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WHITE PAPER

Analyzing Lubricant and Machinery Condition Using Q5800 Portable Oil Analysis Lab

Overview

The United States Marine Corps (USMC) maintains a fleet of thousands of mechanized vehicles consisting of heavy equipment ranging from bulldozers to transport vehicles and armored vehicles. A decade ago, they participated in an oil analysis program as a means to determine lubricant and machinery condition with emphasis on reducing operating costs and improved equipment readiness. Five years ago, they cancelled their participation in the Navy Oil Analysis Program (NOAP) because the response time between sample submission to the nearest laboratory and receipt of maintenance recommendations based on the lab analysis failed to provide the desired benefits. In a mobile environment the information failed to reach the deployed maintainers in time to make the necessary recommendations to either service the lubricant or take appropriate maintenance actions before the vehicle was redeployed. As a result, they returned to an interval based fluid maintenance protocol.

In early 2014, USMC Headquarters Installations and Logistics (I&L) embarked on an effort to reinstate condition based maintenance (CBM) through oil analysis as a result of a directive to reduce lubricant and fuel consumption from the Office of the Secretary of Defense (OSD). In order to effectively accomplish this directive, the USMC pursued an Expeditionary Fluid Analysis Capability (EFAC). The EFAC model is based on having analytical equipment which is portable and provides results in mere minutes, providing maintenance recommendations at the time the vehicle is being serviced by maintenance personnel.

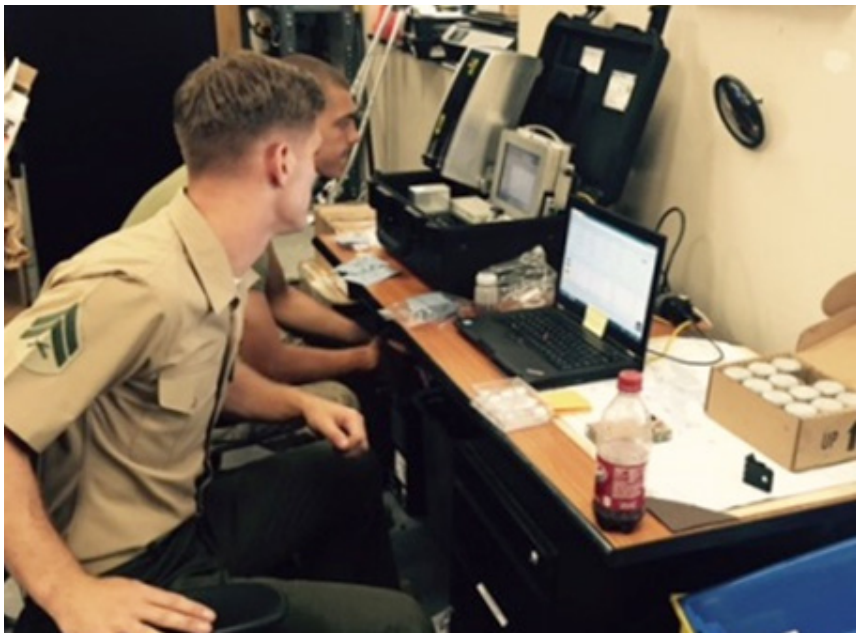
The program consisted of two separate test sites. The first site was tasked to analyze and assess lubricant condition using a FluidScan Q1000 handheld infrared spectrometer combined with a SpectroVisc Q3050 handheld kinematic viscometer. The second site was tasked to analyze and assess the lubricant condition plus the physical condition of the same mechanical assemblies using a Q5800 Portable Oil Analysis Laboratory device.

This white paper will primarily focus on the test site using the Q5800. The Q5800 contains the same analytical capability found in the two separate handheld devices plus it includes in-depth analysis of the mechanical condition of the assemblies by measuring fluid cleanliness as well as the particulate concentration and elemental composition of wear metals contained therein. The test site, test vehicles, test results, business case analysis and conclusions will be explained in this paper.

Objective

The objective of the USMC HQ I&L was to determine if handheld and portable instruments can be used effectively in an operational maintenance environment as well as a forward deployed expeditionary environment. In order to be effective, the equipment must be rugged and capable of being operated in an open field or a maintenance building environment by junior level USMC mechanics. The program must demonstrate cost effectiveness by extending the oil drain service intervals (determined by the lubricant properties and viscosity) while ensuring that the mechanical assembly (engines, transmissions, etc.) are not experiencing mechanical degradation (determined by particulate concentration and elemental composition of wear metals).

A business case analysis (BCA) will be conducted over this program period that will determine if the potential cost avoidance that is achieved through extended oil drain intervals will significantly offset the cost to buy the instrumentation and support the program. In addition to the potential cost avoidance due to extended oil drain intervals, the mechanical integrity of each component will be determined. When abnormal wear is detected, immediate maintenance action can be performed resulting in substantial material and labor cost savings. Examples of these cost avoidances will be detailed in the following sections of this paper.



Test Site

USMC HQ I&L chose USMC Base Camp Lejeune, N.C. as the site for this test and evaluation program due to the availability of equipment and maintenance facilities. Initial training on the operation of the Q5800 and the basics of CBM was conducted for approximately 10 junior level (LCpl and Cpl) mechanics. The Q5800 was set up in a tool room and eventually two mechanics were chosen to be the main operators based on interest and skill level. After an hour of hands on training, both were proficient at data entry and operating the four test modules.

Test Vehicles

This program has been directed towards the maintenance of two heavy vehicles. The first is the Medium Tactical Vehicle Replacement (MTVR) and the second is the Logistics Vehicle System Replacement (LVSR). Other vehicles were included in this test and evaluation program but these two particular vehicles will become the basis of this paper. The MTVR is a vehicle that has up to fifteen individual oil reservoirs depending on configuration and intended purpose. The table below lists each of the reservoirs, their capacities and the cost of fluid replacements. This vehicle is currently on an annual maintenance interval schedule where it undergoes a complete fluids replacement regardless of operating hours.

The LVSR is a larger and more complex vehicle that has up to 21 separate oil reservoirs. This vehicle is currently maintained on an interval basis, meaning that every 12 months it is subject to either a light maintenance inspection where fluids are topped off or replaced if visual indications warrant, or it undergoes a full bi-annual maintenance inspection where all fluids are replaced regardless of operating hours. The table below lists each of the LVSR reservoirs, their capacities and the cost of fluid replacement.

