Worker inclusion in equipment development processes in the modernizing minerals sector in South Africa

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Synopsis
Worker participation in equipment development can result in improved user acceptance and product quality. This paper focuses on worker engagement in equipment development processes in the South African minerals sector. Qualitative data was gathered during interviews with original equipment manufacturers (OEMs) and industry experts. A lack of inclusion in equipment design from workers from all organizational levels in mines was reported. Meanwhile, the historical context and workplace culture of the mining industry (including leadership, trust, training, performance, and remuneration factors) were evident barriers to the implementation of new technology. Worker engagement processes should include securing management commitment, creating multidisciplinary teams, effective facilitation, shared understanding of needs, training and development, and iterative design. Human-centred design approaches and independent platforms for engagement on equipment design requirements are recommended.

Keywords
ergonomics; human-centred design; modernization; original equipment manufacturers.

Introduction
Worker engagement is important for the success of modernization initiatives, as it can result in improved equipment design and ownership, and minimize resistance to change. The aim of the research was to draft a strategy for worker engagement in original equipment manufacturer (OEM) equipment development processes, in the context of modernizing mining and the minerals sector in South Africa. This paper is drawn from a project funded by the Minerals Council South Africa, under the auspices of the South African Mining Extraction Research, Development and Innovation (SAMERDI) strategy's Successful Application of Technology Centred Around People (SATCAP) programme (Pelders *et al.*, 2019).

Review of literature

Modernization in the South African minerals sector
Modernization of the minerals sector in South Africa is required to make operations safer, healthier, more productive, and sustainable (Jacobs and Webber-Youngman, 2017; Minerals Council South Africa, 2018). Modernization involves changes to processes, technologies, skill sets, and the social and environmental impacts of mining (MacFarlane, 2001; Singh, 2017). Modernization takes place in the context of the Fourth Industrial Revolution (Industry 4.0) and will be partly driven by the heightened use of innovative technologies (Jacobs and Webber-Youngman, 2017; Pelders, 2019). For modernization initiatives to be successful, they need to be addressed in a holistic matter, while adopting a systems and people-centred approach (Minerals Council South Africa, 2018).

Success and failure factors for the adoption of new technologies
Mixed successes of attempts to implement new technologies, including machinery and equipment, in the South African mining industry have been reported. Barriers to the successful implementation of new technologies, as listed by a number of authors (Gumede, 2018; Lynas and Horberry, 2011; MacFarlane, 2001; Singh, 2017; Vogt and Hattingh, 2016; Willis *et al.*, 2004), include:
- Premature application of technology
- Initially high or unexpected costs
- Employee attitudes or resistance to change
- Fear of job loss as a result of the technology

- Suspicion of management motives
- Poorly engineered work systems
- Technical failures
- Poor ergonomics
- Inadequate human-machine interface design
- Inadequate training or skills
- New health and safety risks created
- Poor implementation, planning and control
- Difficult mining conditions.

Conversely, numerous factors required for the successful adoption of new technologies are reported in previous literature (François *et al*., 2016; Gumede, 2018; Kinnear and Ogden, 2014; Lynas and Horberry, 2011; MacFarlane, 2001, Pelders, Murambadoro, and Letsoalo, 2019c), and include:

- Optimal design of equipment
- Human-system integration
- Technology appropriate to work system
- Technological maturity
- Usability
- Operator acceptance
- Knowledge transfer
- Training and support
- Communication and coordination
- Ownership of the technology or work system by the workforce
- Worker involvement
- Trust in the technology
- Quantified benefits
- Common vision.

It is evident that although many of these factors are interdependent, a full understanding of human factors affecting the implementation, is required to avoid the failure of adoption (Hattingh, Sheer, and du Plessis, 2010). Ergonomics and the ownership of the technology design by the workforce is important (MacFarlane, 2001). Ergonomics considerations are important for successful implementation to ensure that equipment is designed to suit people's capabilities and limitations (MacFarlane, 2001; Martin, Legg, and Bown, 2013; Schutte and James, 2007). Equipment design can affect its operability, maintainability, safety, productivity, and sustainability (Lynas and Horberry, 2011; Martin, Legg, and Brown, 2013). In addition to technical challenges, change management, culture, leadership, re-skilling and training requirements, business processes, resources, work planning, operation of the mine, and relationships with supporting industries need to be considered (Ritchken, 2017; Singh, 2017; Willis *et al*., 2004).

