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7 Steps to Optimize Lubrication Practices for Maximum Reliability Support

Mike Johnson, Principal Consultant

CMRP, CLS, MLT, MLA

Contact Details

Mike Johnson, CMRP, CLS, MLTII, MLAII

President, AMRRI

Mike.Johnson@PrecisionLubrication.com

3978 E. McEwen Drive

Franklin, Tn., 37067

615.771.6030 – Tel and Fax

615.513.3000 - Cellular

About the Course Presenter

24 years – focus on reliability centered lubrication practices and program development

- ❑ Author of Chapter 33 'Lubrication Program Development' for the CRC Tribology and Lubrication Engineering Handbook, 2nd Edition
- ❑ Author of 45 technical and industry articles published by TAPPI, ILMA, Reliable Plant, Practicing Oil Analysis, Machinery Lubrication STLE, and Uptime Magazine
- ❑ Contributing Editor for ICML - MLT1 and MLT2 test development.
- ❑ SMRP Certified Maintenance and Reliability Professional
- ❑ STLE Certified Lubrication Specialist
- ❑ Creator of 'Lubrication Boot Camp' six-week Immersion Training program.
- ❑ Popular presenter of workshops, public and private seminars, and other industry events. College Instructor and Developer: Introduction to Machinery Lubrication
- ❑ Guest writer for STLE 'Machine Lubrication Best Practices' 24 Article Series (in development)
- ❑ Other stuff…

Available Reliability Services

- **Auditing:** The service includes mapping out lubrication programs requirements from incoming material requirements, storage, handling, equipment requirements, and eventually disposal.
- **Consulting:** Specialists in lubrication, PdM program implementation, and root cause analysis. Trico consultants provide practical solutions for improving equipment reliability.
- **Training:** On-site or off-site training seminars addressing the topic of "lubrication management." These training sessions are intended to help organizations implement effective preventative maintenance programs and improve equipment reliability.

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Available Reliability Services

- **Lubricant Monitoring:** Oil samples are taken and analyzed as a preventative maintenance tool and/or diagnostic means to determine possible causes of equipment failure.
- **Components Solutions:** Lubrication management products to keep machines running productively.
- **Contract Lubrication Program:** Fully contracted lubricant design, selection, application, condition control, sampling and analysis, Root Cause mapping and correction, program effectiveness reporting.
- **Contract Lubrication Management:** This service mirrors the fully contracted approach except that the labor is provided by the client or a third party labor resource. All management functions are provided as though it is a captive program.

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3 Q's to Ponder for Starters

1. What is meant by Total Cost of Plant Lubrication?

2. What influences the Total Cost of Plant Lubrication at our plant?

3. How big of a return would you need to make Precision Lubrication Development one of your reliability engineer's Key Performance Objectives in 2010 - 2011?

Dime for a Dollar – Precision Lubrication

There is a significant cost savings that can be accomplished through optimized plant lubrication!

It is <u>being done</u> by others!

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Dime for a Dollar – on Who's Authority?

What is the basis for this position?

1. Objective multi-environment evidence

2. Subjective singe-environment evidence

3. My humble, but accurate, opinion

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Dime for a Dollar – Show me the Money!

Short List - What's RIPE for Improvement – Low Hanging Fruit!!

1. Sump Contamination Control

- At the time of machine installation
- During and following lubricant installation – ongoing activity

2. Product Selection

- Improving the match-up of lubricant performance property with machine and labor management objectives
  - Viscometric properties
  - Surface protection technologies
  - Long term lubricant Stability

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Dime for a Dollar – Show me the Money

Short List - What's RIPE for Improvement?

3. Man Hours per Year

- **Improved Longevity in lubricants – see #2**
- **Improved delivery efficiency**
  - Multipoint systems
  - Single point systems
  - Things in between

5. Analysis Practices

- **Sample Collection**
- **Test Slate Selection, Interpretation of Data**
- **Response to data, scheduling and follow through**

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Dime for a Dollar – Show me the Money

Short List - What's RIPE for Improvement?

5. Material Use / Waste control

- Leakage – 80 to 90 percent is controllable
- Product handling – particularly drums and kegs
- Waste generation – don't use what you don't have to

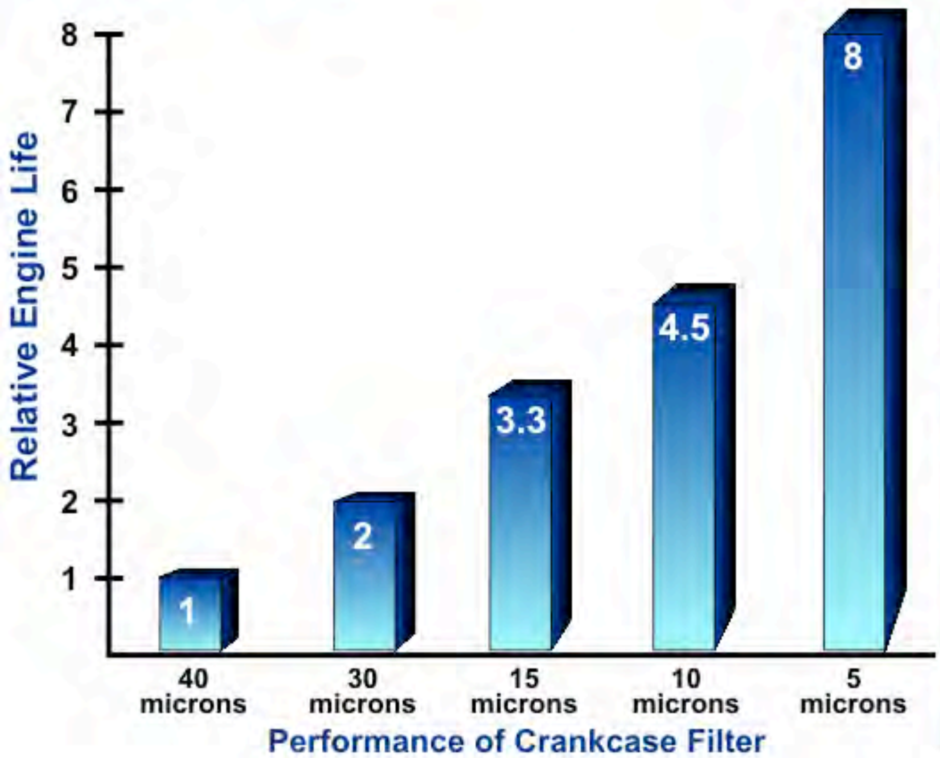
6. Knowledge development

- Develop an attitude of 'chin-up value'
- Find a motivated, no-nonsense change agent
- Develop plant wide / company wide objectives
- Empower and reward, then get out of the way

Objective Measure – NRCC/STLE

Sector	Particle Induced Failure			Non-Particle Induced			Total
	Abrasion	Erosion	Fatigue	Adhesion	Fretting	Other	
Transportation	799	-	202	240	17	68	1326
Agriculture	735	54	45	104	2		940
Mining	551	117	25	15	1	17	726
Pulp & Paper	217	93	13	36	4	19	382
Forestry	101		14	25			
Power Gen	69	30		31	26	34	190
Total	2472	294	299	451	62	144	3722
Percentage by Category		82%			18%		

SAE Engine Study – Gas & Diesel



Study compared wear rates with different qualities of filtration.

40 µm element = baseline

30 µm element = 50% less

15 µm element = 70% less

OEM Engine Filter quality

•$\beta_{35} = 200$

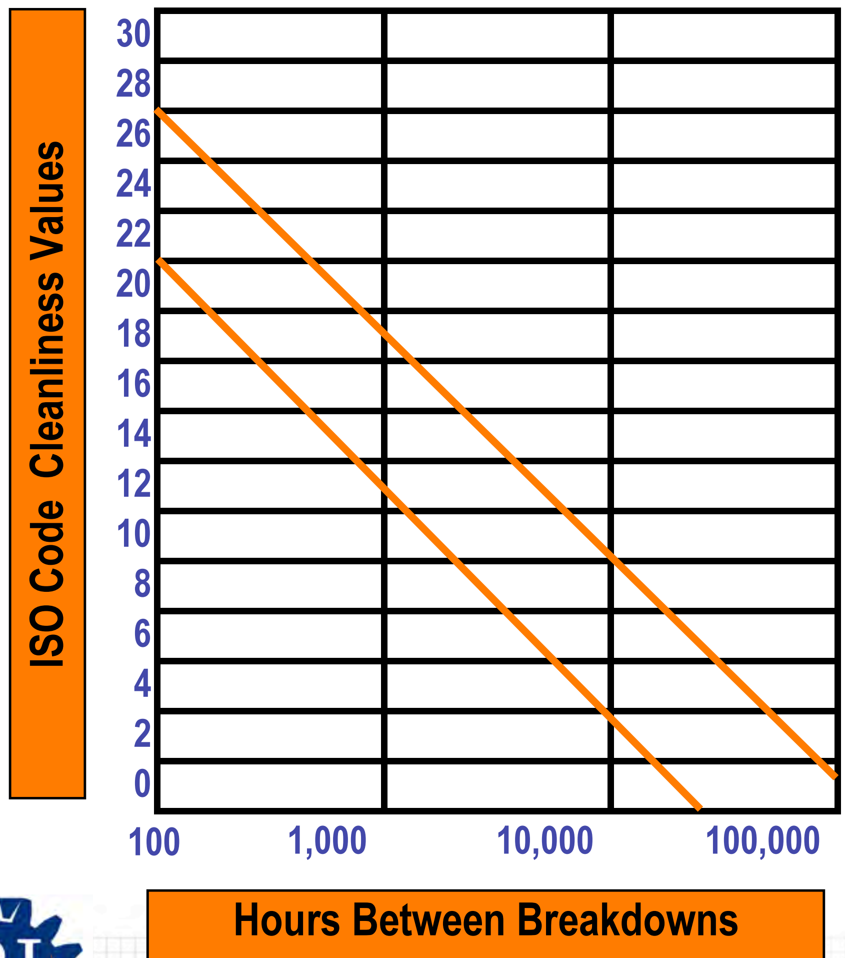
•Corresponds to 99% efficiency at 35 micrometer

Ref: SAE Gasoline and Diesel Engine study, Diagnetics - JFFitch

Objective Measure – BHRC / NEL

BHRC and National Engineering Laboratory

117 Hydraulic Systems Field Study



<u>Reliability Analysis</u>

Injection Molding	13
Metal Working	15
Machine Tools	6
Material Handling	15
Mobile Equipment	22
Marine Systems	16
Test Stands	17
General Machines	3

The purpose of the study is to report the influence of particle size and concentration on machine reliability.

<u>Study Concluded the following:</u>

1) High correlation of failure to contamination levels.

2) Failure data used to create chart showing log relationship of cleanliness to reliability.

3) Significant (50 fold) improvement in reliability exists in reducing dirt load in hydraulic systems.

Ref: Diagnetics Case Study

Mining Hydraulic Shove Study

Hitachi 2500 Shovel - $99,901 annualized savings

- 4 premature pump failures 27 months ($20,000 per exchange, $34,000 per event production losses)
- Plus: 42 hose failures, severe oil oxidation at 2,250 hours, sever servo value failures, 39 hours downtime for repair.

Effect of Precise Lubrication

- 1.94 years into changes
- Achieved 15/12/9, (from 22/20/17); oil lifecycle to 17,000 hrs (from 4,000).
- Eliminated 4 pump replacements and several servo valve failures.
- Increased productivity of the excavating operation

Ref: AV Lubricants, Hypro Fltration, Mobil Oil Case Study

Giant Industries - Energy Savings

8 Machines, poor service factors, closely parallel conditions. Initial readings following oil change to new mineral oil.

Eq. ID	Service Factor	Voltage	Baseline Electrical		Adv Tech Lubricant		Daily Electrical Cost ?	Annualized Value	Annualized Lubricant Cost ?	Net Value
			Amps	Cost / Day	Average Amperage	Electrical Cost / Day				
P105	1.15	460	87	$ 174	85.09	170	$ (3.82)	$ 1,394	$ 60	$ 1,334
P211A	1	460	20	$ 35	19.42	34	$ (1.01)	$ 368	$ 60	$ 308
P507	1	460	41	$ 645	36.91	580	$ (64.31)	$ 23,475	$ 360	$ 23,115
P507A	1	4160	41	$ 645	36.87	580	$ (64.94)	$ 23,704	$ 360	$ 23,344
P902A	1	4160	88	$ 153	85.13	148	$ (4.99)	$ 1,821	$ 360	$ 1,461
P908A	1	460	187	$ 325	157.66	274	$ (51.02)	$ 18,621	$ 60	$ 18,561
PD506	1.15	460	46.8	$ 94	46.65	93	$ (0.30)	$ 109	$ 60	$ 49
P605	1.15	460	48.5	$ 84	44	77	$ (7.82)	$ 2,856	$ 60	$ 2,796
Savings	8.45	11080	559.30	**$ 2,155.00**	511.73	**$ 1,956.00**	**$ (198.21)**	**$ 72,348**	$ 1,380.00	**$ 70,968.00**

Numerical ? in Energy Consumption	47.57
% Differential in Energy Consumption	(0.085)
Cost per Kilowatt Hours	$ 0.0175
Per Machine Typicals	**Value**
Number of Machines	8
Average Daily Amp draw ? per Machine	5.95
Average Daily Electrical Cost ? per Machine	$ (24.78)
Average Annual Saving per Machine - 8 machines	$ 8,871.00
One Time Charge per machine	**Value**
Equipment modifications - hardware & installation	$ 500.00
Typical Product Conversion	$ 250.00
Recurring Charge per machine	**Value**
Annual Lubricant Cost ? per Machine	$ 172.50
Typical Labor - Routine Oil Change per Machine	$ -
Lubrication Skill Development Resource	$ 30,000.0

Method to calculate energy cost savings:

1. **Calculate deltas in amperage per machine**
2. **Convert Amp draw to KWH per day**

   KWH / Day = Volts * Amps * ?3 * Svc Factor * Hours / 1000
3. **Calculate Cost per day**

   $KWH / Day = KWH / day * $$ / KWH
4. **Annualize contribition**

   $$ / year = $KWH / Day * Running Days

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Ref: Royal Purple Case Study

Giant Industries – NPV Analysis

Precision Lubrication Improvement Plan - Balance of Plant (BOP) Converasion						
Year	0	1	2	3	4	5
Annualized Program Benefits for Trial Group	$72,348	$0	$0	$0	$0	$0
5 year Projected Energy Savings Benefit for BOP	$0	$904,350	$904,350	$904,350	$904,350	$904,350
Equipment Modifications - per machine * 100 Machines	$ 50,000	$ -	$ -	$ -	$ -	$ -
Initial Product Conversion - per machine * 100 machines	$ 25,000	$ -	$ -	$ -	$ -	$ -
Per Machine Annual Lubricant Cost ? - * 2 for BOP	$ 34,500	$ 34,500	$ 34,500	$ 34,500	$ 34,500	$ 34,500
Annual Cost for Lubrication Skills Development	$ 50,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000	$ 15,000
Annual Cost Lubrication Program Reliabilty Engineer		$ 120,000	$ 120,000	$ 120,000	$ 120,000	$ 120,000
Miscellaneous improvements - 3 year budget		$ 100,000	$ 100,000	$ 100,000		
Total Costs	$ 125,000	$ 169,500	$ 169,500	$ 169,500	$ 169,500	$ 169,500
Net Cash Flow	$ (125,000)	$ 734,850	$ 734,850	$ 734,850	$ 734,850	$ 734,850
Select Discount Rate	**20%**					
Discount Factor	100%	83%	69%	58%	48%	40%
Discounted Net Cash Flow	-$125,000	$612,375	$510,313	$425,260	$354,384	$295,320
Five Year Net Present Value (NPV)	**$2,072,651**					
Internal Rate of Return (IRR)	**588%**					

Jost Report – Effect of Lubrication in Industry, Agriculture, Natural Resources

The Hub of the Industrial Wheel

What are the Potential Savings to Industry, Agriculture and Natural Resources through Effective Lubrication Education and Application? According to Dr. Peter Jost, the Jost Report (circa 1966)

20.0%	Savings in Lube Buys
0.13%	Labor savings from reduced repairs
1.0%	Savings from utilization and efficiency
5.0%	Savings on New Machine Purchases
7.5%	Less energy use from friction control
20.0%	Savings on maintenance and repair costs

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Jost Report, British Ministry of State for Education and Science. H. Peter Jost., as shown in Bannister, Lubrication for Industry

Dime for a Dollar - Justifciation

What is the bottom line regarding improvement initiatives under the standing economic conditions?