Medium Tactical Vehicle Replacement (MTVR)

MTVR OIL RESERVOIRS AND CAPACITY

ASSET	LUBRICANT TYPE	OIL CAPACITY (qts)	MATERIAL COST ($)
Engine	15W-40	37	$107.30
Transmission	15W-40	45	$130.50
Transfer Case	15W-40	6	$20.46
Power Steering	15W-40	9	$26.10
Hydraulic Reservoir	15W-40	96	$278.40
Winch Drum	85W-140	2	$5.66
Differential Front	80W-90	12.5	$40.88
Differential Intermediate	80W-90	12.5	$40.88
Differential Rear	80W-90	12.5	$40.88
Hub Left Front	80W-90	1.6	$5.49
Hub Left Intermediate	80W-90	1.6	$5.49
Hub Left Rear	80W-90	1.6	$5.49
Hub Right Front	80W-90	1.6	$5.49
Hub Right Intermediate	80W-90	1.6	$5.49
Hub Right Rear	80W-90	1.6	$5.49
	TOTAL	242.1	$724.00

Logistics Vehicle System Replacement (LVSR)

LVSR OIL RESERVOIRS AND CAPACITY

ASSET	LUBRICANT TYPE	OIL CAPACITY (qts)	MATERIAL COST ($)
Engine	15W-40	41	$118.90
Transmission	15W-40	66	$191.40
Transfer Case	15W-40	9	$26.10
Power Steering	15W-40	12	$34.80
Hydraulic Reservoir	15W-40	250	$725.00
Winch Drum	85W-140	2	$5.66
Differential Front 1	80W-90	12.5	$41.16
Differential Front 2	80W-90	12.5	$41.16
Differential Rear 1	80W-90	12.5	$41.16
Differential Rear 2	80W-90	12.5	$41.16
Differential Rear 3	80W-90	12.5	$41.16
Hub Front Left 1	80W-90	1.6	$5.49
Hub Front Left 2	80W-90	1.6	$5.49
Hub Rear Left 1	80W-90	1.6	$5.49
Hub Rear Left 2	80W-90	1.6	$5.49
Hub Rear Left 3	80W-90	1.6	$5.49
Hub Front Right 1	80W-90	1.6	$5.49
Hub Front Right 2	80W-90	1.6	$5.49
Hub Rear Right 1	80W-90	1.6	$5.49
Hub Rear Right 2	80W-90	1.6	$5.49
Hub Rear Right 3	80W-90	1.6	$5.49
	TOTAL	458.5	$1,362.56

Test Protocol

Both the MTVR and LVSR are currently on an interval based maintenance protocol whereby weekly, the maintenance management sofware provides a list of select vehicles to schedule annual or biennial maintenance. These vehicles are scheduled through the maintenance facility where a battery of inspections and services are performed. For the MTVR, this involves a complete drain and replacement of all lubricants, filters and gaskets, whereas for the LVSR this would occur biennially. During the LVRS annual inspection, one or more reservoirs may have a complete fluid replacement based on a visual inspection at the mechanic's discretion.

During this test program, the maintenance protocol was altered based on lubricant and mechanical condition determined by the analytical results produced by the Q5800. When lubricant condition retains chemical and physical properties established by lubricant and equipment manufacturer's specifications, the lubricant will not be replaced. If the lubricant is not heavily contaminated or does not contain excessive wear metal debris, the mechanical integrity of the component shall remain in operational condition. The quality of the lubricant and the integrity of the mechanical system shall be determined by diagnostic software which analyzes the various properties of the lubricant and, based on an extensive knowledge base, makes appropriate maintenance recommendations.

Based on the Q5800 analytical results, maintenance recommendations shall be generated to advise the maintainers which assets require maintenance. For those assets where the diagnostic software determines that all lubricant and mechanical properties are in tolerance, an OPERATIONAL assessment will be advised and no maintenance action will be performed. Assets where one or more of the lubricant properties exceed manufacturer specifications, an INSPECTION NEEDED assessment will be advised. Where a lubricant or mechanical condition is severely out of manufacturer's specifications, a CRITICAL/ ALARM assessment will be issued. All of these assessments are maintenance directives that go to the maintenance lead who will assess the recommendations and advise the mechanics on what functions to perform.

26 PARAMETERS MEASURED

1. Free Water (abs/0.1mm)
2. Oxidation (abs/0.1mm)
3. Total Acid Number (TAN) (mgKOH/g)
4. Total Base Number (TBN) (mgKOH/mg)
5. Water (ppm)
6. Anti Wear Additive (AW Additive) (%remaining)
7. Nitration (abs/0.1mm)
8. Sulfation (abs/0.1mm)
9. Glycol (% present)
10. Soot (%/wt)
11. Viscosity (Visc@40°C)
12. Molybdenum (ppm)
13. Zinc (ppm)
14. Silver (ppm)
15. Aluminum (ppm)
16. Chromium (ppm)
17. Copper (ppm)
18. Iron (ppm)
19. Nickel (ppm)
20. Lead in ppm
21. Tin (ppm)
22. Titanium (ppm)
23. Silicon (ppm)
24. Vanadium (ppm)
25. Fluid Sample Dispensed (ml)
26. Particles >4µm (#/ml)

Test Data

Typically, oil samples are taken at least two weeks in advance of when the vehicle is scheduled into the maintenance facility. Once the analysis is completed, the Maintenance Manager has time to order the necessary material (gaskets/filters, etc.) in a kit based on the maintenance recommendations provided by the diagnostic software. This process expedites the maintenance cycle and improves material handling efficiency. Shown on the folowing page are the analyical results of one MTVR and one LVSR. These spreadsheets are condensed and would be impossible to read in printed form. If reading this document in Acrobat Reader, these spreadsheets can be enlarged to make each analytical parameter easy to read.

The purpose of showing the analytical results of each reservoir (rows in the table) is to highlight the overall condition of the lubricant and component. The color code corresponds to the international code for GO or good (GREEN), Caution or Warning (YELLOW) and STOP or Alarm (RED). These condition indicators respond to the highest status level (WHITE=0, YELLOW=1 and RED=2) indicated from any one of the 26 parameters measured. In this case study, all 26 parameters (columns) had warning and alarm levels programmed into the Q5800. The 26 parameters appear in the spreadsheets starting at the fifth column.

EQUIPMENT NAME	COMPONENT NAME	Date Measured	Alarm Code	Free Water-abs/0.1mm	Oxidation-abs/0.1mm	TAN-mgKOH/g	TBN-mgKOH/g	Water-ppm	AW Additive- (%)	Nitration-abs/0.1mm	Sulfation-abs/0.1mm	Glycol-(%)	Soot-(%wt)	Visc-@40°Cst	Mo-ppm	Zn-ppm	Ag-ppm	Al-ppm	Cr-ppm	Cu-ppm	Fe-ppm	Ni-ppm	Pb-ppm	Sn-ppm	Ti-ppm	Si-ppm	V-ppm	Amt Dispensed-ml	Particle >4m- #/ml
ENGINE	590833E	1/20/2016 19:57	Alarm		11.4		9.5	0	92	2.9	14.2	0	0.04	49	0	25	0	0	0	0	1	0	0	0	0	1	0	3.09	30506
TRANSMISSION	590833T	1/20/2016 20:32	Alarm		11.3		9.5	0	97	2.7	14	0	0	81	0	24	0	1	0	1	3	0	0	0	0	1	0	3.1	12828
TRANSFER CASE	590833X	1/20/2016 19:47	None		13		8.7	454	119	2.1	16.4	0	0.01	114	0	26	0	1	0	1	1	0	0	0	0	2	0	3.09	14333
POWER STEERING	590833P	1/20/2016 19:26	Alarm		11.7		10.5	191	105	3.6	14.8	0	0.01	68	0	25	0	1	0	0	0	0	0	0	0	1	0	3.07	1404
DIFFERENTIAL	590833D1	1/21/2016 6:58	Alarm	No Free Water Detected	8.8	1.13		215						119	0	1	0	2	0	0	1	0	0	0	0	3	0	3.03	7193
DIFFERENTIAL	590833D2	1/21/2016 7:15	Alarm	No Free Water Detected	11	2.02		290						143	0	15	0	18	0	4	61	0	0	0	0	32	0	0.28	2160429
DIFFERENTIAL	590833D3	1/21/2016 7:26	Alarm	No Free Water Detected	8.4	1.46		272						134	0	3	0	13	0	1	10	0	0	0	0	19	0	0.51	873729
HUB	590833HLF	1/21/2016 9:24	Warning	No Free Water Detected	8	1.21		233						166	0	1	0	3	0	0	5	0	0	0	0	3	0	1.77	167327
HUB	590833HLI	1/21/2016 9:34	Alarm	No Free Water Detected	8.4	0.82		229						94	0	1	0	3	0	0	3	0	0	0	0	2	0	1.7	160110
HUB	590833HLR	1/21/2016 9:46	Alarm	No Free Water Detected	9.7	0.91		228						126	0	10	0	15	0	5	82	0	0	0	0	18	0	0.43	1429663
HUB	590833HRF	1/21/2016 7:35	Alarm	Significant Free Water Detected	14.1	12.11		8097						177	0	3	0	6	0	0	21	0	0	0	0	9	0	0.69	516929
HUB	590833HRI	1/21/2016 8:45	Warning	No Free Water Detected	8.8	0.84		218						152	0	1	0	3	0	0	6	0	0	0	0	2	0	1.52	195310
HUB	590833HRI	1/21/2016 7:48	Alarm	No Free Water Detected	8.1	1.29		277						135	0	8	0	13	0	1	63	0	0	0	0	10	0	0.41	1396431

