# Supplementary File 1: Benchmarking Maintenance Practices for Allocating Features Affecting Hydraulic Systems Maintenance: A West-Balkan Perspective

| *Question:* | *Checkbox:* | |
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| **1.** What is the number of employees in your company & what is the number of machines utilising oil-hydraulic control systems in your company? | **The number of your employees?**<br>☐ <50<br>☐ 50-149<br>☐ 150-249<br>☐ 249-750<br>☐ 750-1499<br>☐ 1500-2499<br>☐ 2500-5000<br>☐ >5000<br>☐ Exact number (specify):_____ | **Number of hydraulic machines?**<br>☐ 1-9<br>☐ 10-19<br>☐ 20-49<br>☐ 50-99<br>☐ 100-149<br>☐ 150-299<br>☐ 300-500<br>☐ >500<br>☐ Exact number (specify):_____ |
| **2.** Maintenance Department Size (including all levels of hierarchy within the company)? | **The number of maintenance personnel?**<br>☐ 5<br>☐ 6-10<br>☐ 11-15<br>☐ 16-25<br>☐ 26-50<br>☐ 51-100<br>☐ 101-250<br>☐ >251<br>☐ Exact number(specify):_____ | **Maintenance Department Staff?**<br>☐ Technicians<br>☐ Laboratorians<br>☐ Engineers (BSc or MSc)<br>☐ Third-party personnel<br>☐ Oil analysis experts<br>☐ Hydraulic system specialist<br>☐ Dr Eng.<br>☐ Other(please specify):_____ |
| **3.** Who does perform failure analysis (diagnostics and prognostics) on your hydraulic machinery? | ☐ Maintenance technician<br>☐ BSc engineer<br>☐ MSc engineer<br>☐ Specialists (Dr degree) | ☐ External specialists<br>☐ Outsource company<br>☐ None<br>☐ Other (please specify):<br>_____ |
| **4.** What type of hydraulic control machines are utilised within your organisation (and how machines are you employing? | **4a. Industrial machines**<br>☐ Extruders:<br>☐ Casting, die machines:<br>☐ Paper production machines:<br>☐ Automated production lines:<br>☐ Crushing machines:<br>☐ Textile production machines:<br>☐ Rubber mixing machines:<br>☐ Extrusion machines:<br>☐ Others (specify): | **4b. Mobile machines**<br>☐ Tractors:<br>☐ Mine-drilling machines:<br>☐ Excavators:<br>☐ Manipulation equipment:<br>☐ Dampers:<br>☐ Tunnel boring machines:<br>☐ Trucks:<br>☐ Road paving machines:<br>☐ Oil-drillers:<br>☐ Other (specify):_____ |
| **5.** What is the average nominal pressure within the hydraulic system? | ☐ Low-pressure systems (<65bar)<br>☐ Low-to-medium pressure (65-140bar)<br>☐ Medium pressure systems (141-210bar) | ☐ Medium-to-high pressure systems (211-350 bar)<br>☐ High-pressure systems (351-750 bar)<br>☐ Extreme-pressure systems (>750 bar) |
| **6.** What is the average flow within the hydraulic system? | ☐ Low flow (1-20 l/min)<br>☐ Medium flow (21-55 l/min)<br>☐ Medium-high- flow (55-140 l/min) | ☐ Light-High flow (141-320 l/min)<br>☐ High flow (321-1000 l/min)<br>☐ Extreme (>1000 l/min) |

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| 7. | **What types of fluid are you utilising?** | **Mineral-based**<br>☐ HH – no additives<br>☐ HL – anti-corrosion, antioxidant additives<br>☐ HM – antiwear additives<br>☐ HV – viscosity improver additives<br>**Fire extinguishing fluid**<br>☐ HFA – oil in water emulsion (water >90%)<br>☐ HFB – water in oil emulsion (water >40%)<br>☐ HFC – water glycol<br>☐ HFD - Synthetic fluid (phosphoric ester)<br>**Environmentally accepted fluids**<br>☐ HTG – Vegetal base fluid<br>☐ HPG – Glycol base synthetic fluid<br>☐ HE – Esther base synthetic fluid<br>☐ Other: _____ |
| 8. | **What type of maintenance practice (policy) are you conducting in your company?** | **Maintenance practice:**<br>☐ Failure-based maintenance (FBM, also corrective maintenance)<br>☐ Preventive Maintenance (PM, also time-based maintenance)<br>☐ Condition-Based Maintenance[1] (CBM)<br>☐ Predictive Maintenance[2] (PdM)<br>☐ Opportunity-based maintenance[3]<br>☐ Design-out maintenance[4]<br>☐ Other: (*name please*) _____ |
| 9. | **What specific maintenance analysis program (condition monitoring program) do you conduct for hydraulic systems?** | **Oil monitoring program:**<br>☐ Visual monitoring (temperature, colour, odour, sound, response, other).<br>☐ Contamination Control Program (handling, filtering, monitoring, etc.).<br>☐ Joint Oil Analysis Program (spectrometry analysis, wear analysis, laboratory, statistical analysis, etc.).<br>☐ Oil Condition Monitoring (using APC, Aqua-Sensor, or another instrument for online monitoring).<br>☐ Used Oil Analysis Program (taking samples for offline analysis into the lab – spectrometry, wear debris analysis, FTIR, TBN, TAN, etc.).<br>☐ Prognostics and health monitoring (vibration, ultrasound, thermovision camera, other).<br>☐ None<br>☐ Other: (*name please*) _____ |
| 10. | **What condition monitoring sensors are you using (check more boxes if necessary)?** | ☐ Pressure sensors (transmitters, differential, electronic)<br>☐ Flow rate sensors (transmitters, switches, e-mechanical)<br>☐ Linear position sensors (for cylinder position)<br>☐ Contamination sensors (particle counters, water sensors)<br>☐ Temperature sensors (transmitter, probes, e-switches)<br>☐ Position sensors (linear/rotation position sensors on actuators)<br>☐ Vibroacoustic sensors<br>☐ Other: (name please) _____ |