End-user inclusion in equipment design processes

It is important to involve all stakeholders in the design process (Horberry, Burgess-Limerick, and Steiner, 2015; MacFarlane, 2001; Martin, Legg, and Brown, 2013). End-user inclusion, including personnel from all organizational levels, can help to drive improvement in technology or equipment design (Hattingh and Keys, 2010; Rost and Alvero, 2020). Improved user-involvement is understood to ensure that what is designed is suitable for the users and the environment in which it would be used (Scariot, Heemann, and Padovani, 2012). System design should be undertaken in consultation with potential operators and engineers (Lynas and Horberry, 2011). Meanwhile, workers should be part of the team and act as co-developers rather than being given a complete system to use (Vogt and Hattingh, 2016). Furthermore, the workforce should be included from the early stages of technology design, and in every step of design and implementation (MacFarlane, 2001; Lynas and Horberry, 2011).

There are numerous reported benefits of worker participation in design processes. A range of authors (Burton, 2010; EU-OSHA, 2012; François *et al*., 2016; Hattingh and Keys, 2010; ISO 9241-210, 2010; Kujala, 2003; Lee *et al*., 2009; Martin, Legg, and Brown, 2013; Rost and Alvero, 2020; Scariot, Heemann, and Padovani, 2012; Spinuzzi, 2004; Sundin, Christmansson, and Larsson, 2014) reported benefits which include social and economic factors such as:

- Improved product quality and design
- Improved ergonomics
- Improved understanding of users
- Improved user experience and wellbeing
- Avoidance of costly features that users do not need or use
- Early, and less costly, detection of problems
- Reduced training and support costs as equipment is easier to understand and use
- Increased accessibility for a wider range of people and capabilities
- Increased participation in decision-making
- Improved organizational problem-solving ability
- Improved workforce communication
- Higher sense of ownership
- Improved trust between workers and the employer
- Improved morale, commitment of workers, and organizational culture
- Improved acceptance and uptake
- Increased productivity, efficiency, and profitability
- Competitive advantage
- Improved health, safety, and wellbeing of the workforce
- Reduced discomfort, injury rates, stress, errors, accidents, and absenteeism
- Increased sustainability of the workplace.

As such, improved engagement with stakeholders and workers from all organizational levels in equipment design processes is related to the successful adoption of new technologies.

Human-centred design approaches

Human-centred design approaches are recommended for equipment design and development, and can be used as an umbrella term for approaches such as user-centred, participatory, or ergonomics design (Horberry, Burgess-Limerick, and Steiner, 2015). Human-centred design is defined as 'an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance' (ISO 9241-210, 2010, p. vi).

Human-centred design is a collaborative design approach based on end-user inclusion in the design and development of systems, products, and services, and emphasises the input of numerous stakeholders (ISO 9241-210, 2010; Lee *et al.*, 2009; Scariot, Heemann, and Padovani, 2012). Participatory design combines researchers and developers' knowledge with the tacit aspects of human activity from participants (Lee *et al*., 2009;

Spinuzzi, 2004). The design process is iterative, as the impacts of designs are examined incrementally (Martin, Legg, and Brown, 2013; Spinuzzi, 2004). While human-centred design approaches can be applied in different design phases, they usually become more costly to implement effectively further into the design process (Horberry, Burgess-Limerick, and Steiner, 2015).

Mining companies in South Africa are regarded as slow to embrace human-centred approaches to modernization (Gumede, 2018). Reported barriers include the risk-averse and conservative nature of mining, the time taken for technology development (sometimes being longer than the life of mine), and difficulties in accessing mine sites (Horberry, Burgess-Limerick, and Steiner, 2015). Numerous factors can act as facilitators or barriers to participation in equipment development, and those listed by the Institute for Work and Health (IWH, 2008) and van Eerd *et al*. (2010) include:

- ➤ Support of the intervention among management, supervisors and workers
- ➤ Ergonomics training, knowledge, or abilities
- ➤ Resource availability (*e.g*. time, material, and personnel)
- ➤ Creation of a team with the required members
- ➤ Communication
- ➤ Organizational training, knowledge, or abilities
- ➤ Development and following of a systematic plan or approach
- ➤ Participatory ergonomics specialist, leader, or facilitator
- ➤ Working relations
- ➤ Easy changes to implement
- ➤ Workplace climate
- ➤ Production requirements
- ➤ Personnel turnover at management, supervisor, or worker level
- ➤ Awareness of the intervention among individuals, supervisors, and workers
- ➤ The research methodology
- ➤ Resistance or ability to change among individuals, workers, or supervisors
- ➤ The nature of the work
- ➤ The history of intervention attempts.