Q5800 analytical results for MTVR S/N 590833

A review of the analytical test results of the 13 component oil reservoirs in MTVR above indicates that all but three components are in a warning or alarm condition. This overall status appears in the fourth column from the left.The primary violations appear in three categories. The first is fluid viscosity which is a parameter that may exceed limits by being high or low. The second is fluid contamination as evidenced by the right-most column. High contamination of the fluid can enter the reservoir in the form of external debris such as water,as evidenced by the third component reservoir from the bottom. Particulate may also appear as dust/silica dirt and/or high wear metal contamination due to friction and wear from abrasives or lubricant degradation. In this example, all but one reservoir requires maintenance, but when the degraded and contaminated fluid is removed and replaced with new lubricant of the proper grade, the wear metal degradation should cease or be significantly reduced. Based on the condition of this vehicle, the cost of maintenance will only be slightly less than a complete fluid replacement. After maintenance, this vehicle may be placed in storage where the fluids will not degrade or become contaminated. The next annual maintenance inspection may indicate that no fluids, filters, gaskets or labor are required therefore resulting in full maintenance cost avoidance versus full maintenance cost based on fixed time intervals.

A quick review of the fourth colum from the left (Alarm Code) for the LVSR shown below indicates that the majority of the 19 component oil reservoirs in this vehicle are good and only four component reservoirs are in definite need of maintenance. Similar to the MTVR above, the dominant cause for alarm pertains to degraded oil viscosity. This condition combined with lubricant contamination (last column on the right) is cause for concern about metal surface degradation. In this example and based on the table of oil type and capacity above, maintenance of this vehicle will result in a cost avoidance of $267 in lubricant plus gaskets and labor.

EQUIPMENT NAME	COMPONENT NAME	Date Measured	Alarm Code	Free Water-abs/0.1mm	Oxidation-abs/0.1mm	TAN-mgKOH/g	TBN-mgKOH/g	Water-ppm	AW Additive- (%)	Nitration-abs/0.1mm	Sulfation-abs/0.1mm	Glycol-(%)	Soot-(%wt)	Visc-@40°Cst	Mo-ppm	Zn-ppm	Ag-ppm	Al-ppm	Cr-ppm	Cu-ppm	Fe-ppm	Ni-ppm	Pb-ppm	Sn-ppm	Ti-ppm	Si-ppm	V-ppm	Amt Dispensed-ml	Particle >4m- #/ml
ENGINE	648393E	9/3/2015 18:31	Warning		11.8		9.1	571	78	4.2	14.6	0	0	93	0	24	0	0	0	1	1	0	0	0	0	1	0	3.05	14484
TRANSMISSION	648393T	9/3/2015 18:55	Alarm		19.4		0.2	569	80	3.4	31.7	0	0	80	0	45	0	0	0	1	4	0	0	0	12	0	0	1.54	365339
TRANSFER CASE	648393X	9/3/2015 19:20	Alarm		16.3		5.7	553	89	3.5	21.7	0	0	69	0	84	0	0	0	10	9	0	0	0	0	1	0	1.41	333117
HYDRAULIC RESERVOIR	648393H	9/4/2015 8:34	Alarm		13.8		6.9	404	106	4.2	17.7	0	0	41	0	23	0	0	0	0	0	0	0	0	0	0	0	3.05	18079
DIFFERENTIAL	648393D1	9/4/2015 9:33	None	No Free Water Detected	8	1.9		235						158	0	1	0	1	0	0	0	0	0	0	0	0	0	3.07	15084
DIFFERENTIAL	648393D2	9/4/2015 9:54	None	No Free Water Detected	8	2.04		243						160	0	1	0	1	0	0	2	0	0	0	0	2	0	2.82	39009
DIFFERENTIAL	648393D3	9/4/2015 10:05	None	No Free Water Detected	7.8	1.51		230						154	0	2	0	1	0	0	3	0	0	0	0	2	0	2.69	22179
DIFFERENTIAL	648393D4	9/4/2015 10:15	None	No Free Water Detected	7.9	1.8		219						143	0	1	0	1	0	0	5	0	0	0	0	3	0	2.82	65100
DIFFERENTIAL	648393D5	9/4/2015 10:26	None	No Free Water Detected	7.6	2.76		192						150	0	1	0	1	0	0	1	0	0	0	0	1	0	3.08	28092
HUB	648393HL1	9/4/2015 11:03	None	No Free Water Detected	8.2	1.76		206						148	0	2	0	1	0	1	6	0	0	0	0	1	0	3.07	75648
HUB	648393HL3	9/4/2015 11:43	None	No Free Water Detected	8.4	1.97		229						151	0	1	0	1	0	0	11	0	0	0	0	1	0	2.88	73556
HUB	648393HL2	9/4/2015 12:00	Alarm	No Free Water Detected	8.1	1.93		209						139	0	3	0	7	0	1	7	0	0	0	0	5	0	0.78	603229
HUB	648393HL4	9/4/2015 12:25	None	No Free Water Detected	8.2	1.96		270						150	0	1	0	2	0	0	6	0	0	0	0	2	0	2.87	70394
HUB	648393HL5	9/4/2015 12:48	None	No Free Water Detected	8.2	0.98		260						148	0	1	0	1	0	0	5	0	0	0	0	3	0	2.85	54073
HUB	648393HR1	9/4/2015 13:24	Warning	No Free Water Detected	8.3	0.88		262						152	0	1	0	1	0	0	23	0	0	0	0	2	0	2.59	120370
HUB	648393HR2	9/4/2015 14:37	Warning	No Free Water Detected	8.2	1.59		260						140	0	1	0	1	0	0	6	0	0	0	0	3	0	2.39	135567
HUB	648393HR3	9/4/2015 15:17	None	No Free Water Detected	8.7	1.9		264						134	0	1	0	1	0	0	3	0	0	0	0	2	0	2.79	83082
HUB	648393HR4	9/4/2015 15:46	None	No Free Water Detected	8.4	1.83		249						152	0	1	0	1	0	0	6	0	0	0	0	2	0	2.8	59971
HUB	648393HR5	9/4/2015 15:56	Warning	No Free Water Detected	8.9	2.34		239						143	0	1	0	2	0	0	10	0	0	0	0	2	0	2.36	135406

Q5800 analytical results for LVSR S/N 648393

SUMMARY		
CONDITION	**QTY**	**FREQUENCY**
No Action Required	56	7.89%
Warning	92	12.96%
Alarm	562	79.15%
TOTAL	710	100.00%

A summary of the overall condition of all components for all vehicles that participated in this test program appears below. The statistics may be surprising considering almost 80% are in alarm status, but the reality is these vehicles may have not had the benefit of condition based maintenance over several years of operation and now with this new CBM process, a new maintenance reset shall take place.

