Ground Support 2019 - J Hadjigeorgiou & M Hudyma (eds)

doi:10.36487/ACG_rep/1925_19_Shekhar

A review of mining practices for surface support: an international survey

H Schunnesson *Luleå University of Technology, Sweden*

G Shekhar *Luleå University of Technology, Sweden*

A Gustafson *Luleå University of Technology, Sweden*

D Johansson *Luleå University of Technology, Sweden*

Abstract

This paper reviews mining practices for surface support and identifies four key areas that need attention. An international survey was conducted as part of the Mining Initiative on Ground Support Systems and Equipment III project from 2017 to 2018. The survey used a standardised, web-based questionnaire adapted for personal computers and smartphones. The survey was distributed globally, with data collected from 58 underground mines with different mining conditions and challenges. The results highlight the challenges with regard to safety and automation of surface support for different rock conditions and the advantages and disadvantages of various machines (face drills versus mechanised dedicated bolters versus semi-mechanised bolters) used to install surface support. The survey also shows the ambiguity in the mining community with regard to productivity of mine support. This paper presents an approach for collecting technical data through an online tool, which is inexpensive and effective.

Keywords: *surface support, mesh/screen installation, productivity, qualitative review, mine automation*

1 Introduction

The working environment for ground support installation in mines has improved during the last three decades, with an increasing incidence of fully mechanised installations of different ground support elements. Several types of mesh/screen for rock support are available, and a number of different installation procedures are used (Daehnke et al. 2001; Hadjigeorgiou & Potvin 2011; Szwedzicki 2005), from manual installations to procedures using fully mechanised rigs. The sizes of mesh/screen vary; a larger mesh/screen reduces the overlapping areas but is more difficult to handle, resulting in an increased installation time (Daehnke et al. 2001; Hadjigeorgiou & Potvin 2011). A great deal of research has been done to understand the effects on the support elements in laboratory tests (Hadjigeorgiou & Potvin 2011). Recently, field reviews of ground support practices have been performed for specific mines and mining conditions (Chikande & Zvarivadza 2016; Daehnke et al. 2001; Potvin & Hadjigeorgiou 2008; Szwedzicki 2005). Potvin & Wesseloo (2013) highlight issues of design indeterminacy and note the need for a better understanding of dynamic demand on ground support systems. A review of failure events for seismically active mines shows a need to develop new ground support guidelines for deep underground mines (Morissette et al. 2017). For underground mines, the cost of ground support is considerable, and reducing it can help mines reduce their operating costs. For example, at Kristineberg mine, the total cost of consumables for rock support is 50 million Swedish krona per year, which amounts to 14% of the mine's operating costs (e.g. depreciation) and adds 74 Swedish krona to the unit cost per tonne of ore produced (Haugen 2016).

To select the best mesh/screen for each condition, a worldwide evaluation of the available technology, methods, area of use and the benefits and/or drawbacks is needed. This paper describes an international benchmarking survey of mesh/screen use and installation, conducted within the framework of Mining Initiative on Ground Support Systems and Equipment, its purpose being to gain insight into surface rock support in different parts of the world.

This paper includes a review of the following aspects:

1. Mesh specifications: type of mesh used, mesh dimensions, material composition.
2. Equipment and installation procedures: installation methods, equipment combinations, mine conditions.
3. Productivity and safety: productivity (including methods for measurement), safety issues for different mining conditions.

2 Methodology

This paper reports the findings of an online survey of mining companies around the world. An online survey or internet survey is a popular data-collection method; a set of survey questions is sent to a target group who can respond to the questions online. These surveys can use quantitative research strategies (e.g. questions with numerically rated answers) or qualitative research strategies (e.g. open-ended questions) or a combination of both (i.e. mixed methods). The primary reason for using an online survey was that it is extremely low cost, convenient and within easy reach of mining operations around the world.

The survey reported here was conducted using a standardised, web-based questionnaire adapted for personal computers and smartphones by SurveyMonkey (https://www.surveymonkey.co.uk). The questionnaire was distributed via professional and personal networks and LinkedIn. All questions are presented in the Appendix.

3 Scope of survey

The survey received 58 responses from mines located in all parts of the world. The locations of the responding mines are presented in Table 1.

Table 1 Distribution of responses

Area	Percentage of responses
North America	8%
South America	38%
Europe	19%
Africa	8%
Asia	15%
Australia	12%

The survey covered various mining methods (Figure 1) and a variety of mining depths (Figure 2). The mining depth influences the type of surface support and the preferred installation procedures. The survey also covered several geo-mechanical conditions for ore, hanging walls and footwalls.

