Abstract of dissertation

"A method of comprehensive assessment of the operational efficiency of machines and predictive maintenance based on data from the monitoring system"

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Based on experiences spanning over decades of research, a dissertation titled "A method of comprehensive assessment of the operational efficiency of machines and predictive maintenance based on data from the monitoring system" has been written. The titular method is a set of procedures tied to optimization of machine usage and preventing critical failures of selected subsystems. The need for such a tool arises from sheer scale of KGHM machine fleet; the number of mobile mining machines exceeds 1000 vehicles. The main types of machines (load haul dump loaders, haul trucks, drilling rings, bolting rigs ) significantly differ in terms of construction, purpose and technological processes performed by them.

The topic of the dissertation does not refer to one specific algorithm, but to a philosophy of fusing and aggregating data from multiple sources to allow processing it with various levels of detail, over different time horizons (per hour, per shift, etc.) and for separate processes (transportation, drilling, bolting ...) While the technological processes are very varied, from an analytical point of view the tasks are extremely similar; the objective is to measure the efficiency of the process in terms of work cycle detection (number of transportation cycles, number of drilled holes, number of bolting actions) as well as detection of anomalies in descriptive data related to variability of oil pressure and temperature, as well as rotational speed of the engine shaft.

In the scope of research related to the dissertation, a series of numerical, laboratory and in situ experiments was conducted, during which a unique set of data, describing selected technological processes in copper ore excavation, was obtained. The data was then further analysed with various methods (visual and statistical analysis, correlation analysis, machine learning etc.). Algorithms used for analyses were devised by the Author or in cooperation with research centers at KGHM Cuprum and the Faculty of Geoengineering, Mining and Geology of Wrocław University of Technology, commissioned by KGHM or on the basis of general cooperation.

In long-term analysis, data processing must be based on segmentation, parametrization, aggregation and statistics. Methods proposed in the dissertation, based on simple statistical tools (analysis of percentiles, empirical distribution analysis) allowed for detection of global trends, excluding local changes related to instantaneous variability of speed, load, temperature etc. Contextual analysis can be used to find regularities that are imperceptible in raw data, which leads to an understanding of a highly complex process.

The scientific and practical results, included in the dissertation, are partial results of individual processes. The common denominator of all methods is a combination of data processing

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procedures, aimed at improving efficiency and reliability of mining machines operated in underground copper mines.

Thanks to conducted studies, KGHM obtained credible data about potential benefits of equipping vehicles with lock-up functionality. The biggest user of machines of this type, ZG Polkowice-Sieroszowice mine, accepted lock-up as a standard of machine equipment.

A concept of identifying work cycles of bolting, utilizing laser-based measurement of the distance between the ceiling and a chosen point of the performing subsystem, was proposed. Data registered in a series of experiments confirmed that there exists a possibility of identifying work cycles. It is worth noting that due to the complexity of the process and the unreliability of measurement systems based on detecting changes in pressure, the mines previously resigned from attempting to monitor work cycles. The proposed method opens up new opportunities in monitoring the process of bolting. Automatization of work cycle identification requires further research.

In the case of haul trucks three methods of work cycle identification were proposed. In contrast to previously used methods, the suggested approach is not based on the signal of oil pressure in the performing system, because this variable is prone to large measurement errors. Additionally, the sensors used to register it are unreliable, often experiencing mechanical failures. The last of proposed methods, based on an alternative data source, named „Collision warning system", implemented in second half of 2021, is definitely most efficient, most reliable and cheapest to implement in the data hub. It relies on data assigned to processes of critical priority (safety function). Because of this, the cost of utilizing data for other purposes is relatively low.

Considering the nature of implementation doctorate, which combines regular employment at the company, scientific research and the requirement of implementing the results in practice, the Author deems the achieved results as a success. Introducing new solutions is always difficult, but this dissertation provides methods of data-based management of technological processes and machine fleet, which are innovative not only to KGHM, but also to the Polish mining industry.

Keywords: *monitoring of self-propelled mining machines,* load haul dump loaders, haul trucks, drilling rings, bolting rigs , *diagnostics of technical condition,* drilling, bolting, detection of work cycles for haul trucks , *efficiency assessment, statistical analysis, correlation analysis, machine learning methods, management information reporting*

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