A further analysis of what parameters drove the overall condition depends on how many parameters are included in each of the four test modules. For instance, viscosity is a single parameter and can be easily summarized. Viscosity is the most common cause to warn or alarm for lubricant condition, closely followed by fluid contamination determined by IR spectroscopy and particle count.

However, for Q5800 modules that determine multiple parameters, such as chemical properties from infrared spectroscopy (10), or elemental properties determined by x-ray florescence spectroscopy (13), the overall condition may be determined from multiple parameters. A breakdown of the chemical properties, contamination and wear metals requires diagnostic software to perform a more in-depth analysis.

Test data produced over a 12 month period was used to establish wear metal guidelines for each of the vehicle's components based on ASTM standard D7720-11, Standard Guide for Statistically Evaluating Measurand Alarm Limits when Using Oil Analysis to Monitor Equipment and Oil for Fitness and Contamination. These guidelines became the basis to determine the status for each element; normal (WHITE), warning (YELLOW) and alarm (RED). The table below is a segment of a transfer case record and is an example of this process.

COMPONENT NAME	Alarm Code	Mo-ppm	Zn-ppm	Ag-ppm	Al-ppm	Cr-ppm	Cu-ppm	Fe-ppm	Ni-ppm	Pb-ppm	Sn-ppm	Ti-ppm	Si-ppm	V-ppm	Amt Dispensed -ml	Particle > 4m- #/ml
648086X	Alarm	0	17	0	21	0	5	28	0	0	0	0	28	0	0.38	1490357
648080X	Alarm	0	7	0	7	0	4	8	0	0	0	0	9	0	1.16	227467
648015X	None	0	25	0	1	0	1	1	0	0	0	0	1	0	2.92	66026
591886X	None	0	22	0	1	0	0	0	0	0	0	0	1	0	3.06	12795
648090X	None	0	23	0	1	0	1	0	0	0	0	0	2	0	3.08	46203
591453X	None	0	25	0	1	0	1	3	0	0	0	0	2	0	3.07	5618
648479X	None	0	24	0	1	0	2	1	0	0	0	0	1	0	3.05	15320
648313X	Alarm	0	193	0	6	0	16	11	0	0	0	0	8	0	0.47	787109
648396X	Alarm	0	120	0	3	0	14	7	0	0	0	0	9	0	0.81	702124
590810X	None	0	16	0	1	0	0	0	0	0	0	0	2	0	3.08	0
648380X	None	0	23	0	0	0	1	1	0	0	0	0	5	0	3.1	47324
648404X	Alarm	0	286	0	8	0	5	312	0	2	0	0	8	0	0.32	2252252
648389X	Alarm	0	57	0	2	0	4	5	0	0	0	0	4	0	1.36	210231
648412X	Alarm	0	41	0	1	0	6	3	0	0	0	0	2	0	2.69	1179536
648452X	Alarm	0	162	0	3	0	27	13	0	1	0	0	17	0	0.53	1208603
597731X	Alarm	0	63	0	1	0	76	3	0	6	0	0	3	0	1.23	224827
648477X	Alarm	0	21	0	1	0	4	2	0	0	0	0	2	0	3.1	46039
597731X	None	0	29	0	7	0	11	6	0	1	0	0	6	0	0.63	1022109
669484X	Alarm	0	130	0	5	0	48	6	0	3	0	0	7	0	0.67	770399
669491X	Alarm	0	72	0	3	0	26	3	0	3	0	0	4	0	1.35	329713
591858X	None	0	25	0	1	0	1	1	0	0	0	0	2	0	3.08	19611
648463X	Warning	0	38	0	1	0	1	0	0	0	0	0	3	0	1.74	184867
592337X	None	0	25	0	1	0	2	1	0	0	0	0	1	0	3.06	41189
591792X	None	0	27	0	1	0	1	1	0	0	0	0	4	0	3.11	59161
648227X	None	0	25	0	0	0	2	1	0	0	0	0	1	0	2.86	75143
648414X	None	0	33	0	0	0	5	2	0	0	0	0	1	0	2.61	54513
591925X	Warning	0	26	0	0	0	51	1	0	6	0	0	0	0	1.81	192553
597237X	Warning	0	56	0	0	0	29	2	0	2	0	0	2	0	1.69	190210
597237X	None	0	20	0	0	0	0	0	0	0	0	0	0	0	3.09	310
648527X	None	0	27	0	0	0	5	1	0	0	0	0	1	0	2.89	60434
590857X	Alarm	0	156	0	2	0	20	5	0	3	0	0	6	0	0.62	1131500
648393X	Alarm	0	84	0	0	0	10	9	0	0	0	0	1	0	1.41	333117
591590X	None	0	15	0	0	0	1	2	0	0	0	0	0	0	3.09	67533
669535X	Alarm	0	208	0	6	0	118	16	0	9	15	0	0	0	0.43	1603256
669269X	Alarm	0	104	0	0	0	54	8	0	3	0	0	0	0	0.93	555486
	AVERAGE		57		2		14	11		1	0		4			
	STD DEV		62		4		24	48		2	2		5			
	RSD (%)		92		58		59	23		47	15		71			
	NORMAL		58		2		15	12		1	0		3			
	WARNING				10		62	107		5	5		14			
	ALARM				13		86	155		7	7		19			

This process was followed for each oil wetted component reservoir in both the MTVR and LVSR test vehicles. In the example shown above one transfer case from an LVSR contained an iron concentration twice that of the alarm limit (154.7 ppm) and over 2 million paricles of debris per milliliter of fluid. Greater than 200,000 p/ml is the alarm level for particle count. The full Q5800 analysis (chemical and physical properties excluded from the example above) produced the following maintenance recommendation.