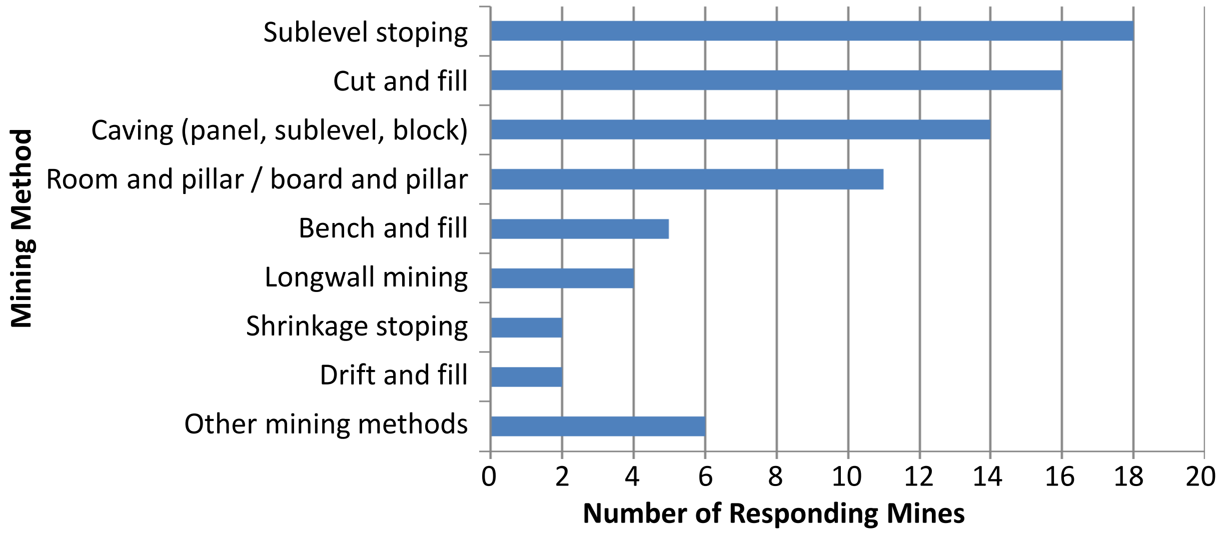

Figure 1 Mining methods at responding mines

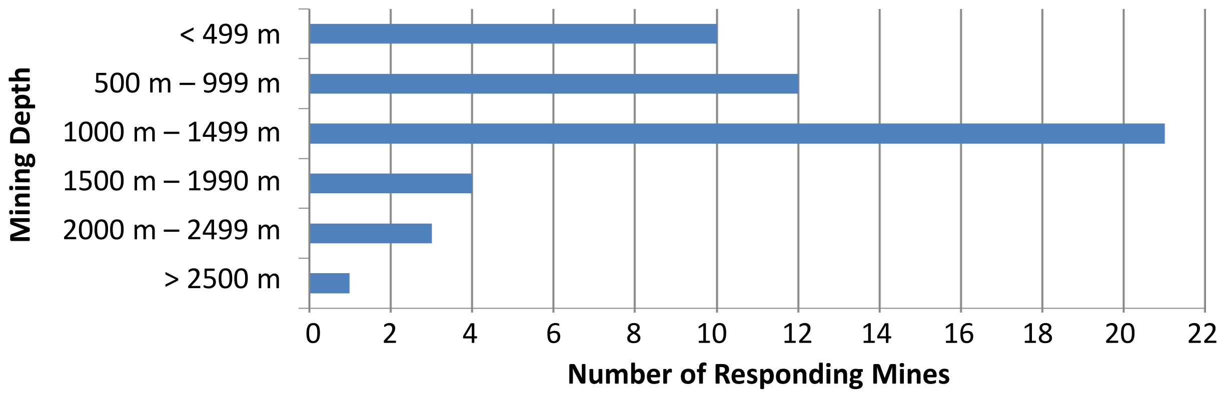

Figure 2 Operating depth at responding mines

4 Results and discussion

Almost all responding mines (88%) have a standard operating procedure or ground control plan to guide their ground support. The purpose of a ground control plan is to provide a systematic approach to the ground control strategy. It should include support patterns, support components, detailed element description, installation procedures, rehabilitation plans and strata monitoring systems.

4.1 Support components

The support components in the responding mines are fairly standardised; rockbolts, cable bolts, mesh/screen support and shotcrete are commonly used, as shown in Figure 3. These standard components also appear to be used to a similar extent in all regions, as indicated in Table 2.

Straps and steel sets/arch supports show a strong regional variation, however. These components are rarely used in Europe and South America but are common in Australia and North America. Straps are often also used for rehabilitation of damage support. In deeper mines, arch supports and steel sets are more commonly used.

