PDHonline Course M107 (4 PDH)

Assessing Risk Factors in Machinery

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Course Content

Introduction

Power plants, oil refineries, factories, and other manufacturing and industrial facilities utilize a variety of machines. It is important to identify high risk machines so those risks can be mitigated.

Those risks can be to personnel, to the environment, or to the successful operation of the business.

Assessing risk is an important part of a plant engineer or maintenance engineer's responsibilities. Higher risk assets demand more rigorous attention to operations and maintenance.

Risks can be safety risks to plant personnel and neighboring communities, risk of damaging the environment, risk of failure to perform to the level required to meet business demands, and the risks of excessive costs to operate and maintain the asset.

If risks are not identified and assessed properly the resulting costs can be excessive.

If risk is underestimated, a failed machine can cause loss of life, release of toxins to the environment, or a loss of production that could mean financial ruin.

If the risk is overestimated, unneeded spare machines may be purchased, maintenance costs may be excessive due to unnecessary monitoring, repair or preventive maintenance, or perhaps the project will not even be started due to the anticipated liabilities and the cost of insurance.

Effective risk management is important to obtaining reasonably priced insurance and in some cases the availability of insurance.

The risk of each machine in a machine train (system) is assessed separately but the overall risk of the system is the risk of the highest risk machine in the train. For example, a train might consist of a motor, gearbox, and compressor. If any of these machines in the train fails the entire train is considered failed. If the risk of the motor and compressor is low but the risk of the gearbox is high, the entire train risk is high. The mitigation strategies for each machine in a train may be different.

Overall risk evaluation includes not only the risk associated with what may happen but also the likelihood of that event happening. The likelihood or frequency of failure is best based on operating history in the application.

Risk assessment can be applied to plants in design, plants prior to start up, and plants that are operational. Plants in operation that have documented machine histories can provide accurate information on the frequency of failure. Where history is not documented or in the case of new plants, frequency of failure must be based on manufacturer's and industry experience for similar machines in similar applications.

If the machines are already in operation, and are identified as high risk, it is imperative that the current condition of the machine be assessed. This assessment could include external inspection, internal inspection, thermal scanning, lubrication sampling, ultrasonic thickness measurement, vibration analysis, and other non destructive testing.

In the first course, *Identifying Risk Factors In Machinery,* you learned to identify the basic information required to assess basic risk factors in the categories of:

General Reliability Factors - Minor Problems, Cycling, Service Difficulty, Remote Location, Life Risk Evaluation, Maintainability, Major Failures

Machine Design Factors - Power Factor, Energy Factor, Design Experience Factor, Machine Motion, Machine Speed, Acceleration, Pressure, Lubrication, Resonances.

Plant Production – Sensitivity Factors - Spared Machines, Throughput Effected, Loss of Production, Effect on Product Quality, Start Up Effects, Machine Output Capability

Life Cycle Costs - Purchase or Replacement Cost, O&M Costs, Energy Costs

Environmental Impact – Releases, Spills, Radiation, Thermal, Noise, Smells, Appearance, Long Term

Safety Hazards - On-Site, Off-Site

In this course you will learn ways to assign a risk level to each factor so the overall risk can be assessed.

Additional factors will be offered for consideration. Control systems will be briefly discussed.

We will also weaknesses in the method presented.

We will examine risk multipliers and weighting risk factors and categories.

Overall Risk Evaluation

The overall risk of a machine train (system) is measured by the consequences of failure of the machine to meet requirements and the likelihood that the failure will occur.

Obviously a machine failure that causes plant shutdown that occurs often is a higher risk than a machine failure that causes a small loss of product that rarely occurs.

Risk evaluators often use a risk matrix that has consequence on one axis and frequency on the other.

If your customer has an existing risk matrix, it's best to follow their predefined levels and frequencies.

Matrices often are too simple or too complicated. In general a matrix smaller than 3X3 or larger than 4X4 should be avoided.

The smaller 3X3 gives nine possible risk levels while the 4X4 yields sixteen.

Less than nine usually causes too many machines to be designated high risk and low risk with little in between while more than sixteen usually creates so many possibilities that assessment becomes complicated and time consuming.

This 4X4 has increasing consequence from bottom to top and increasing frequency from left to right.

Catastrophic	Some Risk	Some Risk	High Risk	Extreme Risk
Moderate	Some Risk	Some Risk	High Risk	High Risk
Little	No Risk	Some Risk	Some Risk	Some Risk
None	No Risk	No Risk	No Risk	No Risk
	Rare	**Unlikely**	**Possible**	**Likely**

Traditionally machines have been divided into three basic categories regarding risk; Critical (sometimes called Vital), Essential, and Auxiliary (sometimes called Balance of Plant).

For the matrix shown above, a Critical (Vital) machine might be any machine that falls into any one of the upper right corner boxes (Catastrophic-Likely, Catastrophic-Possible, or Moderate-Likely). This criteria is judgmental, may be set by the client, but should be used consistently for machines at the same plant site.

Some plants may choose to only consider costs. This doesn't preclude considering safety and environmental factors. It does require associating costs with each consequence. For example, rather than saying a safety incident causing an OSHA recordable injury is automatically classified as a say moderate consequence, the cost of such an injury must be estimated. That cost is then used to determine cost consequences. A cost based matrix could look like:

> $ 50K	Some Risk	Risk	Risk	Extreme Risk
$ 10K to $ 50K	Some Risk	Some Risk	Risk	Risk
1K to 9.99K	Some Risk	Some Risk	Risk	Risk
< $ 1K	No Risk	No Risk	Some Risk	Some Risk
	Rare	**Unlikely**	**Possible**	**Likely**

There are matrices that attempt to look at the four major areas of risk at the same time.

Impact on Safety and Environment

	Very High	**High**	**Moderate**	**Low**	
Non Reliable	Extreme Risk	Extreme Risk	Extreme Risk	Extreme Risk	**Very High Production Loss**
Just Reliable	Extreme Risk	Extreme Risk	High Risk	High Risk	**High Production Loss**
Reliable	Extreme Risk	High Risk	High Risk	Moderate Risk	**Moderate Production Loss**
Reliable & Self Diagnostic	Extreme Risk	High Risk	Moderate Risk	Low Risk	**Low Production Loss**
	Very High	**High**	**Moderate**	**Low**	

Cost of Repairs

This approach ignores frequency. The result is often too many assets defined as high or extreme risk. However, this matrix will be modified into a useful tool in the next course that addresses risk mitigation.

The key point is that the matrix you use for assessing risk has to have a basis in measurements that can be defined such as the consequence of unreliability and the likely frequency of that consequence happening. However, the resulting assessment (no risk, risk, high risk, etc.) has some level of subjectivity based on your experience and your client.

For example, a client maintenance professional might place more importance on reliability while a client financial manager may place all the importance on yearly costs. It is vital that you “align” the matrix to meet your client’s definition(s).