SHOW ME THE MONEY!

Question 1

- Which of the following represents the biggest possible impact for financial improvement for the facility?
  A. Reduce cost of lubricant purchases.
  B. Reduce cost of lubricant labor expense.
  C. Reduce cost of component replacement.
  D. Avoiding production losses from scheduled and unscheduled machine outages.

Question 2

- Which of the following is possible from development of Precision Lubrication Practices?

A. Reduce costs associated with lubricant purchase, use and replacement.
B. Reduce cost of energy through friction control.
C. Reduce direct cost of maintenance, repair and production losses.
D. All of these occur with Precision Lubrication.

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7 Step to Reliability Centered Lubrication

1. Develop the business case.
2. I - Assess the current lubrication process and practices

   II - Assess the relative criticality of each machine

   III - Develop and Communicate Goals and Objectives
3. Determine How Information will be Managed – IT Decision
4. Conduct a reliability centric lubricant requirements assessment
   - Product type, grade, volume, frequency
   - Operating environment severity
   - Component contamination sensitivity
   - Oil analysis requirements and alarm settings set by machine priority
5. Implement Using Modern Tools for Work Flow Management and Documentation
6. Analyze results against the objective, make adjustments, improve the process
7. Adjust the plan to stay on course, update the plan as needed for new business challenges.

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Establishing Cost of Improvement

Step 1: Make the Business Case

- Catalog the machines
- Estimate the total cost to make improvements
  - Verifying, defining lubricant requirements
  - Verifying, defining relubrication activities (volumes, frequencies, route sequences, simple but needed machine upgrades)
  - Tools for program management,
  - Cost of upgrading knowledge level
- Establish the cost basis
- Perform a financial analysis review.

Cost of Improvement Estimates

- Catalog the machines – type, number, complexity,

Item Number	Machine Type/Description	Number of Type (or Estimate)	Machine Complexity	Baseline Manhours for One Machine	Total Manhours for Machine Type Design	Total Manhours for Routing andWork Leveling	Total Manhours for Modification Supervision and Coaching	Estimated Installation Hardware - Parts and Supplies	Estimated Installation Manhours
1	Conveyors	12	Low	2	9.3	1.2	1.2	$1,200	24
2	Repulper	3	Moderate	4	9.8	0.3	0.6	$300	6
3	Pulp Machine	2	Very High	15	27.0	1.0	2	$2,000	30
4	Pumps	50	Low	2	10.0	2.5	5	$2,500	50
5	Vessels / Agitators	3	Moderate	4	9.8	0.3	0.6	$300	6
6	Tissue Machine	1	Very High	15	15.0	0.5	1	$1,000	15
7	Kitchen Towel Machine	3	Very High	15	36.6	1.5	3	$3,000	45
8	Printing Press	1	Very High	15	15.0	0.5	1	$1,000	15
9	Hand Towel Machine	2	Very High	15	27.0	1.0	2	$2,000	30
10	Hand Towel Printing Press	1	Very High	15	15.0	0.5	1	$1,000	15
11	Kitchen Wrapper Packer	1	Very High	15	15.0	0.5	1	$1,000	15
12	Hand Towel Wrapper Packer	3	Very High	15	36.6	1.5	3	$3,000	45
13	Conveyance - tow motors	4	Moderate	4	11.8	0.4	0.8	$400	8
14	Stretchwarppers	4	Moderate	4	11.8	0.4	0.8	$400	8
Total	**15**	**90**			**249.6**	**12.1**	**23.0**	**$19,100**	**312**

Cost of Improvement Estimates

- Create a cost basis projection

Program Design Cost Estimate

Activity	Complexity	Man Hours	Hourly Rate	Cost
Planning and Scoping	Low	24	$169	$4,050
Detailed Design		249.6	$169	$42,122
Routing and Work Leveling		12.1	$169	$2,042
Modification Supervision/Coaching	16	16.0	$169	$2,700
Total Design, Routing and Modification Support		**301.7**		**$50,914**

Hardware Installation		Man Hours	Hourly Rate	Cost
Hardware - Parts and Supplies				$19,100
Client wishes to outsource installation labor	Yes			
Installation labor hours		312.0		
Labor - if outsourced to AMRRI / Local Labor Pool			$90	$28,080
Labor - if provided by client- **Input Rate Here**	$35		$0	$0
Total Hardware Installation				**$47,180**

Education and Training	Number Upfront	Number Ongoing	Cost Per Course Day / Hour	Total Upfront Cost
Single Event, Multi-Day On-Site Training Course(s)	1		$2,500	$2,500
10 - Session, year long training program	10		$1,350	$13,500
Hours of Online Training (Per Year)	0	24	$169	$0
Total Training				**$16,000**

Looking for Value

Repair Parameter	**Comments**
Total Maintenance Cost: Input total annual maintenance costs to nearest thousand	Parts, labor, supervision, management, overhead, insurance, risk-based, incidentals, etc.
Repair Cost: Select percentage of maintenance and other costs attributable to repair	Excludes PVMs, inspections, etc. Includes inspection/PDM follow-up work and scheduled rebuilds and replacements.

Actual	Best Guess	Confidence	Basis
$10,000,000.00 ✓	$100	95%	**$10,000,000.00**
50% ✓	10%	95%	**$5,000,000.00**

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Looking for Value

Repair Parameter	**Comments**
Mechanical Repair Cost: Select percentage of repair that is attributable to mechanical wear of lubricated components	Abrasion, fatigue, adhesion, cavitation, corrosion, etc. Excludes operations failures, electrical failures, etc.
Mechanical Wear Cost: Select estimated percentage of mechanical wear that is attributable to poor lubrication	Poorly selected lube, over lubrication, under-lubrication, ineffective contamination control, ineffective oil analysis, etc.

Actual	Best Guess	Confidence	Basis
50% ✓	10%	95%	**$2,500,000.00**
50% ✓	10%	95%	**$1,250,000.00**

Looking for Value

Repair Parameter	**Comments**
Reduction Potential: Estimate percentage of lubrication-related wear that could have been avoided with a well-defined and executed lubrication program	Improvement potential that could be achieved by Precision Lubrication. **(Assume half of this value is associated with 'skill', & half is associated with machine configuration.)**

Actual	Best Guess	Confidence	Basis
50% ✓	10%	95%	**$625,000.00**

Looking for Value

Repair Parameter	Comments
Total Lubrication Costs: Input percentage of total maintenance costs attributable to scheduled lubrication PM activities	Include all aspects of lubrication related tasks and materials, including, management, supervision, labor, lubricant supplies, sample regreasing, changes, top-ups, collection, overhead, etc.

Actual	Best Guess	Confidence	Basis
0%	10% ✓	90% ✓	**$900,000.00**

Looking for Value

Repair Parameter	Comments
Skills Penalty: What percentage of the total lubrication cost improvement could be acheived through improvements in skill and knowledge level	Work that is not done, done improperly or is not recognized as meaningless work (redundant, overkill). (**This value is lost to poor skills)**
Hardware and Configuration Penalty: What percentage of lubrication cost improvement could be achieved by use of automation, by retrofitting machines to be lubrication friendly	Includes hardpiping of reservoirs, staging lubricant supply substations (grease refill, oil refill), installation of permanent bypass filters, use of automatic lubricators.

Actual	Best Guess	Confidence	Basis
0%	10% ✓	90% ✓	**$81,000.00**
0%	10% ✓	90% ✓	**$81,000.00**

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Looking for Value

Repair Parameter	**Comments**
PM Def. Penalty: What potential improvement in lubrication labor efficiency could be achieved by replacing current activities with Precision Based lubrication activities	Elimination of wasteful practices, defining precise requirements in scheduled PM. **Assume half of effect due waste elimination.**
Lubricant Technology Penalty: What percentage of the total lubrication costs could be saved through the use of 3rd generation lubricants.	Use of advanced technology products to extend change intervals, replacement intervals, machine lifecycle, reduce energy cost

Actual	Best Guess	Confidence	Basis
0%	10% ✓	10% ✓	**$9,000.00**
0%	10% ✓	90% ✓	**$81,000.00**

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Looking for Value

Lubrication Corrective Work Efficiency Parameter	Comments
Input percentage of total lubrication costs attributed to unscheduled lubrication activities,	Activity rescheduled due to operating requirements, activities that are 're-done', 'on-demand' activities.(Unplanned oil changes, regrease activities, stoping leaks, sample collections, filter replacement, troubleshooting)
Input estimated percentage of unscheduled machine lubrication activities that are a complete waste of time	Regreasing hot bearings following the normal grease schedule, performing work that could not be done on the normal schedule - **Issues related to skill & knowledge**

Actual	Best Guess	Confidence	Basis
0%	10% ✓	90%	$81,000.00
0%	10% ✓	95%	$7,695.00

Looking for Value

Production Loss to Machine Availability	Comments
Input estimated annual downtime costs and risk-based costs to nearest thousand	Includes unscheduled downtime, excessive scheduled downtime, production derate costs, energy costs, excessive inventory costs, safety and other risk-based costs. Use net numbers.

Based on Lubrication Related Portion of Repair Cost, as noted above, the prorated Risk portions is

Actual	Best Guess	Confidence	Basis
$0	$100,000 ✓	50%	**$50,000.00**
			$3,125.00

Looking for Value

Estimated Potential Annual Savings	
Scenario 1 - Knowledge based improvements only	Review and redefine work practices to , provide training
Scenario 2 - Knowledge & capital improvements	Provide machine fittings, retrofits, filtration hardware, handling tools, automation

[redacted]	**Basis**
[redacted]	**$403,410.00**
[redacted]	**$722,695.00**

Looking for Value

Financial Benefits Analysis						
Select Financial Evauation Case	**Scenario 1**					
Year	**0**	**1**	**2**	**3**	**4**	**5**
Value Allocation	**$ 403,410**	**⅓ - Y1**	**⅔ - Y2**	**Full Value**	**Full Value**	**Full Value**
Targeted Improvements		$133,125	$266,251	$403,410	403,410.0	$403,410
Program Costs						
Planning and Scoping - Gap Analysis, RCFA	**$4,050**	$ -	$ -	$ -	$ -	$ -
SOP Review and Design ($500 x 100)	**$42,122**	$ -	$ -	$ -	$ -	$ -
Tour development and workload balancing (10% of development)	**$2,042**	$ -	$ -	$ -	$ -	$ -
Automation - Development, Planning and Installation	**$0**	$ -	$ -	$ -	$ -	$ -
Training and Development (80 hrs @ $168 per hr plus books)	**$2,500**	**$13,500**	$4,050	$4,050	$4,050	$4,050
On-site program support	**$2,700**	$1,350	$2,700	$1,350		
Modification Installation and Hardware ($500 x 500)	**$47,180**	$ -	$ -	$ -	$ -	$ -
		$ -	$ -	$ -	$ -	$ -
Total Costs	**$100,594**	$14,850	$6,750	$5,400	$4,050	$4,050
Net Cash Flow	-$100,594	$118,275	$259,501	$398,010	$399,360	$399,360
Select Discount Rate	15%					
Discount Factor	1.00	0.8696	0.7561	0.6575	0.5718	0.4972
Discounted Net Cash Flow	-$100,594	$102,848	$196,220	$261,698	228,335.38	$198,553
Summary Investment Analysis						
Five Year Net Present Value (NPV)	$887,060					
Internal Rate of Return (IRR)	146%					

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Purposes for this Presentation

- Focus on what financial management wants TODAY – <u>short term cost reduction</u>

- Find Cash Flow Improvements
  - Eliminate unnecessary oil changes (at least ⅓ of your planned lubricants consumption)
  - Eliminate premature aging of your lubricants (extend lubricant lifecycles by 2 to 5 times baseline.
    - Reduces ½ of your oil consumption.

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ROI vs. Cash Flow Improvement

- <u>Short Term Cost Reduction</u>
  - Eliminate unnecessary trips with the grease gun
  - Reduce by ½ (or more) the amount of grease wasted through automation
    - is your automation just an improvement, or is it accurate?
  - Eliminate wasteful practice of product duplication, excess inventory

Purposes for this Presentation

We Could Focus on… – <u>short term cost reduction!!</u>

Before you get too excited about this angle, a couple things you should know.

- If you eliminated all your lubricant purchases it wouldn't budge your profitability #'s.

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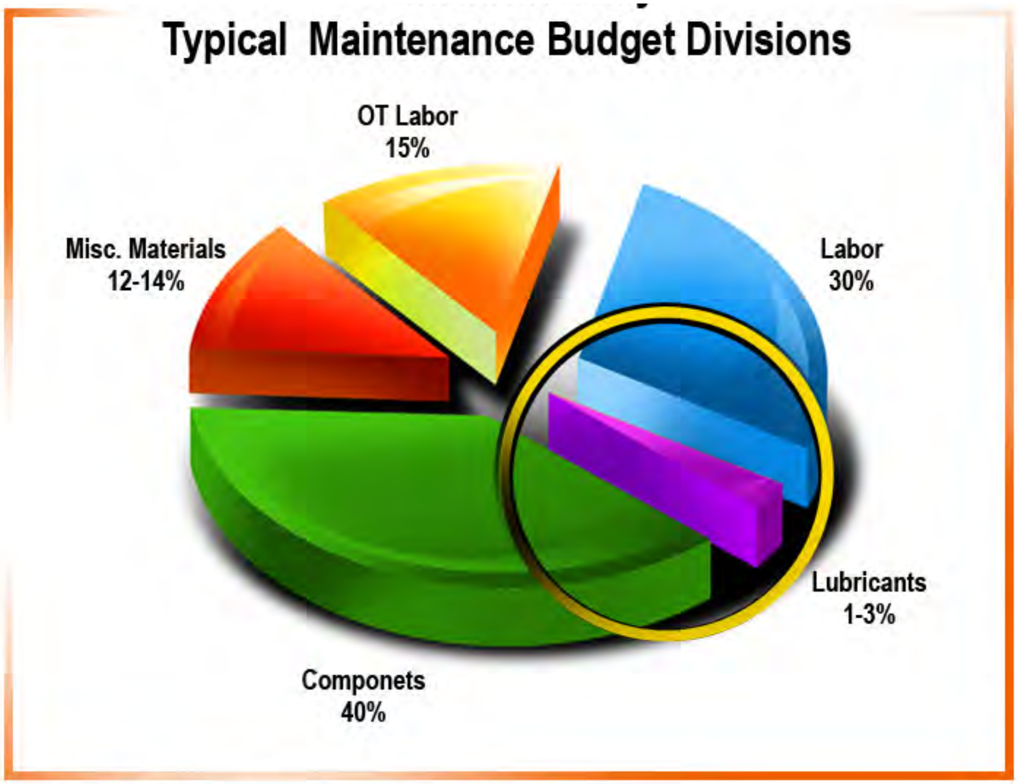
Focus On Meaningful Results

One of the smallest cost items in the budget directly influences 55% of total maintenance cost.



