Analyzing Engines and Compressors in Economic Terms

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Course Overview

This short course discusses and illustrates how we can develop economic measures of machinery behavior and how we can use these measures to help improve the corporate bottom line. The session will include examples and illustration.

Typical condition monitoring programs in the past have driven maintenance primarily from a technical perspective. The detection of a fault, such as a compressor valve leak, would result in a call for maintenance. Superior bottom line results will be achieved if we can prioritize and plan maintenance on the basis of the economic implications of deviations in mechanical condition or performance.

Economic measures can be used to:

- justify maintenance
- prioritize maintenance
- improve operating procedures
- help justify upgrades and revamps
- justify the condition monitoring program itself

Dollars vs. Technical Terminology

It is common to utilize technical terminology to describe the performance of engines and compressors. Typical examples are horsepower per million standard feet of gas moved (HP/MMSCFD) and brake specific fuel consumption (BTU/BHP-HR). While these measures have significance as technical indicators, managers and corporate accountants do not understand the impact of changes in these values. However, everyone understands the importance of dollars and time. These measures will allow communication across the entire organization. In fact, many technical measures can be directly converted to dollars and time.

Management Ready Information

Most managers, foremen, and supervisors have a very limited amount of time. While they might want to understand the technical data collected and at a previous time might have collected the data, it is your job as an analyst to filter and transform this data for them. It is most important to provide:

- an estimate of the consequences arising from any deviation in performance or mechanical condition, preferably in dollar terms
- probability of experiencing these consequences
- options to mitigate the risk

The manager is then in a position to make a decision, rather than having to engage in further analysis.

Prerequisites for Economic Analysis

Many companies have been collecting machinery and operational data for years but have not transformed this raw data into information that can directly affect the bottom line. They have a "DRIP" problem - data rich and information poor. Activities such as routine engine/compressor analysis programs and operating data logs typically fall into this pattern.

The amount of additional information that must be collected to complete an in depth economic analysis depends on the practices that are in place. In many operations, useful economic measures can be generated using only data that is readily available. Generally, the major need is not more data, but more analysis of existing data. The type of analysis required is not difficult; just some basic calculations, as this session will illustrate.

Economic measures need to be developed at the individual unit level; aggregated costs for a facility will not adequately reveal economic losses. For example, it is very unlikely that ten units at the same location would have the same fuel efficiency. Every location has a "bad unit" that costs additional money for maintenance. These costs need to be captured to develop baselines and to track improvements over time.

It has been said that you can't improve what you don't measure. Making economic measures can confirm perceptions of personnel in the field, but unless you have hard evidence you are just another person with an opinion. Only quantitative economic measures enable prioritization across the entire fleet.

To be successful, some change of culture might be required. Openness to change will determine the level of success. Personnel involved in the technical programs will need to be trained and equipped in order to make decisions that are best from a bottom line or return-on-investment perspective.

The goal of economic analysis is to provide the maximum return on the machinery investment. This requires determination of both costs and benefits of the proposed action (or inaction). There will often be several alternatives that must be compared.

Be Careful What You Measure

The measures that we put in place can have unintended consequences. Here are some extreme, but real, examples:

Minimum Fuel Cost

A manager gets rewarded for a low fuel rate. His equipment regularly operates 2000 BTU/BHP-HR below the manufacturer's curve and similar units on this system. The orifice plate size was either entered incorrectly or the plates have been modified.

Minimum Overtime

After collecting data on a unit in obvious distress, the supervisor sent the analyst home to avoid overtime charges for completing the analysis. Gas control did not want to shut the unit down until the repairs could begin. The unit had a catastrophic failure that night.

Minimum Maintenance Costs

For three years a supervisor was rewarded for the lowest maintenance cost on the system. He received a promotion and the new supervisor had the highest costs on the system for the next two years.

Maximum Availability

A unit catastrophically fails at a location with spare units. The availability at the location was not affected by the failure due to the spare units. A similar unit has a minor failure at a different station with no spare units. This location is penalized for availability during the repair.

In each case the measure was valid, but the implementation was poor. Beware of unintended consequences. Ultimately, it is the *bottom line* impact that matters.

Basic Economic Decisions

Decisions driven by considerations of best bottom line impact can be broken into two categories:

- performance degradations in which the cost can be calculated with reasonable accuracy
- mechanical degradation requiring a risk assessment perspective

In this section we will present some general equations which can be used when performance degradation has been identified. The equations include the cost associated with wasted energy plus the general operations and maintenance cost. The latter factor is necessarily imprecise. However, we know from experience that as load increases, O&M costs do also. We will assume that there is an average value available.