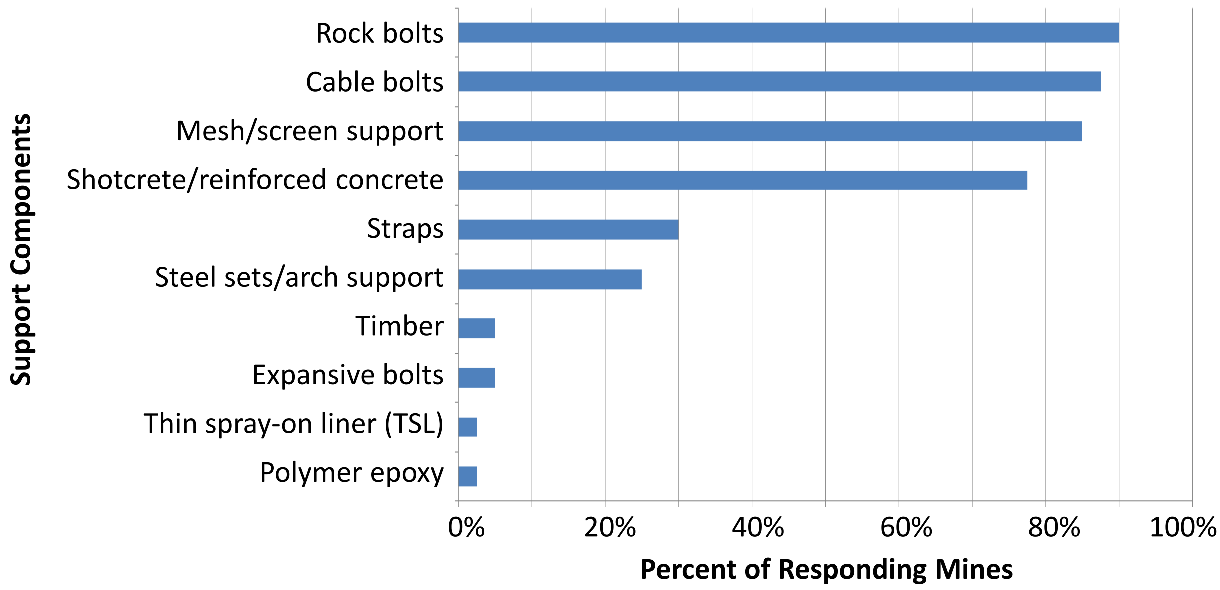

Figure 3 Support components used by responding mines

Table 2 Support components used in different regions

Continents	Cable bolts	Rockbolts	Mesh/screen support	Shotcrete/reinforced concrete	Straps	Steel set/ arch support
Australia	67%	67%	67%	67%	83%	17%
Asia	63%	75%	75%	63%	50%	50%
Africa	75%	75%	75%	50%	25%	75%
Europe	60%	70%	50%	70%	0%	0%
South America	60%	65%	55%	50%	0%	5%
North America	100%	75%	100%	75%	50%	25%

4.1.1 Mesh/screen support components

Figure 4 shows the mesh/screen support components used by the responding mines. Most use welded wire mesh/screen; only a few use chain-link mesh. Mesh straps are the preferred strap component, but steel and Osro or Oslo straps are also used.

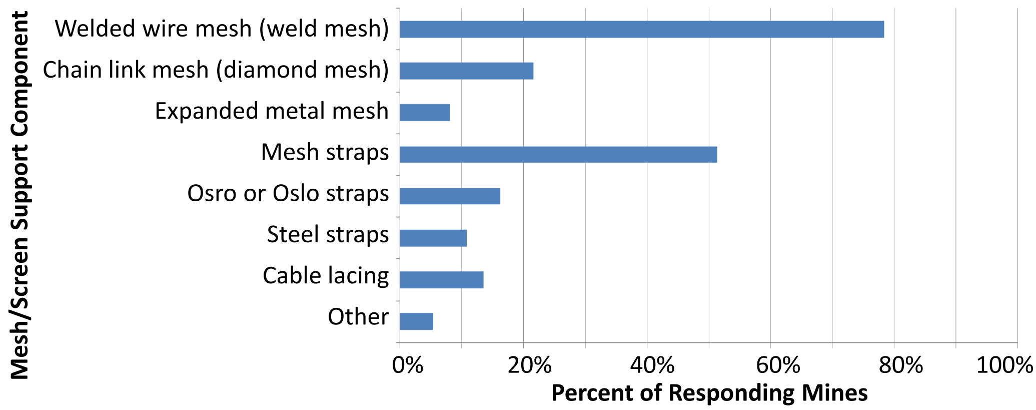

Figure 4 Mesh/screen support components used by responding mines

Two-thirds of all responding mines use a standardised size of mesh/screen, and the remainder use two sizes of mesh/screen. The argument for using only one or two sizes is that it simplifies storage and logistics. The size and shape of mesh/screen varies significantly. Mesh/screen with dimensions 2.4 m by 3.0 m is most commonly used, but there are large variations, and adaptation to the local conditions is common (Figure 5).