It is evident that factors required for the success of participatory approaches include senior management leadership, buy-in from all levels, investment in training, and the use of change agents (Hattingh and Keys, 2010). The programmes should be developed to suit local needs, conditions, and culture, and be adapted to suit specific workplaces (Burton, 2010; Hattingh and Keys, 2010; Helali, 2009; IWH, 2005). Horberry, Burgess-Limerick, and Steiner (2015, p. 2) listed essential principles for mining human-centred design, as follows:

- ➤ 'The design is based on an explicit understanding of the user, their tasks, and the environment/use context.
- ➤ Users and other stakeholders should be involved throughout design and development. Their needs, wants, and limitations are given attention at each stage of the design process.
- ➤ It fits the equipment, system, or interface to the user, not *vice versa*.
- ➤ The design is iterative, evolutionary, and incremental.
- ➤ It is driven by user-centred safety evaluation criteria during the design process and for the end product.
- ➤ A multidisciplinary design team is used, including HF [human factors]/usability champions.
- ➤ The design is integrated with the wider work system organization.
- ➤ The human-centred design process must be customizable: capable of being adapted to different mine sites conditions.'

Worker engagement process

Figure 1 illustrates a recommended process for human-centred design, which was compiled based on a review of literature on the topic (*e.g*. de Koker and Schutte, 1999; ISO 9241-210, 2010; van Eerd *et al*., 2010). Key phases are elaborated on in this section.

Firstly, it is necessary to define the scope of work, which includes the users, tasks, and the environment in which the equipment will operate (Horberry Burgess-Limerick, and Steiner, 2015; ISO 9241-210, 2010). Thereafter, senior management support, commitment, and involvement is required for successful implementation and sustainability of participatory programmes (de Koker and Schutte, 1999; Hattingh and Keys, 2010; Helali, 2009; Sundin, Christmansson, and Larsson, 2004). Meanwhile, understanding of the intervention and buy-in from all major stakeholders (including owners, managers, union leaders, and workers) is important to minimize resistance to change and build trust (Burton, 2010; de Koker and Schutte, 1999; Hattingh and Keys, 2010).

Multidisciplinary teams should be created with participation and accountability from executive, management, union, supervisory, and employee levels (de Koker and Shutte, 1999; Horberry, Burgess-Limerick, and Steiner, 2015; IWH, 2005; van Eerd *et al*., 2010). It is important to identify a good leader or facilitator for the process (de Koker and Schutte, 1999). Workers affected by the initiative, and worker representatives, should be actively involved in each step of the process, including planning, problem identification, problem solving, implementation, and evaluation (Burton, 2010; Schutte and James, 2007). The involvement of workers at all stages of the process increases support and provides access to knowledge and experience (Hattingh and Keys, 2010).

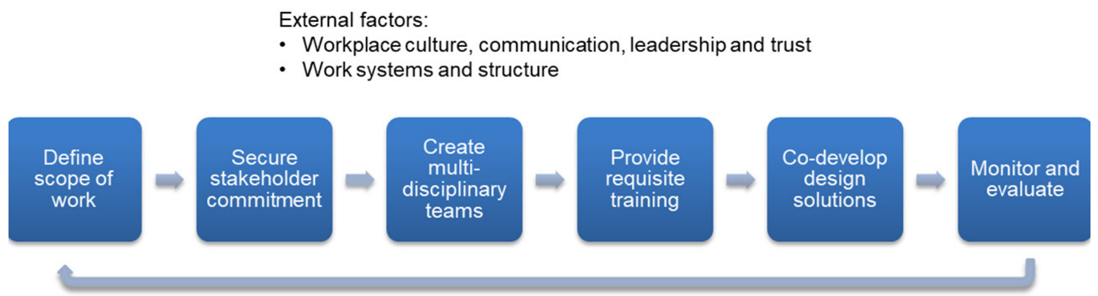

Figure 1—Process for engaging workers in equipment design

Training and development requirements for the successful implementation of participatory approaches include basic introductory training in ergonomics, learning about technical issues, how to communicate knowledge and experience, and the development of problem-solving skills (de Koker and Schutte, 1999; Hattingh and Keys, 2010; IWH, 2005). Further training and skills needs include those that suit changing requirements as mining modernizes (Lynas and Horberry, 2011; MacFarlane, 2001; Vogt and Hattingh, 2016).