For this course we will assume four levels of machine risk. A Level 1 machine is little risk while a Level 4 is high risk.

Level 4 - A **mission critical** machine. Loss in performance and/or low availability has a significant impact on production, usually causes plant shutdown. Could present an environmental or safety hazard. Generally these machines will also be expensive to maintain or replace.

Level 3 – A **critical** machine. Loss in performance and/or low availability has an impact on production. Generally these machines will also be expensive to maintain or replace.

Level 2 – A **moderate risk** machine, often spared. Loss in performance and/or low availability has little or no immediate impact on production. These machines individually are not expensive to maintain or replace but as a group represent a significant cost.

Level 1 – A **low risk** machine, often spared, often not run continuously. Loss in performance and/or low availability has no impact on production. Maintenance costs are generally low.

Using these exact definitions is not mandatory, they will vary from client to client. It is critical that there are definitions or it will be difficult to get agreement when evaluating machine levels.

Each factor identified in the basic course will be defined further to have four criteria from lower to higher risk. Of course, if you decide on three levels of risk then you would define three criteria.

This is more easily seen by reviewing the survey factors in the next sections.

As you have learned in the earlier course, any machine that has the likely potential of shutting the plant down, or causing serious environmental or safety problems is automatically considered high risk. So why answer all the questions for those machines you may ask?

Assessing all the factors will help determine the reasons why a machine is likely to fail and what the specific consequence could be. That information will help when determining a mitigation plan.

You have most likely noted that the values produced are “soft” subjective values. It is always better to have true quantitative ”hard” facts. However, when looking at hundreds or thousands of assets, a detailed quantitative basis would be cost prohibitive.

It is reasonable to allow some level of subjectivity to establish which assets present the most risk.

These high risk assets can then be analyzed in more detail using probability based on historical data, fault tree analysis, and Failure Mode Effect Analysis (FMEA). Part of the mitigation process, indeed part of any reliability centered maintenance system, should include Root Cause Failure Analysis (RCFA).

These processes will yield a quantitative assessment.

The more subjective initial approach offered here is to help you identify and concentrate on the high risk assets.

Basic Machinery Information

As you prepare to evaluate factors you should also obtain basic information on the machine train (system).

A machine train always has a driving machine (source of power) and a driven machine (machine with function) such as a motor and pump. Sometimes there is a transmission or gearbox between to change speed or motion or to allow one or more drivers to power one or more driven machines.

It is important that you collect the “nameplate” information and determine the nomenclature used to designate the machine train in this application.

A simplified form below provides some idea of the basic information required.

It is also useful to provide a sketch of the machine train diagram for machines with multiple drivers and driven machines.

BASIC MACHINE SYSTEM INFORMATION

Client ___________________________________

Site/Location _______________________________

Machine Train(system) _______________________________

Machine Designation(s) _______________________

Item	**Driving Machine**	**Transmission/Gearbox**	**Driven Machine**
Manufacturer			
Model			
Machine Type			
Rated Output			
Normal Output			
Rated Speed			
Line Speed			
Bearing Type			
Seal Type			
Coupling Type			
Foundation Type			

Manufacturer – Original Equipment Manufacturer of machine
Model – The OEM model designation of the machine
Machine Type – Steam Turbine, Motor, Gas Turbine, Compressor, Pump, etc.
Rated Output or Load – The OEM's rated capability, Driving machine HP or KW, driven in KW, flow at pressure, etc.
Normal Required Output or Load – The actual value normally required
Rated Speed (RPM) – The OEM maximum rated speed
Line Speed (feet/minute or meters/minute) for conveyors or mills if applicable
Bearing Type – SFCB, Fluid Film plain, Tilt Pad, Rolling Element, etc.
Seal Type – Carbon Ring, Packing, Dry Gas, Labyrinth, etc.
Coupling Type – Diaphragm, Gear, Universal Joint, Plain Flange, etc.
Foundation Type – Reinforced Concrete, Steel Frame Skid, Skid on Concrete, etc.

COMMENTS:

GENERAL RELIABILITY FACTORS

Factors to evaluate the reliability of the machine train.

Minor Problems – The frequency of minor problems. Higher frequency means higher risk. Rate the frequency of minor problems (minor parts breakage or wear, need for adjustment) that can be easily rectified by operations without special tools or spare parts or by a technician, generally with simple tools and parts on hand:

> **1 High –** If minor problems rarely occur or they
>
> **2 Good –** If minor problems are occasional
>
> **3 Fair –** If minor problems are reasonably probable (expected)
>
> **4 Poor** – If minor problems are frequent.

Cycling – Machines that are frequently cycled are more likely to have problems than those that operate at a single operating point. Rate cycling of the machine load, speed, or process based on the following:

> **1 Never –** The machine runs for a long period of time under relatively constant conditions. The plant operation is continuous and the machine is base loaded.
>
> **2 Some –** The machine runs for long periods of time but is subject to some fluctuation of load, speed, or process (pressure, flow, density, etc.)
>
> **3 Often –** The machine is started often or is subject to frequent fluctuation of load, speed, or process (pressure, flow, density, etc.)
>
> **4 Always -** The machine is started often and is subject to frequent fluctuation of load, speed, or process (pressure, flow, density, etc.)

Service Difficulty – A factor to adjust for harsh conditions. Rate the difficulty of service based on the following criteria:

> **1 None –** The machine is rarely subjected to corrosive or erosive processes, dust or moisture, shock loading, or environmental extremes.
>
> **2 Low –** The machine is subjected to mildly corrosive or erosive processes, dust or moisture, or minor shock loading.
>
> **3 Moderate** - The machine is subjected to corrosive or erosive processes, dust or moisture, shock loading, or environmental extremes.

4 High - The machine is subjected to highly corrosive or erosive processes, or high shock loading.

Remote Location – Remote machines are higher risk since it's more difficult to make decisions based on limited information. Rate the impact of machinery location from the decision making process as:

1 No – The machine is closely located.

2 Yes - - The machine is some distance away but information is available in a manned control room.

3 Yes – The machine is remotely located from the decision making process but the site is manned and some information is available at a command center.

4 Yes + - The machine is remotely located at an unmanned site with little or no information available at a command center.

Life Risk Evaluation – Brand new machines and older machines nearing the end of life are higher risk.

1 Low – Machine in mid life per manufacturer's specifications that has been maintained

2 Moderate – Machine in mid life with minimum or unknown maintenance

3 Concern – Machine that is brand new or near the end of life based on manufacturer's specifications

4 High – Machine that is past life

Maintainability – Rates the degree of difficulty required to maintain the machine based on our experience and the experience of the customer. Higher cost is associated with machines that are more difficult to maintain. Rate the maintainability as:

1 None – if the machine is run to destruction and replaced

2 Easy – if the machine can be easily restored to as new condition generally in situ, with spare parts on hand, by locally available technicians

3 Average – if the machine sometimes requires shop work in addition to in situ repairs, some spare parts must be ordered, and specialists are needed in addition to local technicians

4 Difficult - if specialized shop work or OEM assistance is required and spare parts are long lead time.

Major Failures – Major failures are expensive both in terms of maintenance costs and lost production. Rate the frequency of failure requiring significant down time or repair costs.