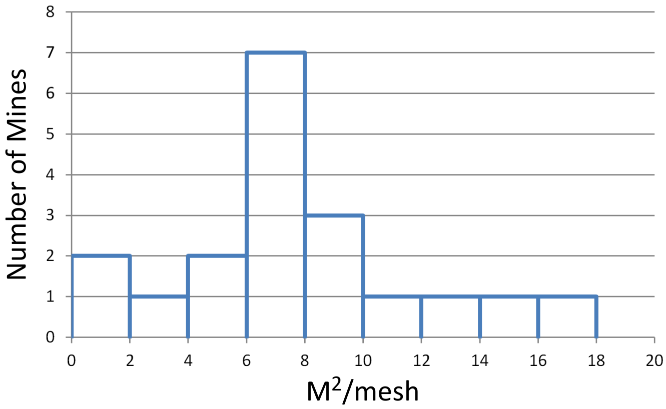

Figure 5 Size of mesh/screen used by responding mines

The diameter of the wires varies between 3 mm and 6 mm. The most commonly used mesh/screen has an aperture of 10 cm by 10 cm (65% of the responding mines). The remaining 30% of the mines use a mesh/screen with a smaller aperture: 75 mm or 50 mm. Steel or galvanised steel mesh/screen is used by almost all responding mines. Only a few indicated they use higher quality material, such as stainless steel or high-tensile steel, most likely for a chain-link mesh/screen. The size, shape and specification of the mesh/screen are important for the manoeuvrability of the mesh/screen and its adaptation to uneven rock surfaces. Large mesh/screen with a large wire diameter and small aperture will be difficult to install manually, but even mines with mechanised installation report that the size is limited by the strength of the grip and the turning tool's adaptation to the mesh/screen. Hence, a small to medium mesh/screen dimension is preferred at both manual and mechanised operations, even though this increases the overlap area.

The mesh/screen used by mines is often provided by local suppliers. Most suppliers mentioned in the survey are used by one or two mining companies; suppliers used by more than two companies are Dywidag-Systems International (six responses) and Geobrugg (four responses).

4.2 Support practices/installation procedures

Mesh/screen is applied to prevent rockfall and to stabilise the rock mass. The behaviour of mesh/screen is completely different from that of shotcrete because relatively large deformations are required before mesh/screen will start taking the load. The application of mesh/screen therefore depends on the site-specific conditions (mining depth, stress conditions, seismicity, et cetera), and it should vary within a specific mining operation.

Figure 6 presents the answer to the question, 'How is mesh/screen installed?' Systematic installation of mesh/screen clearly dominates over more-adaptive rock support, as indicated by the answers 'locally under special conditions' or 'when needed'. A systematic approach is more efficient from a mechanisation point of view and when accompanied by standard operating procedures for rock support. The drawback with a uniform systematic support scheme is that openings are over supported in areas with better rock conditions and under supported in areas with poor rock conditions. A larger number of standardised support classes may reduce this risk.

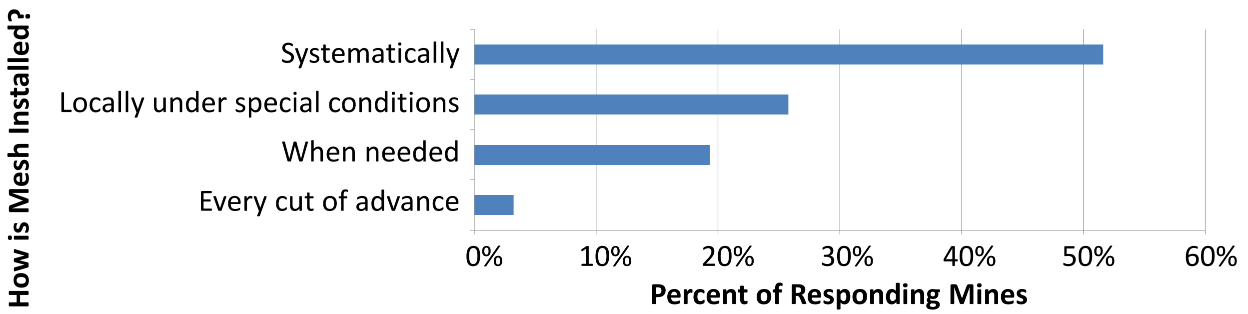

Figure 6 How is mesh/screen installed?

The sequence of mesh/screen installation is presented in Figure 7. The sequence is interesting and is most likely influenced by the equipment used. Mechanised installation of bolts and mesh/screen is most efficiently accomplished when both are done simultaneously. If cable bolts are used, however, they have to be installed afterwards with a separate rig. Manual or semi-mechanised reinforcement work has more flexibility in terms of sequencing the installation of different support components, whether installation is simultaneous or not.