The equipment and design solutions should then be co-developed (de Koker and Schutte, 1999; van Eerd *et al*., 2010). There are various methods and tools that can be used to support the participatory design process, from the initial exploration of work, in discovery processes, to prototyping (Spinuzzi, 2004; Sundin, Christmansson, and Larsson, 2004). Some of these methods include observations, workshops, focus group discussions, interviews, organizational games, and artefact analysis (Lee *et al*., 2009; Spinuzzi, 2004). Action checklists, ergonomics, and time analyses are also used (Helali, 2009; Sundin, Christmansson, and Larsson, 2004). Assessments can be made using three-dimensional digital models, physical mock-ups or prototypes, and graphic computer-based simulation and analysis (Sundin, Christmansson, and Larsson, 2004). The equipment design process should also involve a task-based risk assessment process such as the Operability and Maintainability Analysis Technique (OMAT) (Horberry, Burgess-Limerick, and Fuller, 2013). The design process should be iterative, which involves evaluation and refining of the solutions (Hattingh and Keys, 2010; Horberry, Burgess-Limerick, and Steiner, 2015; Martin, Legg, and Brown, 2013; Spinuzzi, 2004). The Deming ('Plan-Do-Check-Act') Cycle is often used to promote continuous improvement (Hattingh and Keys, 2010).

The findings from the literature review were compared to outcomes from data gathered in the South African mining sector in order to gain an understanding of worker engagement in equipment design processes, and to make recommendations for implementation.

Methods

The study employed a cross-sectional qualitative design. This methodological approach was chosen to obtain in-depth data and enable inductive reasoning to develop new understanding of the topic. Interviews were held with stakeholders from five OEMs and a range of industry experts, who were purposively selected. Data collection took place from April to May 2019. Informed consent was given by each of the participants prior to participation. The discussion guides for the project consisted of open-ended, semi-structured questions relating to the extent of worker engagement in equipment design and development, benefits or barriers to worker engagement, potential training implications, and recommendations for improvement. Thematic analysis was used to identify themes or patterns in the data. Ethics approval for this project was granted by the CSIR Research Ethics Committee (Ref: 239/2017).

Results

Participation of workers in equipment design

In general, the participants did not consider workers to be adequately engaged in the design and development of equipment for the South African mining sector. This was particularly the case for lower level workers. For example, a participant commented that '*The input into the design of tools underground has never involved the workers, the user*'. If there was involvement, it was usually with individuals from higher levels at mines, including engineers, and consultants. However, it was evident that mining companies were often not involved in the conceptualization or design of equipment developed for the industry. In other cases, equipment was developed around specific needs identified by mines.

Workers or end-users were often involved only once the equipment prototype had already been developed, or when equipment was piloted at mines. The participants reported that feedback was provided to the OEMs at this stage or once the equipment was already in use. This feedback included that from service teams, artisans and operators, and from meetings or workshops held with mine personnel, including supervisors, mine engineers, and worker representatives. The feedback obtained could be used to customize or retrofit equipment, while it was usually used towards upgrades or new versions of the machinery. The participants observed that it was not always practical or feasible to retrofit equipment. Local OEMs were considered to be more able than international OEMs to design specifically for South African conditions. However, it was also noted that innovation of global OEMs was usually ahead of local OEMs.

A summary of the participant responses about the benefits and barriers to worker engagement in equipment design and development in the South African mining industry is shown in Table I and detailed in the following sections.

Barriers to worker inclusion

A number of barriers to the participation of workers in equipment development were noted by the research participants, and included matters relating to the history and culture of the South African mining industry, performance and remuneration, mining company involvement, and problem prioritization.

The culture and historical context of the South African mining industry was a highlighted cause of the lack of worker engagement. Prevailing mind-sets and attitudes were seen as hampering the involvement of lower level workers.

