

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

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

<p>7. What types of fluid are you utilising?</p>	<p>Mineral-based</p> <p><input type="checkbox"/> HH – no additives</p> <p><input type="checkbox"/> HL – anti-corrosion, antioxidant additives</p> <p><input type="checkbox"/> HM – antiwear additives</p> <p><input type="checkbox"/> HV – viscosity improver additives</p> <p>Fire extinguishing fluid</p> <p><input type="checkbox"/> HFA – oil in water emulsion (water >90%)</p> <p><input type="checkbox"/> HFB – water in oil emulsion (water >40%)</p> <p><input type="checkbox"/> HFC – water glycol</p> <p><input type="checkbox"/> HFD - Synthetic fluid (phosphoric ester)</p> <p>Environmentally accepted fluids</p> <p><input type="checkbox"/> HTG – Vegetal base fluid</p> <p><input type="checkbox"/> HPG – Glycol base synthetic fluid</p> <p><input type="checkbox"/> HE – Esther base synthetic fluid</p> <p><input type="checkbox"/> Other: _____</p>
<p>8. What type of maintenance practice (policy) are you conducting in your company?</p>	<p>Maintenance practice:</p> <p><input type="checkbox"/> Failure-based maintenance (FBM, also corrective maintenance)</p> <p><input type="checkbox"/> Preventive Maintenance (PM, also time-based maintenance)</p> <p><input type="checkbox"/> Condition-Based Maintenance¹ (CBM)</p> <p><input type="checkbox"/> Predictive Maintenance² (PdM)</p> <p><input type="checkbox"/> Opportunity-based maintenance³</p> <p><input type="checkbox"/> Design-out maintenance⁴</p> <p><input type="checkbox"/> Other: <i>(name please)</i> _____</p>
<p>9. What specific maintenance analysis program (condition monitoring program) do you conduct for hydraulic systems?</p>	<p>Oil monitoring program:</p> <p><input type="checkbox"/> Visual monitoring (temperature, colour, odour, sound, response, other).</p> <p><input type="checkbox"/> Contamination Control Program (handling, filtering, monitoring, etc.).</p> <p><input type="checkbox"/> Joint Oil Analysis Program (spectrometry analysis, wear analysis, laboratory, statistical analysis, etc.).</p> <p><input type="checkbox"/> Oil Condition Monitoring (using APC, Aqua-Sensor, or another instrument for online monitoring).</p> <p><input type="checkbox"/> Used Oil Analysis Program (taking samples for offline analysis into the lab – spectrometry, wear debris analysis, FTIR, TBN, TAN, etc.).</p> <p><input type="checkbox"/> Prognostics and health monitoring (vibration, ultrasound, thermovision camera, other).</p> <p><input type="checkbox"/> None</p> <p><input type="checkbox"/> Other: <i>(name please)</i> _____</p>
<p>10. What condition monitoring sensors are you using (check more boxes if necessary)?</p>	<p><input type="checkbox"/> Pressure sensors (transmitters, differential, electronic)</p> <p><input type="checkbox"/> Flow rate sensors (transmitters, switches, e-mechanical)</p> <p><input type="checkbox"/> Linear position sensors (for cylinder position)</p> <p><input type="checkbox"/> Contamination sensors (particle counters, water sensors)</p> <p><input type="checkbox"/> Temperature sensors (transmitter, probes, e-switches)</p> <p><input type="checkbox"/> Position sensors (linear/rotation position sensors on actuators)</p> <p><input type="checkbox"/> Vibroacoustic sensors</p> <p><input type="checkbox"/> Other: <i>(name please)</i> _____</p>

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.