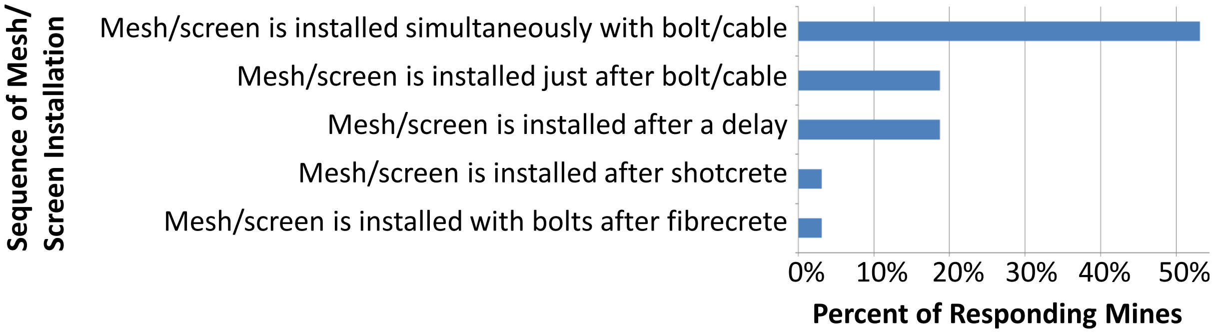

Figure 7 Sequence of mesh/screen support installation

4.3 Equipment and mechanisation

The equipment used to install surface support can roughly be divided into face drill rigs, dedicated mechanised bolters and dedicated semi-mechanised/manual bolters (used to install surface support manually). Figure 8 shows the different categories of equipment used for the installation of mesh/screen support. Each method has benefits and drawbacks.

Figure 8 Categories of equipment for the installation of mesh/screen support: (a) Face drill rig; (b) Dedicated mechanised bolter; (c) Dedicated semi-mechanised bolter

Face drill rigs are used to drill the holes, after which bolts are installed from a rig basket. One argument for using face drills is that the drilling efficiency is higher than for a dedicated bolter. Another is that the rig can be navigated using the on-board automation system to align holes and bolts in a predefined pattern. Lastly, only one rig is used for both face drilling and rock support, thus reducing capital costs. The major drawback with face drill rigs is the manual installation of rock support from a basket close to the rock face; this is inefficient and may introduce safety issues. In a cyclic operation, however, this system is preferable.

With dedicated mechanised bolters, the entire support sequence (installation of mesh/screen and bolts) is done from the rig cabin; the operators are not exposed to unsupported rock close to the face. The net cycle time to install mesh/screen and bolts is low, but the efficiency is somewhat reduced because of consumable logistics and maintenance. A drawback with these bolters is that they are designed to install standardised rock support (mesh/screen and bolts of standard length) and are not particularly flexible. Cable bolts cannot be installed, and they require a different rig. Straps, cable lacings or other support components are also difficult to install.

Dedicated semi-mechanised bolters are used to install surface support manually. They are highly flexible and can install a variety of different rock support components. They have slightly lower efficiency than dedicated mechanised bolters but are more efficient when more complicated rock support is needed, requiring two different mechanised bolters. The major disadvantage is that all support work is done under an unsupported roof, increasing the risk for the operator.

In addition to these three methods, a separate mesh/screen handler is used by many mines. A specific type is the roller mesh handler for chain-link mesh that can be installed as a separate unit on different rig types. Figure 9 shows the frequency for each category.

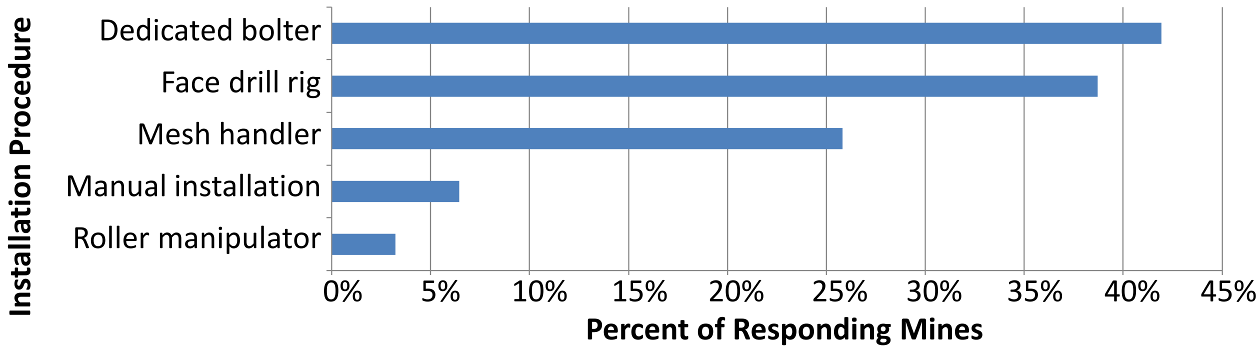

Figure 9 Equipment used for the installation of mesh/screen support

A similar number of mines use manual (38%), semi-mechanised (36%) and fully mechanised (42%) installation methods, but there are regional variations. Manual installation is more common in Southern Africa and South America, and mechanised installation is more common in Europe and Australia (Table 3). Another significant difference is that face drills are more commonly used in Australia and Asia, and dedicated bolters are more commonly used in Europe and North America (Table 3). It is important to note, however, that 'dedicated bolters' can be anything from highly mechanised equipment to semi-mechanised rigs where most of the work is done manually from a platform, a technique common in North America.