Plant Engineering Magazine Survey

Purposes for this Presentation

Focus on … – short term cost reduction!!!!!!!!!!!!

…. It's a rounding error!   **A false economy**

Mathematically, focusing on lubricants' cost control can't lift profits, the % values are too small.

However, simply cost-cutting without a plan – a strategy, a set of goals, a set of defined changes – can have the opposite effect.

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If You Want a Reliable Plant ….

- You Need to Develop a Strong Machine Lubrication Plan!
- The plan must be purposefully oriented toward *improving machine reliability, but you can sell short term cost reduction @ the same time!*
- The plan must have Visible, Vocal management support for an extended period of time.

Question 3

- What is the purpose of the financial analysis?
  A. To demonstrate to management how money will be used.
  B. To project to management how much is expected to be paid back to the company.
  C. To project how quickly money will be paid back to the company
  D. All of these should be included.

Question 4

- Why is short term cash flow an important consideration?
  A. Because the payback is bigger than the long term return from improved machine health.
  B. Because it is impossible to calculate a long term ROI.
  C. Because the short term improvements are highly desirable in a down economy.
  D. Short term cash flow is not really important because the returns are too small.

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Step 2: Assess the current process and practices

Find Out Where You Are Now, Because…

It's hard to know the right course to take if you don't know the starting point!

Conduct a survey and gap analysis, compare existing practices to an objective standard.

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Assessment Criteria

Program Measurement Topics

1	Vendor Selection Process
2	Lubricant Delivery, Storage & Handling Process
3	Lubricant Technical Selection Practices
4	Lubricant Application Practices
5	Oil Analysis Program Practices
6	Condition Control Practices
7	Program Management & Personnel Development
8	Lubrication Practices Standardization (SOP's)
9	Safety, Health and Environmental Practices

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Step2, Part I: Conduct a Survey…

The starting point of the survey probably should be ***Lubricant Receipt & Storage.***

Lubricant Storage, Delivery and In-plant Handling Process	0.44	6.06	2.69
In-plant receipt and handling practices	0.80	7.75	6.20
The lubricant is delivered to a covered storage area	0		
The lubricant container is tightly sealed, and in good condition	1	9	
The lubricant container is clearly marked	1	9	
The lubricant container displays the date of packaging	1	8	
Upon receipt, the lubricant container is marked with the internal proprietary plant lubricant coding system	1	5	
In-plant Central storage practices	0.50	4.00	2.00
A min-max inventory control level is established for each product at central stores	1	5	
The lubricant is stored in a climate controlled location (covered, dry, constant temperature)	1	3	
Products are rotated upon receipt such that the oldest material is always pulled for use first (FIFO)	0		
All containers at and greater than 55 gallons are storeed with an appropriate level of containment	0		
Semi-bulk storage containers are scheduled for periodic cleaning and DOT fitness testing			

Survey Part I : Survey Results

In-plant Open Stores Practices	0.33	5.50	1.83
A min-max inventory control level is established for each product at each inventory location	0		
The number of units (gallons, drums, pails, etc..) of each product at each location is maintained between the min/max levels	0		
The open lubricant stores are maintained in a near climate controlled location (covered, dry)	0		
The open oil containers are fitted with breathers on their air relief vent ports	0		
Grease packaged in tubes is stored in a vertical orientation	1	8	
Only one container of a given product is open at a given time (only 1 drum of X, only 1 pail of X, only 1 keg of X) at each in-use stores location	1	3	
In-plant Handling Practices	0.14	7.00	1.00
All lubricant handling utensils (funnels, brushes, oil dispensers, etc..) are staged in a dedicated storage cabinet when not in use	0		
All lubricant handling containers are clearly marked with their designated product type	1	7	
All lubricant handling containers are maintained in a clean condition	0		
All lubricant handling utensils are clearly marked with their designated product type	0		
All lubricant handling utensils are maintained in a clean condition	0		
Lubricants that are in-use (in a dedicated handling container) are staged in clearly designated locations inventory locations	0		
All Lubricants (except ISO 680+) designated for highly critical applications are pre-filtered prior to placement in the machine	0		

Existing Practices Survey

Lubrication Program Item	Obj. Score	Qual. Score	Rating
Lubricant Delivery, Storage & In-plant Handling	0.4	6.1	2.7
In-plant receipt and handling practices	0.8	7.8	6.2
In-plant Central storage practices	0.5	4.0	2.0
In-plant Open Stores Practices	0.3	5.5	1.8
In-plant Handling Practices	0.1	7.0	1.0

- Central storage, in-use storage, and handling practices compromise the health of both lubricants and machines.
- Lubricant storage requires isolation (dry, steady moderate temperature, isolated from atmosphere)
- Lubricant handling requires same care plus limiting any risk of cross contamination of lubricants by tagging machines, containers and stores, clearly identifying all applications by product type and grade

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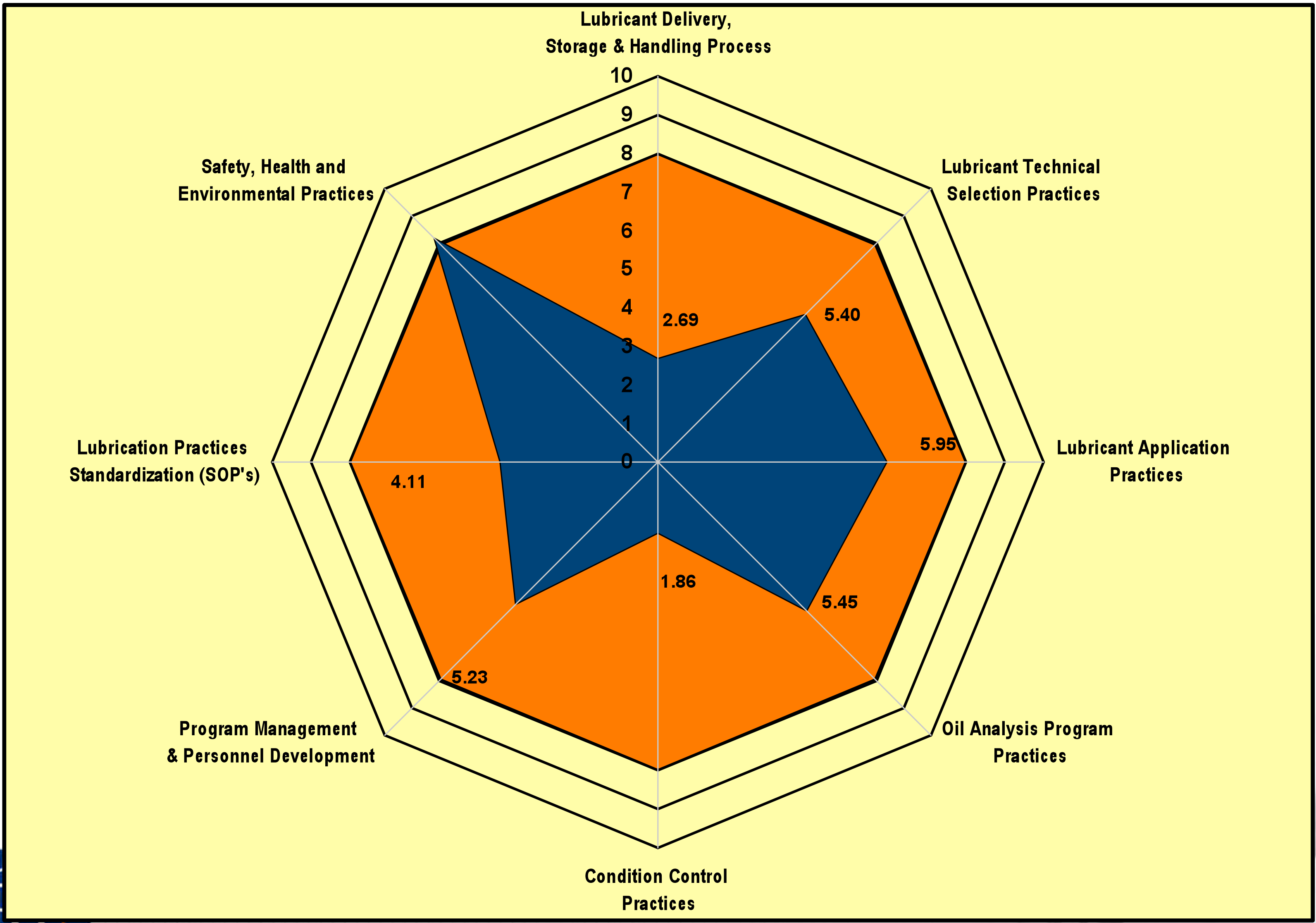
Survey Overview Diagram



Question 5

- Why is the value of a objective assessment of program conditions?
  A. Sets the starting point for all to see.
  B. Enables accurate comparison to original conditions over times
  C. Helps clearly define what is important to the plant
  D. All of these are highly valuable.

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Step 2, Part II: Criticality Assessment

Conduct a Machine Criticality Assessment

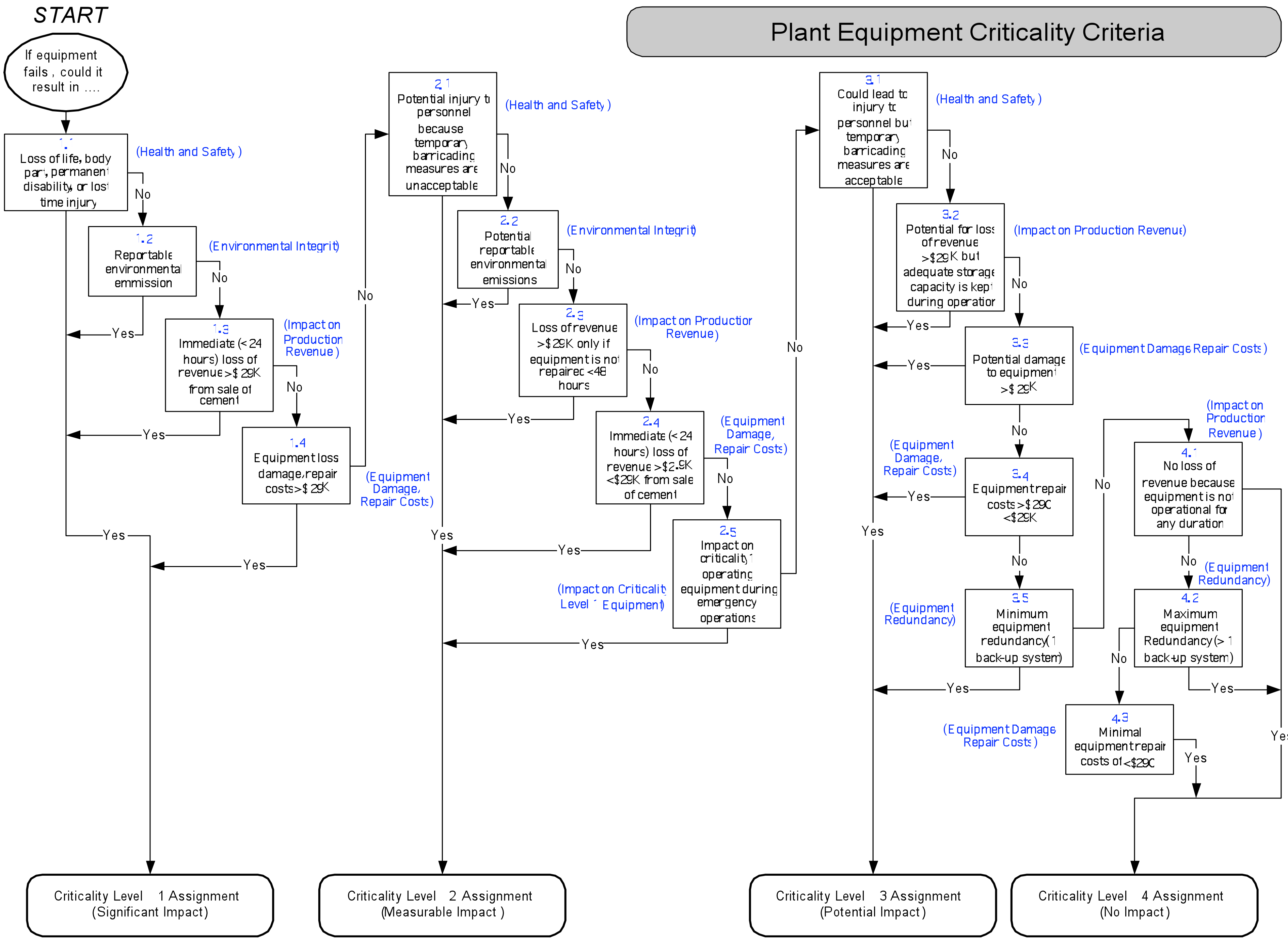
- Risk Assessment - Incorporates risk evaluation for:
  - Environmental Hazard
  - Employee Health and Safety
  - Lost Production Potential
  - High Maintenance Cost Potential
  - Plant specific points of interest

Step 2, Part II…..

You will need to find an Assessment Tool

The tool helps to keep all the details organized

for example ….



NOTE: Impact is measured during peak demands for production

Equipment Relative Importance Criteria Table

		Equipment Classification (Duty Cycle / Operating Environment)			
		Severe / Harsh	**Severe / Mild**	**Non-Severe / Harsh**	**Non-Severe / Mild**
Equipment Criticality	**Level 1**	Level A	Level B	Level B	Level C
	Level 2	Level B	Level C	Level C	Level D
	Level 3	Level C	Level D	Level D	Level E
	Level 4	Level D	Level E	Level E	Level F

Equipment Relative Importance Level Legend:

Criticality Level 1 + Severe Duty Cycle + Harsh Operating Environment =	**Level A**
Criticality Level 2 + Severe Duty Cycle + Harsh Operating Environment =	**Level B**
Criticality Level 1 + Severe Duty Cycle + Mild Operating Environment =	**Level B**
Criticality Level 1 + Non-Severe Duty Cycle + Harsh Operating Environment =	**Level B**
Criticality Level 3 + Severe Duty Cycle + Harsh Operating Environment =	**Level C**
Criticality Level 2 + Severe Duty Cycle + Mild Operating Environment =	**Level C**
Criticality Level 2 + Non-Severe Duty Cycle + Harsh Operating Environment =	**Level C**
Criticality Level 1 + Non-Severe Duty Cycle + Mild Operating Environment =	**Level C**
Criticality Level 4 + Severe Duty Cycle + Harsh Operating Environment =	**Level D**
Criticality Level 3 + Severe Duty Cycle + Mild Operating Environment =	**Level D**
Criticality Level 3 + Non-Severe Duty Cycle + Harsh Operating Environment =	**Level D**
Criticality Level 2 + Non-Severe Duty Cycle + Mild Operating Environment =	**Level D**
Criticality Level 4 + Severe Duty Cycle + Mild Operating Environment =	**Level E**
Criticality Level 4 + Non-Severe Duty Cycle + Harsh Operating Environment =	**Level E**
Criticality Level 3 + Non-Severe Duty Cycle + Mild Operating Environment =	**Level E**
Criticality Level 4 + Non-Severe Duty Cycle + Mild Operating Environment =	**Level F**

Impact from Criticality Differences…

Level A and B	High Performance Products, Continuous Feed, Continuous Lubricant Filtration / Conditioning, Planned and Scheduled Replenishment and Inspection, Weekly Onsite and Monthly Lab Based Analysis
Level C and D	Conventional Products, Periodic Filtration, Planned Replenishment, Quarterly Analysis
Level E and F	Conventional Products, Planned Replenishment

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Question 6

- Why is the value of a machine criticality assessment?
  A. Prevents waste of time on unimportant machines.
  B. Helps to ID which activities should incorporate advanced condition assessment tools
  C. Helps to ID the machines that should be considered for upgrades
  D. All of these are highly valuable.