1. For engine drives in cases where we can identify wasted horsepower:

$$\text{cost (\$/yr)} = \text{wasted HP} * \left(\frac{\text{BSFC} * \text{FC}}{\text{LHV} * 1000} + \text{OMC} \right) * 24 * 365 * (\text{UF}/100)$$

where BSFC = nominal or known brake specific fuel consumption
FC = fuel cost, $/MCF
LHV = lower heating value
OMC = operations and maintenance cost, $/HP-Hr
UF = utilization factor for unit, %

2. For motor drives in cases where we can identify wasted horsepower:

$$\text{cost (\$/yr)} = \text{wasted HP} * (0.746 * \text{KWC} + \text{OMC}) * 24 * 365 * (\text{UF}/100)$$

where KWC = energy cost, $ per KWH

3. For engines where we can detect a deviation in BSFC

$$\text{cost (\$/yr)} = \text{BSFC dev} * \text{BHP} * \left(\frac{\text{FC}}{\text{LHV} * 1000} \right) * 24 * 365 * (\text{UF}/100)$$

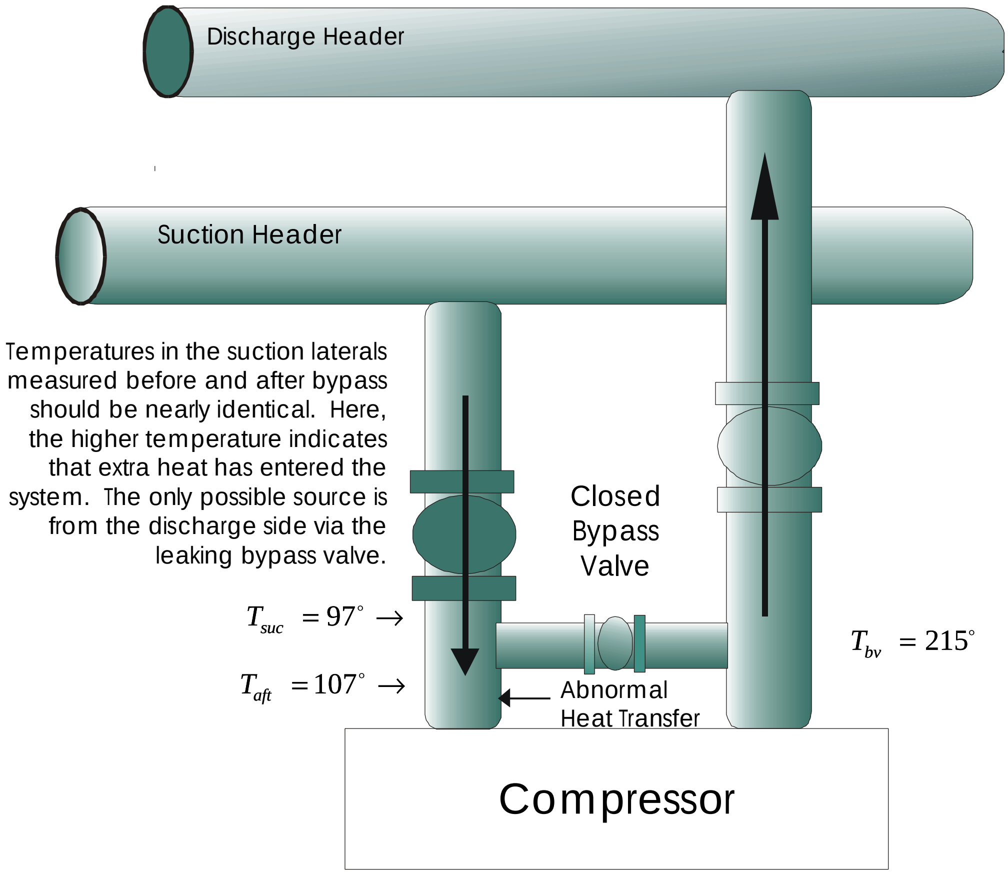
where BSFC dev = actual BSFC - baseline BSFC

An important issue is what we use as a baseline or reference in these analyses. There is seldom much to be gained from using ideal theoretical behavior as a baseline. We should view wasted horsepower or BSFC deviation as the difference between the current value and what is achievable in practice. We should try to develop a realistic but conservative estimate of the available economic improvement.

Examples of Direct Economic Measures

The following examples show how we can develop direct dollar measures.

1. Bypass Valves:



Temperatures in the suction laterals measured before and after bypass should be nearly identical. Here, the higher temperature indicates that extra heat has entered the system. The only possible source is from the discharge side via the leaking bypass valve.