Table 3 Regional variations in equipment used to install mesh/screen support

Continents	Face drill rig	Dedicated bolters	Mesh handlers
Australia	83%	33%	0%
Asia	100%	0%	0%
Africa	67%	0%	67%
Europe	17%	67%	33%
South America	10%	40%	40%
North America	0%	100%	0%

The use of labour-intensive support components, such as straps (steel, mesh and Osro) and cable lacings, may increase as the operating depth of mines increases around the world. These components act as additional support in places with poor rock condition or in high-stress environments. Mechanised mines have more difficulty using these components as they are very labour intensive. A modification in present equipment to facilitate automation of these support components could provide a boost for automation in mines operating at greater depths.

4.4 Productivity of surface support

The performance of rock support in underground mines is important for reasons of both safety and productivity. It is increasingly important with increasing depth because, with greater depth, rock support causes significant bottlenecks in production for many mines. A challenge is how to measure productivity in a structured and relevant way.

A structured way to measure productivity is also important for comparing the performance of different support elements, mechanisation/automation levels, equipment brands, shift forms et cetera. Gustafson et al. (2016) have suggested a framework to evaluate bolting productivity. A similar procedure should be developed for mesh/screen productivity. Figure 10 presents the different measures of productivity mentioned by the responding mines.

The applied productivity measures vary significantly and are generally based on units, square metres or drift length. The base can be time (hours, shifts or days), tonnes or metres. The large variations may be influenced by the specific local conditions for each mining operation, but they may also reflect the unclear productivity definitions presented by Gustafson et al. (2016).

A uniform, well-established unit for measuring the productivity of surface support is currently lacking. The results of the survey suggest the need to define and establish a uniform productivity index for mesh/screen support operations that will help mines to compare their support operations with industry benchmarks and optimise their support productivity. Conversion equations to convert one unit of productivity into another is also lacking, making the comparison and benchmarking of support productivity across mines difficult.

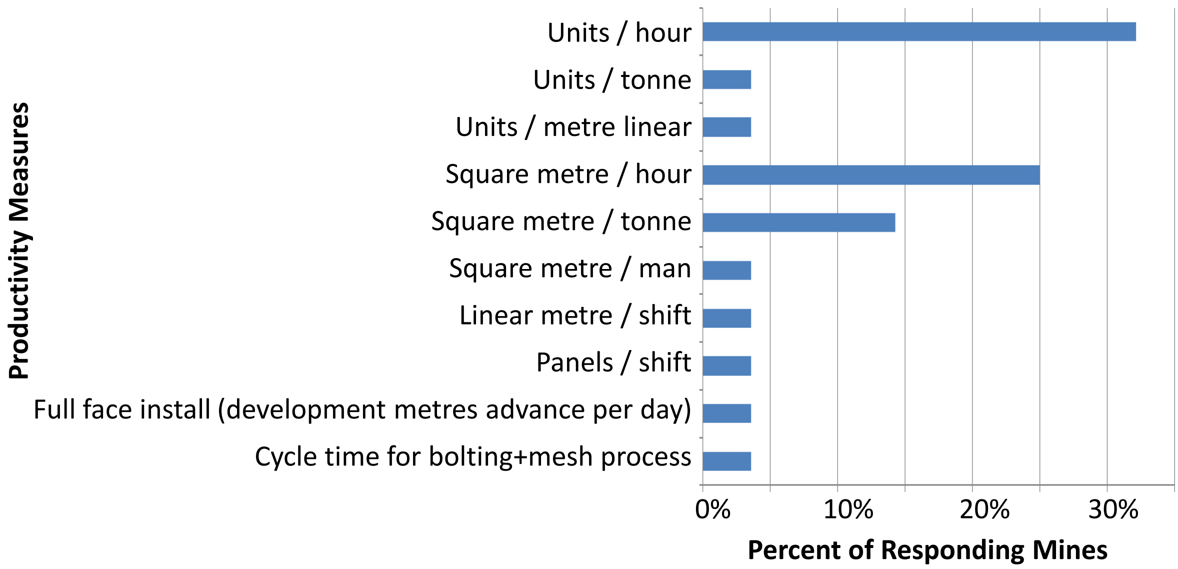

Figure 10 Productivity measures used for mesh/screen support

4.5 Rehabilitation

Figure 11 presents the response to the question, 'How often is mesh/screen checked for damage?' Even though some mines have fixed intervals for reinforcement control (e.g. three months, six months, one year), many mines are more reactive than proactive. In most cases, mesh/screen rehabilitation is heavily dependent on human presence underground, with significant dependence on other categories of personnel (not rock mechanical trained personnel) who are supposed to identify and report malfunctions of the rock support. This implies that more frequently visited underground locations will have better and more sensitive monitoring of damage than rarely visited locations. The rehabilitation practice is mostly just to check and replace old or damaged mesh/screen. It is also quite common to use anti-corrosion coating, and in some cases, straps are used to restore the damaged part of the mesh/screen (Figure 12).

