Stakeholder inclusion in the design and development of equipment for the modernizing mining sector in South Africa

S. Ngobese[1], J. Pelders[1], W. Botha[2], F. Magweregwede[1], and S. Schutte[1]

Affiliation:
[1]CSIR Mining Cluster, Johannesburg, South Africa.
[2]Enterprises University of Pretoria, Pretoria, South Africa.

Correspondence to:
S. Ngobese

Email:
sngobese1@csir.co.za

Dates:
Received: 1 Aug. 2022
Published: April 2023

How to cite:
Ngobese, S., Pelders, J., Botha, W., Magweregwede F., and Schutte, S. 2023
Stakeholder inclusion in the design and development of equipment for the modernizing mining sector in South Africa.
Journal of the Southern African Institute of Mining and Metallurgy, vol. 123, no. 4. pp. 193–202

DOI ID:
http://dx.doi.org/10.17159/2411-9717/2253/2023

ORCID:
S. Ngobese
http://orcid.org/0000-0001-8125-9927
J. Pelders
http://orcid.org/0000-0003-4671-1951
F. Magweregwede
http://orcid.org/0000-0002-4824-2266

Synopsis

A people-centric, systematic approach that involves different stakeholders is considered necessary to successfully address changes associated with modernizing the South African mining industry. In this paper we discuss the inclusion of various South African mining industry stakeholders, particularly the employees, in equipment design and development processes. Data was acquired through a literature review and inputs from South African mining industry stakeholders through focus group discussions, interviews, and an online survey. It was suggested that some of the areas that could be improved by the inclusion of employees in the process are design quality, ergonomics, equipment acceptance by the workforce, safety, efficiency, skills, insight into context of use, and early design iterations and identification of problems. Among the issues considered to be barriers to inclusion were lack of buy-in, lack of resources, difficulty in manufacturers accessing the mines, difficulties in involving too many people, intellectual property concerns, and unavailability of mine employees due to their key responsibilities. Identified critical factors in the equipment design and development process include iterative design, stakeholder participation throughout the process, needs analysis through consultation, and change management. A guideline was developed for worker inclusion in equipment design and development that could be used by the South African mining industry. The study identified several economic and social benefits of including stakeholders in the early stages of design and development. It is recommended that the South African mining industry considers using the developed guideline.

Keywords

ergonomics, human-centred design, systems engineering, original equipment manufacturers, end-users.

Introduction

The mining industry has been one of the strategic economic development vehicles of the South African economy for more than a century (Magweregwede, Mpofu, and Ngobese, 2019). However, over the past few years, the viability of the mining sector has been under threat due to challenges such as increasing operational costs, fluctuating commodity prices and foreign currency exchange rates, depletion of high-grade ores, increasing mining depths, and stringent legislative requirements (Magweregwede, Mpofu, and Ngobese, 2019). A people-centric modernization approach presents an opportunity to progressively introduce new technologies into the mining sector and subsequently realize benefits such as improved occupational health and safety (OHS), improved productivity and mining efficiencies, and reduced operating costs (Fraser, 2017; Minerals Council South Africa, 2020; Pelders *et al.*, 2021). A people-centric, systematic approach that involves different stakeholders is considered necessary to successfully address changes associated with modernization across the whole value chain in the South African mining industry.

Modernization refers to the process of transformation of the mining industry to make it safer, more efficient, cost-effective, and sustainable (Minerals Council South Africa, 2019). Modernization involves changes to people, processes, and technologies, and aims to address challenges facing the mining industry, including increased costs, decreased productivity, and OHS, environmental, and social issues. Moreover, modernization takes place in the context of the Fourth Industrial Revolution (4IR or Industry 4.0), which is increased characterized by the heightened use of innovative technologies (Pelders, 2019).

Improved inclusion of stakeholders is related to the successful adoption of new technologies. Stakeholder (including employee) inclusion in equipment design and development can result in improved product quality and increased buy-in and ownership (Pelders *et al*., 2019). Human-centred design approaches are recommended (Horberry, Burgess-Limerick, and Steiner, 2015; ISO 9241-210, 2010).

This paper is based on research commissioned by the Mandela Mining Precinct, with funding from the Department of Science and Innovation, as part of the Successful Application of Technology Centred Around People (SATCAP) Programme of the South African Mining Research, Development and Innovation (SAMERDI) strategy. The work package was titled 'People-centric modernisation' (Pelders *et al*., 2021). This work also built on a previously conducted project which aimed to draft a 'Globally benchmarked strategy for the engagement of workers in Original Equipment Manufacturer (OEM) equipment development processes' (Pelders *et al*., 2019; Pelders and Schutte, 2021).

The objectives of the project were as follows:

- ➤ To understand the benefits and shortcomings of stakeholder inclusion in equipment design and development
- ➤ To gain insight into the (current and best practice) process for inclusion of employees in equipment design, applicable for mining modernization
- ➤ To develop a guideline for worker inclusion in equipment design and development, applicable for mining modernization.

The aim of this paper is to inform approaches, methods, and processes for the inclusion of stakeholders in equipment design and development.