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[1] Using current component state information (signal and data processing) to conduct appropriate actions based on signals and data.

[2] Using current and prognostic information, like the remaining useful lifetime of components, to optimally schedule maintenance actions.

[3] The failure of one subsystem results in the possible opportunity to undertake maintenance on other subsystems (opportunistic maintenance).

[4] Design Out Maintenance aims to redesign those parts of the equipment which consume high levels of maintenance effort or spares cost or which have unacceptably high failure rates.

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| **11.** | **What condition monitoring instruments are you using for the oil contamination analysis program (check more boxes if necessary)?** | **Oil monitoring instruments:**<br>☐ Automatic Particle Counters (APC)<br>☐ Metallic Contamination Sensor (MCS)<br>☐ Water (Aqua) Sensors<br>☐ Viscometers<br>☐ None<br>☐ Other: (*name please*) _____<br><br>**What instruments are utilised for elemental analysis in hydraulic oil:**<br>☐ FTIR (Fourier-transform infrared spectroscopy)<br>☐ ICP-OES/AES (Inductively Coupled Plasma/Atomic Emission)<br>☐ RDE-OES/AES (Rotating Disc Electrode)<br>☐ Wavelength dispersive X-ray fluorescence spectrometry (WDXRF)<br>☐ None<br>☐ Other: (*name please*) _____ |
| **12.** | **What mathematical or statistical tools are you employing for analysis and maintenance-decision making (check more boxes if necessary)?** | **Mathematical/Statistical tools for maintenance decision-making:**<br>☐ Regression analysis (least squares, linear, polynomial, etc.)<br>☐ Survival analysis (reliability theory, proportional hazard modelling, etc.)<br>☐ Decision tree analysis (FTA)<br>☐ FMEA (or FMECA) analysis<br>☐ Multi-criteria decision-making analysis (MCDM)<br>☐ Quality control charts (XR charts, XS charts, *p* chart, *u* chart, etc.)<br>☐ None<br>☐ Other: (*name please*) _____ |

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| **13.** | **What is the average age of your hydraulic machinery?** | ☐ From 1 – 5 years no. machines:_<br>☐ From 05 – 10 y. no. machines:__<br>☐ From 10 – 15 y. no. machines:__<br>☐ From 15 –20 y. no. machines:__<br>☐ From 20 – 25 y. no. machines:__<br>☐ From 25 – 30 y. no. machines:__<br>☐ From 30 – 35 y. no. machines:__ | ☐ From 35 – 40 y. no. machines:__<br>☐ From 40 – 45 y. no. machines:__<br>☐ From 45 – 50 y. no. machines:__<br>☐ From 50 – 55 y. no. machines:__<br>☐ From 55 – 60 y. no. machines:__<br>☐ From 60 – 70 y. no. machines:__<br>☐ Other or specific:_____ |
| **14.** | **What is the average time between your <u>hydraulic</u> machinery's hydraulic failures (TBHF)?** | ☐ 0 - 100 hours<br>☐ 100 – 200 hours<br>☐ 200 – 300 hours<br>☐ 300 – 400 hours<br>☐ 400 – 500 hours<br>☐ 500 – 600 hours<br>☐ 600 – 700 hours<br>☐ 700 – 800 hours<br>☐ 800 – 900 hours<br>☐ 900 – 1000 hours<br>☐ 1000 – 1100 hours<br>☐ 1100 – 1200 hours<br>☐ 1200 – 1300 hours | ☐ 1300 – 1400 hours<br>☐ 1400 – 1500 hours<br>☐ 1500 – 1600 hours<br>☐ 1600 – 1700 hours<br>☐ 1700 – 1800 hours<br>☐ 1800 – 1900 hours<br>☐ 1900 – 2000 hours<br>☐ 2000 – 2100 hours<br>☐ 2100 – 2200 hours<br>☐ 2200 – 2300 hours<br>☐ 2300 – 2500 hours<br>☐ >2500 hours<br>☐ Other: _____ |
| **15.** | **What is your hydraulic machine failures' mean (average) time to repair (TTR)?** | ☐ 0-1 hours<br>☐ 1-2 hours<br>☐ 2-3 hours<br>☐ 3-4 hours<br>☐ 4-5 hours<br>☐ 5-6 hours<br>☐ 6-7 hours<br>☐ 7-8 hours | ☐ 8-9 hours<br>☐ 9-10 hours<br>☐ 10-11 hours<br>☐ 11-12 hours<br>☐ 12-13 hours<br>☐ 13-15 hours<br>☐ >15 hours<br>☐ Exactly (specify):_____ |