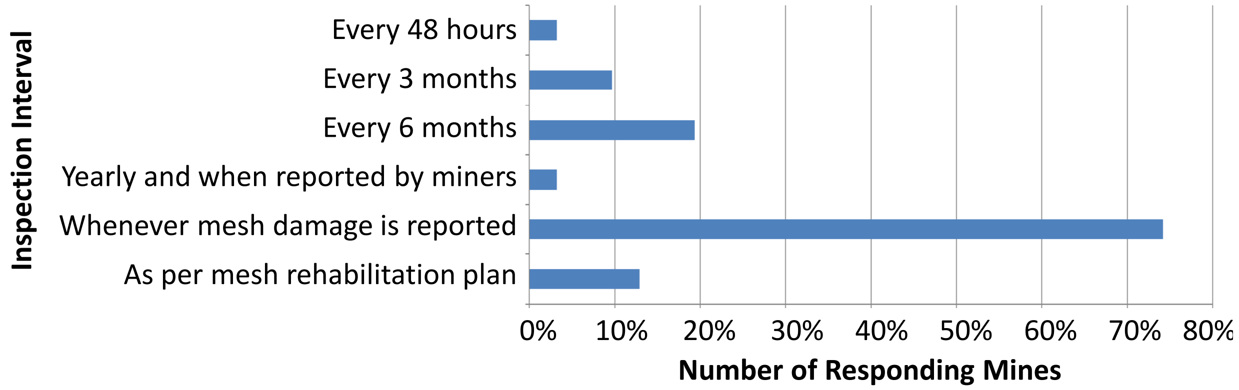

Figure 11 How often is mesh/screen checked for damage?

The global trend towards mechanisation and automation will reduce the number of humans working underground; this will reduce the quality of damage identification if it is based only on reporting by humans.

The present global initiatives in digitalisation and communication have influenced mining, and several attempts have recently been made to monitor bolting using the new technology. Song et al. (2017) reviewed techniques for rockbolt monitoring using smart sensors. Delsing et al. (2015) demonstrated how data from installed rockbolts could be communicated in real time using an IoT (Internet of Things) network. Similar attempts regarding other support elements, such as mesh/screen, would make an important contribution to support rehabilitation when increasingly fewer humans work underground. An automatic analysis technique based on images (fixed or autonomous drones) would also provide greater awareness and better safety.

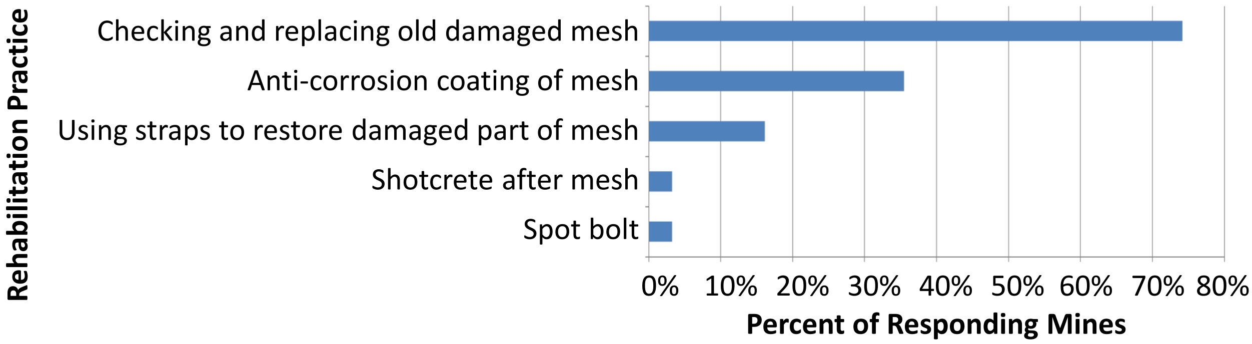

Figure 12 Rehabilitation practices applied

5 Conclusion

This paper has presented the results of a web-based survey that was used to collect information on current mesh/screen support practices in mines around the world. The data represent a diverse group of mines with different mining conditions and challenges. Based on the results from the survey, four key areas need attention from the mining community:

- **Equipment selection, mechanisation level and total efficiency**. The equipment used can roughly be divided into face drill rigs, dedicated mechanised bolters and dedicated semi-mechanised bolters to install surface support manually. All three types of systems have benefits and drawbacks, and there is a strong regional preference for specific equipment. This may not promote an open-minded and logical comparison of the efficiency of different technologies and mechanisation levels.