1 Rare – Can't remember one.

2 Some – We had one once.

3 Often – We have them often enough to budget for them.

4 Frequent – We have them so often they are embarrassing but our crew is expert at repair.

Associated Machinery – Failures of one machine system can cause loss of associated machinery systems. For responses of 3 or 4 please identify the other system(s).

1 Never - Causes loss of another machinery system.

2 Rarely - Causes loss of another machinery system.

3 Sometimes - Causes loss of another machinery system.

4 Always - Causes loss of another machinery system.

MACHINE DESIGN FACTORS

Categories based on general machine characteristics. In general machines that are larger, run faster, and change motion are higher risk.

Power Factor – Power is an indication of the size, complexity, and cost of a machine, all effect risk. What is the power output range of the machine?

1 Low – Less than 500 HP (370 kW)

2 Moderate – Between 500 HP (370 KW) and 4000 HP (2980 kW)

3 High – Between 4000 HP (2980 kW) and 25,000 HP (18,640 kW)

4 Very High – Above 25,000 HP (18,640 kW)

Energy Factor – How much potential and kinetic energy is stored in the machine during operation? More energy means more risk. Identify the amount of stored energy in the machine

1 Low – Low speed, low mass or very low speed, any mass

2 Moderate – Average speed, average mass

3 High – High speed, low or average mass or high mass and average speed

4 Very High – High speed and mass

Design Experience Factor – Newer designs or no experience means more risk. Is this machine an experiment or a high proven design?

1 Proven design – Many of them around for a long time

2 Some Experience – We have good experience on this machine design

3 Modified Design – Recent modifications based on new design.

4 New – Prototype or first one we've seen.

Machine Motion – Multiple direction motion raises risk Reciprocating machines are generally more risky than rotary machines. Rate the motion.

1 if Rotation in one direction, or linear motion no shock loading

2 if Rotation in one direction, then reversing, or stopping then in the same direction, or back and forth linear motion no shock loading

3 if Reciprocating motion, load on one stroke or linear motion with shock loads

4 if Reciprocating motion, load on both strokes, or back and forth linear motion with shock loading

Machine Speed – In general, higher speeds mean higher risks.

1 if **1 to 2,000 RPM**

2 if **2,000 to 5,000 RPM**

3 if **5,000 to 10,000 RPM**

4 if **10,000 RPM or higher**

Acceleration – Higher acceleration means higher risk.

1 Low – Machine gradually brought up to speed

2 Moderate – Turbines, and turbine driven machines with no gearing

3 High – Motors, turbine driven machines with gearing or motor driven machine without gearing

4 Very High – Motor driven machines with gearing

Pressure – Higher pressure means more stress and sealing problems.

1 Low – Machine operates at no more than 10 times ambient pressure

2 Moderate - Machine operates at no more than 20 times ambient pressure

3 High - Machine operates at no more than 30 times ambient pressure

4 Very High - Machine operates at more than 30 times ambient pressure

Lubrication – Reliable lubrication reduces risk. Please note that a lubrication management system includes proper selection, application, maintenance, testing of lubricants, and trending of lubricant condition. A management system must include an individual accountable for machine lubrication.

1 if If there is a lubrication management system in place and functioning and: lube oil is cooled and contaminants are controlled or grease is sealed in the bearings or dispensed from a central lube system.

2 if If there is a lubrication management system in place and functioning and lubricants are sampled, analyzed, and trended for condition and planned maintenance.

3 if A system is in place but there is no one individual accountable for machine lubrication.

4 if The machine is not part of a lubrication survey.

Resonances – If known are a useful tool in assessing risk. Please note that “critical speeds” published by machinery OEM’s are often based on rotor alone, only their machine in the train rather than the entire train as a system, and on empty (no fluid or gas) response. Operation above a resonance means that the machine must go through resonance during start up and shutdown which adds risk. Operation at half of second resonance could cause excessive 2X if a crack occurs which will accelerate crack growth. Operation slightly above half of the second will cause excessive 2X if a crack occurs as the stiffness decreases and the second resonance drops to twice operating speed.

1 if The machines operates below first resonance and at less than half of second resonance.

2 if The machines operates below first resonance but at or slightly above than half of second resonance.

3 if If unknown or the machine operates above first resonance but below second.

4 if The machine operates above second resonance.

PLANT PRODUCTION - SENSITIVITY FACTORS

Categories that have an effect on the plant or process.

Spared Machines – Identify the availability of spare machines on the following criteria:

> **1 Multiple –** There are multiple spares on standby immediately available for service.
>
> **2 Yes –** A spare machine is on standby immediately available for service.
>
> **3 Stored –** A spare is available but requires some reasonable period of time to be made available.
>
> **4 No –** There is no spare or the spare requires an excessive period of time before it's available. The spare might be in storage.

Throughput Effected – The machine is higher risk if it can affect the plant production rate. While it might not cause a loss of production it could affect the plant's capability to produce surplus. Rate the effect of machine faults or low performance on process output.

> **1 No –** The machine cannot affect throughput.
>
> **2 Minor –** The machine has some minor and temporary effect on throughput.
>
> **3 Considerable -** The machine has a considerable or long lived effect on throughput.
>
> **4 Catastrophic –** The machine can cause loss in production if faulty or operating below expected levels of performance.

Loss of Production – The machine's poor performance or minor faults may not affect production rate but a machine shutdown could cause loss of production. Rate the effect of machine failure or other unavailability on production loss.

> **1 No** – The machine cannot effect production.
>
> **2 Minor –** A minor temporary loss will occur.
>
> **3 Considerable -** A considerable amount of product will be lost and cannot be recovered.
>
> **4 Catastrophic –** Can cause plant shutdown.

Effect on Product Quality – Product quality effects can be subtle since we don't often think of the quality of intermediate processes. An example would be an air compressor. Perhaps the pressure and moisture content of the output air affect quality downstream.

Rate the frequency that a machine faults or failure can effect the quality of the product processed by the machine as:

1 No – Product quality is never effected.

2 Some – The product quality is effected by some faults or failure or is effected some what.

3 Often - The product quality is often effected by some faults or failure.

4 Always – Machine faults or failure always affect the product quality.

Start Up Effects – If it takes a long time for a machine or process to stabilize after start up, trips and unscheduled shutdowns make for more risk. Rate the effect of starting up the machine on how long it takes the process to stabilize as follows:

1 Instantly – The start up has no effect on the process or the process stabilizes so rapidly after start up that there is no effect.