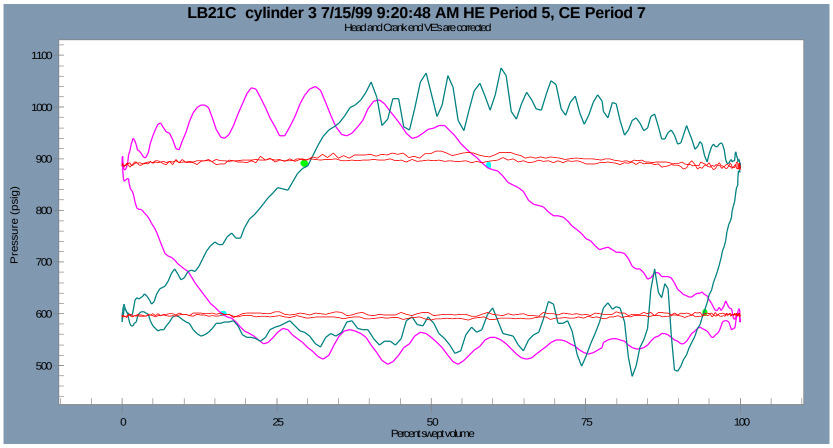
The increased temperature reflects the heat transferred to the mass of the suction gas. The temperature change is proportional to the mass, therefore, the leak % can be calculated as follows:

$$Leak\% = \frac{mass\ of\ leak}{mass\ of\ suction\ gas} = \frac{T_{aft} - T_{suc}}{T_{bv} - T_{aft}}$$

Leak % for this case was over 9%. Using a fuel cost of $2 per MCF and LHV of 950 BTU per cubic foot, the "lost"gas was worth over $17,000.
Let's assume that Maintenance Cost Per HP-hr was ½ cent ($0.005). The additional cost of maintenance due to the leaked gas would be 0.005 x 1540 HP x 8000 x 0.093 = > $5500.
Total cost of this leak was more than $23,,000.
Beta's Machinery Optimization group routinely checks for bypass valve leaks, because of the available savings. The check is simple, and the return can be great.

2. The cost of compressor valve and passage losses

Pressure drops through compressor passages and valves are unavoidable. However, it is possible and desirable to limit these losses to reasonable levels. The best way to judge what is reasonable, at least for an existing unit, is to measure the performance and then determine the cost of the losses.



In the pressure-volume curves shown above, the area between the suction or discharge event and the nozzle trace represents the power loss due to valve and passage losses. The loss on the discharge sides of both the head end and the crank end appear to be quite large. Since the analyzer reports these horsepower losses, it is quite easy to calculate the cost.

For this unit, the analyzer has already calculated and reported the unit valve and passage losses as shown below in the section titled "COMPRESSOR COST OF LOSSES". Note that the total of valve and passage losses is shown as 789 HP. The "adjusted losses" are those in excess of 10% of compressor gas horsepower, to indicate more accurately the potentially recoverable power. The daily cost associated with these losses is then reported as about $249 per day.

Information of this type permits and supports business driven decisions. The analyst or engineer needs to determine the cost of recovering some or all of the losses and then make a decision based on ROI (return-on-investment) considerations.

Unit Name:	**LB21C**	**Model:**		**Date:**	
Location:		**Unit Mfr:**	**ENTERPRISE**	**Serial No.:**	

Load Step:	**13**
Percent Load:	**96.9 %**

UNIT COSTS

Fuel Cost:	**1308.48**	**$/day**
Brake Power from the load:	**3733.33**	**bhp**
Cost of Each BHP:	**0.35**	**$/bhp-day**

ENGINE COSTS

			Percent of Fuel Cost	
Actual Fuel Consumption:	**6749.21**	**BTU/BHP - hr**		
Predicted Fuel Consumption:	**6800.00**	**BTU/BHP - hr**		
Deviation From Predicted:	**-50.79**	**BTU/BHP - hr**		
Cost of Deviation:	**-9.85**	**$/day**	**-0.8**	**%**
	-299.69	**$/month**		
	-3596.28	**$/year**		

COMPRESSOR COST OF LOSSES

	Total Losses		Adjusted Losses (Note 7)		Estimated Cost of Losses		Percent of Fuel Cost	
Valve and Passage Losses:	**789.04**	**bhp**	**710.13**	**bhp**	**248.89**	**$/day**	**19.0**	**%**
Pulsation Losses:	**24.72**	**bhp**	**22.25**	**bhp**	**7.80**	**$/day**	**0.6**	**%**
Gas Recirculation Losses:	**3.76**	**mmscfd**			**40.28**	**$/day**	**3.1**	**%**
Total Compressor Cost:					**296.97**	**$/day**	**22.7**	**%**
					9039.02	**$/month**		
					108468.23	**$/year**		