Spectro Scientific
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USMC Tier II
Oil Evaluation Report

Asset Name:	TRANSFER CASE	Component Name:	648404X
Asset Serial #:	648404X	Component Serial #:	
Asset Type:		Component Type:	GEAR
Asset Hours:		Lube Used:	CL15W-40
Idle Hours:			

Critical / Alarm

Most Recent Test - Taken on 03/02/16 06:13

648404X Evaluation Comments and Advisories

Recommended Diagnostics	* Conduct external, non-invasive inspections, such as clearances or endplay, and similar diagnostics, as may be appropriate * VISCOSITY is SEVERELY LOW, based on indicated Grade; confirm Grade or investigate for incorrect lube fill or top-off
Physical Inspection	Based on any diagnostics efforts undertaken, as well as onsite information available, consider inspecting the following areas for abnormal wear: * Gears or Housing * Bearings or Bushings/Thrusts
Fluid and Filter Maintenance	* Particle Count is HIGH - Drain lube * If silicon (Si) is flagged, check oil handling and storage methods for clean practices and technique and/or check for compromised breathers or seals
Observations and Reasoning	* Copper and Iron logical sources, dependent on ratio, suggest BUSHING or THRUST metal, along with Gear, Shaft, or Bearing/Bearing Race or Retainer wear

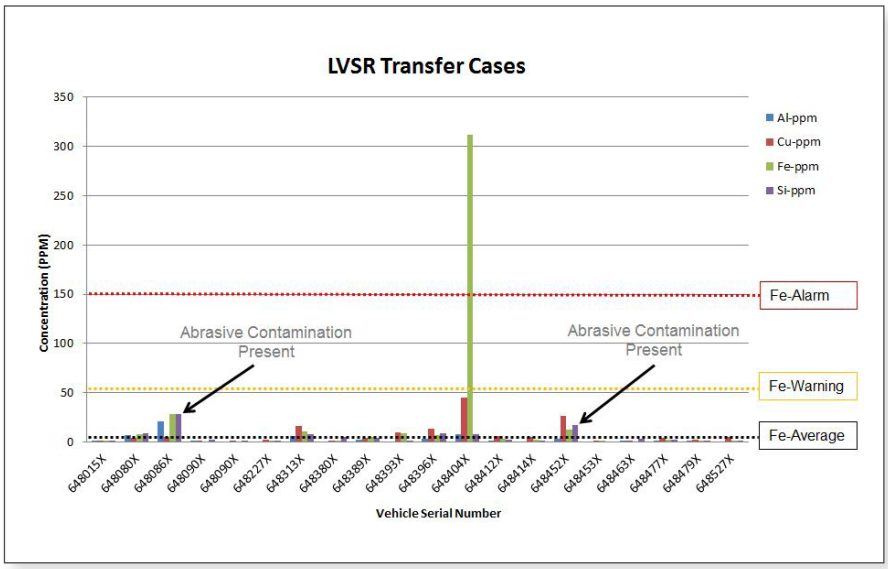
Results Outside of Normal Range

Test Name	Test Value	Severity Range		
Iron (ppm)	312	< 16	< 32	> 32
VIS 40 (cSt)	64.0	> 51.0	> 37.0	< 37.0
PC > 4 mic	2252232	< 100000	< 200000	> 200000
Amt Dispensed (mL)	0.32			
Copper (ppm)	45	< 44	< 75	> 75

Results Within Normal Range

Aluminum (ppm)	8	Tin (ppm)	0	Soot (ppm)	0.0	Water, KF (ppm)	759.0
Lead (ppm)	2	Nickel (ppm)	0	IR-Ox (abs/cm)	18	BN (mgKOH/g)	5.6
Silicon (ppm)	8	Silver (ppm)	0	IR-Nit (abs/cm)	4	Antiwear	105
Molybdenum (ppm)	0	Titanium (ppm)	0	IR-Sulf (abs/cm)	23	Glycol (%)	0
Chromium (ppm)	0	Vanadium (ppm)	0				

Based on the analytical results, the Oil Evaluation Report clearly and succinctly details what parameters exceed severity ranges, offers recommended corrective actions, advises what maintenance should be performed and explains why these conclusions have been drawn. In this case, the lubricant viscosity is approximately one half of the nominal specification of 15W-40, which is 118 cSt. Based on the particle count, the lubricant is heavily contaminated with (2,252,232) particles per milliter of fluid, and considering that silica at 8ppm is well within normal operating levels and iron is high, the conclusion is the majority of the debris is wear metals.

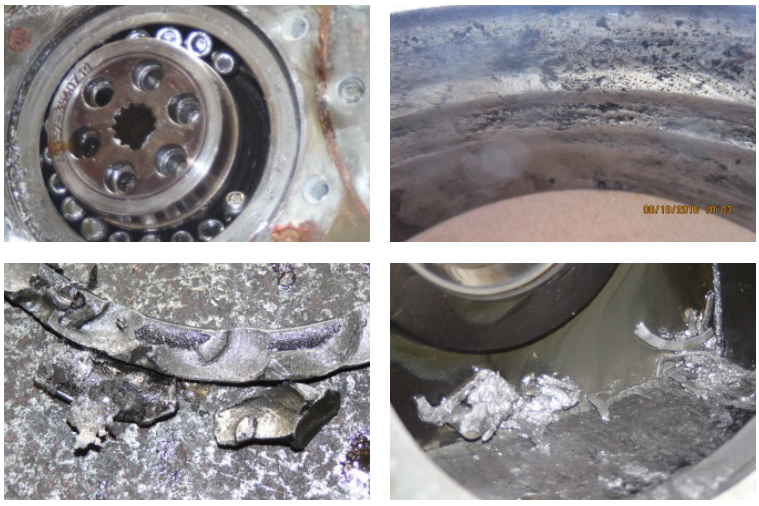


Comparison of identical transfer cases from identical LVSR vehicles

Comparing the key wear metal elements (iron, copper, lead, tin and aluminum) of this transfer case to all other identical transfer cases, it is evident that this transfer case is in catastrophic failure. To the left is a graph depicting this comparison.

This vehicle was driven to a third level maintenance depot where it was placed in deadline status. The operation and mantenance log for this vehicle had no entries indicating excessive noise or vibrations prior to the removal of this transfer case.

When the transfer case was opened, the root cause of the maintenance action was isolated to the cup and cone tapered roller bearing. This bearing was severely degraded where the bearing cage had disintegrated allowing the bearings to misalign and score against themselves and the bearing races. At left are images of the wear created by the degradation of this bearing cage and rollers.

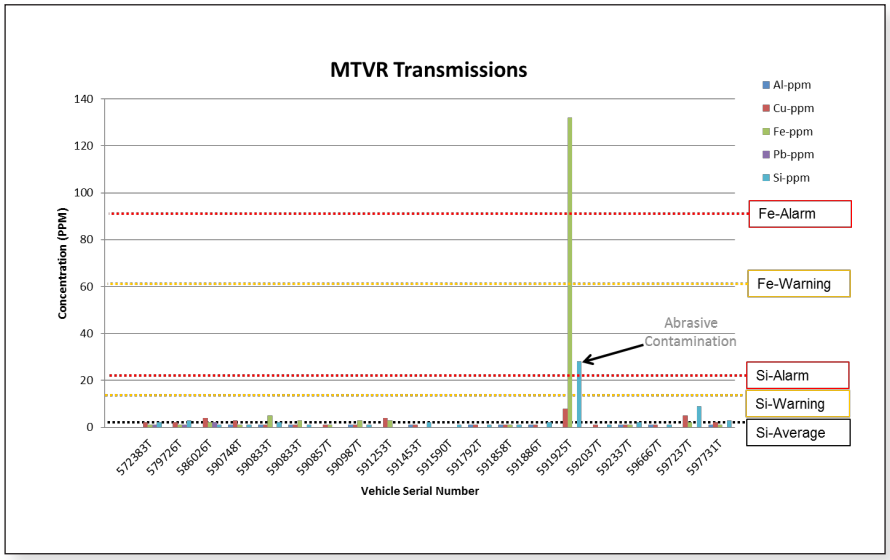


Physical damage to LVSR transfer case tapered roller bearing

The overhaul facility was unable to completely disassemble this component because the inner bearing race was welded to the shaft due to high temperature friction. Complete disassembly was only achieved by burning off the inner race with an oxygen/acetylene torch destroying the shaft and adjacent components.

