Supplementary file for:

Evaluating complex mine ventilation operational changes through simulations

Andries J. H. Nel, Jan C. Vosloo, Marc J. Mathews

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1. Method development

As part of method development, various existing practices are combined to add new value. Existing practices are improved by considering an integrated and more comprehensive approach to method development. As such, several factors must be considered to produce repeatable, accurate and dependable method results [1], [2]. These factors can, subsequently, be categorised according to the type of data such as by the high-level data categories included in the method:

- service delivery data;
- operational data; and
- technical data.

The KPI or KPIs is/are identified under each of these data categories to form part of the method. For example, wet-bulb temperatures and air mass flows can be included as KPIs for the service delivery category. The raise bore hole diameter can be included as a KPI for the operational category. Future production planning (tonnes) can be included as a KPI for the technical category. It is not necessary to select KPIs for each of the categories. However, most of the KPIs for complex ventilation networks can be divided into the listed data categories. The KPIs should therefore be clearly defined, since the simulation model and final evaluation are measured according to these indicators.

These high level data categories have lower boundaries and constraints that govern the state of the simulation [3], [4]. It is crucial to determine the level at which the simulation data is required to evaluate and optimise the ventilation network effectively. Such constraints, imposed by each data category, should be established and accounted for by the method, permitting the desired level at which the simulation is to be conducted. The resulting scalable method for evaluating and optimising operational changes in mine ventilation networks is illustrated by Figure 1. This method is applicable to evaluating any operational changes that influence ventilation parameters. Any simulation package that incorporate mass flow balance- and thermo-hydraulic solvers can be used [5], [6].

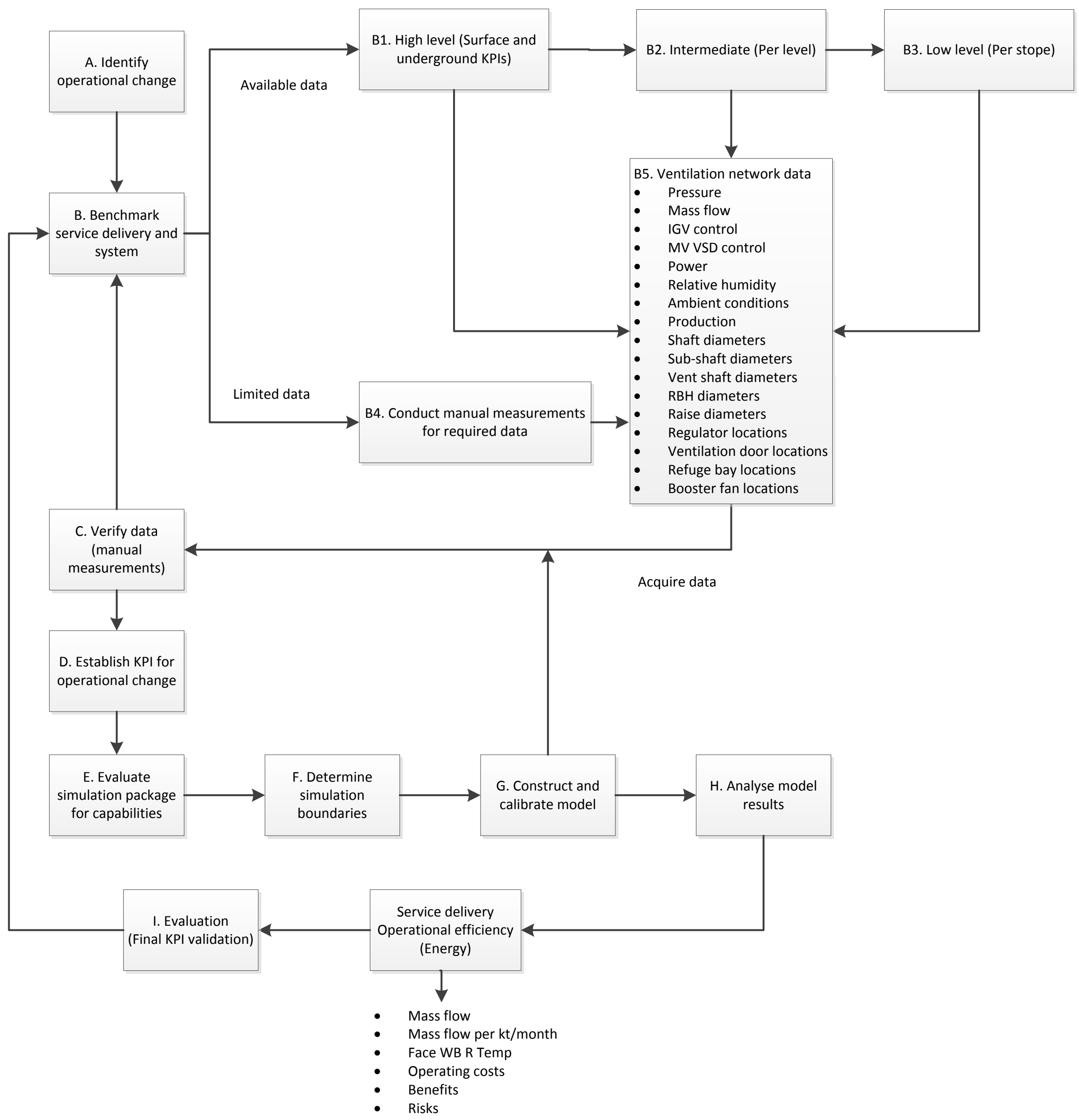

Figure 1: Newly developed scalable method for mine ventilation networks.