- **Definition of benchmarking productivity**. To be able to compare and benchmark support productivity across regions and countries, or even across mines, it is important to develop a uniform, well-established unit to measure the productivity of surface support.
- **Mesh/screen rehabilitation**. Mesh/screen rehabilitation tends to be reactive when activities depend on reported damage. With increasing automation, fewer humans will be stationed underground, and the responsibility for and quality of damage reporting must be solved using new and innovative technologies.
- **Automation of labour-intensive support components**. The combined use of standard support components, such as bolts, mesh/screen and cable bolts, and labour-intensive support components, such as straps (steel, mesh and Osro) and cable lacings, will increase as the operating depth of mines increases. How to install these components efficiently and mechanically with preferably one rig type will be a challenge for equipment suppliers around the world.

Acknowledgement

The authors acknowledge financial support from Rock Teck Centre's Mining Initiative on Ground Support Systems and Equipment.

Appendix 1

1. What is the name of your mine?
2. Where is the mine located?
3. What mining method do you use?
4. Currently, what is the operating depth of your mine?
5. What is the RMR/GSI of the rock mass? (hanging wall, orebody, footwall).
6. Do you have a standard operating procedure/ground control plan for ground support?
7. If yes, can you please add a document? (We will treat it as a confidential document).
8. What rock support components are you currently using in your mine?
9. Why do you use mesh/screen support in the mine?
10. Which type of mesh/screen support components is used?
11. What is the specification of the mesh/screen used in your mine?
    a. How many types of mesh/screen are used in the mine?
    b. Sheet size
    c. Diameter of wire / # gauge number
    d. Mesh aperture
    e. Material specification
12. Which type of bolt plates are used to install mesh/screen?
13. Which mesh/screen suppliers do you use? (Kindly mention all suppliers.)
14. What is the average height of openings (drift, crosscut, declines etc.) where you use mesh/screen support?
15. What is the average width of opening (drifts, crosscut, declines etc.) where you use mesh/screen support?

16. Where is mesh/screen installed?
17. What is the sequence of installation for mesh/screen support in the mine?
18. How many squares of mesh/screen overlap is practised in the mine?
19. How is mesh/screen support installed?
20. What kind of equipment is used for installation of mesh/screen support?
21. Which equipment supplier is used?
22. What kind of rehabilitation practices are done at the mine?
23. How often is mesh/screen checked for damages?
24. What kind of productivity measure do you have for mesh/screen supports?
25. What is the average mesh/screen support productivity for your mine?
26. What are the major productivity issues with handling and installation of mesh/screen support?
27. What are the major safety issues with handling and installation of mesh/screen support?
28. If you wish to receive a short summary of the results of the survey, kindly fill in your email address below.

References

Chikande, T & Zvarivadza, T 2016, 'Review of support systems used in poor ground conditions in platinum room and pillar mining: A Zimbabwean case study', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 116, no. 4, pp. 323–332.

Daehnke, A, van Zyl, M & Roberts, MKC 2001, 'Review and application of stope support design criteria', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 101, no. 3, pp. 135–164.

Delsing, J, Eliasson, J, Punal, P & Gebart, J 2015, 'The IoT rockbolt', paper presented at the 5th International Conference on the Internet of Things (IoT 2015), Seoul, October 2015.

Gustafson, A, Schunnesson, H, Timusk, M & Hauta, R 2016, 'Productivity of rock reinforcement: Methodology development', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 116, no. 12, pp. 1127–1134.

Hadjigeorgiou, J & Potvin, Y 2011, 'Hard rock ground control with steel mesh and shotcrete', in P Darling (ed.), *SME Mining Engineering Handbook,* vol. 1, SME Publishing, pp 573–595.

Haugen, S 2016, 'Rock support in cut and fill mine—from the operational perspective of a mine manager', in E Nordlund, T Jones & A Eitzenberger (eds), *Proceedings of the 8th International Symposium on Ground Support in Mining and Underground Construction*, Luleå University of Technology, Luleå, p. 856.

Morissette, P, Hadjigeorgiou, J, Punkkinen, AR, Chinnasane, DR & Sampson-Forsythe, A 2017, 'The influence of mining sequence and ground support practice on the frequency and severity of rockbursts in seismically active mines of the Sudbury Basin', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 117, no. 1, pp. 47–58.

Potvin, Y & Hadjigeorgiou, J 2008, 'Ground support strategies to control large deformations in mining excavations', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 108, no. 7, pp. 397–404.

Potvin, Y & Wesseloo, J 2013, 'Towards an understanding of dynamic demand on ground support', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 113, no. 12, pp. 913–922.

Song, G, Li, W, Wang, B & Ho, SCM 2017, 'A review of rock bolt monitoring using smart sensors', *Sensors 2017*, vol. 17, no. 4, p. 776, https://dx.doi.org/10.3390/s17040776

Szwedzicki, T 2005, 'Reviewing support requirements for existing excavations in underground mines', *Mining Technology*, vol. 114, no. 1, pp. 21–28.