This LVSR transfer case above does not represent an isolated incident during this test program. The following two graphs provide comparisons of an MTVR transmission and a second LVSR transfer case with a different wear mode.

The graph is a comparison of MTVR transmissions, serial number 591925T shows an iron concentration well above the alarm limit of 90 parts per million along with the presence of copper. What is causing the mechanical degradation of this assembly is the abnormal concentration of silica which is abrasive. It is unknown whether a lubricant drain and replenishment was sufficient to restore the assembly to operational condition. In this example, this component should be scheduled for an accelerated lubricant analysis interval to conclusively determine if a lubricant service has removed the abrasive contamination and the wear mode has returned to normal.

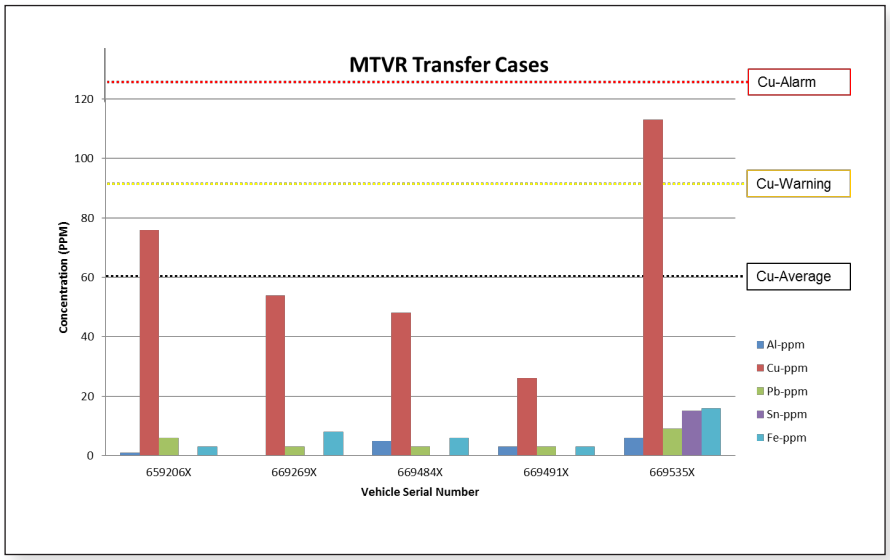


Comparison of identical transmissions from identical MTVR vehicles

The third and final example from the data set achieved throughout the test program at Camp Lejeune appears below. This graph compares MTVR transfer case serial number 669535X to four others which exhibit the presence of babbit material comprised of the three elements copper, lead and tin.

The presence of these elements together could be a bearing sleeve or bushing which is wearing abnormally and causing misalignment of the rotating component which it supports, such that iron and aluminum are also present.

In this case there is no presence of abrasive silica contamination and the lubricant properties are all within manufacturers' specifications. This example appears to be component degradation and should be scheduled for an accelerated lubricant analysis interval to monitor this wear condition.



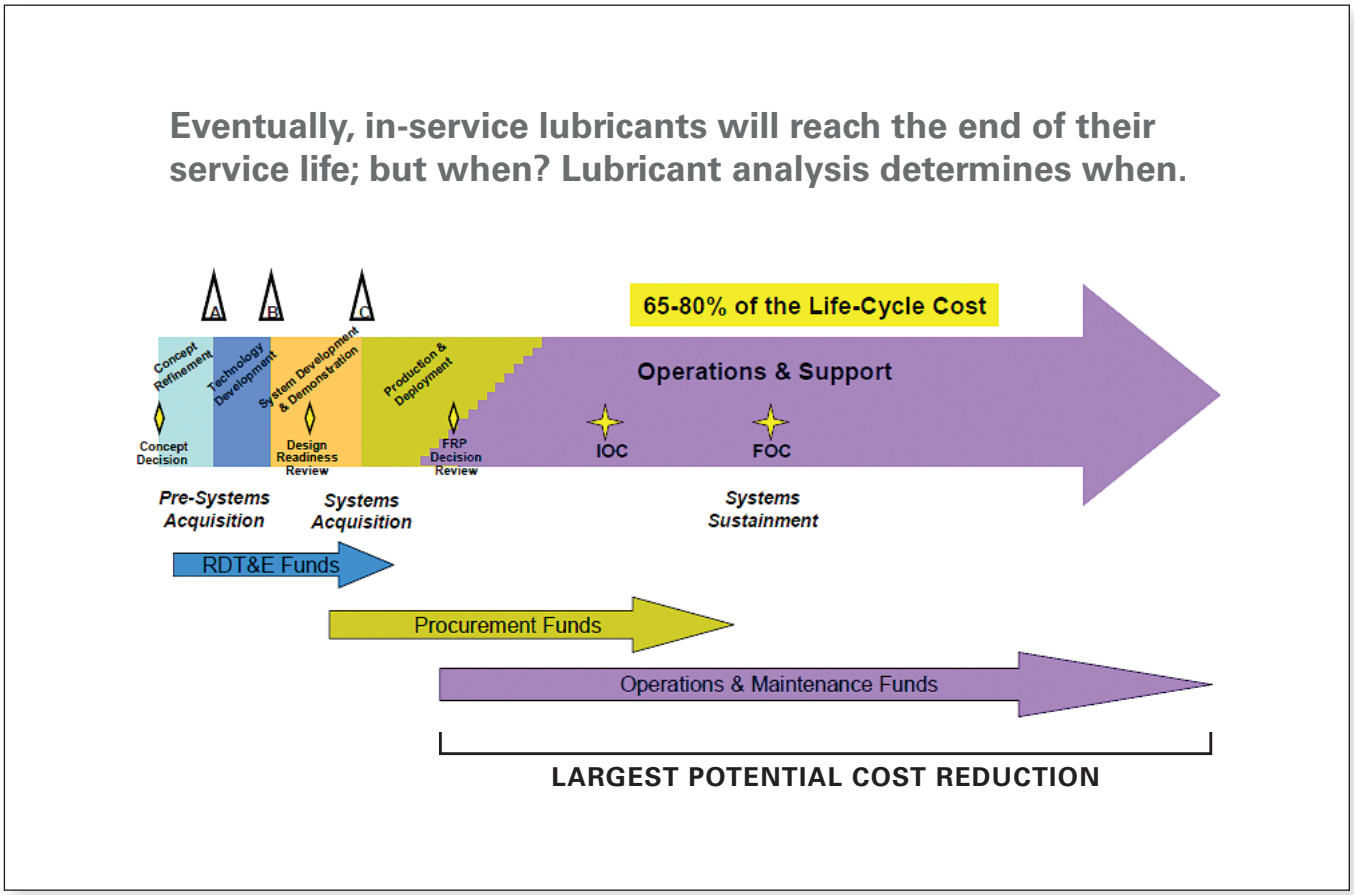
Comparison of identical transfer cases from identical MTVR vehicles

Business Case Analysis

A business case analysis (BCA) based on analytical data produced over a 12 month period was conducted. This effort analyzed the cost avoidance achieved from a combination of lubricant and component condition analysis using handheld (FluidScan Q1000 and SpectroVisc Q3050) and portable oil analysis lab (Q5800) instrumentation.