The first step in the method is to identify the operational change/s (A) to be implemented. The operational change is typically a result of mine development or network configuration changes [7]. Different operational change scenarios can be identified through mine planning and evaluated, according to the developed method. Operational changes can also be as a result of constraints imposed on the complex ventilation network which need to be changed in order to satisfy the constraints.

The next step in the method is to benchmark the ventilation network (B) according to current operations. This can be done by using available mine data (B1 to B3) or by manual measurements (B4). The accuracy thereof is of extreme importance, especially when manual readings are collected with portable instruments [8]. Refer to (B5) in Figure 1 for typical complex ventilation network data required to be able to construct a simulation model. The level at which the data is available provides an indication towards the degree of simulation accuracy that is achievable.

Due to the variations in magnitude of operational changes, the methodology specifically incorporates scalability. The methodology can, therefore, be implemented to evaluate and optimise various degrees of operational changes, ranging from high-level (surface and KPI) to detailed low-level (per mine stope) changes. It is vital to verify the collected data to ensure the simulation provides an accurate representation of the current operations (C).

Mines typically incorporate supervisory control and data acquisition (SCADA) systems to monitor, gather and store real-time data [9]. These systems' accuracies are dependent on the existing measuring equipment. The available SCADA data should be verified by the user with manual measurements using calibrated measuring equipment or calibration certificates. If limited SCADA data is available, data should be acquired through manual measurements. The verification step is the central focal point between two iterative processes including benchmarking and simulation calibration. The benchmarking process can therefore be iterated until the user is satisfied with the accuracy of the acquired data. The accuracy of the data is defined as the quality of allowable percentage error for each measurement [1]. The percentage error is determined by comparing actual measurements with available data or calibration certificates. If different calibrated measuring equipment are used and the measurements have a small percentage error, the data should be of a high accuracy.

Subsequently, the KPIs of the proposed operational change should be determined (D), which is an important step in the method since the simulation objectives and evaluation are based on these indicators. The KPIs typically relate to the drivers behind the operational changes and are most often operational efficiency and underground environmental conditions. Indicators such as air mass-flow, air velocity, underground wet-bulb temperature, energy consumption, suction pressure and intake flow rates are typically selected as a KPI, depending on the operational change and subsequent simulation objectives. The KPIs are also be used to validate the impact of any operational changes made.

In the next step, the different simulation packages should be evaluated according to the simulation objectives and capabilities (E). Certain simulation packages provide different network capabilities. The correct package should consequently be selected to align with the level of data acquired [10]. For instance, if underground wet-bulb temperature is selected as a KPI for service delivery, then only simulation packages incorporating thermal-hydraulic solvers have the capability to evaluate and provide results relating to temperature. The simulation package should, therefore, be selected as a result of the selected KPIs. Simulation packages that typically incorporate thermal hydraulic solvers are Process Toolbox, Vuma3D and VentSim [11], [1].

Thereafter, the critical simulation boundaries (F) should be established and prepared to be incorporated in the simulation. These boundaries form part of the individual constraints of each of the KPI categories. In other words, service delivery as well as operational and technical boundaries are to be included such as minimum wet-bulb temperatures, planned production targets, shaft diameters, velocities and so forth.

The next step involves the construction and calibration of the ventilation network simulation (G). This is achieved by incorporating the verified data into the simulation and comparing the simulated results with the actual measurement. In this manner, the accuracy of the simulation can be determined by comparing, for example, KPI1 and KPI2 with the actual measured KPI1 and KPI2 of the verified data set. The simulation is then calibrated by manipulating the simulation parameters so that the results correspond to within 10% of the actual network values, thereby verifying the simulation. The calibration of the simulation should be conducted as required when changes in parameters occur.

After the simulation is calibrated, the proposed operational change can be simulated and the results analysed (H). As a result of the analysis, the simulation can be refined and any user input faults detected [10]. The simulation results are analysed according to the service delivery and the operating efficiency for each operational change scenario. Since not all changes can be quantified, the method includes a benefit and risk analysis included in step H as part of the qualitative evaluation. This provides a comprehensive approach to the method so that improved evaluations can be made.

The different operational change scenarios can then be evaluated according to the selected KPIs, comparing apples with apples (I). The typical KPIs that form part of the final evaluation are the wet-bulb face return temperatures, air mass flows and operating costs. The initial evaluation focuses on the comparison of the absolute performance improvement in operational KPI between scenarios. The secondary evaluation focuses on the relative cost and performance intensity improvement achievable between scenarios. These evaluations are then used to determine the most feasible operational change to implement, which would satisfy all service delivery requirements resulting in the highest operational efficiency.

The success of the scalable method was validated by applying the newly developed method to a case study. The simulated and actual measured results of the selected KPIs were compared. The success of the methodology was measured according to the accuracy achieved in terms of the post-implementation KPI results. The scalable method for evaluating and optimising operational changes through simulations was explained according to a case study mining complex. The validity of the methodology was confirmed by considering the long-term performance of the operational changes that were implemented based on the results of the methodology.

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