2 Rapidly – The process stabilizes rapidly after machine start up.

3 Slowly – It takes a period of time for the process to stabilize, possibly causing some product to be recycled, reprocessed, or rejected.

4 **Very Slowly -** It takes a long period of time for the process to stabilize, causing product to be recycled, reprocessed, or rejected.

Machine Output Capability – This rates the machines capability as a single unit to meet the rate desired. Rate the machine's capability to perform at rate required

1 Excess Capacity – machine has excess capacity

2 Meets Current Need – machine can routinely perform at required level

3 Meets Design – machine performs as designed but that doesn't meet needs

4 Less than Expected – machine doesn't meet design output or needed output

LIFE CYCLE COSTS

Purchase or Replacement Cost of the Machine

1 Low – Less than US $ 5 K

2 Moderate – Between US $ 5K and 10K

3 High – Between US $ 10K and 100 K

4 Very High – Greater than US $ 100 K

O & M Cost – Operations and maintenance costs can be more than 3 to 2o times higher than the purchase price over the life of the machine. Rate the yearly operations (excluding energy costs) and maintenance cost:

1 Low – So low we don't know what they are.

2 Moderate – We track the costs closely and can provide last year's costs. $ _____

3 High - We track the costs closely and can provide last year's costs. $ _____ Replacement is capital budget and is estimated at $ _______.

4 Exec Level – Repairs require executive management approval of expenditures. We track the costs closely and can provide last year's costs. $ _____ . Replacement is capital budget and is estimated at $ _______.

Concern about Energy Costs (Thermal Performance/Efficiency) – Energy costs can be important factor and efficiency may require measurement. Rate your concern about these costs.

1 Little Concern – Energy used and/or costs are low, no performance measurements needed

2 Some Concern – Energy used and/or costs are moderate, occasional performance measurements needed

3 Concern – Energy used and/or costs are important concern, regular performance measurements needed

4 Vital – Energy costs are high, on line performance measurements needed

Environmental Impact

More potential damage to the environment rapidly escalates risk, potential fines, and punitive damages. Rate the effect of machine failure or availability to environmental impact.

1 None – There is no adverse impact on the environment.

2 Low – There is some local impact on the environment that can be resolved on site with no lingering effects.

3 High – There is an impact that requires reporting, requires expensive clean up, or has a long-term effect.

4 Catastrophic – The impact is significant, has adverse public relations effects, and may result in fines.

Safety

If the machine is unavailable can safety be in jeopardy? If the machine fails can it cause injury or death to people inside or outside the plant? Is taking data in close proximity of the machine dangerous? This is a hidden insurance cost.

Rate the effect of the machine's unavailability or failure or operation on personnel safety.

1 No – Machine failure cannot cause injury and unavailability has no effect on safety.

2 Minor – Machine failure can cause minor injuries or its unavailability has a minor effect on safety.

3 Considerable – Machine failure can cause major injuries or death or its unavailability affects a plant safety function (fire, purge, ventilation, etc.) or it is not usually advisable for people to be in close proximity to the machine when it is running. On site hand held data collection requires special safety equipment or procedures.

4 Catastrophic – Machine failure can cause injuries and deaths outside the plant boundaries or it is never advisable for people to be in close proximity to the machine when it is running. On site hand held data collection is not permitted.

CONTROL SYSTEMS

The approach so far has ignored the effect of the machine's control system on the overall assessment of risk.

I have done so for the following reasons:

- Control systems are highly diverse, and due to electronics and computers, changing often.
- Data on controls systems by machine system are often only available for major machines. Machines that are often already designated as "critical" or "high risk".
- Clients often want the control systems evaluated by control systems engineers who commonly address the entire plant rather than individual machines. That is important because overall plant control is much more than the sum of all asset controls.
- There are few "rules of thumb" when it comes to control systems. A complex older pneumatic control system may or may not be more reliable and effective than a state-of-the-art programmable logic controller.

How can we address the issue of controls as it applies to machines?

There are two approaches. First by machine. Here I would recommend basing your survey strictly on documented operations and maintenance history.

The survey question might look like this:

CONTROL SYSTEM

Machine controls have an effect on machine reliability. Machine control problems that create environmental or safety hazards should be addressed under those sections.

> **1 Simple –** There are few documented control system problems such as machine trips, failure to start, unintended cycling. Required maintenance attention is minimal. Preventive and routine maintenance is done by operators or on site maintenance personnel. No adjustment or reprogramming is required.
>
> **2 Basic –** There are some documented control system problems such as machine trips, failure to start, unintended cycling. These problems were quickly resolved by operators or on site maintenance personnel. Preventive and routine maintenance is done by operators or on site maintenance personnel with some specialized training. No adjustment or reprogramming is required.
>
> **3 Advanced/Unknown –** There is no documentation available or this system is a higher order control system with a history of frequent problems. The problems can only be resolved by a few key highly trained maintenance personnel. Preventive and routine

maintenance can only be done by these same key individuals. Adjustment of the system is common and reprogramming is sometimes required.

4 Complex – The system is complex requiring the regular attention of select individuals who have been factory trained. These individuals may not be based on site. They must perform all maintenance. Adjustments are common as are reprogramming and software updates.

A second approach would be to use a multiplier. In this case you would assess the overall controls and use the result to define a multiplying factor to be applied to all the machines.

The same survey question used as a multiplier could look like:

CONTROL SYSTEM

Machine controls have an effect on machine reliability. Machine control problems that create environmental or safety hazards should be addressed under those sections.

Simple – There are few documented control system problems such as machine trips, failure to start, unintended cycling. Required maintenance attention is minimal. Preventive and routine maintenance is done by operators or on site maintenance personnel. No adjustment or reprogramming is required. Use **0.9**

Basic – There are some documented control system problems such as machine trips, failure to start, unintended cycling. These problems were quickly resolved by operators or on site maintenance personnel. Preventive and routine maintenance is done by operators or on site maintenance personnel with some specialized training. No adjustment or reprogramming is required. Use **1.0**

Advanced/Unknown – There is no documentation available or this system is a higher order control system with a history of frequent problems. The problems can only be resolved by a few key highly trained maintenance personnel. Preventive and routine maintenance can only be done by these same key individuals. Adjustment of the system is common and reprogramming is sometimes required. Use **1.1**

Complex – The system is complex requiring the regular attention of select individuals who have been factory trained. These individuals may not be based on site. They must perform all maintenance. Adjustments are common as are reprogramming and software updates. Use **1.2**

In this case the resulting number is a multiplier between 0.9 and 1.2 which can be used to factor all the machines.

There is a separate section below on other multipliers and their use.

OTHER FACTORS

There are other considerations that can be factored in that may fall outside the factors generally associated with the environment and safety.