This concept of operation yields two independent goals: cost avoidance and cost savings. Cost avoidance refers to maximizing efficiency in lubricant maintenance. Maintenance is performed only when the analysis of the lubricant indicates it is time to be replaced. This concept of periodic lubricant analysis enables the maintainer to safely extend lubricant service life, avoiding expenditure of assets (material and labor) prematurely. A well-organized CBM based on lubricant condition will reduce maintenance costs sufficiently to fund and maintain the cost of the CBM program.

The following illustration provides an example of cost avoidance. Maintenance represents 65-80% of the overall cost of a vehicle throughout its life cycle. By applying CBM using on-site analytical tools to determine lubricant and mechanical condition, the cost to maintain a vehicle through the operations and support phase (purple segment) of its life cycle will achieve maximum service life from the lubricants and perform maintenance when it is most cost effective.



MOTOR TRANSPORT EQUIPMENT BIENNIAL FLUID / FILTER / LABOR COSTS -V- FLUID SAMPLE TEST COSTS

LVSR (Biennial)

REPLACE ENGINE OIL AND FILTER

Part NIIN	Part Nomenclature	Part / Quart Qty	Part Cost	Labor Time	Labor Cost	Sub-Total Cost
01-421-1432	15w-40 oil	41	$123.41	1:00	$28.09	$183.37
01-533-3470	Filter, C15 ACERT Engine, Oil	1	$31.87			

REPLACE TRANSMISSION OIL AND FILTER

Part NIIN	Part Nomenclature	Part / Quart Qty	Part Cost	Labor Time	Labor Cost	Sub-Total Cost
01-421-1432	15w-40 oil	38	$114.38	2:00	$56.18	$409.62
01-575-9611	Service, Filter, XMSN Oil, 4700SP	1	$239.06			

REPLACE TRANSFER CASE OIL

Part NIIN	Part Nomenclature	Part / Quart Qty	Part Cost	Labor Time	Labor Cost	Sub-Total Cost
01-421-1432	15w-40 oil	8	$24.08	1:00	$28.09	$52.17

REPLACE HYDRAULIC RESERVOIR OIL DIFFUSER FILTER & THREE PRESSURE FILTERS

Part NIIN	Part Nomenclature	Part / Quart Qty	Part Cost	Labor Time	Labor Cost	Sub-Total Cost
01-421-1432	15w-40 oil	250	$752.50	0:20	$14.48	$1,205.95
01-566-1155	Element Assy	1	$83.53	0:15	$8.68	
01-566-1103	Element Assy	1	$59.66	0:15	$8.68	
15636813	Diffuser, Hydr Fluid	1	$63.69	0:20	$14.48	
15661424	Element Assy	1	$114.55	0:30	$17.36	
15661103	Element Assy	1	$59.66	0:15	$8.68	
TOTAL LVSR BIENNIAL FLUID / FILTER / LABOR COST -						**$2,571.17**

LVSR (Fluid Sample)

SAMPLE ENGINE OIL

Sampling Consumables	Consumable Cost	Sample Time	Labor Cost	Sub-Total Cost
Model Q3000 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe	$1.66	0:15	$7.02	$8.68
Model Q4500 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe, (1) Syringe, (1) Filtergram	$5.12	0:20	$9.36	$14.48

SAMPLE TRANSMISSION OIL

Sampling Consumables	Consumable Cost	Sample Time	Labor Cost	Sub-Total Cost
Model Q3000 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe	$1.66	0:15	$7.02	$8.68
Model Q4500 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe, (1) Syringe, (1) Filtergram	$5.12	0:20	$9.36	$14.48

SAMPLE TRANSFER CASE OIL

Sampling Consumables	Consumable Cost	Sample Time	Labor Cost	Sub-Total Cost
Model Q3000 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe	$1.66	0:15	$7.02	$8.68
Model Q4500 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe, (1) Syringe, (1) Filtergram	$5.12	0:20	$9.36	$14.48

SAMPLE HYDRAULIC OIL

Sampling Consumables	Consumable Cost	Sample Time	Labor Cost	Sub-Total Cost
Model Q3000 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe	$1.66	0:15	$7.02	$8.68
Model Q4500 - (1) Sample bottle, (1) tube, (1) Pipette, (1) Wipe, (1) Syringe, (1) Filtergram	$5.12	0:20	$9.36	$14.48
MODEL Q3000 TOTAL LVSR FLUID SAMPLE COST -				**$182.28**
MODEL Q5800 TOTAL LVSR FLUID SAMPLE COST -				**$304.08**

- On average, 62.3% of all samples analyzed produced NORMAL (No Action Required)

LVSR (20 OIL RESERVOIRS)	COST
CHANGE OIL/ FILTERS INCLUDING LABOR	$2,571.17
COST OF TOTAL OIL Q5800 CONSUMABLES FOR TESTING	$304.08
WORST CASE (AFTER ANALYSIS, ALL RESERVOIRS NEED TO BE REPLENTISHED)	$2,875.25
ON AVERAGE, ONLY 37.7% OF ALL RESERVOIRS NEED TO BE REPLENTISHED	$1,083.97
TOTAL COST SAVINGS	$1,791.28

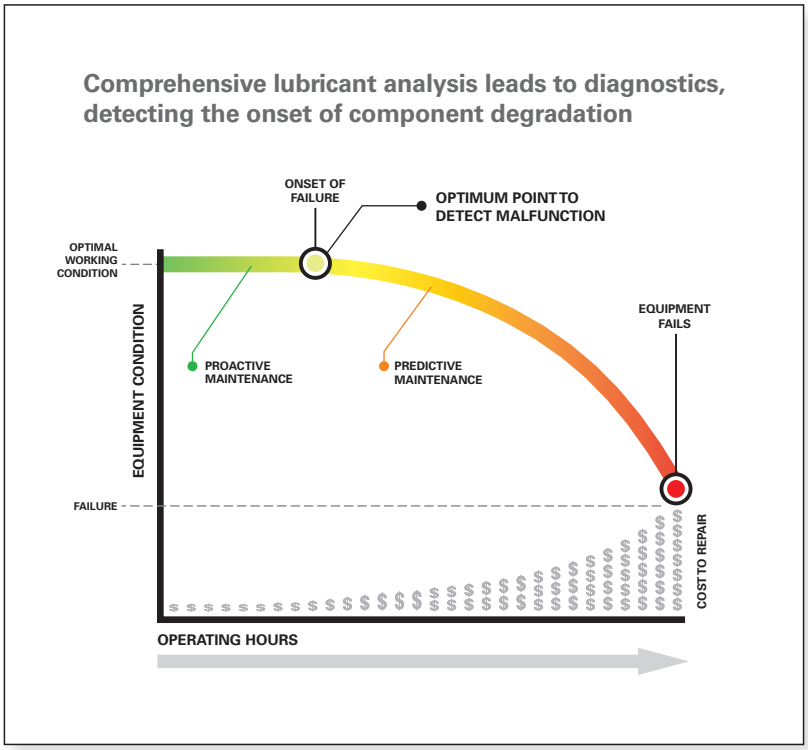
USMC I&L calculate that 60,809 man-hours of labor and $6.5M of material and disposal costs can be avoided for the MTVR and LVSR over a two year period at Camp Lejeune by applying EFAC devices and implementing CBM.