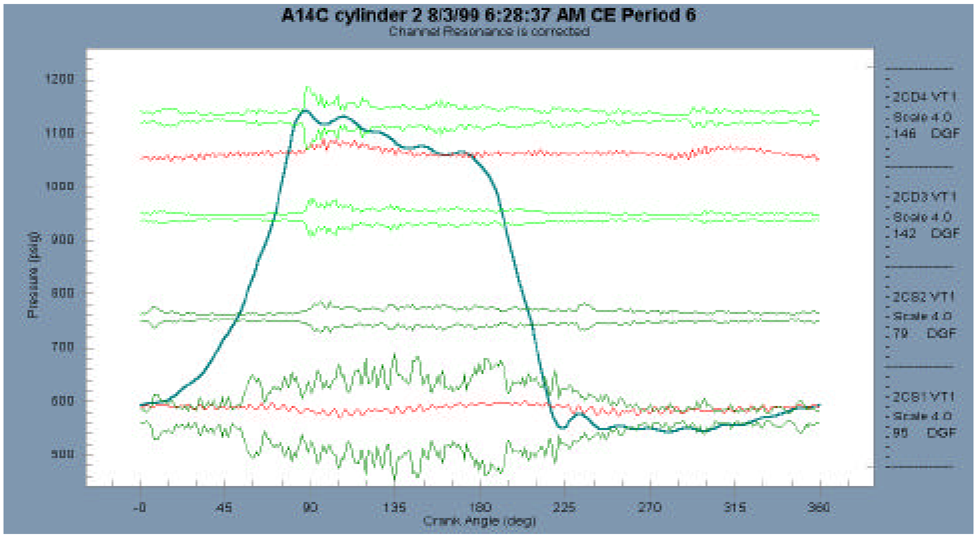
TOTAL DEVIATION FROM PREDICTED

			Percent of Fuel Cost	
	287.12	**$/day**	**21.9**	**%**
	8739.33	**$/month**		
	104871.95	**$/year**		

Unit running 365.25 days per year

3. The cost of leaking compressor valves

Analysts will recognize that the patterns shown below indicate a significant leak in suction valve 2CS1. The flow balance (ratio of capacity from suction volumetric efficiency to that from discharge volumetric efficiency) was 1.13, which tends to confirm the diagnosis.



There is a natural inclination on the part of the analyst to call for correction of this problem. It is informative, however, to assess the cost of this leak.

In this specific case, suction valve leaks were indicated on all four head ends. The economic analysis report which is produced as part of the analysis reported a cost of about $20 per day due to these leaks. This assumes that the reduced capacity can be made up and is not lost.

The same report shows the cost of pulsation losses to be around $47 per day and that due to valve and passage losses was $128 per day.

So the fact is that the economic consequence of the valve leaks is far less than the other losses. This type of information provides a much improved basis for prioritizing maintenance.

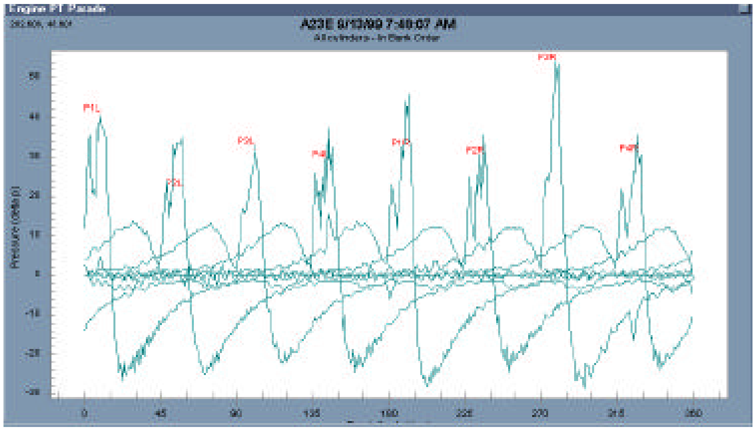
4. Cost saving due to operational improvements

Subtle deviations in operating parameters can significantly affect performance. These situations frequently are a result of several factors combining to create an overall increase in fuel consumption or decrease in capacity. Detection and correction require good tools in the hands of skilled, experienced technicians.

One of the most common operational differences is ignition timing. It is not uncommon that ignition timing will be changed to mask mechanical problems and overcome shortcomings in performance. These changes directly affect the amount of fuel that the engine must consume to deliver the horsepower required by the compressor. Frequently similar units running at different locations have different ignition setpoints due to the operating experience of the crews.

In one case there were two identical units sitting side by side at a location. Both units were in good mechanical condition, but unit 1 was consuming 2.5% less fuel than unit 2. The units were analyzed using a state-of-the-art engine/compressor analyzer and the results were compared.

The “first derivative” curves from the two engines provided an important clue about the cause of the discrepancy. An example of such a curve is shown below. The presentation shows the rate of pressure rise as a function of crankshaft angle for each cylinder. We are mostly interested in the maximum value achieved; uniformity from cylinder to cylinder and, in this example, comparison with a like unit.