Implementing Reliability Centered Lubrication

Step 2, Part III : Develop, communicate objectives

Set some goals and objectives!

- ✓ They should reflect the findings of the benchmark / practices survey.
- ✓ They should be criticality specific
- ✓ May also be machine specific
- ✓ They should be measureable.

7 Steps…., Step 2, Part III

Examples of Useful Goals and Objectives

1. Purpose to:
   - improve efficiency of task scheduling
   - achieve 95% compliance for 'first run' completion of scheduled relubrication work orders (Year 1, maybe better in the following years).
   - reduce oil consumption without hurting machines
2. Put all Level A and Level B machine oil sumps on some kind of lubricant analysis –
   - the Navy way – Color Right, No Sediment, No Haze – Done!
   - any observed differences – to a lab we go
   - all sumps over X gallons get looked at frequently (you decide the limit)
3. Maintain a cleanliness rating of ISO 21/19/17 or better on <u>all</u> oil-based sumps; 19/17/15 on Level A/B static sumps;16/14/13 on Level A/B circulation and hydraulic systems.

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Continued…

4. Put all Level C and D sumps on routine analysis and convert all sumps at >= 35 gallons to condition based change intervals.
5. Rationalize all grease intervals for machine operating context.
   - Open Gears – huge waste of lubricants and labor is common
   - Show you more shortly
6. Automate grease requirements with ≤ weekly planed intervals.
7. Teach Operators how to properly check oil levels, and set up a bi-weekly schedule to make sure it gets done
   - starts with Plant Production Manager, Production Supervisors
   - DAILY FOLLOW-UP for at least 1 Month, weekly thereafter

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Continued…

9. Shift lube techs to addressing the problems that make you drink oil:
   - Find and fix the machine leaks
     - Only 20% - specialized fittings and redesigns
   - Repair gaskets, close lids, install vent filters
   - Replace lip seals before there's a runny mess
   - Identify need for and install passive shields
   - Fix and re-set the automatic lubrication systems
     - Compressors – oil lost to poor separator function – tighter control
     - Grease supply – 10 to 100 times TOO MUCH GREASE is common. If you need that much, you are using the wrong product
   - Improve sump oil condition (fans, heat exchangers, headspace blowers/vacuums, kidney loop filtration)
   - Use HP greases to extend relube intervals, synthetics and HP mineral oils to triple sump change intervals, but DON"T DO IT BLIND!

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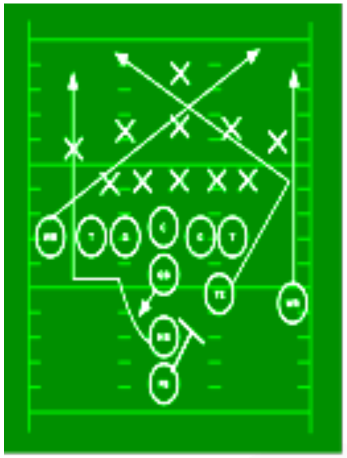
Step 2 – Communicate the Plan

Installing a new offense requires that the coach:

1. Communicate CLEARLY what is going to happen
2. Provide a playbook with the plays clearly diagramed.
3. Match the talent to the role – responsibility
4. Drill, Drill, Drill, Drill, Drill

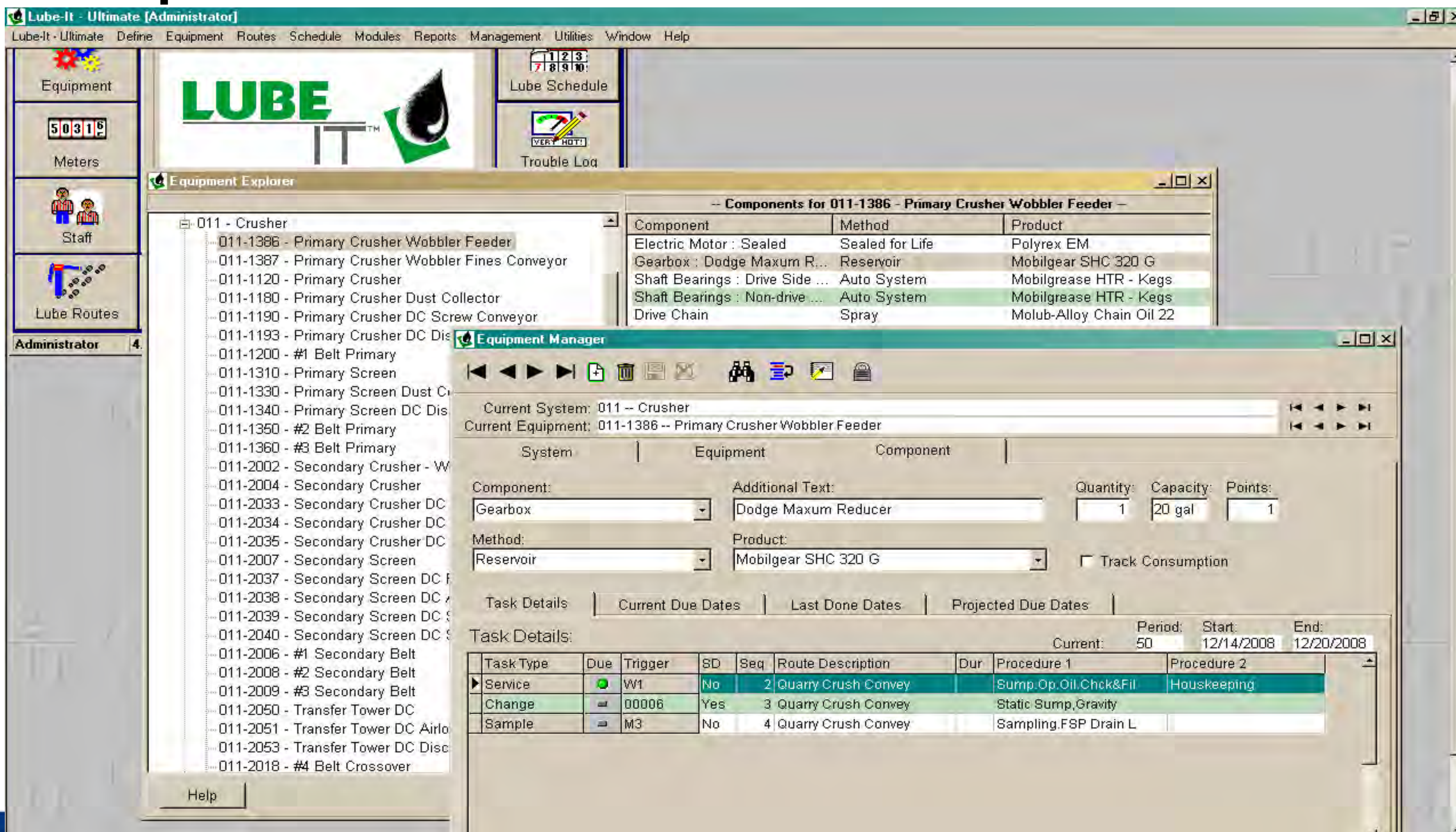


Play Number 2

Program Development –
Multi-Department Responsibility

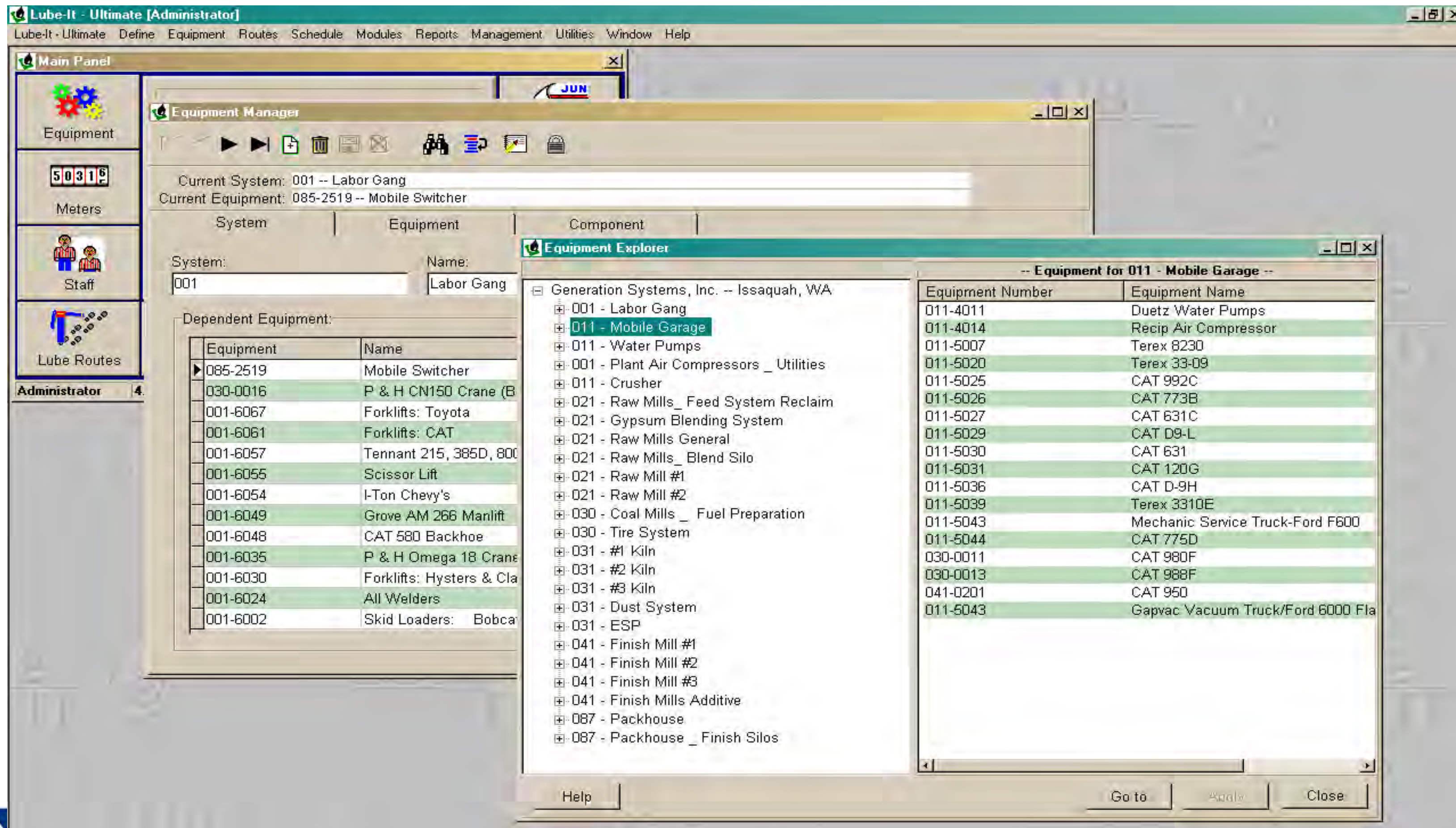
Implementing Reliability Centered Lubrication

Step 3. Decide how the information will be stored, managed



Completing the Survey

Step 3. Lubrication Management Program



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Implementing Reliability Centered Lubrication

Options to consider

- CMMS – Quality Routing Function
  - If it exists in your version
  - If your hierarchal structure ends with the component (vs. the machine, or asset)
  - If you can schedule and close entire routes with a keystroke
- Viable Programs – based on personal experience
  - Maintelligence (Desmaint.com)
  - LubeIT (Generationsystems.com)

Implementing Reliability Centered Lubrication

Step 4 : Conduct a reliability centered lubricant requirements assessment

Define the lubrication requirements for each machine, and each lubricated part!

Physical audit –

- Product type, grade, volume, frequency
- Contamination sensitivity and requirements
- Oil analysis requirements and alarm settings set by machine priority

Contrast with machine OEM recommendations.

Document your findings

Create SOP's for each machine

System Components to Consider

Coal Conveyor Drive System

Building the Survey

Begins with, Define Detail of Lubricated Components

Items	Make	Model	Details
Drive Train - Conveyor A1			
Motor	GE	5KS511SN3260HB	Frame
			Shaft Diameter
			RPM
			Orientation (Horizontal vs Vertical)
			Each Bearing Number
			Each Bearing Make and Model
			OEM Lubricant Fill
			Operating Conditions
Coupling	Falk	1080T	Type
			Physical Dimensions
			OEM Stated Lubricant Capacity
			OEM Stated Relube Interval

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Implementing Reliability Centered Lubrication

Step 4, continued. Create a Database of Machine Details

Bearing info: SKF standard steels			**convert inches to mm**		
	INPUTS		dimension in inches	3	in
outer diameter (mm)	76.2	mm	dimension in mm	76.2	mm
bore diameter (mm)	38.1	mm			
rpm	600	rpm			
min vis for EHD: v(L10)	35.91173	cSt	at operating temp		
			http://www.geocities.com/CapeCanaveral/3655/VI.html		
current vis at op temp	26	cSt	current MTBF	54	
EP? (Y/N)	Y		Particle count (PC)	21	ISO 4406 range # > 14 microns
K	0.723997		current moisture	800	ppm
L10 lubricant correction factor	0.828166				
			proposed (PC)	19	ISO 4406 range # > 14 microns
proposed vis at op temp	60	cSt	particle life extension factor	1.441379	
EP? (Y/N)	Y		proposed moisture	600	ppm
K	1.670763		moisture life extension factor	1.163705	
L10 lubricant correction factor	1.343851				
					factors included
lubricant life extension factor	1.622684		life extension factor	1.622684	lubricant
			expected MTBF	87.62491	lubricant
include lubricant? (Y/N)	Y				
include particle? (Y/N)	n				
include moisture? (Y/N)	n				

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Implementing Reliability Centered Lubrication

Step 4, continued. Compile the details, create the schedule

Name	Sub-Assembly	Product	Qty.*	Number of Points	Relubrication Cycle	Method of Application	Analysis	Test Slate	Lubrication Procedure
Conveyor A1									
	Motor	#2 RB	14	2	Semi Annual	Pressure Gun	NA	NA	Motor Relubrication
	Coupling	#2 Cplg	6	2	Annual	Pressure Gun	NA	NA	Gear Coupling
	Gearbox	220 - EP	55	1	Weekly	Oil Bath	Quarterly	Tests	Gearbox Top-up
	Drive Roll	#2 EP	121	2	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	Snub Drive Roll	#2 EP	95	2	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	High Tension Roll	#2 EP	95	2	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	Tail Pully Roll Brng	#2 EP	95	2	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	Bend Pully Roll Brng	#2 EP	41	8	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	Snub Head Roll Brng	#2 EP	95	1	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	Head Pully Roll Brng	#2 EP	95	1	Bi Monthly	Pressure Gun	NA	NA	Bearing Relubrication
	Idler Bearings	#2 EP	2	Misc.	Annual	Pressure Gun	NA	NA	Bearing Relubrication

* Volume in shots for grease, gallons for oil.
#2 EP = #2 Extreme Pressure Grease
#2 RB = #2 Ball and Roller Element Grease
#2 Cplg = #2 Coupling Grease
To calculate shots for a given grease gun, estimate ..0352 grams per oz., and extrapolate to number of shots.

Motor Relubrication Procedure   Coupling Relubrication Procedure   Filtration

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Completing the Survey

Step 4, continued. Create Standardized Practices

Thorough, practical procedures are a precursor to efficient and sustainable precision lubrication.