CORPORATE IMPACT

Sometimes the failure of a machine can cause problems at corporate levels.

Insurance – The failure of machinery systems can cause higher premiums and deductibles and sometimes even the loss of insurance.

1 if There is no effect on insurance if the machine system fails.

2 if Loss of the machinery system can cause higher premiums or deductibles.

3 if Loss of the machine can cause both higher deductibles and premiums.

4 if Loss of the machine can cause the loss of underwriter's insurance

Image – The loss of a machinery system can cause a negative image of the plant or corporation as perceived by the public.

1 if Loss of the machinery system has no effect on image.

2 if Loss of the machinery system has an effect on image but no effect on sales.

3 if Loss of the machinery system effects image and sales.

4 if Loss of the machinery system effects image and could lead to sales boycott.

Regulations – The loss of a machinery system could cause the plant or corporation to be in violation of regulations.

1 if Loss of the machinery system has no effect on compliance with regulations.

2 if Loss of the machinery system has an effect on regulations leading to fines.

3 if Loss of the machinery system has an effect on regulations leading to shutdown.

4 if Loss of the machinery system has an effect on regulations leading to arrest.

MULTIPLIERS

There are additional factors which are sometimes best used to adjust all the machines in the survey. They are used as multipliers. For example, if you determine that the maintenance practices and execution of work are uniformly inadequate, you may want add a level of risk to all the machines in your survey.

Some examples of ways to account for additional general factors are noted for Maintenance Support, Operations Practices, Decision Support Technology, Product Market Conditions, Automated Machinery Protection, and Machinery Information Management.

The number of these factors is almost unlimited. You could include factors for things like Risk Based Inspection Programs, Government Oversight/Inspection, etc.

The key to success is use only those that truly apply and try not to use so many that the results are clouded. Again, this is your opportunity to exercise good engineering and business judgment.

Maintenance Support – Rate the machinery maintenance support capability.

> **Best Practice –** Proactive system (PdM, RCM, TPM, CBM, etc.) supported by enthusiastic well trained professionals using adequate tools. Use **0.8**
>
> **Good –** Proactive and reactive approach attempting to become more proactive supported by trained professionals. Use **0.9**
>
> **Average –** Mostly reactive approach, usually insufficient resources. Use **1.0**
>
> **Inadequate –** Reactive maintenance performed by under trained insufficient resources with little management support. Use **1.2**

Operations Practices – Rate the machinery operations capability.

> **Best Practice –** Well trained dedicated professional operations personnel supported by good control systems attempting to optimize the process. Use **0.8**
>
> **Good –** Dedicated professional operators supported by good control systems. Use **0.9**
>
> **Average –** Operators with multiple tasks including maintenance supported by older control systems. Use **1.0**
>
> **Inadequate –** Operators that lack training supported by over stressed control systems. Use **1.2**

Decision Supporting Technology

Best Practice – Oil analysis, thermography, borescoping, thickness testing, and other technologies are used on a regular basis to support vibration, performance, and process information. Use **0.95**

Some Tools Used – Some support tools used on a regular basis. Use **1.0**

Problem Solving – Tools only used when there is problem. Use **1.0**

None – There is no supporting technology used. Use **1.05**

Product Market Conditions – What is the current state of the market for the plant's products?

Surplus – There is a surplus of product on the market. Use 0**.8**

Average – Plant operation at less than full output always meets demand and allows some product in reserve. Use **0.9**

Good – Plant operation at full output meets demand, no reserve Use **1.0**

Great – Plant operation at full output cannot keep up with demand Use **1.2**

Automated Machinery Protection – Rate the current machinery protection as:

Best Practice – Full compliment of right transducers, properly mounted in the right location, appropriate monitoring, reasonable settings for alert and danger, trip on danger, adequately maintained for all machines in train. Use **0.8**

Minimal - Some of the right transducers, properly mounted in the right location, appropriate monitoring, reasonable settings for alert and danger, may be set to trip on danger, adequately maintained. Use **1.0**

Inadequate – Any combination of wrong transducers, location, mount, monitor, settings, or maintenance. Use **1.1**

None – No machinery protection, either because there are no transducers or data is not collected frequently enough. Use **1.2**

Machinery Information Management – Rate the machinery management tools:

Best Practice – On-line system supported by automated decision support system. Use **0.8**

On-line Diagnostics - Continuous on-line diagnostics software. Use **0.9**

Scanning – Scanning system with diagnostics software. Use **1.0**

Off-Line Diagnostics – Portable "walk around" data collection/analysis or as needed diagnostics. Use **1.1**

None – No system for machinery management. Use **1.2**

Adding Up the Results

Now that we have rated each machine in each factor it is of course necessary to tally the results.

It's recommended that you create a spreadsheet that keeps each category separate. That will allow flexibility when weighing the results. A basic spreadsheet has been provided as part of this course as an example and starting point. (Do not use the sample to generate final results. You must customize the spreadsheet based on your application and your engineering judgement.)

For example, a sample interim result for reliability might look like:

Asset	Minor	Cycling	Service	Remote	Life	Maintain	Failures	Total	Ave	Result
Compressor	4	3	2	2	3	3	3	20	2.86	3
Pump	4	4	3	2	2	2	3	20	2.86	3
Generator	2	2	2	2	2	3	2	15	2.14	2
Crane	3	4	3	3	2	3	2	20	2.86	3
Fan	2	2	3	2	2	3	2	16	2.29	2
Mixer	3	4	3	2	2	3	3	20	2.86	3
Turbine	2	3	2	2	3	2	2	16	2.29	2
Crusher	2	1	2	3	4	4	4	20	2.86	3
Conveyor	1	1	2	2	2	3	2	13	1.86	2
Gear Drive	2	2	2	2	2	3	2	15	2.14	2

The column marked Result is a rounding of the average. You may want to use the raw average score for further processing instead.

So why not average all the factors or at least the category values, round that off and use that result as the final assessment?

Not all categories carry equal weight. As noted previously a machine that is rated a 4 in safety, environment, or production loss is certainly an extreme risk. Therefore any machine assessed a 4 in any of these three critical categories should be assessed as a 4 overall no matter what the arithmetic average is for all factors.

Suppose the machine in question is not a 4 in any of the critical categories, how should the factors be weighed?

This is where you stop being a student and are required to use engineering judgement. There is no correct weighting method or strategy that will fit all possible applications and scenarios.

There are some examples and exercises to help start the judgement process. Please note that real life problems rarely fit a simple course example.

EXAMPLE - UTILITY WATER PLANT IN CONCEPTUAL DESIGN

A process plant is in the conceptual design stage. The area being assessed is the system for providing utility water.

While the plant includes tanks, piping, valves, electrical switch gear, and controls, we will only consider the machines and machinery support equipment. The machines include motor driven pumps, a motor driven air compressor, a motor driven mixer for water softening chemicals, a motor driven exhaust fan, a diesel generator to provide emergency power, and a small hydraulic motor driven jib crane for maintenance use.