USMC example of cost avoidance by extending lubricant drain intervals over a two year period.

The spreadsheet above provides an example of cost avoidance calculated by the USMC for one LVSR based solely on lubricant condition. Over the 12 months of testing, 62.3% of all component reservoirs analyzed were within manufacturer's specification for lubricant chemistry and viscosity. In this example, if the lubricants in all 20 reservoirs had to be replaced in the LVSR (including the cost of lubricant, filters and labor) the total cost would be $2571.17. The cost to analyze the lubricants from these 20 reservoirs (including labor and consumables) totals $304.08. In the worst case, if the analysis indicates that the lubricants in all 20 reservoirs had to be replaced, the total cost would be $2875.25.

Statistically, based on analytical test results, 62.3% of the oil in these 20 reservoirs retain their chemical and physical properties to manufacturer's specifications. This means on average only 37.7% of these reservoirs (8 reservoirs) need to be serviced. The cost to service these 8 reservoirs is $1,083.97 and that results in an overall cost avoidance of $1,791.28 per vehicle.

Based on effective condition based maintenance of just the lubricants for the MTVR and LVSR at Camp Lejeune, the USMC HQ I&L projects a cost avoidance of $6.5 million dollars over a two year period. The savings of approximately 60,000 man-hours of labor over the two year period can be utilized for more efficient workflow and training.



P-F (Potential-Failure) Curve

The second goal of the CBM concept is to realize true cost savings of maintenance dollars by early detection and prevention of catastrophic component degradation. Preventing catastrophic failure by performing component maintenance as soon as it is detected is the most cost effective approach to achieving true cost savings. The graph to the left illustrates this concept.

During this 12 month period multiple components, many of which were differentials and hubs, were identified as having abnormal wear metal concentrations, high water content and lubricants that far exceeded industry standards for cleanliness levels. Only one component was removed from service where a teardown analysis was performed and that component (LVSR Transfer Case S/N 648404X) was detailed earlier in this paper.

In an effective CBM program whereby the lubricants are analyzed on a reasonable interval, the development of mechanical degradation can appear as a result of premature lubricant degradation or contamination, but can also appear as a result of a mechanical shift or imbalance. In the P-F curve example above, the objective is to detect the development of an abnormal condition while in the proactive maintenance stage. Once an abnormal condition develops and is confirmed, the most cost effective time to conduct a maintenance inspection is at the onset towards failure. This results in the minimum amount of labor and resources required to identify the source of the problem and correct it before secondary damage occurs. Locating the source of the failure is guided by the knowledge of the specific assembly and the metallurgical chemistry of its components as described in the Oil Evaluation Report above.

USMC Labor Cost to Remove	$350
USMC Material Cost to Remove	$0
Contractor Labor Cost to Repair	$6,400
Contractor Material Cost to Repair	$3,260
USMC Labor Cost to Re-Install	$520
USMC Material Cost to Re-Install	$15
Shipping Costs 2X	$2,500
TOTAL COST	$13,045
Days in Deadline Status	97

Cost breakdown to overhaul LVSR transfer case

In the example of the LVSR Transfer Case detailed previously, the extremely high particle count, iron and copper concentration with the absence of silica debris coupled with very low viscosity would definitely have been detected and could have been corrected at the onset. It is not known if the low viscosity or excessive loading of the bearing was the root cause of the failure. On left is a spreadsheet listing the total cost to repair this transfer case and system downtime. The cost of a new transfer case assembly is $2,712.85. The cost of repair combined with 97 days in deadline status severely hampers mission readiness.

Conclusion

The United States Marine Corp (USMC) has a very large contingent of machinery across several continents. In years past, they participated in condition based maintenance by sending oil samples to the nearest land based oil analysis laboratory. Because of long response time and ambiguous maintenance recommendations, they dis-enrolled from the Navy oil analysis program and adopted a policy of maintaining the fluid integrity on an interval (annual or biennial) basis. In a Department of Defense wide policy to reduce lubricant and fuel consumption, the USMC embarked on a program to reinstate CBM through oil analysis using handheld and portable instrumentation manufactured by Spectro Scientific Inc.

A test and evaluation program was initiated in January 2014 at Camp Lejeune, N.C. The program consisted of one depot maintenance unit using a combination of handheld lubricant analyzers (FluidScan Q1000 and SpectroVisc Q3050) and a second depot maintenance unit that conducted a comprehensive oil analysis program using a portable oil analyzer, the Q5800. All of these instruments are simple to use and provide results within minutes. By avoiding the extended delays associated with sending samples to a commercial testing service, these instruments were able to provide actionable recommendations while the vehicle was still being actively serviced, and thus greatly increasing the value of the recommendations provided.

Several thousand oil samples were analyzed and evaluated to establish industry standard limits for oil chemistry, viscosity, particle count, wear metals and contaminants. Applying these limits to the data set enabled GO NO-GO limits to be programmed into the instruments that provide maintenance actions to the maintainers. The Q5800 also had guidelines established as a means of highlighting an abnormal condition but in addition, a diagnostic rules-based software received the analytical results, analyzed the 26 parameters and provided analysis and actionable recommendations to the maintainers in about one minute.

On average, when analyzing the chemistry and viscosity of the lubricants 62.3% of all fluids met or exceeded manufacturer's specifications and were not replaced resulting in a substantial cost avoidance. When expanding the analysis to include contamination, particle count and wear metal analysis the percentage of overall condition dropped to 17.6% because an additional 14 parameters were being measured. Of these 14 additional parameters, fluid cleanliness, contamination and wear metals were of sufficient count and concentration to change the category from normal to warning or alarm.

One sample analyzed on the Q5800 from a transfer case in an LVSR flagged an alarm that coincided with debris found on the drain plug. This vehicle was taken to heavy maintenance where the component was removed. This component underwent an overhaul where the tapered roller bearing failed in a catastrophic manner. There was no other indication this component was in a failure mode and would not have been detected without oil analysis.

A business case analysis was conducted by USMC HQ I&L whereby, based on this study, 6.5 million dollars can be saved and over 60,000 man-hours can be reassigned to other tasks and training over a two year period at one facility alone. Expanding that capability across the USMC enterprise to include all oil wetted vehicles; the cost savings could be substantial. In addition, by conducting a comprehensive analysis on-site with the Q5800 and diagnostic software, a full (laboratory quality) assessment of the readiness of the vehicle can be determined. Conducting maintenance at the first sign of mechanical degradation will result in true cost savings

The USMC has since expanded their CBM program to include Twentynine Palms, CA for fluid chemistry and viscosity. The test program for the Q5800 at Camp Lejeune has come to a close and the final data will be summarized and presented to the USMC HQ I&L leadership for evaluation and program development.

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