A thorough survey will lead seamlessly to the development of reliability centric work procedures

Lubrication Standard Operating Procedure

Relube - LC&I	Oil Level Check and Top-up	0
Procedure ID	Procedure Name	Machine ID

#2 Finish Mill	Motor	Plain Bearing	
Machine Name/Type	Component Type	Sub-Component Type	
High	Running	In-board / Out-board	Gallon
Criticality	Required Machine Operating State	Component Position	Volume Unit

Relubrication Activity

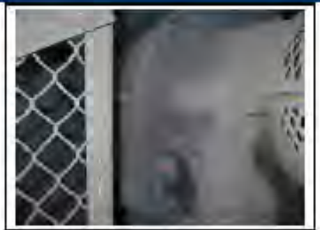
ISO 68 - R&O	Oil Level Check and Top-up	1	Week	1	Gallon
Lubricant Type	Relubrication Function	Service Frequency		Sump Volume	

Procedure name: Machine Relubrication Oil Level Check and Top-Up

Procedure Purpose: This procedure provides a step by step explanation for checking the oil level and adding lubricant to a reservoir that is low.

Material Requirements: Minimum 5 liter lubricant top-up container fitted with a spout, appropriate lubricant, channel locks, clean cloth, waste oil pan, note pad.

Safety Precautions: Follow plant guidance on Zero Energy State work requirements.



Page 1 of 3

Relube - LC&I	Oil Level Check and Top-up	0
Procedure ID	Procedure Name	Machine ID

Step 1: **Secure a safe energy state for the activity.**
This procedure is typically conducted while the machine is running. Follow site lock-out / tag-out guidelines for non-invasive relubrication and inspection work.

Step 2: **Verify that the work order and machine ID match.**
Verify that the machine ID and sump type identified on the work order matches the sump under consideration. If it doesn't then locate the correct machine or machine sump and proceed.

Be careful to use only the designated lubricant, and no substitutes.

Step 3: **Inspect the sump oil level indicator for proper fill.**
Locate the sight glass, dipstick, level port and inspection port locations on the lubricant sump.

Remove and secure any covers or guards as required to verify the correct sump level.

Using a clean, lint-free cloth, wipe any remaining soil, deposits and debris from the fitting of interest and the surrounding area.

Carefully remove any debris or accumulated lubricant from around the lubricant sump to allow for observation of the seal area during and following the application of lubricant.

If the sump level indicator shows the oil level to be above the 'high' or below the 'low' level marks for the current operating state, a volume adjustment is required.

Step 4: **Correct the sump oil level by adding or draining the appropriate lubricant.**
Carefully remove any inspection plates or port covers that must be removed for proper lubricant application.

Remove the fill port plug(S) and set it aside. Be careful to assure that it does not become contaminated.

If quick connect couplings have been installed on the unit, then a portable filter pump may be used to handle the lubricants during top-up, drain and fill activities.

Using an appropriate application device, carefully add an adequate volume of the designated lubricant to the lubricant sump to bring the oil to the designated 'full' mark on the sump level indicator.

Page 2 of 3

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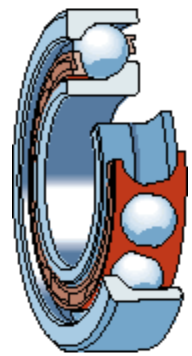
Example #1

Lubrication Practice Method for Greased and Oiled Element Bearings

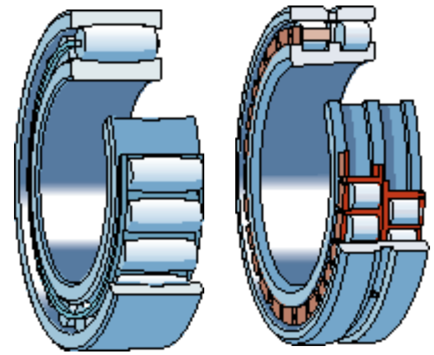
Selection Guidelines – Element Bearings

Ball - Axial

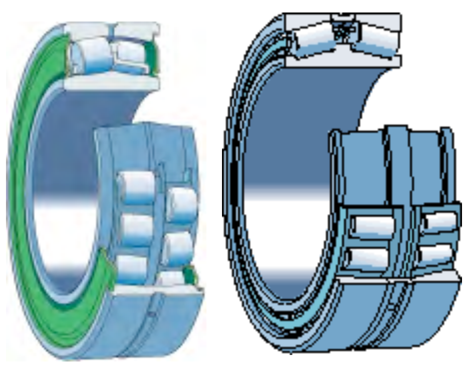
Ball - Thrust



Cylindrical Roller



Spherical Roller



Needle Roller

Courtesy Lubcon, GMBH

Selection Guidelines – Element Bearings

Oil or Grease?

Step 1 - Estimate Bearing Angular Velocity,

$$nDm = n * \frac{(ID + OD)}{2}$$

where,

nDm = Pitch Line Velocity of the Element,

speed that the middle of the element moves around the circle.

n = shaft speed

ID = Bore Diameter

OD = Outside Diameter

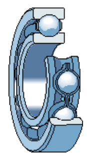
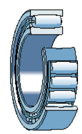
Selection Guidelines – Element Bearings

Step 2 - Compare nDm values to recognized standards

Note: These parameters are a reflection of concern over grease stability more than bearing construction.

Border line values are not absolute. If an element is operating above the noted speed limit it will require more frequent lubrication to maintain long term reliability.

Common Element Bearing Speed Factors, nd_m

Bearing Type [c]	Oil Lubricated [a]	Grease Lubricated
Radial Ball Bearing 	500,000	340,000
Cylindrical Roller Bearing 	500,000	300,000
Spherical Roller Bearing 	290,000	145,000 [b]
Thrust, Ball and Roller 	280,000	140,000

a. Oil lubrication is preferred where heat dissipation is required

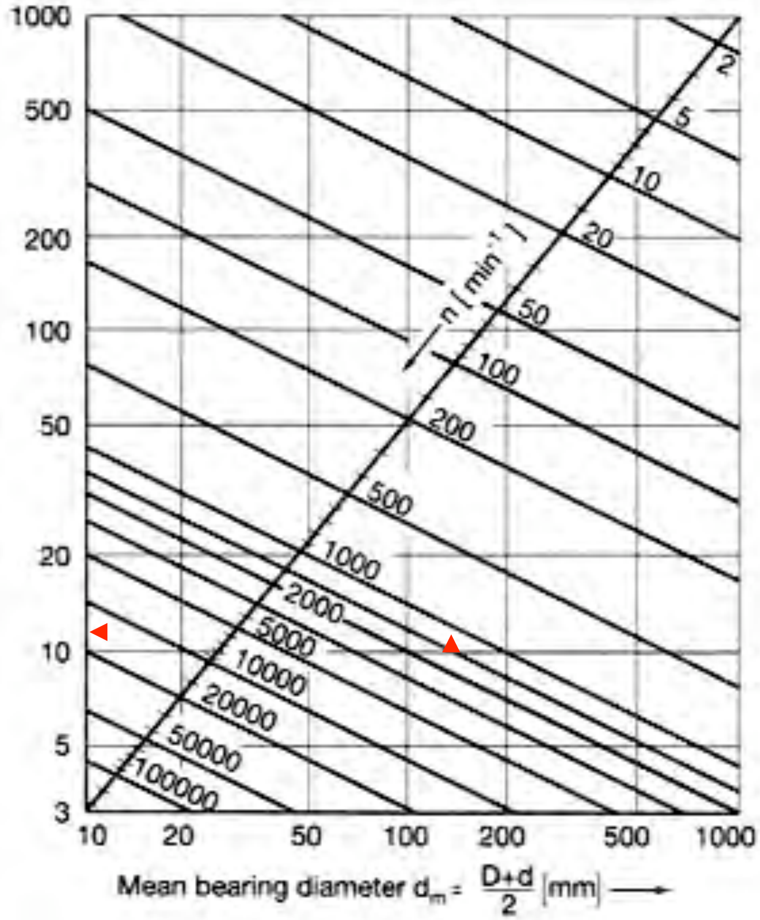
b. Grease lubrication is not recommended for spherical roller thrust bearings

c. Precision bearings and high performance lubricants allow 5 to 50% higher operating ranges.

Piro, Wessel. Lubrication Fundamentals, 2nd Edition. Page 197

Viscosity and Lubricant Selection

Step 3. Estimate required operating viscosity



V_{min} =27,878 * RPM $^{-0.7114}$ * Dm $^{-0.52}$

or

a. Using Chart, plug Dm.

b. At intersection of Speed and Dm line, find minimum allowable viscosity

c. Ideal Viscosity = 3 * lower limit.

FAG Bulletin WL 115/4 EC/ED 97/6/2000

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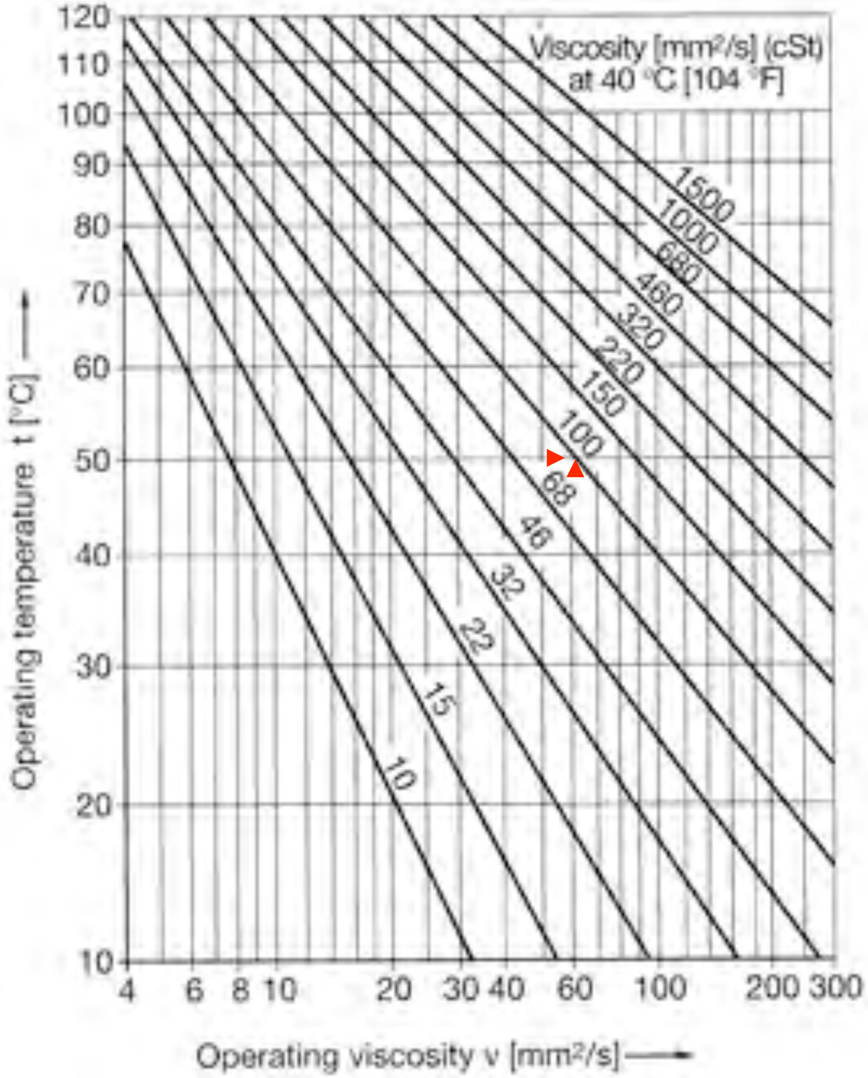
Viscosity and Lubricant Selection

Step 4. Verify actual viscosity vs. required viscosity.

a. Identify the viscosity type from the available options.
b. Find the operating temperature on the left axis.
c. Draw a line to the intersection point of the select VG Grade.
d. The 'expected' operating viscosity is at the bottom of the chart.



FAG Bulletin WL 115/4 EC/ED 97/6/2000

Grease Application Frequency

Step 5: Replacement Interval

$$T = K \times \left\{ \left(\frac{14{,}000{,}000}{n \times (d^{0.5})} \right) - 4 \times d \right\}$$

T = Time until next interval, hours

K = Product of Conditional Factors

n = Shaft Speed

d = Shaft Size (bore) in millimeters

(1 inch = 25.4 millimeters)

	Bearing Relubrication Frequency Correction Factors			
	Condition	Average Operating Range	Factor	Value
	Bearing Bore (in)	3.425		3.425
	Shaft Speed (rpm)	1785		1785
1	Svc Factor (Ft)	Temperature		1
		Housing below 150 F	1	
		150 to 175 F	0.5	
		175 to 200 F	0.2	
		Above 200 F	0.1	
2	Svc Factor (Fc)	Contamination		1
		Light, non-abrasive dust	1	
		Heavy, non-abrasive dust	0.7	
		Light, abrasive dust	0.4	
		Heavy, abrasive dust	0.2	
3	Svc Factor (Fm)	Moisture		1
		Humidity mostly below 80%	1	
		Humidity between 80 and 90%	0.7	
		Occasional condensation	0.4	
		Occasional water on housing	0.1	
4	Svc Factor (Fv)	Vibration		1
		Less than 0.2 ips velocity, peak	1	
		0.2 to 0.4 ips	0.6	
		Above 0.4	0.3	
5	Svc Factor (Fp)	Position		1
		Horizontal bore centerline	1	
		45 degree bore centerline	0.5	
		Vertical centerline	0.3	
6	Svc Factor (Fd)	Bearing Design		1
		Ball Bearings	10	
		Cylindrical and needle roller bearings	5	
		Tapered and spherical roller bearings	1	
			Calculated PM cycle (hr) ……..	493
			Calculated PM cycle (day) ……..	20.5382
			Calculated PM cycle (mo.) ……	0.685

Machine Re-grease Frequency Factors

- All machines operate differently.
- This provides a 'volume' correction based on the operating condition.
- Multiply the factors (green) to arrive at a frequency to relubricate the elements.
- Less volume, more frequently is always better

	Bearing Relubrication Frequency Correction Factors			
	Condition	Average Operating Range	Factor	Value
	Bearing Bore (in)	3.425		3.425
	Shaft Speed (rpm)	1785		1785
1	Svc Factor (Ft)	Temperature		1
		Housing below 150 F	1	
		150 to 175 F	0.5	
		175 to 200 F	0.2	
		Above 200 F	0.1	
2	Svc Factor (Fc)	Contamination		1
		Light, non-abrasive dust	1	
		Heavy, non-abrasive dust	0.7	
		Light, abrasive dust	0.4	
		Heavy, abrasive dust	0.2	
3	Svc Factor (Fm)	Moisture		1
		Humidity mostly below 80%	1	
		Humidity between 80 and 90%	0.7	
		Occasional condensation	0.4	
		Occasional water on housing	0.1	
4	Svc Factor (Fv)	Vibration		1
		Less than 0.2 ips velocity, peak	1	
		0.2 to 0.4 ips	0.6	
		Above 0.4	0.3	
5	Svc Factor (Fp)	Position		1
		Horizontal bore centerline	1	
		45 degree bore centerline	0.5	
		Vertical centerline	0.3	
6	Svc Factor (Fd)	Bearing Design		1
		Ball Bearings	10	
		Cylindrical and needle roller bearings	5	
		Tapered and spherical roller bearings	1	
			Calculated PM cycle (hr)	493
			Calculated PM cycle (day)	20.5382
			Calculated PM cycle (mo.)	0.685

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Viscosity and Lubricant Selection