The client is concerned about any impact of the water system on plant production. We are always concerned about safety and environmental factors. Cost is important but not a key issue in this relatively inexpensive support area. Note that if the client's only business was the utility plant, cost could be a major factor.

There is usually enough information in the project description, process diagrams, and procurement specifications to perform a basic risk assessment.

From this information we learn:

- The utility water is used for washing equipment and for use in non-critical production processes. If the supply of utility water is lost for less than one shift, there is no impact on production. At this point we could use our judgement to set Production at 2 for all the machines but we'll go through the exercise for assessing production in detail.

- If water is spilled, there is little environmental impact. The water system can be rated a 1 in this category. We can assume some minor local impact if the exhaust fan doesn't operate. Let's assume a 2. The diesel generator will create some level of noise and exhaust gases but no more than a automobile. We also know that it shouldn't be running often. Let's assume a 2 for it.

- The water cannot be consumed by the plant personnel, is not part of the fire protection system, and quickly drains away if spilled. There may be some hazard if spilled water freezes in Winter. The rating for safety is 2 for the water system but we'll assume 3 for the Generator that provides back up power during emergencies.

Therefore no machines in the utility wash area are a 4 in any of the categories that the client has designated critical.

Since no detailed selection process has been completed for the individual machines in the utility wash area, we have no design information about energy, speed, acceleration, lubrication or resonances. We can get some information on power requirements and design pressures.

Now we need to make some assumptions based on good practices and experience:

Machine Design Factors

- All the machine are certainly less than 500 HP (370 kW) so this factor is a 1.

- Energy stored in machines like these is typically low since they are slow speed low mass. Factor is 1.

- This application is common. The equipment will be basically of-the-shelf machines of existing design so the design experience factor is 1.

- Except for the crane and diesel, motion is rotary in one direction. The crane fits a factor of 2 while the diesel is a three. Note here that we could have rated the generator separately from the diesel and then looked at the worst case of the diesel generator system. Based on experience we know that the diesel is the higher risk part of the system so we've based our scoring on it. However, when it comes to mitigating risk we should consider all parts of the machine train.

- In general the machines are electric motor driven less than 2000 rpm so the maximum machine speed is Level 1. The crane speed is very slow. We can call it a 1 or even emphasize it more by rating it a 0.

- The pumps, compressor, mixer, fan, and diesel generator fit an acceleration factor of 3 while the cane is a 1.

- Since design pressure for the entire system is found to be less than ten times atmospheric pressure, pressure risk is 1 for the pumps. Neither the air compressor, fan, or mixer are high pressure. We'll rate the compressor and fan a 1 and set the mixer at 0. The diesel cylinder pressure could justify a 2.

- We can assume lubrication is sealed greased bearings for all the motors and water for the pump bearings. The client has committed to a lubrication supply and monitoring program from a single vendor. Therefore another case of low risk at level 1 if we assume a lubrication management program. Lubrication for the diesel may present a somewhat higher risk but we'll assume a lubrication program a risk factor of 2.

- Generally, low speed systems like this operate below first resonance. The most likely problem with resonance will be the diesel. We have no detailed information so we'll assume a 3.

The results from the Design Factor Section look like:

Asset	Power	Energy	Exp	Motion	Speed	Accel	Press	Lube	Res.	Total	Ave	Result
Air Comp	1	1	1	1	1	3	1	1	1	11	1.22	1
Pump A	1	1	1	1	1	3	1	1	1	11	1.22	1
Diesel Gen	1	1	1	3	1	3	2	2	3	17	1.89	2
Jib Crane	1	1	1	2	0	1	0	1	1	8	0.89	1
ExhaustFan	1	1	1	1	1	3	1	1	1	11	1.22	1
Mixer	1	1	1	1	1	3	0	1	1	10	1.11	1
Pump B	1	1	1	1	1	3	1	1	1	11	1.22	1
Pump C	1	1	1	1	1	3	1	1	1	11	1.22	1
Pump D	1	1	1	1	1	3	1	1	1	11	1.22	1
Pump E	1	1	1	1	1	3	1	1	1	11	1.22	1

Everything is a low design risk even the diesel, should we have dropped this category altogether?

General Reliability Factors

Reliability for machines for plants in the design stage must be based on experience with similar machines in similar applications.

- It is safe to assume that for machines and this application that minor problems are to be expected, especially during the start up phase of the plant. All will be rated 3.

- The pumps will cycle on and off to fill the storage tanks to the desired level. The air compressor will also cycle on and off as air is drawn off the pressure tank. We'll assume that consumption plan is accurate and that controls are properly set. The factor will be 2 for the pumps and compressor. The other machines either run for a long time (fan) or are normally down and only started as needed (mixer, crane, diesel). They will be factored at 1.

- The process fluids are clean air and water. The plant is to be sited in Eastern Tennessee and all machines except the diesel generator will be housed in a prefabricated insulated metal building. In general the service is not difficult. The diesel will be a 2 and the rest a 1.

- The utility area is remotely located from the main control room but on the route for operators during each shift per the client's operating plan. The remote location factor is a 2 or 3. We'll be conservative selecting a 3.

- All the equipment will be purchased new and therefore presents risk due to potential "infant mortality". We'll rate it all as a 3.

- The pumps, fan, mixer, diesel, and crane can be maintained on site but motors must be shipped out to a shop. The client's plan calls for routine maintenance on site for all assets while major repairs will be done off site. A factor of 3 best fits this scenario.

- Based on the clients maintenance plan, major failures shouldn't be a factor. All be assessed at 1.

The results for General Reliability are:

Item	Asset	Minor	Cycling	Service	Remote	Life	Maint	Fail	Total	Ave	Result
1	Air Comp	3	2	1	3	3	3	1	16	2.29	2
2	Pump A	3	2	1	3	3	3	1	16	2.29	2
3	Diesel Gen	3	1	2	3	3	3	1	16	2.29	2
4	Jib Crane	3	1	1	3	3	3	1	15	2.14	2
5	ExhaustFan	3	1	1	3	3	3	1	15	2.14	2
6	Mixer	3	1	1	3	3	3	1	15	2.14	2
7	Pump B	3	2	1	3	3	3	1	16	2.29	2
8	Pump C	3	2	1	3	3	3	1	16	2.29	2
9	Pump D	3	2	1	3	3	3	1	16	2.29	2
10	Pump E	3	2	1	3	3	3	1	16	2.29	2

Does this tell us anything other than the risk is relatively low?

Plant Production Factors

As we noted early on, based on the interaction between the Utility and the Process plant, the risk to production is relatively low. We said a 2. Should we review all the factors anyway?

