. **Plant operators** who attended because they saw it as a quick way of finding out how to "cherry pick" the low or no cost maintenance-related energy saving measures at their sites.

Short pocket guides produced in partnership with Trade Unions listing simple activities that operatives can undertake to both save energy and improve plant OEE.

4. **Third party maintenance companies** who have an interest in using energy saving as a selling point. As this sector of the market grows, companies are increasingly looking for ways to differentiate themselves, with some already including energy efficiency as part of their offerings, (Blandford 2001).

This is the final group to address, which we have deliberately postponed talking to formally until we have built up some credibility through initial events and publications. In 2003-04 we intend to take this forward through more formal dialogue with the relevant trade associations.

We had expected to have little interest from "mission critical" industries that have safety as a key business driver, but in fact have had many delegates from aerospace, petro-chemicals and the railway sectors. This unexpected outcome shows that even companies that already have to have very good maintenance systems are always looking to do things better, and/or at lower cost.

Conclusions

From an overall business perspective the productivity benefits of improved maintenance, including avoidance of the sometimes huge costs of unplanned plant failure, make it a higher management priority than energy efficiency. As a result, industry is much more likely to spend money on maintenance than energy saving work. The many strong links between maintenance and energy saving best practice therefore led to the decision by the UK Action Energy programme to start a new initiative promoting maintenance rather than energy saving as the "hook". This has indeed led to our attracting new audiences who have a very strong interest in making changes in maintenance practice, and crucially in the management support to do so. Although it is too early to have done any formal impact assessment, strong anecdotal evidence suggests that we are indeed getting indirect energy savings "through the back door" from companies and practices that would never have been reached through the conventional "Energy Efficiency only" route. In particular, organizations really appreciate having ongoing technical problems solved, rather than just receiving sometimes bland energy saving recommendations that don't get to the heart of their problems.

After the first year of promotional work, we have found that the audience is more diverse than was expected, and so we now have to develop different activities and materials in order to address their very different needs. Despite this unexpected outcome, the first year of the programme has been successful, and we are now going forward in to the second year with a much clearer idea of how to address the needs of this new audience.

References

Action Energy Programme. 2000. *Energy Savings From Motor Management Policies,* General Information Leaflet 56 (GIL056).

Action Energy Programme. 2003. *Maintenance Decisions Matter - A Guide for Senior Executives*, General Information Leaflet 75 (GIL075).

Action Energy Programme. 1998. *Purchasing Policy for higher efficiency motors*, Case study at ECC International (GPCS222).

Action Energy Programme. 1997. *Cutting Energy Losses Through Effective Maintenance (Totally Productive Operations),* (GPG217).

Association of Electrical and Mechanical Trades. 1996. *The repair of induction motors, Best Practices to maintain energy efficiency*, available from the UK AEMT, also EASA.

Blandford, Richard. 1999. *Electric Motor Management Scheme*, Proc EEMODS, P.571-578, Bradford, England.

European Copper Institute. 2001. *The Costs of Poor Power Quality*, Brussels., www.cda.org.uk.

Europump / Hydraulic Institute. 2001. *Life Cycle Costing Guide to Pumping Systems*, Europump, Brussels.

Falkner, Hugh. 1999. *The UK Energy Efficiency Best Practice Programme – Lessons learnt,* Proc EEMODS.

Finman, Hodayah and Laitner, John A. "Skip". 2001. *Industry, Energy Efficiency and Productivity Improvements*, Vol. 1, Proc ACEEE 2001, Summer Study.

Laitner, John A. "Skip", Ruth, Michael B. and Worrell, Ernst. 2001. *Incorporating the Productivity Benefits into the Assessment of Cost-Effective Energy Savings Potential Using Conservation Supply Curves.* , Vol.1, Proc ACEEE 2001 Summer Study.

Maintech. *The Route to Maintenance Best Practice Case Book*, Maintech / Conference Communications, UK, 2002.

Petrie, Sandie. 2003. *Presentation at Action Energy Maintenance Decisions Matter Seminar*, Livingston, Scotland.

Tutterow, Vestal, McKane, Aimee, and Hovstadius, Gunnar. 2001. *Going with the Flow, Life Cycle Costing for Industrial Pumping Systems.* Vol. 2, Proc ACEEE 2001 Summer Study.

Wroblewski, Ron, Elliott, R.Neal, and Emerson, Tari. 2001. Estimating Maintenance and Productivity Benefits of Motor Decision Policies, Vol.2 P.451 - 461, Proc ACEEE 2001 Summer Study.