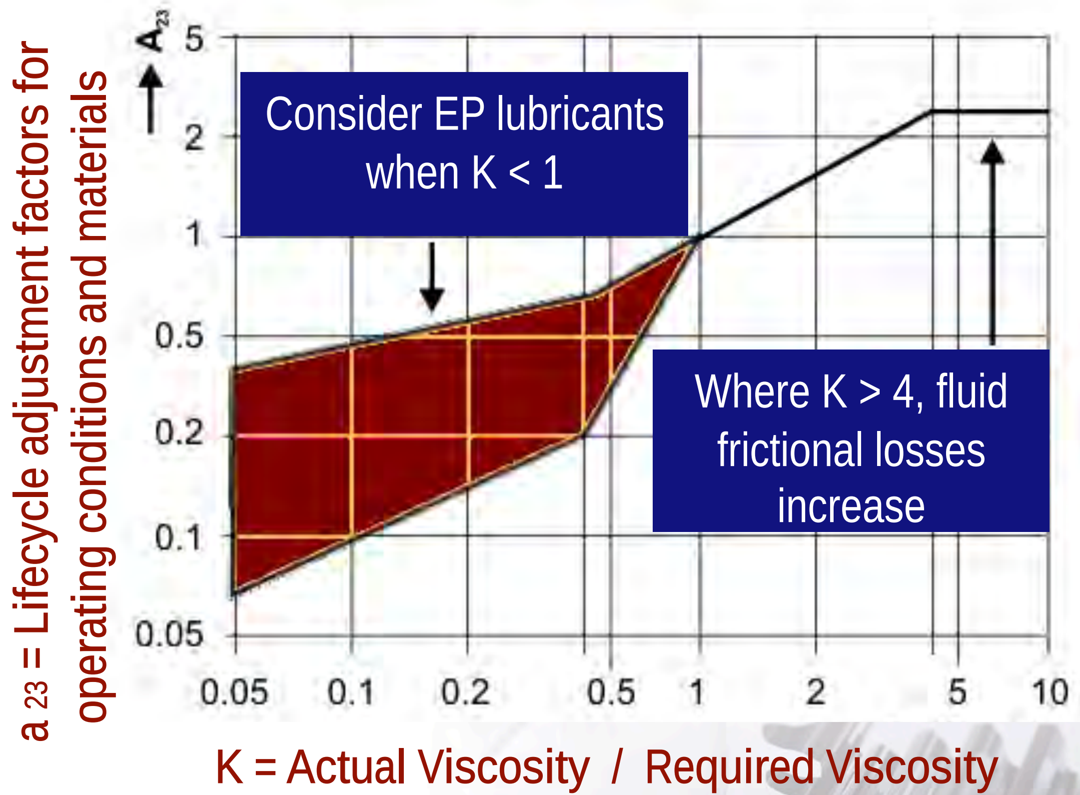
Step 6. Select the additive type.

a. A K (Kappa) value of 1 – 3 is preferred.

b. There is no benefit to operating above K=4. Higher values create fluid friction losses.

c. If actual viscosity is > 1 times minimum required, an AW or R&O type lubricant is appropriate

d. If actual viscosity is ≤ 1 times the allowable minimum, expect to see boundary lubricating films. These require the use of EP type additives.



Moller Boor. Lubricants in Operation.

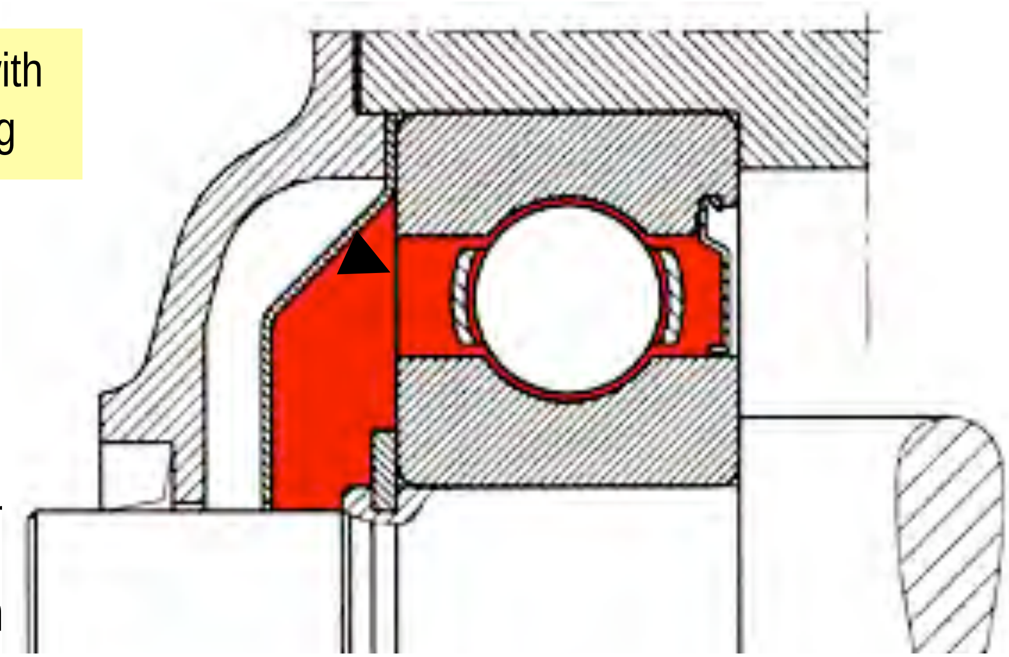
Grease Housing Fill Amount

Step 7. Select the correct volume

Baffle installed with element bearing

Replacement Volum

- W = bearing width
- O.D. = Outer Diameter
- .005 = Space Factor - mr
- .114 = Space Factor - in



The SKF Volume Estimate is a qualified estimate of the needed volume of the grease between the elements. The new displaces the old. It is not intended to 'fill' the housing void.

Grease Lubrication Management

There are tools available to help determine the technically correct state.

<u>Grease Wheel,</u> based on bearing size and speed:

- Oil viscosity
- Starting point viscosity
- EP vs R&O
- Frequency
- Volume (grease)

There shouldn't be <u>any</u> guessing and loose estimates!!

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Example #2

Lubrication Practice Method for Geared Drives

Gear Oil Requirements

Correct Viscosity

- Determined by tooth geometry, ratio, shaft speed, loading, environmental conditions, lubricant type, operating temperature.

Load Support

- Lubricant must be able to prevent wear and seizure under extremely high unit loads and poor oil film conditions

Corrosion Control

- Lubricant must react instantly at activation temperature, but not below that point.
- Lubricant must be benign toward soft metal surfaces.

Chemical Stability

- Prevent oxidation at elevated temperature

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Photo: John Brown Company

Selection Guidelines – Gears

The tooth form dictates the initial frictional mode (sliding, rolling).

Speed, surface area and viscosity determine the operating frictional mode.

Sliding & Rolling

Sliding

Lubrication Regimes

Film type is determined by oil vis., wheel speed & load, tooth form

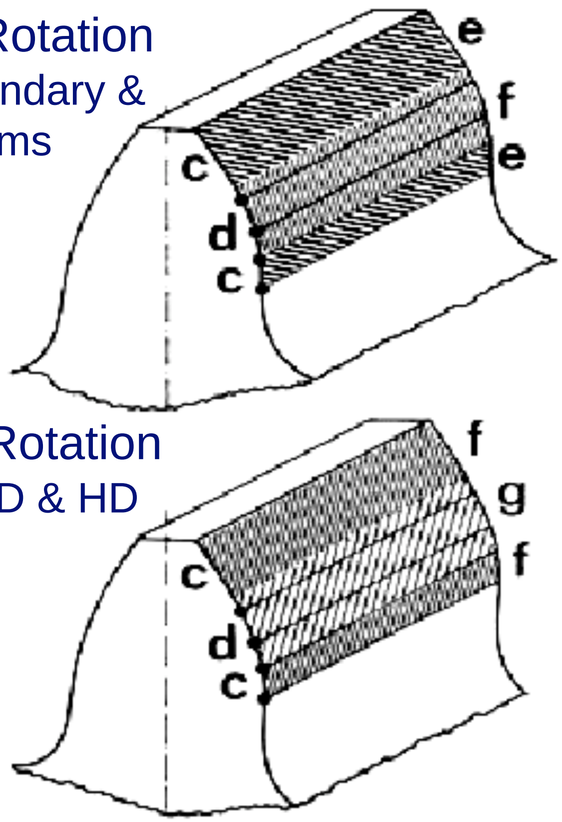
Gear Tooth Type	Low Speed Wheel <100 RPM			High Speed Wheel > 1000 RPM			EP
	Pitch Line	Tip	Root	Pitch Line	Tip	Root	
Spur	Boundary	Boundary	Boundary	EHD	HD	HD	Yes
R. Angle Spur	Boundary	Boundary	Boundary	EHD	HD	HD	Yes
Helical	Boundary	Boundary	Boundary	EHD-HD	HD	HD	Yes
R. Angle Helical	Boundary	Boundary	Boundary	EHD-HD	HD	HD	Yes
Hypoid	Boundary	Boundary	Boundary	HD	HD	HD	Yes
Worm	Boundary	Boundary	Boundary	HD	HD	HD	NO
Open Gear	Boundary	Boundary	Boundary	NA	NA	NA	Yes

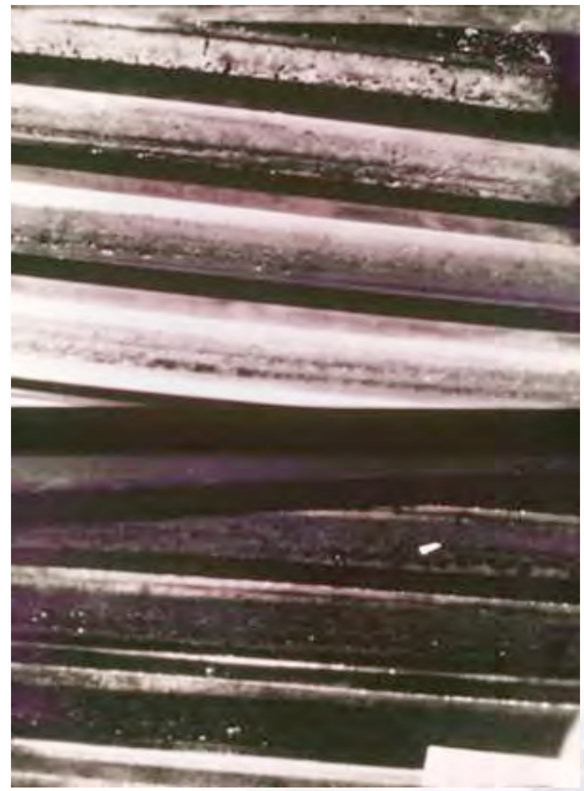
HD = Hydrodynamic Lubrication; EHD = Elasto-hydrodynamic Lubrication

Selection Guidelines – Gears

Low Speed Rotation
Produces Boundary & Mixed Films

High Speed Rotation
Produces EHD & HD Films

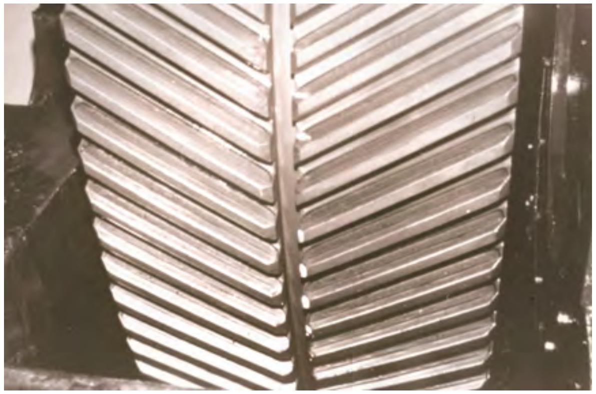




c. Single engagement Region d. Double engagement Region

d. Boundary Film e./f. (Top) Mixed Film f./g. (Bottom) Mixed Film

Selection Guidelines – Gears



1. Viscosity must flow well enough to coat surfaces with high angular velocities, AND must be stiff enough to resist the squeezing of the lower speed gears.
   - Identify the viscosity designation provided by the OEM – 150 cSt to 460 cSt
     - Verify the OEM selection through comparison to AGMA standards.

2. The additive type is selected based on the type of materials used in gear tooth construction, and based on the expected lubricant film condition.
   - Non-EP oils (Compounded oils) for Sliding gears (which rely on soft metals that can corrode under common operating conditions)
   - EP oils for non-sliding gears (Spur, helical, bevel, spiral bevel, hypoid)

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Selection Guidelines – Gears

<u>Falk 'Cube'</u>

- Helical Gears
- Element Bearings
- Moderate input speeds
- Low output speeds
- Durable when properly engineered

<u>Operating Conditions</u>

- Tend to run hot
- Film Conditions
  - EHD, HD
    - Pinion, Bearings
  - Mixed, Boundary
    - Intermediates
    - Final reduction

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AGMA Enclosed Gear Classification

ISO VG Grade	R & O	EP	Synthetic
32	0		0S
46	1		1S
68	2	2EP	2S
100	3	3EP	3S
150	4	4EP	4S
220	5	5EP	5S
320	6	6EP	6S
460	7	7EP	7S
680	8	8EP	8S
1000	8A	8AEP	
1500	9	9EP	9S
2200	10	10EP	10S
3600	11	11EP	11S
6120-7480 cSt @ 40ºC	12	12EP	12S
190-220 cSt @ 100ºC	13	13EP	12S

Selection Guidelines - Gears

Table B-3 - Viscosity grade[1)] at bulk oil operating temperature for oils having a viscosity index of 160[2)]

Temp °C	Pitch line velocity, m/s[3)]							
	1.0 - 2.5	2.5	5.0	10.0	15.0	20.0	25.0	30.0
10	32	32						
15	46	32	32					
20	68	46	32					
25	68	46	32	32				
30	100	68	46	32				
35	150	100	68	46	32			
40	150	100	68	46	32	32	32	
45	220	150	100	68	46	46	32	
50	220	150	100	68	46	46	46	32
55	320	220	150	100	68	68	46	32
60	460	220	150	100	68	68	68	46
65	460	320	220	150	100	100	68	46
70	680	460	220	150	100	100	100	68
75	680	460	320	220	150	150	100	68
80	1000	680	320	220	150	150	150	100
85	1500	680	460	320	220	220	150	100
90	1500	1000	680	320	220	220	220	150
95	2200	1500	680	460	320	220	220	150
100	3200	1500	1000	460	320	320	220	150

NOTES:

1) ☐ Consult gear, bearing and lubricant suppliers if a viscosity grade of less than 32 or greater than 3200 is indicated.
☐ Review anticipated cold start, peak and operating temperatures, service duty and range of loads when considering these viscosity grades.
☐ Select the viscosity grade that is most appropriate for the anticipated stabilized bulk oil operating temperature range.
☐ Baseline stabilized bulk oil operating temperature and bearing lubrication requirements.

2) This table assumes that the lubricant retains its viscosity characteristics over the expected oil change interval. Consult the lubricant supplier if this does not apply.

3) Determine pitch line velocity of all gear sets. Select viscosity grade for critical gear set taking into account cold startup conditions.