For the two units being analyzed, it was noted that the maximum pressure rise rates on unit 2 were consistently less than on unit 1. This means that the heat release rate was lower and/or that ignition timing was later. It was suspected that unit 2 was running slightly lean, even though instrumentation in place indicated the same air manifold pressures.

The air manifold pressure was lowered on unit 2 and the fuel consumption dropped by 2%. Ignition timing was advanced by one degree, reducing the fuel consumption by 0.5%. The cost saving resulting from optimizing these operational parameters was $113.00 per day.

Measuring the economic impact of this type of activity is important because:
a) it helps the analyst/technician prioritize his own activity
b) properly captured and reported, it helps justify the analysis program.

5. Economic impact of empirical performance tests

Performance testing of compressors, either centrifugal or reciprocating, is a special test sequence from which baseline performance characteristics are generated. Results can be presented in the form of empirical equations and/or performance curves. The characteristics generated include power, throughput and efficiency all expressed as functions of suction pressure, discharge pressure, suction temperature, speed and gas properties. Additionally, results show operating limits such as rod load limit for reciprocating compressors and surge limit for centrifugal compressors.

Test results are used for the following purposes:

- Daily station operations to determine the first unit on and last unit on
- Gas control to determine the best possible method to move gas across the system
- System planning to complete increases in capacity utilizing existing horsepower effectively
- Targeting the best and worst units on the system to improve individual performance
- Deviation from the tested baseline to alarm for performance problems
- Basis for accurate algorithms for engine control PLC

Existing performance data is often unreliable; errors can be as great as 10-20%. This occurs because of the use of theoretical curves or generic curves for a type of compressor. Even where test based curves are provided, they generally do not reflect the operating characteristics as installed in this location. In addition, there have often been changes made over the years without new performance baselines being generated.

As a result, the unit can be overloaded or the capacity can be under utilized and/or safe operating ranges can be exceeded. For example, surge limits in centrifugal compressors tend to be conservative, resulting in unnecessary amounts of recycle and loss of efficiency.

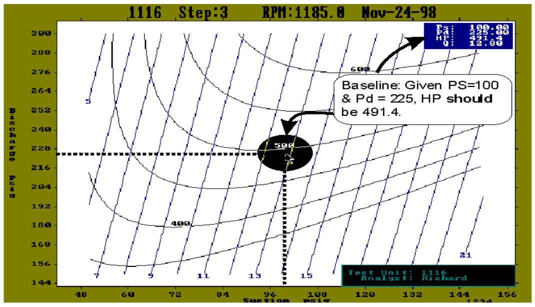
The economic impact of accurate performance data can be very large. To illustrate, suppose we have a centrifugal compressor operating such that, on average, we recycle 1% more flow than necessary. Let us assume this is a 10,000 HP unit with a BSFC of 10,000 BTU/HP-hr. Then since we are wasting 1% of the power and, therefore, of the fuel, we can calculate the cost of the wasted fuel. Suppose fuel costs $2 per MCF. If the fuel has a lower heating value of 1000 BTU/ft**3, then the cost of wasted fuel, per year is:

Excess cost = (10000*10000 /1000) * 1/1000 * $2. *8000 *0.01 = $16,000 per year

Alternatively, consider the economic impact of under utilization of capacity. Suppose we have a unit capable of moving 100 MMSCFD, but which is operating 1% below its capability. If the value of compressing gas is $.50/MSCF (an arbitrary but representative value), then the opportunity cost would be:

Opportunity cost = (100 / 24) *1000 *0.01 * 0.50 * 8000 = $167,000 per year

Excess costs due to unit overloading (arising from loss of availability and increased maintenance costs) can also be very significant.



Baseline: Given PS=100 & Pd = 225, HP **should** be 491.4.

Today's Reading
(from analyzer)

Actual	530
Baseline	491
Deviation	39
% Dev	8

Empirical performance tests provide the best base lines for ongoing performance monitoring. Here, the actual HP exceeds the baseline by over 8% for the current operating point. This indicates performance and/or mechanical degradation requiring investigation, and likely, correction.

6. Dynamic Pressure Drop and Instantaneous Flow

Two 2 stage 13000 HP 327 RPM separable compressors operating in hydrogen services were experiencing rod loads above the allowable limit on first stage under certain operating conditions, thus limiting operation. Field measurements determined that the excessive rod loads were due to a large interstage pressure drop. This behavior not only had cost implications for the production, but also implied excess electrical cost due to the large pressure drop.

Field analysis and computer modelling determined that the problem was caused by a dynamic pressure drop effect. As the pressure fluctuates in a reciprocating compressor piping system, the flow velocity of the gas also fluctuates. If the instantaneous or dynamic velocity fluctuations are significant, the pressure drop through system components such as choke tubes, orifice plates and coolers can be significantly higher than what would be caused by the mean or steady state flow alone.