11. What condition monitoring instruments are you using for the oil contamination analysis program (check more boxes if necessary)?	Oil monitoring instruments: <input type="checkbox"/> Automatic Particle Counters (APC) <input type="checkbox"/> Metallic Contamination Sensor (MCS) <input type="checkbox"/> Water (Aqua) Sensors <input type="checkbox"/> Viscometers <input type="checkbox"/> None <input type="checkbox"/> Other: <i>(name please)</i> _____ <hr/> What instruments are utilised for elemental analysis in hydraulic oil: <input type="checkbox"/> FTIR (Fourier-transform infrared spectroscopy) <input type="checkbox"/> ICP-OES/AES (Inductively Coupled Plasma/Atomic Emission) <input type="checkbox"/> RDE-OES/AES (Rotating Disc Electrode) <input type="checkbox"/> Wavelength dispersive X-ray fluorescence spectrometry (WDXRF) <input type="checkbox"/> None <input type="checkbox"/> Other: <i>(name please)</i> _____	
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: <input type="checkbox"/> Regression analysis (least squares, linear, polynomial, etc.) <input type="checkbox"/> Survival analysis (reliability theory, proportional hazard modelling, etc.) <input type="checkbox"/> Decision tree analysis (FTA) <input type="checkbox"/> FMEA (or FMECA) analysis <input type="checkbox"/> Multi-criteria decision-making analysis (MCDM) <input type="checkbox"/> Quality control charts (XR charts, XS charts, <i>p</i> chart, <i>n</i> chart, etc.) <input type="checkbox"/> None <input type="checkbox"/> Other: <i>(name please)</i> _____	
13. What is the average age of your hydraulic machinery?	<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <input type="checkbox"/> From 1 – 5 years no. machines: __ <input type="checkbox"/> From 05 – 10 y. no. machines: __ <input type="checkbox"/> From 10 – 15 y. no. machines: __ <input type="checkbox"/> From 15 – 20 y. no. machines: __ <input type="checkbox"/> From 20 – 25 y. no. machines: __ <input type="checkbox"/> From 25 – 30 y. no. machines: __ <input type="checkbox"/> From 30 – 35 y. no. machines: __ </div> <div style="width: 48%;"> <input type="checkbox"/> From 35 – 40 y. no. machines: __ <input type="checkbox"/> From 40 – 45 y. no. machines: __ <input type="checkbox"/> From 45 – 50 y. no. machines: __ <input type="checkbox"/> From 50 – 55 y. no. machines: __ <input type="checkbox"/> From 55 – 60 y. no. machines: __ <input type="checkbox"/> From 60 – 70 y. no. machines: __ <input type="checkbox"/> Other or specific: _____ </div> </div>	
14. What is the average time between your <u>hydraulic</u> machinery's hydraulic failures (TBHF)?	<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <input type="checkbox"/> 0 - 100 hours <input type="checkbox"/> 100 – 200 hours <input type="checkbox"/> 200 – 300 hours <input type="checkbox"/> 300 – 400 hours <input type="checkbox"/> 400 – 500 hours <input type="checkbox"/> 500 – 600 hours <input type="checkbox"/> 600 – 700 hours <input type="checkbox"/> 700 – 800 hours <input type="checkbox"/> 800 – 900 hours <input type="checkbox"/> 900 – 1000 hours <input type="checkbox"/> 1000 – 1100 hours <input type="checkbox"/> 1100 – 1200 hours <input type="checkbox"/> 1200 – 1300 hours </div> <div style="width: 48%;"> <input type="checkbox"/> 1300 – 1400 hours <input type="checkbox"/> 1400 – 1500 hours <input type="checkbox"/> 1500 – 1600 hours <input type="checkbox"/> 1600 – 1700 hours <input type="checkbox"/> 1700 – 1800 hours <input type="checkbox"/> 1800 – 1900 hours <input type="checkbox"/> 1900 – 2000 hours <input type="checkbox"/> 2000 – 2100 hours <input type="checkbox"/> 2100 – 2200 hours <input type="checkbox"/> 2200 – 2300 hours <input type="checkbox"/> 2300 – 2500 hours <input type="checkbox"/> >2500 hours <input type="checkbox"/> Other: _____ </div> </div>	
15. What is your hydraulic machine failures' mean (average) time to repair (TTR)?	<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <input type="checkbox"/> 0-1 hours <input type="checkbox"/> 1-2 hours <input type="checkbox"/> 2-3 hours <input type="checkbox"/> 3-4 hours <input type="checkbox"/> 4-5 hours <input type="checkbox"/> 5-6 hours <input type="checkbox"/> 6-7 hours <input type="checkbox"/> 7-8 hours </div> <div style="width: 48%;"> <input type="checkbox"/> 8-9 hours <input type="checkbox"/> 9-10 hours <input type="checkbox"/> 10-11 hours <input type="checkbox"/> 11-12 hours <input type="checkbox"/> 12-13 hours <input type="checkbox"/> 13-15 hours <input type="checkbox"/> >15 hours <input type="checkbox"/> Exactly (specify): _____ </div> </div>	