- Looking at the diagrams and expected consumption water we can tell that Pump A is the only system drain pump for speeding drainage of the mixing tank. Pumps B, C, D, and E are all used to pump water to the storage tanks. Only two are required at any one time. The fan, mixer, crane, air compressor, and diesel are not spared. Therefore, Pumps B,C,D,and E rate a 1 while the rest of the equipment should be a 4.

- The utility plant as a whole has no effect on Process plant throughput. All machines are a 1.

- Production loss based on the given criteria is not clear. While the shutdown of the Utility plant can shutdown the process plant after a day, if properly spared and maintained, it's unlikely that any machine would be down for more than a day with the possible exception of the air compressor. The loss is likely something between 2 and 3. At this point we'll be conservative and select a 3 for the supply pumps and mixer and a 1 for the other machines since they have little or no effect on the supply of water to the process.

- It is unclear from the information available if the utility water quality or amount supplied has an effect on process quality. We'll assume a factor of 1 until we get more information.

- The Utility plant has little effect on the Process plant assuming the storage tanks are at a reasonable level. Therefore start up effects are likely negligible. We'll select a 1 for the supply pumps and mixer and a 0 for the rest.

- We are still in the design stage so we can assume that the machines will meet design. Rate them a 2.

The results of the Plant Production section are:

Asset	Spared	Thru' put	Loss	Quality	Start Up	Output	Total	Ave	Wt'd Ave*	Result
Air Comp	4	1	1	1	0	2	9	1.50	1.50	2
Pump A	4	1	1	1	0	2	9	1.50	1.50	2
Diesel Gen	4	1	1	1	0	2	9	1.50	1.50	2
Jib Crane	4	1	1	1	0	2	9	1.50	1.50	2
ExhaustFan	4	1	1	1	0	2	9	1.50	1.50	2
Mixer	4	1	3	1	1	2	12	2.00	2.00	2
Pump B	1	1	3	1	1	2	9	1.50	1.50	2
Pump C	1	1	3	1	1	2	9	1.50	1.50	2
Pump D	1	1	3	1	1	2	9	1.50	1.50	2
Pump E	1	1	3	1	1	2	9	1.50	1.50	2

Again, all are relatively low risk. Is the score on the mixer telling us something?

Life Cycle Costs

- ♦ All machines except the diesel/generator and the air compressor are below $ 5,000. Those two items are budgeted at $ 15,000 and $ 22,000 respectively. Therefore they are rated 3 while the others are a 1.

- ♦ If the client follows the documented maintenance plan, costs should be moderate. A rating of 2.

- ♦ There is some concern about energy costs although there will be no premium paid for energy efficient motors. Rate this one a 2.

The resulting Life Cycle Cost summary is:

Asset	Purchase/Replace	O&M	Energy	Total	Ave	Result
Air Comp	3	2	2	7	2.33	2
Pump A	1	2	2	5	1.67	2
Diesel Gen	3	2	2	7	2.33	2
Jib Crane	1	2	2	5	1.67	2
Exhaust Fan	1	2	2	5	1.67	2
Mixer	1	2	2	5	1.67	2
Pump B	1	2	2	5	1.67	2
Pump C	1	2	2	5	1.67	2
Pump D	1	2	2	5	1.67	2
Pump E	1	2	2	5	1.67	2

A final assessment that weighs all categories equally would look like:

Asset	Safety	Environ	Prod	Costs	Reliability	Design	Arith Ave	Assessment *
Air Comp	1	1	2	2	2	1	1.50	**2**
Pump A	2	1	2	2	2	1	1.67	**2**
Diesel Gen	3	2	2	2	2	2	2.17	**2**
Jib Crane	2	1	2	2	2	1	1.67	**2**
Exhaust Fan	1	2	2	2	2	1	1.67	**2**
Mixer	2	1	2	2	2	1	1.67	**2**
Pump B	2	1	2	2	2	1	1.67	**2**
Pump C	2	1	2	2	2	1	1.67	**2**
Pump D	2	1	2	2	2	1	1.67	**2**
Pump E	2	1	2	2	2	1	1.67	**2**

Should all categories count equally? No, the arithmetic average is too simplistic, even with the “automated” Level 4 for any safety or environmental factors of 4.

You can see that the diesel generator and the exhaust fan were both higher in environmental but the end results were still 2 for all.

If we were to design a weighting formula what could it look like? Anything that is representative of your engineering judgment and the client’s priorities.

Does that sound like you’re designing a formula to give the answers you and the client want? Yes, that’s exactly what you want to do within the bounds of good engineering practices.

Why? This example is just that, an example. A “real world” problem would likely involve assessing hundreds of machines. It’s easy to get caught up in averaging. A weighting formula that can be applied to all the machines that proves to match engineering judgment is a valuable tool. A tool that can be used to help you concentrate on identifying the higher risk machines so the risks can be mitigated.

The risk assessment process presented here does not yield detailed quantitative results. It is not meant to do that. It is meant to provide a rapid consistent way to identify those risks that need a more detailed quantitative approach.

An example of a weighting formula is:

(C1*Safety+C2*Environment+C3*Production+C4*Costs+C5*Reliability+C6*Design)/K

Where C1 through C6 are weighting constants and K is constant used to bring the result into range (what some might call a “fudge” factor).

Those who can’t consider anything but an absolute result such as that from a formula such as F=MA will have great difficulty with weighting formulae.

In deference to those people, I’ll stop calling the weighting formula a formula and call it a “risk assessment model” which of course it is.

Think of it as a mathematical model of the machinery risk designed to identify high risk assets.

Let’s design a model for the Utility plant.

There should be more weight on Safety and Environment. While the risk in a plant like this is low, we’d like to surface the higher risks machines in those two categories. We already know none are level 4’s in these categories. It would be good if we could push the ones we know are higher risks to a Level 3 overall assessment without pushing all assessments to level 3.

By setting C3, C4, C5, and C6 = 1 and setting C1 and C2 much greater than 1, we can add more weight to Safety and Environment. Since we can see that the Environmental factor is what sets the diesel generator and exhaust fan apart from the other machines, we should set C2 higher than C1. Then we must adjust K to drive the results into the Level 3 overall range.

Through experimenting on the spreadsheet, we find that this model yields the desired result:

(100*Safety+275*Environment+Production+Costs+Reliability+Design)/250

The new results using the weighted risk model look like:

Asset	Safety	Environ	Prod	Costs	Reliability	Design	Wt'd Risk	Arith Ave	Assessment *
Air Comp	1	1	2	2	2	1	1.53	1.50	**2**
Pump A	2	1	2	2	2	1	1.93	1.67	**2**
Diesel Gen	3	2	2	2	2	2	3.43	2.17	**3**
Jib Crane	2	1	2	2	2	1	1.93	1.67	**2**
Exhaust Fan	1	2	2	2	2	1	2.63	1.67	**3**
Mixer	2	1	2	2	2	1	1.93	1.67	**2**
Pump B	2	1	2	2	2	1	1.93	1.67	**2**
Pump C	2	1	2	2	2	1	1.93	1.67	**2**
Pump D	2	1	2	2	2	1	1.93	1.67	**2**
Pump E	2	1	2	2	2	1	1.93	1.67	**2**

Are there other models that would yield the same results? Most definitely, the model I created is one of many that give the desired results. If you are familiar with more sophisticated techniques by all means use them.