Table I

Reported benefits of and barriers to worker inclusion in equipment design and development

Benefits of worker inclusion	Barriers to worker inclusion
• Improved equipment design • Buy-in and ownership of the equipment • Time and cost implications • Customization to local conditions • Skills and development opportunities	• History and culture of the South African mining industry • Performance and remuneration • Mining company involvement • Problem prioritization • Skills and development requirements

Meanwhile, a lack of trust was a further barrier, and included employee concerns about job displacement resulting from the implementation of new technologies in mines. An understanding of how performance and remuneration would be affected by modernization and by the provision of input into the design of new equipment, was considered important to obtain worker buy-in. Measurement systems and pay structures would need to change according to changes in the mine environment. For example, the roles of operators and artisans could become more interlinked, while the current incentive system was not perceived to encourage operators to assist with the maintenance of equipment. Further challenges noted included haphazard change management processes, a lack of insight into change management principles by those responsible for the implementation of new equipment at mines, and a lack of support throughout the organization. The maturity level of mining houses was also considered to affect the implementation of new equipment on mines.

A further barrier reported by OEMs was difficulty in gaining access to mines to engage with workers and test equipment. Reduced funding for research and development in the mining industry in the past few decades was cited as a reason for the lack of involvement of mining companies in equipment development. Additionally, the time and cost implications of gaining and incorporating worker feedback were a consideration for OEMs and mining houses. Difficulty in managing information received and prioritizing feedback gained was another concern when involving workers. Differences in understanding were considered, including difficulties for lower-level workers to engage in the concept stages of design, rather than with tangible products. The use of third-party suppliers of systems used in OEM equipment was a further challenge relating to managing user feedback.

Benefits of worker inclusion

Participants mentioned number of benefits associated with including workers in equipment design. These benefits were categorized under the themes of improved equipment design; buy-in and ownership of the equipment; and time and cost implications.

Input from end-users, including those from high and low positions, was considered to be beneficial in the design of equipment to make it easier to use and repair, and therefore operate more effectively. Higher levels of engagement with industry would assist OEMs to understand what equipment is needed and how best to design it. Worker experience could help to increase understanding of the use of the equipment, the work that is performed and practicalities in the work environment, and identify and resolve potential issues. For example, a participant commented '*… you must listen to them, because they sit with that knowledge and that experience*'.

Engaging with workers was perceived to be an important mechanism to gain buy-in and a sense of ownership of the equipment by the workers. Early involvement was noted to help end-users to understand the benefits of the equipment, gain faster acceptance, take better care of equipment, and enhance the likelihood of successful implementation of new technologies.

Gaining user input into equipment design up-front was noted to have time and cost benefits. Although additional time might be required at the initial stages of design, improved input was understood to reduce time to market. Participants commented that it was difficult, costly, and time-consuming to make changes to equipment once it had already been prototyped or manufactured. If equipment was designed correctly in the first place, the costs of redesign would be reduced, while avoiding threats to credibility and abandonment of the equipment. Additionally, ineffective design could make it difficult for workers to operate or fix equipment, resulting in safety risks and/or a loss of production, while if machines are designed with the proper input, they would be easier to inspect, maintain and repair.

Training and skills matters

Training and skill-related implications of the use of new technologies and worker inclusion in equipment design processes were considered. The participants explained that training is usually provided for operators and engineering staff when new equipment is introduced to mines, to help ensure that it is used correctly. The length of the training would depend on the familiarity of the workers with similar types of equipment and the time taken to adapt to the technology. Simulators are sometimes used to train people on how to operate equipment or machinery.

Literacy levels, experience, and technical skills of the workforce were discussed. Basic levels of literacy were considered important for the use of new technologies. Participants noted that those with higher levels of literacy would likely engage with new concepts or ideas more easily, and be more willing and able to provide input and feedback. The experience of workers and engineers in the design teams was seen as helping to inform equipment design. A lack of experience and design skills in South Africa was a perceived challenge, and could be attributed to a lack of technical colleges and training in the country. It was noted that capability and education systems needed to be in place before mines could transition to the use of new technologies. A current divide between operators and artisans was commonly mentioned, and was further associated with the culture, hierarchy, and remuneration practices at the mines. A participant further commented '*I imagine a degree would help. But … personally, I think the reason that operators don't develop the necessary skills is because of the culture in a mine that does not allow them to develop the necessary skills*.'

Opportunities for new skills development were evident for all levels of workers. It was noted that there was a shift from labour-intensive to more mechanized work, along with the need for increased knowledge-based, manufacturing or maintenance, and electronics-related skills. Differences in mind-sets between younger and older workers and managers were also noted in terms of adaptation to the use of new technologies. A shift in skills of mine managers was also regarded as important. Change management skills were considered to be necessary.