Pitch Line Velocity

(Meters Per Second)

= ((P.D. mm * RPM) / 19098))

Assumptions:

1. VI = 160, table for PAO oils ONLY. Full set of tables available at AGMA.
2. Measure Ea. Reduction
3. Select Vis that is best fit for each set of reductions

9005 – EO2 Standard

www.AGMA.org

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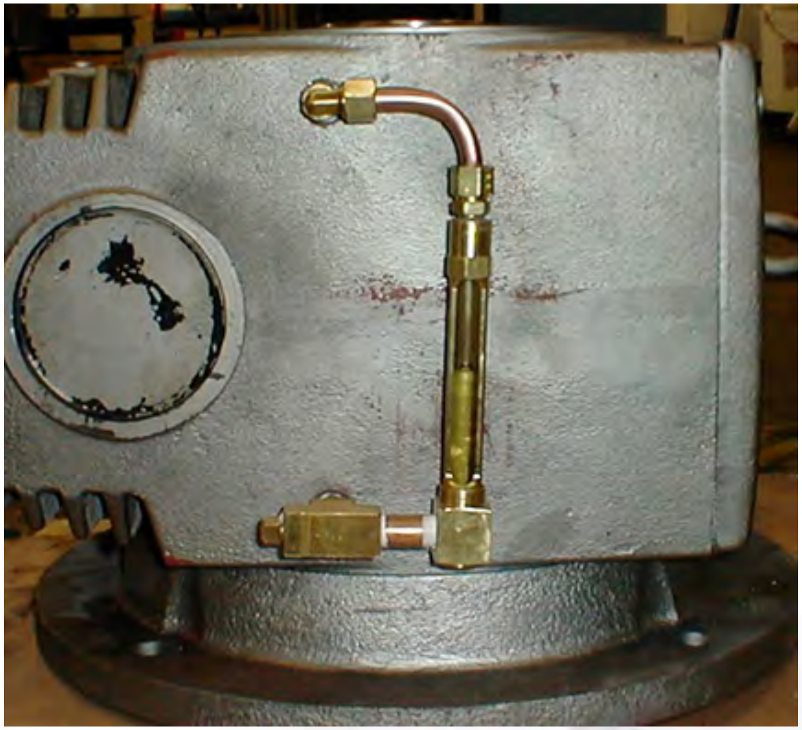
Lube Selection - Worm Gears

<u>Production Worm Drive</u>

- Worm Gears
- Element or Babbit Brngs
  - Two shafts to consider
- Low to medium input speeds
- Low output speeds
- Typical Failures – gears, bearings

<u>Operating Conditions</u>

- Tend to run cool
- Film Conditions
  - Bearings (EHD, HD, ??)
  - Gears (Mixed, Boundary ?)
    - Intermediates
    - Final reduction



AGMA Worm Gear Lubricant Selection Guideline

Additional Factors:

Drives with temperatures above the ambient limits, or PLV speeds above 10 m/s require the input of the gear OEM. AGMA recommends lubricant forced feed application and viscosity adjustments for these conditions.

ISO VG

Pitch Line Velocity of Final Reduction

(PLV Meters/Sec = (PD mm x RPM) / 19098; VI = 100

Ambient Temp °C	PLV <2.25 m/s	PLV > 2.25 m/s
-40 to - 10	ISO 220	ISO 320
-10 to +10	ISO 460	ISO 460
+10 to +55	ISO 680	ISO 460

Other Notes: a.) Synthetics: PAG's offer improved sliding performance over PAO synthetics. PAO product have been used successfully. b.) At temperatures above 180°F, PAOs provide better lubricity than mineral oils. At temperatures above 200°F, PAGs provide better lubricity than PAO's and MO's. The gear interface contact temperature is 40°F ± above case temperature. c.) Worm gear wear debris (Copper and Iron) is highly catalytic. Lubricants with superior oxidation resistance versus competitive brands is preferred. Although many companies use EP products in worm gear applications, the stronger additive chemistry coupled with the synergy of the combined wear metals makes this less desirable, if not to be expressly avoided. Coupled with wet oil and high temperatures, oxidation rates can be significant.

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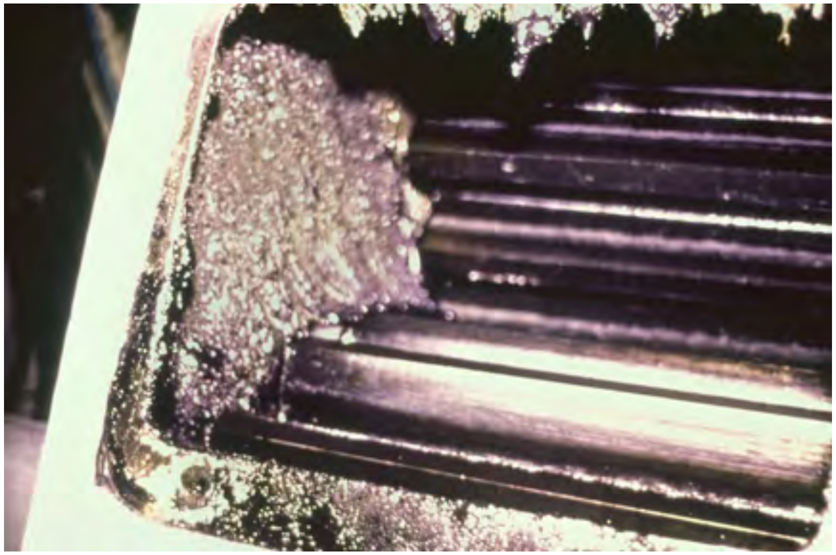
AGMA 9005 – EO2, page 23

Lube Selection - Open Gears



Open Gear Drive

- Gear Type?
  - ❑ Helical or Spur
- Input speeds ?
- Output speeds ?
- Durability?

Operating Conditions

- ❑ Very Heavily Loaded -
  - • Hi Viscosity grade Lubricant
- ❑ Tend to run hot (influences: ambient & kiln temp, forced draft)
- ❑ Film Conditions (Mixed, Boundary – too slow for HD, EHD)

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Kiln Girth Gear – Open Gears

Lubricant Type	Open Gear Lube General Description	Typical Operating Condition	Applied by	Effectiveness
Asphaltic (residual)	Made from Refining 'bottoms', or residuals. (AGMA 13EP, 14R, 15R) Viscosity measured @ 100C Same material used to make roofing tar	Large, slow turning, heavily loaded gears ▪Old gears, degraded ▪<60 RPM ▪12 – 40 " face	Spray Intermittent	Spray application – traditionally good Bath application – tends to dry out.
Semi-Fluid (grease)	Made from polymer thickened bright stock mineral oils, tackifiers (pine tar) and metallic and non-soap grease thickener (lithium, fumed silica) Some synthetic base stocks	Large, slow – moderate speed, heavily loaded gears ▪ New applications and where gear condition is good ▪ 60 – 180 RPM± ▪ 12 – 40 " face	Spray Intermittent Bath	2nd Gen Lube Highly effective as a flushing lubricant Use dependent on gear profile and condition
Fluid	Made from high viscosity grade synthetics Appearance of grease but without thickener Very tenacious, some require heat to apply, maintain as fluid	Large, slow turning, heavily loaded gears ▪ New applications and where gear condition is good ▪ 60 – 180 RPM± ▪ 12 – 40 " face	Spray Intermittent Bath	2nd Gen Lube Highly effective as a flushing lubricant Use dependent on gear profile and condition

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Ref: AGMA 9005-EO2, page 25, Annex D.

AGMA Application Guidelines

Continuous Application							
Ambient temperature, °C	Type of operation	Splash lubrication		Pressure-fed lubrication		Idler immersion
		Pitch line velocity[2]		Pitch line velocity[2]		Pitch line velocity[2]
		v_t<5 m/s	v_t>5 m/s	v_t<5 m/s	v_t>5 m/s	v_t<1.5 m/s
-10 to +10	Continuous	220	150	220	150	680 - 1500
	Reversing or start - stop	460	320	220	150	680 - 1500
+10 to +30	Continuous	460	320	460	320	1500 - 2200
	Reversing or start - stop	1500	680 - 1000	460	320	1500 - 2200
30 to 50	Continuous	2200	1500	460	320	4600
	Reversing or start - stop	2200	1500	460	320	4600

Intermittent Lubricant Application (vt <7.5 m/s)			
Ambient temperature °C	Intermittent spray		Gravity feed or forced drip
	Non-residual lubricant	Residual type lubricant	
-10 to +5	4140 cSt at 40°C	428.5 cSt at 100°C	4140 cSt at 40°C
+5 to +20	6120 cSt at 40°C	857 cSt at 100°C	6120 cSt at 40°C
20 to 50	190 cSt at 100°C	857 cSt at 100°C	190 cSt at 100°C

Notes:
1. All viscosities shown are in mm^2/s at 40°C.
2. Pitch line velocity = (Pitch Diameter in millimeters X RPM) / 19098 = meters/second

Refer to AGMA 9005 E02 for a complete description of these charts (www.AGMA.org). See table D-3 of this standard for application rate (ml/sec.) for intermittent application methods.

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Ref.: AGMA 9005-EO2

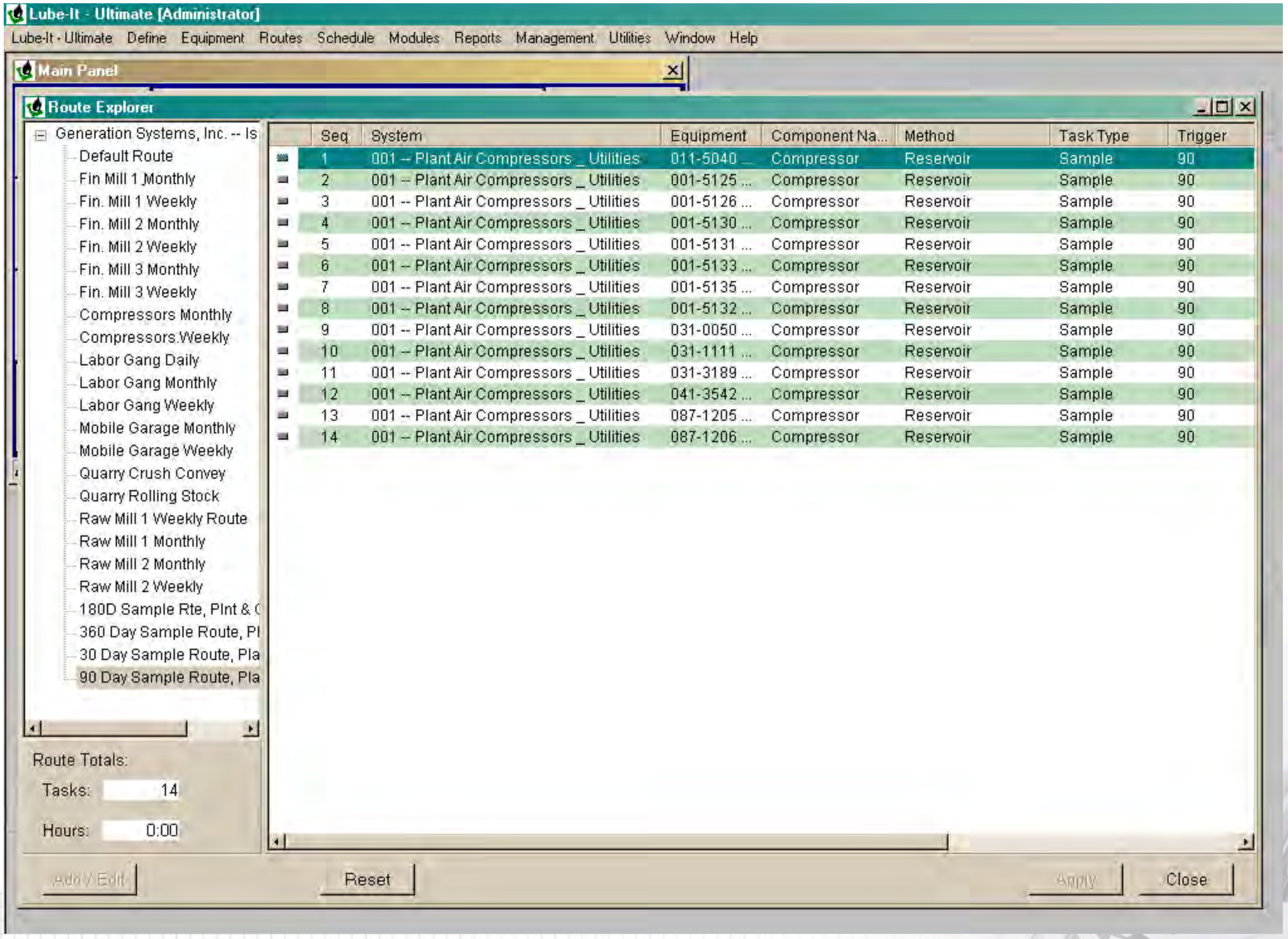
Planning for Precision Lubrication

Other machine & component types for consideration

- ✓ Plain Bearings
- ✓ Compressors
- ✓ Circulation Systems
- ✓ Chains
- ✓ Cables
- ✓ Couplings
- ✓ Hydraulic Systems

Step 5. Initiate Activates

Begin Route Based Lubrication Practices



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Step 5 - Initiate Activates (continued)

Incorporate Modern Tools – Data Collector

- Better record keeping
- Very low administrative cost
- Ability to Inspect and Report
- Cost ranges between
  - $350 for PDA – Compaq
  - $2K for a industrial, hardened handheld

Step 6. Analyze results against the objective, make adjustments, improve the process

- Lubricant based machine analysis
  - Reflects effectiveness of contamination control efforts
  - Reflects effectiveness of selected lubricants
    - Product performance – surface protection
    - Chemical stability – longevity
- Scheduled work completion analysis
  - Reflects effectiveness of SOP development
  - Reflects effectiveness of route development
  - Reflects effectiveness of labor allocation

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Effectiveness Analysis

Based on Oil Based Analysis and UE

Test Selection

One Size Doesn't Necessarily Fit All

Rotary Equipment

Emphasis should be on particulate quantities and their nature

Particle count for basic sizing and quantification is often a 'key' test Wear particle analysis [ferrography, scanning electron microscope techniques, etc.] for identification and morphology

Reciprocating Equipment

Combustion engines have the greatest contaminant varieties; a greater number of tests might be used Spectro metals are generally very small and, therefore, data are more complete or dependable from this test

Ref.: Condition Monitoring Intl

Test Slate Selection

Application	Hydraulic System	Gear Train	Steam Turbine	Gas Turbine	Rotary Compressor	Reciprocating Compressor	Diesel Engine
Spectrometry (metals)	R	R	R	R	R	R	R
Particle Count	R		R-O	R-O	R		
Ferrography (DR/PQ)	O	R Fe		O	O	O	Low/Medium Speed
Particle Debris Filter	O	R Cu O Fe	R-O	R-O	O	O	
Viscosity	R	R	R	R	R	R	R+fuel
Infra-Red (FT-IR)	R	R	R	O	R	R	R
Acid Number (AN)	R	R	O	O	R	R	R-O
Base Number (BN)							R-O
Fuel / Soot							R
Water (Crackle Test)		R	R		O	R	R
Water (Karl Fischer KF)	R		O		O	O	

R – Recommended, O - Optional

Wear Particle Analysis | **Degradation Factors** | **Contamination Factors**

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Ref: Jack Poley, CMI

Test Method Strengths, Weaknesses

Test Category	Targeted Symptom	Visual Screen	Viscosity	Acid Number (AN)	Base Number (BN)	Infra-Red (FT-IR)	Spat / Crackle	Karl Fischer (KF)	Glycol – Schiff's	Fuel Dilution (GC)	Particle Count (PC)	AE Spectrometry	Particle Debris Filter	PQ / DR-Ferr, etc.	Analytical Ferrography	LaserNet Fines (LNF)
Contamination	Dirt & Particles	Indicator									Very accurate	Accurate	Indicator		Good indicator	Very accurate
Contamination	Water	Poor indicator	Poor indicator			Poor accuracy	Indicator	Very accurate							Good indicator	Accurate
Contamination	Glycol					Poor accuracy	Poor indicator		Accurate			Good indicator				
Contamination	Soot		Indicator			Accurate										
Contamination	Fuel		Indicator			Poor accuracy	Poor indicator			Very accurate						
Contamination	Sulfation & Nitration				Poor indicator	Accurate										
Contamination	Process Contaminants	Indicator				Poor indicator					Indicator	Accurate*	Indicator		Accurate	Indicator
Contamination	Improper Oil Make-up		Indicator	Indicator	Indicator	Poor indicator						Very accurate				
Fluid Degradation	Additive Depletion			Accurate	Accurate	Poor accuracy									Indicator	
Fluid Degradation	Oxidation		Indicator	Accurate	Indicator	Accurate									Poor indicator	
Fluid Degradation	Thermal Degradation	Poor indicator	Poor indicator	Poor indicator	Poor indicator	Poor indicator									Poor indicator	
Wear & Fatigue	Wear & Fatigue	Indicator									Indicator	Very accurate	Good indicator	Accurate	Very accurate	Very accurate