Should the same model be used for other applications? Only if the applications are identical.

Caution: Do not get so enamoured of your model that you lose sight of reality. The model must deliver results that match good engineering judgment. If the model doesn't match engineering judgement, the model is wrong.

If you do not feel comfortable with a model, there may still be a reasonably fast way to identify those machines that are "different".

Save your base spreadsheet then create a copy with a different name.

Temporarily delete any categories where the results are the same for all machines. In our example we could eliminate Production, Costs, and Reliability. I would also recommend deleting any categories where all the results are a Level 1 or a Level 2 with the exception of Safety and Environment. In our example that would also eliminate Design.

This spreadsheet would look like:

Asset	Safety	Environ	Arith Ave	Result
Air Comp	1	1	1.00	**1**
Pump A	2	1	1.50	**2**
Diesel Gen	3	2	2.50	**3**
Jib Crane	2	1	1.50	**2**
Exhaust Fan	1	2	1.50	**2**
Mixer	2	1	1.50	**2**
Pump B	2	1	1.50	**2**
Pump C	2	1	1.50	**2**
Pump D	2	1	1.50	**2**
Pump E	2	1	1.50	**2**

The diesel generator still stands out while the exhaust fan no longer does. That is still a reasonable result since the diesel is more risky in regards to Safety and has environmental impact inside and outside the plant while the exhaust fan only is an issue with the internal (building) environment.

No matter what model or elimination process you use, always include a "sanity" check.

Do the results match your judgement?

Do the results match those for similar applications?

Does the client feel that the results are indicative of their experience (more helpful on an existing plant with a history).

Do the results differ widely from available text book or other documented results?

Would a colleague reach the same results?

Are there other factors that must be considered (controls, insurance, image, regulations, etc.)?

Should multipliers be applied for maintenance, operations, protection systems, etc.?

Once you are satisfied that the results are reasonable it is vital that you document not only the results but your assumptions. Assumptions are especially important for plants in the design stage like this example. Designs change. Designs are sometimes applied in a “cookie cutter” fashion. Would you want your risk assessment for a water plant in Tennessee to be applied to a diluted detergent wash system on an Alaskan wildlife refuge?

We haven’t used any multipliers yet, why not? Multipliers are another layer of subjective weighting. They make the model more complex not necessarily better. They are best used as “what if” examples after you have made your initial risk assessment. We’ll look at this below.

What do the base results tell us? Some of conclusions are:

1. As we expected the Utility plant machinery is relatively low risk.

2. The diesel generator is the highest risk due to safety, environmental, and cost factors and could also be a maintenance problem. We might recommend the client review the need for emergency power since the facility can be shutdown for quite some time without effecting production in the process plant.

3. The exhaust fan while a minor risk could be troublesome. Since it is relatively inexpensive, a good choice might be to install a second fan as a spare.

4. It appears that the client could get by with only three of the four supply pumps. That would be a savings in purchase, construction, operations, and maintenance costs.

5. The mixer for water softening chemicals requires more review. If soft water is critical to the Process plant product quality then loss of the mixer is serious. A spare mixer might be needed. However, if soft water is important but not vital, then hard water may be tolerated for some period of time until the mixer is repaired. We need to find out.

6. The jib crane is a nice maintenance tool but possibly there is some portable lifting equipment in the Process plant that could be used to lift the small pumps, motors, compressor, etc. The jib crane is not the best tool for the diesel generator. However, it’s situated outside the building, accessible to mobile cranes. It may make sense to eliminate the jib crane.

7. Pump A, the drain pump, is not spared since it is only to speed draining. The design calculations for the gravity draining of the tanks need to be verified. The piping and valves need to sized so that the drain time meets the minimum requirements or a spare pump should be considered.

8. The reliability of all the machines was based on a managed program of lubrication condition monitoring and replacement. Programs like this are often dropped before the plant is completed. The client needs to know that the risk level of 2 was in part based on a lubrication program.

I’m sure you can come up with other conclusions.

A matrix summarizing our results might look like:

Catastrophic	Some Risk	Some Risk	High Risk	Extreme Risk
Moderate	Some Risk	Some Risk	High Risk	High Risk
Little	No Risk	Some Risk	Some Risk	Some Risk
None	No Risk	No Risk	No Risk	No Risk
	Rare	**Unlikely**	**Possible**	**Likely**

As we look back on our assumptions, we'll see that we have assumed that good operations and maintenance practices would be followed. We also assumed that the control system would keep the pumps and compressor from cycling excessively.

We can also see from the information that there is nothing in the design in regards to machinery protection or information systems or decision support.

We can look at the effect of these factors on either each machine or the entire Utility plant. It's best to take an overall look first.

The effect of these multipliers could be:

Level 2*Controls*Mainteance*Operations*DecisionSupport*Protection*Information = "What if " Result

Each of the multipliers has a worst and best case.

The "What if" Results could half the assessed level or double it if all applied in the same direction.

Again, apply some of your engineering judgement. It is highly unlikely that this Level 2 Utility plant could ever be a Level 4 risk and it's much too expensive to add the processes and systems to drive it to Level 2.

Based on the assumptions we did make about operations and maintenance we should look at the scenario where practices are not followed.

Level 2*1.2*1.2 = 2.88

So we could estimate that poor operations and maintenance could drive the risk to a Level 3.

This should be used to stress the importance of these practices in our assumptions.

Try some practice exercises. As you become more familiar with the assessment process, you'll see it's capabilities in helping you focus your judgement to assess risk.

Initial machinery risk assessment is not "rocket science". It is the application of engineering judgement, common sense, and experience applied in a structured process.

Once you are experienced, you will quickly come up with more sophisticated tools based on your unique experience.

Last words of caution. Rely on judgement. Be the master of your model. Let it be the result of your judgment don't let the model results become your judgement.

Exercise 1

Assess your automobile. If you don't have one then assess the normal mode of transportation you use.

Assess a future automobile purchase. Maybe compare a Jaguar to a Toyota.

Consider it as complete system first. How would you rate the overall Safety, Environmental, Production (delivery of personal transportation), Cost, Reliability, and Design. Consider other categories (Fun, Impress the Neighbors).

Then evaluate subsystems like the engine, power train, air conditioning, seating, etc.

Do the subsystem results match the overall?

Do you think insurance costs are based partly on risk as well as on actuarial tables?

Exercise 2

Assess a small industrial facility you are familiar with.