Participant recommendations for improved inclusion

The study participants made recommendations for improving the engagement of workers in equipment design and development. Participants noted that it would be worthwhile for stakeholders, including managers, supervisors, and users of the technology, to be engaged from the initial stages of equipment design, so that perceptions and needs are understood, ideas are discussed, and issues are better identified and resolved from the onset.

Culture transformation of the mining industry was recommended to better engage workers in equipment design. These suggestions included changes to leadership style, relationships between management and labour, reconstitution of teams, and assessment of performance and reward. Mining modernization would affect work structures, schedules, measures used, organizational culture, team compositions, and skills. Building of trust between stakeholders and improved communication are necessary, which would involve creating a shared understanding of the potential benefits of modernization initiatives and the use of new technologies.

The participants recommended the establishment of industry forums or platforms for engagement about equipment needs and design in the industry. A platform for OEMs and stakeholders to engage was considered valuable for enabling the development of equipment needed in the South African mining sector in the future. The need for a neutral facilitator to chair these platforms was highlighted. The development of standards and specifications for the South African minerals sector was further suggested to govern the design of equipment by OEMs. Frameworks for engagement and implementation were also recommended.

Discussion

Both similarities and differences between findings from the data gathered and findings from the review of literature were evident. It was surprising that there was an evident lack of worker engagement in equipment design processes in the South African minerals sector. The lack of engagement with mining companies and feedback from end-users is likely to hinder the successful design and implementation of new technologies. Improved engagement can help to address barriers to the implementation of new technologies, such as resistance to change and a lack of trust (Burton, 2010; Willis *et al*., 2004).

The benefits of worker engagement were emphasised, and the participants noted that improved involvement would lead to improved equipment design, buy-in and ownership of the equipment, and reduced overall time and cost for successful implementation. These conclusions were in line with findings from the literature (Burton, 2010; Hattingh and Keys, 2010; Horberry, Burgess-Limerick, and Fuller, 2013; Horberry, Burgess-Limerick, and Steiner 2015; ISO 9241-210, 2010; MacFarlane, 2001; Martin, Legg and Brown, 2013; Rost and Alvero, 2020).

Barriers to worker inclusion in equipment design processes were reported. Matters relating to the culture and historical context of the South African mining industry, mind-sets, attitudes, and a lack of trust were commonly mentioned. Performance and remuneration matters relating to involvement in equipment design and development, and to modernized mine environments, also needed to be addressed prior to these engagements. Inadequate change management was a further barrier. Meanwhile, time and cost implications for research and development were a concern. These factors further made it difficult for local OEMs to design what is likely to be required in the industry. These barriers were linked to findings from the literature.

Training and skills-related matters that were discussed included the need for improved literacy levels, technical skills, and experience in the industry. Skills requirements and opportunities relating to modernization initiatives were noted, and included a potentially reduced divide between operators and artisans, and the need for change management skills in all levels of industry stakeholders.

Limitations of the study

This research focused on the perspective of local OEMs and selected industry stakeholders. Further input from a more diverse range of representation, including mining company management, unions, employees, government, and community stakeholders, is recommended prior to the development of a framework or guideline for the inclusion of workers in equipment design and development processes.

Conclusion and recommendations

It is evident that improved engagement for equipment design and development needs to take place for successful modernization in the minerals industry. Improved worker engagement in OEM equipment design processes will help to improve acceptance, ownership, equipment design, quality, health, safety, and productivity.

Human-centred design, which includes participatory and ergonomics approaches, is recommended. It is important to engage all stakeholders in the design process. Furthermore, workers should be included as co-developers from the concept stage of equipment design through to product manufacture, implementation, and evaluation. A successful participatory design process requires senior management commitment, buy-in and involvement from all levels, investment in training, the use of change agents, and monitoring and evaluation.

Platforms for engagement, with independent facilitators, are recommended for discussing equipment needs and designs for the South African minerals sector. The Earth Moving Equipment Safety Round Table (EMESRT) working group has developed an engagement process that could be emulated in the South African mining industry (EMESRT, 2018). These engagements will further enable growth in the capacity and capability of local manufacturers to develop what is required for the industry in the future. Culture transformation in the South African mining industry is required for modernization initiatives to be successful, and incorporates change management, leadership, trust, work structures and teams, performance and remuneration systems, and education, training, and skills requirements.

Recommendations for future work are further engagements to provide input into the development of a guideline or framework for including employees in equipment design and development in the South African minerals sector. The assessment of pilot or case studies relating to the engagement of workers in equipment design is also recommended. This work is planned to take place in the SATCAP programme going forward.

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