Legend

- ✓p Very accurate
- ✓ Accurate
- ✓ Poor accuracy
- ⚐p Good indicator
- ⚐ Indicator
- ⚐ Poor indicator
- (grey) Not applicable

Ref.: Condition Monitoring Intl

Test Alarm Types, Limits

Parameter	Units	Critical	Caution	Normal
ICP – Additive	Percent	+/-50	+/- 25	Baseline
ICP – Wear Debris	Stat	+2 σ	+ 1 σ	<+1 σ
FTIR – Ox, Ni, S	%	+/-75	+/- 25	Baseline
FTIR – Additives	%	+/-50	+/- 25	Baseline
Fe Density (DR, FW, PQ)	Stat	+2 σ	+ 1 σ	Average
Acid Number	Absolute	1.0 >base	0.2 >Inflection	Inflection Point
Analytical Ferro.	Qualitative	NA	NA	

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Contaminant Limits by Machine Type

Equipment Type		Hydraulics Servo-Controlled	Hydraulics >1000 psi	Hydraulics <1000 psi	Filtered Gearboxes	Unfiltered Gearboxes	Pumps, Bearings, Centrifuges	Compressors	Blowers
Criticality Level			High/Low	High/Low	High/Low	High/Low	High/Low	High/Low	High/Low
Water % Target		<0.03	<0.03/<0.05	<0.03/<0.05	<0.05/<0.1	<0.05/<0.1	<0.03/<0.05	<0.03/<0.05	<0.03/<0.05
Water % Caution		0.03	0.03/0.05	0.03/0.05	0.05/0.1	0.05/0.1	0.03/0.05	0.03/0.05	0.03/0.05
Water % Critical		0.1	0.1/0.2	0.1/0.2	0.3/0.4	0.3/0.4	0.1/0.2	0.1/0.2	0.1/0.2
ISO >4 Target		15	15/16	16/17	18	20/21	18/19	17	18/19
ISO >6 Target		13	13/14	14/15	16	18/19	16/17	15	16/17
ISO >14 Target		11	11/13	13/14	14	16/17	14/15	13	14/15
ISO >4 Caution		16	16/17	17/18	19	21/22	19/20	18	19/21
ISO >6 Caution		14	14/15	15/16	17	19/20	17/18	16	17/18
ISO >14 Caution		12	12/13	13/14	15	17/18	15/16	14	15/16
ISO >4 Critical		17	17/18	18/19	20	22/23	20/21	20	20/21
ISO >6 Critical		15	15/16	16/17	18	20/21	18/19	18	18/19
ISO >14 Critical		13	13/14	14/15	16	18/19	16/17	16	16/17

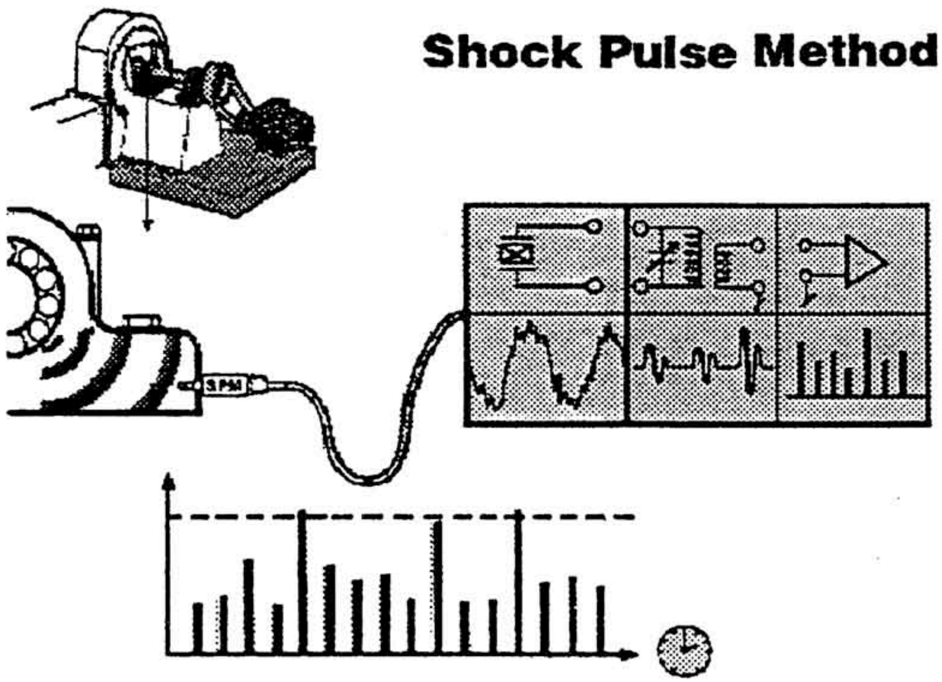
Ultrasonic Energy Measurement

The shock pulse transducer reacts with a large amplitude oscillation to the weak shock pulses.

Because the 'tuned' to respond to a 32kHz frequency energy, the lower energy caused by machine filtration is 'filtered out'.

The height of the vertical bar represents the strength of the pulse signal that is collected from surface contacts in the load zone.

Ideally the bars would short (against the vertical axis) and would be consistent.



Ref: SPM Corporation

Ultrasonic Energy Measurement

This overhung bearing on a motor is monitored with the transducer at the center of the most heavily loaded zone of the bearing, and with the minimum number of surface layers to overcome.

The wave represents a vibration signal in the 0 to 20kHz range (hypothetically) and the transient on the wave represents the surface contact condition from poorly lubricated surfaces.

The shock pulse is measuring the ultrasonic energy produced by the poorly lubricated bearing surfaces experiencing intermittent.

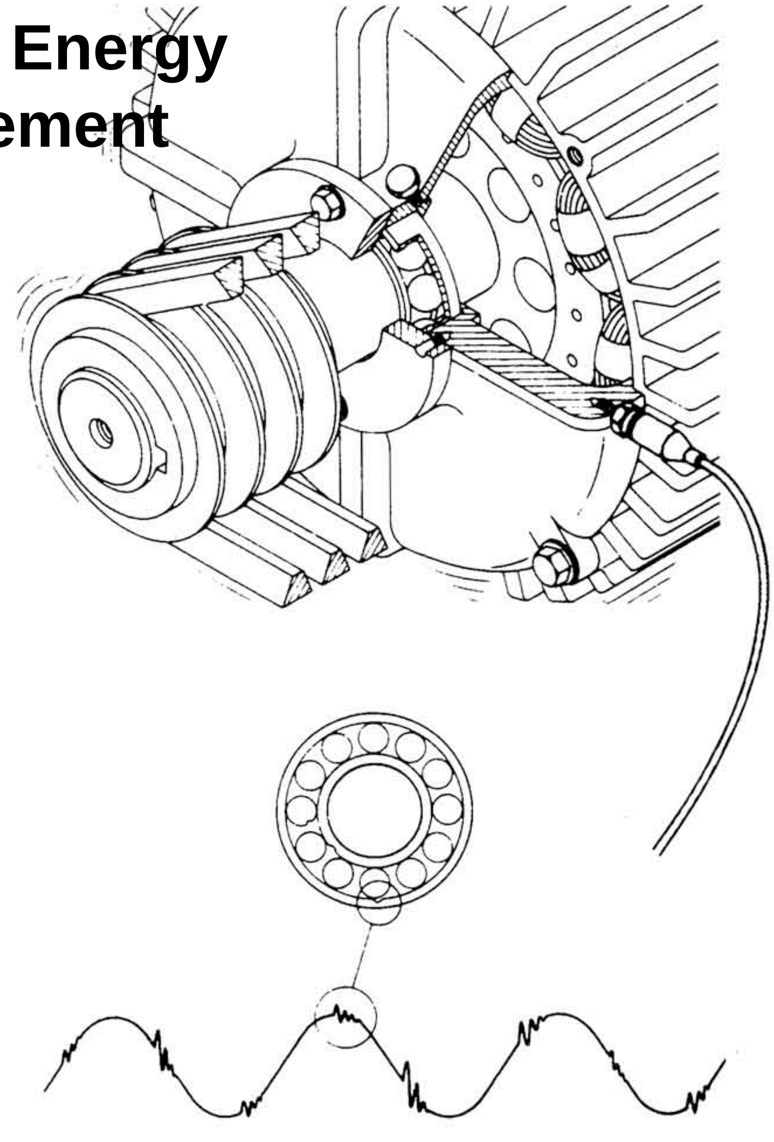


Figure 2

Ref: SPM Corporation

Ultrasonic Energy Measurement

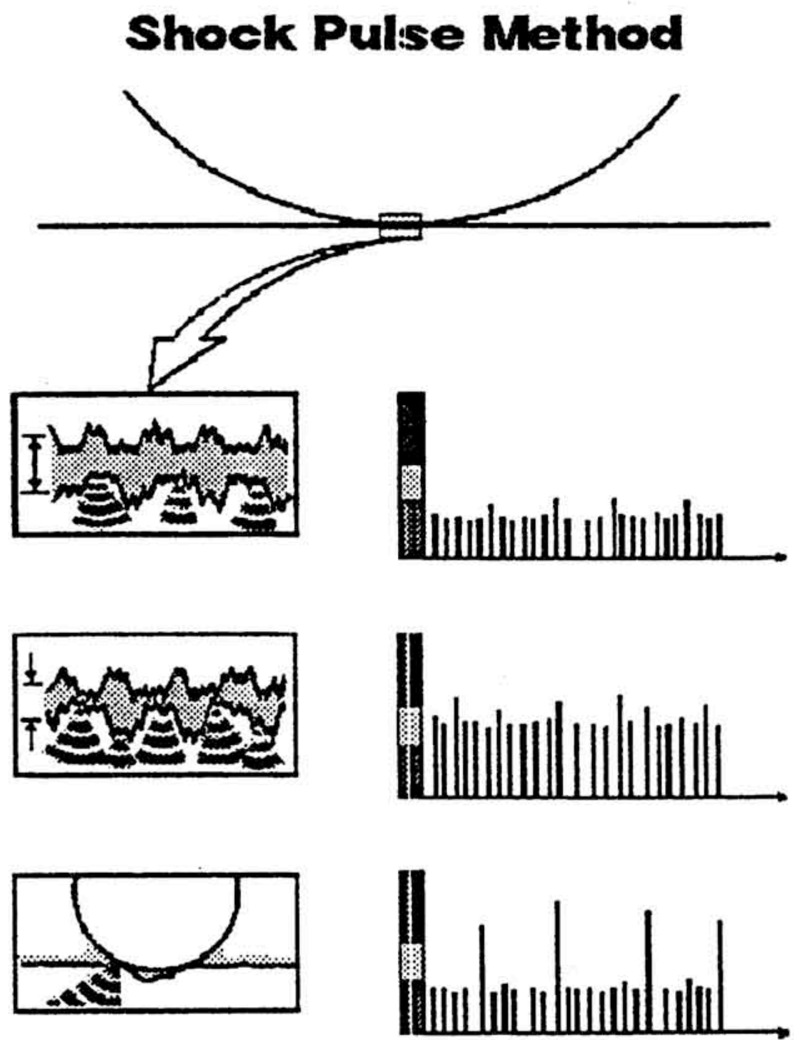
The top chart reflects the type of energy level expected from a well lubricated bearing.

The pulse energy is very low and there are no strong shock events due to a hydrodynamic or elastohydrodynamic fluid film separation.

As the oil film dissipates and the surfaces collide with a greater frequency the 'carpet' level increases.

At the point that the bearing is damaged the transducer will register strong and perhaps inconsistent 'jolts' where the bearing surface is colliding with the race.

The effect is similar to a shock event that occurs when a tire runs through a pothole.



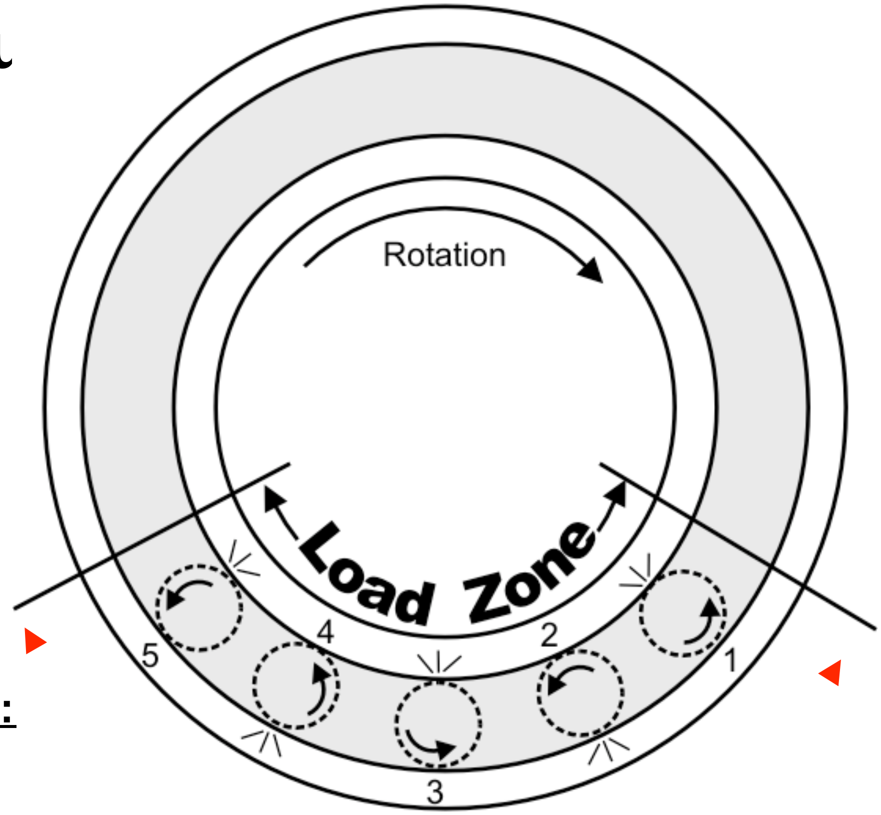
Ref: SPM Corporation

Keys to Good Ultrasonic Measu

1.Location!

2.Location!

3.Location!



Recommended Sensor Location for UE Measurements

Other Data Collection Considerations:

- ✓Total Load
- ✓Angle of Load
- ✓Access to load zone
- ✓Number of layers between sensor and element
- ✓Speed of Bearing
- ✓Size of Bearing

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Step 7, Evaluate and Adjust Course

Annual Review of

- Progress toward improvement targets – OA based
- Rate of materials consumption
- Progress toward target on scheduled work 1st time completion rates.
- Knowledge development improvement
- Whether plan is still in line with business needs

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Question 7

- If you were going to skip on of the steps, which one would it be?
  A. Financial Justification.
  B. Benchmarking and Criticality Assessment.
  C. Practices Development.
  D. Program review for changes, updates.

Closing Thoughts

- We didn't discuss lubricants. These are process challenges. You can't fix a weak process by picking a different lubricant.
- Precision Lubrication is a fundamental requirement for Dependable Plant Capacity.
- Couple your initiative, particularly capital requirements to your politically empowered reliability initiatives. (Just remember: Oil's oil & grease's grease, but reliability is important!)
- Pursue Precision… Be relentless with the details!
- This is likely the best ROI opportunity on the radar screen. It isn't difficult or expensive to achieve tremendous returns and results.

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