| 16. | **What are your hydraulic machinery's most common component failures (check more boxes if necessary)?** | ☐ Hoses or pipes<br>☐ Actuator failure – hydraulic cylinder<br>☐ Actuator failure – hydraulic motor<br>☐ Pump failure<br>☐ Solenoid valve failures<br>☐ Proportional valve failures – directional valve<br>☐ Servo-valve failures – directional valve<br>☐ Electro-motor failure or ICE failure (for pump drive)<br>☐ Accumulator failure<br>☐ Sensors failure<br>☐ Filter failure<br>☐ Other: (*please specify*):_____ | |
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| 17. | **What are the most common root causes of failure of your hydraulic machinery (check more boxes if necessary)?** | ☐ Overloading the system<br>☐ Temperature (overheating the system)<br>☐ Inadequate oil in the system<br>☐ A mixture of the oil<br>☐ Oxidation of the oil (depletion of additives and viscosity drop)<br>☐ Contamination (particle contamination)<br>☐ Contamination (water and moisture)<br>☐ Maintenance personnel mistakes<br>☐ Seals<br>☐ Other: (*please specify*):_____ | |
| 18. | **What is the period for your filter replacement?** | ☐ 0-50 working hours<br>☐ 50-150 working hours<br>☐ 150-250 working hours<br>☐ 250-500 working hours<br>☐ 500-750 working hours<br>☐ 750-1000 working hours<br>☐ 1000-1250 working hours | ☐ 1250-1500 working hours<br>☐ 1500-1750 working hours<br>☐ 1750-2000 working hours<br>☐ 2000-2500 working hours<br>☐ 2500-3000 working hours<br>☐ If you have precisely specified hours, specify:_____ |
| 19. | **What oil viscosity grade do you use in your machines (if you have a specific table for each of your systems, can you attach it?)?** | ☐ ISO VG 22<br>☐ ISO VG 32<br>☐ ISO VG 37<br>☐ ISO VG 46<br>☐ ISO VG 68<br>☐ ISO VG 100<br>☐ ISO VG 150 | |
| 20. | **How often do you refill the system with oil?** | ☐ After 25 hours<br>☐ After 50 hours<br>☐ After 60 hours<br>☐ After 75 hours<br>☐ After 90 hours<br>☐ After 100 hours<br>☐ After 125 hours | ☐ After 150 hours<br>☐ After 200 hours<br>☐ After 250 hours<br>☐ After 300 hours<br>☐ After 500 hours<br>☐ After 750 hours<br>☐ Other (*please specify*):_____ |
| 21. | **What is the average time of complete oil change in your hydraulic machine, and based on which criteria do you conduct it?** | **Time of complete oil change:**<br>☐ After 100 hours<br>☐ After 250 hours<br>☐ After 500 hours (15 days)<br>☐ After 720 hours (monthly)<br>☐ After 1440 hours (two months)<br>☐ After 2160 hours (quarterly) | **Criteria:**<br><br>☐ Routine<br>☐ Oil check<br>☐ Historical data analysis<br>☐ Contaminated oil<br>☐ OEM suggestions<br>☐ The response of the system |

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|  | ☐ After 4320 hours (six months.) | ☐ Other (*please specify*): |
|  | ☐ After 8640 hours (yearly) | _____ |
|  | ☐ Other (*please specify*):_____ |  |
| **22. What is the average oil filling of hydraulic machines in your everyday usage, and how many litres do you spend monthly?** | **Average machine oil filling:**<br>☐ <50 litres<br>☐ 50-100 litres<br>☐ 100-150 litres<br>☐ 150-200 litres<br>☐ 200-250 litres<br>☐ 250-300 litres<br>☐ 300-500 litres<br>☐ 500-1000 litres<br>☐ 1000-2000 litres<br>☐ 2000-3000 litres<br>☐ 3000-4000 litres<br>☐ Other (*please specify*):_____ | **Hydraulic oil spent monthly)?**<br>☐ 0-500 litres<br>☐ 500-1000 litres<br>☐ 1000-2000 litres<br>☐ 2000-3000 litres<br>☐ 3000-4000 litres<br>☐ 4000-5000 litres<br>☐ Other (*specific number, please add*):<br>_____ |

Thank you for filling out the survey! If you wish to receive an email of the final results, please click the checkbox and leave the email you want to receive the results!

☐ Contact/email: _____