As is common practice, orifice plates had been added at the bottle to cylinder flange connection to control pulsations. If these orifice plates are sized based on mean flow only, as would appear to be the case here, the actual pressure drop can be much larger than expected. The peak instantaneous flow during the valve open period can be much larger than the average flow. These dynamic flow effects can not only increase the system pressure drop, and hence operating cost, but in extreme cases can limit the performance of the compressor.

In this case, the pressure drop through the cylinder nozzle orifice based on mean flow was calculated to be 1.2 psi, while the pressure drop through the orifice including the instantaneous flow effects was calculated to be 23 psi. A huge difference.

The same considerations apply to choke tube entrance and exit losses. In this case, computer modelling indicated large volume velocities occurring at the entrance of the choke tube in the first stage discharge bottles. The pressure drop through the choke tube due to mean flow was calculated to be 7.1 psi. The total pressure drop through the choke tube, including the effects of the high volume velocities at the entrance to the choke tube, was calculated to be in the range of 25 psi. This agreed with the pressure drop measured in the field.

At the then current operating conditions, horsepower loss due to mean flow was 83 HP and due to total flow was 482 HP. Correction was achieved by increasing the size of the cylinder nozzle orifice and moving the choke tube. These changes greatly reduced the interstage pressure drop but maintained adequate pulsation and vibration control.

At an electricity cost of $0.05 per KWH, the annual saving in energy cost was well over $100,000. But even more significantly, the compressors could be safely run at maximum throughput.

The table below summarizes a number of economic measures and calculations for engines and compressors.

Economic Measure	Calculation method
compressor suction and/or discharge losses: • due to pressure drop • due to pulsation • total	wasted HP from P-V curves; then use equation 1 on page 3
compressor HP/MM increase from baseline	wasted HP = HP/MM deviation * thruput rate
recirculating gas due to leaking rings or valves	wasted HP = HP/MM * capacity loss Capacity loss estimated as ½ of deviation in flow balance
deviation in fuel consumption	use equation 3 on page 3
dead power cylinder:	wasted HP = 1/(number of cylinders - 1) * total BHP
misfiring cylinder:	wasted HP = MFR/(number of cylinders - MFR) * total BHP where MFR = misfire ratio, % misfires/100
system pressure drop	excess BHP/MM = Zs * Ts * k/(11.67*Me*(k-1)) *(R2**(k-1)/k) - R1**(k-1)/k) where Zs = compressibility at suction Ts = suction temperature k = ratio of specific heats Me = mechanical efficiency R1 = compression ratio at reference condition R2 = compression ratio with increased pressure drop wasted HP = excess BHP/MM * thruput (MMSCFD)
leaking bypass valve	wasted HP = HP/MM * capacity loss See P4.
cost of suction pressure control	same calculation as system pressure drop
engine misadjustments, including ignition timing, cam timing, air/fuel ratio	determine impact on BSFC; then use equation 3 on page 3
air inlet restriction; increased exhaust back pressure: treat as increased pumping loss	wasted HP = PLAN/33000 where P = amount of pressure restriction in psi
turbocharger degradation	wasted HP = PLAN/33000 where P is increase in exhaust back pressure due to degradation

Table 1 Specific Economic Measures

Risk Driven Decisions

For situations in which mechanical degradation has been identified, we approach an economically driven decision differently. In these cases there is generally no current economic impact; but there is a potential future impact. For example, a degrading camshaft gear drive may have no significant performance penalty now. But if it fails completely, there will be a cost, possibly large.

For our purposes, risk is formally defined as the product of the consequences of failure, possibly in dollar terms, and the probability of a failure. Thus, risk is the statistically likely cost of the problem.

RISK = CONSEQUENCES OF FAILURE * PROBABILITY OF FAILURE

Consequences

Economic consequences of a failure include cost to repair the failed parts, cost to repair any secondary damage that could occur and the cost of lost production. Other possible consequences involve safety and environmental damage.

It is difficult to put an accurate cost an any given failure mode, since the actual failure mechanism could vary widely; for example, lots of secondary damage or none; lots of down time waiting for maintenance resources or very little. For current purposes, it is proposed to rate consequences in qualitative terms: insignificant, marginal, critical or catastrophic.

In practice we would try to establish some guidelines for each category. For example, we could decide that any failure where the likely total of all costs is less than $1000 will be classified as "insignificant".

Probability

For the equipment analyst, the probability of experiencing a specified failure must be evaluated against some time frame (since everything fails eventually). The question might be something like: "What is the probability that the turbocharger will fail before the next inspection one month from now?"

Quantifying probability of any failure will be impractical, since we would have to research failure statistics, if they were available, which they probably are not. Again we can use a qualitative judgment approach: unlikely, possible, likely or certain.