16. What are your hydraulic machinery's most common component failures (check more boxes if necessary)?	<input type="checkbox"/> Hoses or pipes <input type="checkbox"/> Actuator failure – hydraulic cylinder <input type="checkbox"/> Actuator failure – hydraulic motor <input type="checkbox"/> Pump failure <input type="checkbox"/> Solenoid valve failures <input type="checkbox"/> Proportional valve failures – directional valve <input type="checkbox"/> Servo-valve failures – directional valve <input type="checkbox"/> Electro-motor failure or ICE failure (for pump drive) <input type="checkbox"/> Accumulator failure <input type="checkbox"/> Sensors failure <input type="checkbox"/> Filter failure <input type="checkbox"/> Other: <i>(please specify)</i> : _____	
17. What are the most common root causes of failure of your hydraulic machinery (check more boxes if necessary)?	<input type="checkbox"/> Overloading the system <input type="checkbox"/> Temperature (overheating the system) <input type="checkbox"/> Inadequate oil in the system <input type="checkbox"/> A mixture of the oil <input type="checkbox"/> Oxidation of the oil (depletion of additives and viscosity drop) <input type="checkbox"/> Contamination (particle contamination) <input type="checkbox"/> Contamination (water and moisture) <input type="checkbox"/> Maintenance personnel mistakes <input type="checkbox"/> Seals <input type="checkbox"/> Other: <i>(please specify)</i> : _____	
18. What is the period for your filter replacement?	<input type="checkbox"/> 0-50 working hours <input type="checkbox"/> 50-150 working hours <input type="checkbox"/> 150-250 working hours <input type="checkbox"/> 250-500 working hours <input type="checkbox"/> 500-750 working hours <input type="checkbox"/> 750-1000 working hours <input type="checkbox"/> 1000-1250 working hours	<input type="checkbox"/> 1250-1500 working hours <input type="checkbox"/> 1500-1750 working hours <input type="checkbox"/> 1750-2000 working hours <input type="checkbox"/> 2000-2500 working hours <input type="checkbox"/> 2500-3000 working hours <input type="checkbox"/> 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?)?	<input type="checkbox"/> ISO VG 22 <input type="checkbox"/> ISO VG 32 <input type="checkbox"/> ISO VG 37 <input type="checkbox"/> ISO VG 46 <input type="checkbox"/> ISO VG 68 <input type="checkbox"/> ISO VG 100 <input type="checkbox"/> ISO VG 150	
20. How often do you refill the system with oil?	<input type="checkbox"/> After 25 hours <input type="checkbox"/> After 50 hours <input type="checkbox"/> After 60 hours <input type="checkbox"/> After 75 hours <input type="checkbox"/> After 90 hours <input type="checkbox"/> After 100 hours <input type="checkbox"/> After 125 hours	<input type="checkbox"/> After 150 hours <input type="checkbox"/> After 200 hours <input type="checkbox"/> After 250 hours <input type="checkbox"/> After 300 hours <input type="checkbox"/> After 500 hours <input type="checkbox"/> After 750 hours <input type="checkbox"/> Other <i>(please specify)</i> : _____
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: <input type="checkbox"/> After 100 hours <input type="checkbox"/> After 250 hours <input type="checkbox"/> After 500 hours (15 days) <input type="checkbox"/> After 720 hours (monthly) <input type="checkbox"/> After 1440 hours (two months) <input type="checkbox"/> After 2160 hours (quarterly)	Criteria: <input type="checkbox"/> Routine <input type="checkbox"/> Oil check <input type="checkbox"/> Historical data analysis <input type="checkbox"/> Contaminated oil <input type="checkbox"/> OEM suggestions <input type="checkbox"/> The response of the system

	<input type="checkbox"/> After 4320 hours (six months.) <input type="checkbox"/> After 8640 hours (yearly) <input type="checkbox"/> Other (<i>please specify</i>): _____	<input type="checkbox"/> Other (<i>please specify</i>): _____ _____
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: <input type="checkbox"/> <50 litres <input type="checkbox"/> 50-100 litres <input type="checkbox"/> 100-150 litres <input type="checkbox"/> 150-200 litres <input type="checkbox"/> 200-250 litres <input type="checkbox"/> 250-300 litres <input type="checkbox"/> 300-500 litres <input type="checkbox"/> 500-1000 litres <input type="checkbox"/> 1000-2000 litres <input type="checkbox"/> 2000-3000 litres <input type="checkbox"/> 3000-4000 litres <input type="checkbox"/> Other (<i>please specify</i>): _____	Hydraulic oil spent monthly)? <input type="checkbox"/> 0-500 litres <input type="checkbox"/> 500-1000 litres <input type="checkbox"/> 1000-2000 litres <input type="checkbox"/> 2000-3000 litres <input type="checkbox"/> 3000-4000 litres <input type="checkbox"/> 4000-5000 litres <input type="checkbox"/> Other (<i>specific number, please add</i>): _____ _____

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: _____