Note that, more formally, risk should be calculated as the sum of various scenario costs. That is, each potential failure has a number of possible scenarios, each of which has certain consequences and some associated probability. The more valid risk estimate is made up of the sum of each of these scenario risks. But this level of analysis is not practical for the purposes of the machinery analyst.

Risk Matrix
A risk rating can be achieved by using the matrix below, utilizing the classification system for probability and for consequences discussed above. This suggests that there are 16 different levels of risk. However, this can be simplified to five priority levels as indicted by the numbers 1 to 5 shown. The level of risk then has a maintenance priority attached.

		Consequences of Failure			
		Catastrophic	**Serious**	**Marginal**	**Insignificant**
Probability of Failure	**Certain**	**1** (C,C)	**1** (C,S)	**2** (C,M)	**3** (C,I)
	Likely	**1** (L,C)	**2** (L,S)	**3** (L,M)	**4** (L,I)
	Possible	**2** (P,C)	**3** (P,S)	**4** (P,M)	**5** **(P,I)**
	Unlikely	**3** (U,C)	**4** (U,S)	**5** **(U,M)**	**5** **(U,I)**

Maintenance Priorities:

1. Take **immediate** action
2. Perform action as soon as possible
3. Take action at next available opportunity
4. Monitor only
5. No action required

This matrix is used to assess the risk of component failure and the consequence of such failure based on its “as found” condition (performance) at the time of the inspection. The assessed risk level code is then shown with each specific report recommendation.

Example: A burned exhaust valve has a high risk of breaking off at the stem and possibly causing a complete engine failure. The assessed risk code could be: “(L,C)” or “Likely-Catastrophic”. The maintenance priority would then be a 1, calling for immediate replacement of this cylinder head.

Each location in the matrix has a maintenance priority from 1-5 in it. These numbers should be used to aid in scheduling of the report recommendations into your regular maintenance program. The component condition, the possibility of the failure and the consequence of such failure should be the factors when determining the risk level i.e. a need for action.

Example of a typical decision making situation

As part of a routine predictive maintenance program, you detect signs of a failing bearing in a 900 RPM induced draft fan. During the course of five days, the vibration amplitude at a key bearing fault frequency more than doubled. The fan is essential for production in a chemical plant. The cost of lost production is around $250k per day.

Where would you place this situation on the risk chart?

This situation was detected late on a Friday afternoon. It was decided that a mechanic should be paid overtime to replace the bearing immediately rather than wait until regular time Monday morning. How would you make the case to the plant manager that this was the best economic decision?

This incident actually occurred during the startup of a predictive maintenance program. How would you use it to provide cost/benefit justification?

Risk ranking exercise

Rank the following items from one to four, with one being the highest priority, given the information shown.

Case Description	Rank
Discharge valve leak on second stage of a three stage field compressor	
Crosshead knock in unspared plant compressor	
High vibration in a pump, where we have spare units	
High flow past an exhaust valve during low pressure flow testing of power cylinders on engine driving a field compressor	

Complete the ranking a second time. Include the knowledge that the crosshead knock has been present for two years.

Case Description	Rank
Discharge valve leak on second stage of a three stage field compressor	
Crosshead knock in unspared plant compressor has been present for two years	
High vibration in a pump, where we have spare units	
High flow past an exhaust valve during low pressure flow testing of power cylinders on engine driving a field compressor	

Complete the ranking a third time, given the additional information that the field compressor is at the rod load limit and has a history of failures.

Case Description	Rank
Discharge valve leak on second stage of a three stage field compressor that has a history of rod failures and is at rod load limit	
Crosshead knock in unspared plant compressor has been present for two years	
High vibration in a pump, where we have spare units	
High flow past an exhaust valve during low pressure flow testing of power cylinders on engine driving a field compressor	

Most people change their rankings when the additional information is available. Typically, the first ranking places the crosshead knock first and the spared pump vibration last due to consequences. However, once you know the crosshead knock has been present for two years, its likelihood of immediate failure is much less, so other needs take priority. Similarly, when you know that the field compressor has a history of rod failures, a valve leak, which could change the rod loading on the compressor, becomes much more important.

Thinking in terms of risk (consequences * probability), consider why you arrived at your initial ranking. Now consider what changed (consequences or probability) to cause you to change the rankings.

Cost Benefit Analysis

When an opportunity for economic improvement has been identified, it is still necessary to evaluate whether the improvement is attractive from an investment perspective. Changes required to achieve economic improvement will generally require a significant expenditure. The benefits expected from an upgrade project must be compared with the costs. The benefit from improved performance or decrease in risk is determined from the technical data acquired in analysis programs. The costs for a project must be determined separately.

These costs and improved revenues do not occur at the same point in time, so an accounting method is often used to bring the dollars to the same time for comparison; this is called the net present value of a project. A simpler method of assessing the attractiveness of a proposed project is to calculate a payback period in months or years. Subsequently, the actual costs and benefits should be tracked and compared to the predictions. This will assure the economic impact of the modification is meeting expectations.

Benefits

The benefits associated with a proposed action or project should be directly provided by or derived from technical data produced by the machinery analysis program. Comparing the estimate with actual benefits after completion permits a better future estimate.

Increased Production

A production increase is possible by either reduced downtime or increased capacity.

Decreased Operating and Maintenance Costs

Completing the scheduled tasks in a shorter period of time and optimizing the schedule interval can reduce maintenance costs. Operating costs can be reduced with improvements in efficiency.

Reduced Risk

Improvements could pursue either a reduction in the probability of failure or a decrease in the consequences of failure. The expected decrease in risk, expressed in dollar terms, represents the project benefit.

Costs

The costs associated with a project should be estimated. Initially, orders of magnitude can be used to perform a quick analysis. If encouraging, better cost estimates should be derived. Comparing the estimate with actual costs after completion will permit a better future estimate.

Lost Production due to Shutdown

If the project requires a shutdown that can not be scheduled with other projects, then the cost for lost production should be included in the cost to complete the project. Alternately, there could be a cost to rent temporary replacement capacity.

Labor Charges

The cost of labor including both contract and internal must be included in the estimate. Be sure to include the appropriate loading factors for the internal costs. These might include such items as administrative loading, benefits loading, and engineering loading. The labor costs vary widely depending on the organization.

Parts and Materials Cost

This cost category consists of determining the parts that require replacement, the consumables used, and the new materials or components that are installed to complete a project.

Net Present Value Calculation

The benefits and costs will occur at different points in time; the expenditure occurs now, the benefits accrue over years. This should be taken into account. One methodology used is known as a net present value analysis. It will determine the present value of future savings or earnings. A simpler and more obvious assessment is to calculate pay back period. The project cost is divided by the monthly increase in revenue or decrease in cost to determine how many months elapse to reach break even. Most companies have a threshold which must be met for a project to be considered.

Cost/Benefit Examples

Example #1

A writer in the April 1997 issue of Plant Services magazine describing the application of pumps under intermittent operation said that turning pumps on and off on a regular basis will prove fatal to any pump. His view is that the design should be modified (perhaps with a recirculation loop) to run the pump continuously. Is this a good decision?

Even if the writer is correct by describing on and off service as fatal to a pump, his solution is not guaranteed to be the best from an economic perspective. His recommendation will presumably reduce maintenance costs. There could be a benefit of increased throughput and revenue if these pumps are critical to production.

On the other hand, continuous operation would increase energy cost. In most cases energy costs are the largest expense over the life of the machinery. Another factor is the capital cost of making the necessary changes. The best alternative will increase revenues and decrease costs to provide the highest return on machinery investment.

Example #2

A gas production operation has three large integral units, factory rated at 330 RPM. The owner is now operating these units at 350 RPM. Was this a good decision? What must be considered?

The major considerations are:

- Potential to increase throughput and revenue by approximately 6%.
- Possible decrease in availability
- Possible increase in maintenance cost
- Project cost to allow the units to operate at the increased speed

If the actual increase in revenue exceeds the increase in costs providing an appropriate return on machinery investment, then this was a good decision.

Example #3

A location has multiple crankcase explosions in one year after over 20 years of operation without a single such failure. The system consists of multiple locations with similar historical operation but only a few are exhibiting the increase in explosions. Should the increase in explosions be included in the budgeting for next year’s maintenance costs at the remaining locations? Can the reduced potential for explosion be used as a benefit of the appropriate maintenance or operational changes to resolve the problem?

Conclusion

Much progress has been made in the capabilities of analysis equipment to provide meaningful technical measures of performance and condition. These measures can be utilized as a foundation to complete an economic justification for maintenance or for performance improvement. In some way there must be a conversion of the technical terms to dollar implications.

This short course has illustrated that the transformation of technical measures into money measures is not “rocket science”. A major problem is the amount of data and the number of economic measures that can and should be developed. The analysts, technicians and engineers involved need some tools that help automate the process.

Handling of mechanical failures and reliability issues can be improved by adopting risk management methodologies. In this way, these situations are also approached from an economic perspective.

Key issues for a more complete economically driven approach to machinery operations, maintenance and engineering:

- evolution of corporate culture
- acceptance and adoption of the economic analysis methods across the organization
- increasingly automated tools for acquiring valid economic measures
- dissemination of economic measures to all stakeholders in the organization
- development of accounting methodologies to determine impact and provide feedback

These developments will enable organizations to determine the best return on incremental investments in existing machinery with relative ease.