Literature review

This literature review provides an overview of an approach, process, and methods for stakeholder inclusion in equipment design and development. Additionally, an indication is provided of potential benefits and barriers to stakeholder inclusion in equipment design and development in the South African minerals industry. Local and international studies, including previous research conducted in the SATCAP programme, were reviewed.

Human-centred design approach, process, and methods

Human-centred design has been identified as a good practice approach for equipment design and development (ISO 9241-210, 2010; Maguire, 2001). This approach is seen to be aligned with the view of Minerals Council South Africa (2019), who stated that for modernization to be successful, it needs to be addressed in a holistic manner while adopting a systems and people-centric approach. Human-centred design is understood to provide economic and social benefits for users, employers, and suppliers (ISO 9241-210, 2019; ISO 9241-220, 2019). 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).

The referenced term, ergonomics, or the study of human factors, is defined as the '*scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance*' (ISO 9241-210, 2019, p. 2). *A -systems engineering model 'provides a paradigm for enabling a structured, systematic human-centred design approach, incorporating ergonomics knowledge and allowing ergonomists to contribute throughout the system development process*' (Samaras and Horst, 2005, p. 73).

The principles of human-centred design, as detailed in ISO 9241-210 (2019) and Horberry, Burgess-Limerick, and Steiner (2015), include the following.The design is based upon an explicit understanding of users, tasks, and environments (*i.e*. the context of use)

- ➤ Users and other stakeholders are involved throughout design and development
- ➤ The design fits the equipment/system to the user, not *vice versa*
- ➤ The design is driven by user-centred evaluation
- ➤ The process is iterative
- ➤ The design addresses the whole user experience, and is integrated with the wider work system organization
- ➤ The design team includes multidisciplinary skills and perspectives
- ➤ The design process is customizable.

Human-centred design can be incorporated throughout the product life-cycle, as technology or equipment design and development extends to implementation and use (ISO 6385, 2016). Key human-centred design activities, as indicated in ISO 9241-210 (2019), include:

- ➤ Planning the human-centred design process
- ➤ Understanding and specifying the context of use
- ➤ Specifying the user and organizational requirements
- ➤ Producing design solutions
- ➤ Evaluating the design against requirements.

There are numerous methods that can be used for human-centred design. Table I shows some of these methods, categorized according to each human-centred design phase as listed by Maguire (2001). The methods and tools used can be tailored according to the criticality and complexity of the system (Samaras and Horst, 2005). The Earth Moving Equipment Safety Round Table (EMESRT) working group has developed an engagement process that could be emulated in the South African minerals industry. This process involves mining companies, equipment designers, and other stakeholders (EMESRT, 2019). EMESRT has further developed the Operability Maintainability Assessment Technique (OMAT), which is a user-engagement process in mining equipment design that uses a structured task-based methodology, and the EMESRT Design Evaluation for Earth Moving Equipment Procurement (EDEEP) process (EMESRT, 2012, 2019).

Stakeholder inclusion in equipment design and development in the South African mining sector

Preliminary work conducted in the South African mining industry has indicated that there is limited participation of stakeholders, including mining company management and employees, in equipment design and development (Pelders and Schutte, 2021). The research found that barriers to participation include the historical context and organizational culture of the sector. Further barriers include performance and remuneration implications, difficulties with problem prioritization, inadequate change management, skills and development requirements, and a lack funding for research and

Table I

Methods for human-centred design (Maguire, 2001, p. 590)

Planning	Context of use	Requirements	Design	Evaluation
Usability planning and scoping Usability cost-benefit analysis	Identify stakeholders Context of use analysis Survey of existing users Field study/user observation Diary keeping Task analysis	Stakeholder analysis User cost-benefit analysis User requirements interview Focus groups Scenarios of use Personas Existing system/competitor analysis Task/function mapping Allocation of function User, usability and organisational requirements	Brainstorming Parallel design Design guidelines and standards Storyboarding Affinity diagram Card sorting Paper prototyping Software prototyping Wizard-of-Oz prototyping Organisational prototyping	Participatory evaluation Assisted evaluation Heuristic or expert evaluation Controlled user testing Satisfaction questionnaires Assessing cognitive workload Critical incidents Post-experience interviews

development. Benefits of early stakeholder (particularly end-user) engagement included a better understanding of needs, improved equipment design, buy-in and ownership of the equipment, reduced cost and time to market, customization to local conditions, and the provision of opportunities for skills development (Pelders *et al.*, 2019; Pelders and Schutte, 2021). Further research was recommended towards the development of a guideline for the inclusion of stakeholders in equipment design and development processes in the South African mining sector.

Methodology

Research design

This research was cross-sectional and used a mixed methods approach. Qualitative and quantitative data were collected using interviews, focus group discussions (FGDs), and online surveys. Workshop engagements were also held to discuss and gain inputs into the project.

Participants

A range of stakeholders were invited to participate in the project. These stakeholders included representatives from the Mandela Mining Precinct, research institutions, consultants, mining companies, organized labour, original equipment manufacturers (OEMs), and mining-related institutions such as Mining Equipment Manufacturers of South Africa (MEMSA), Minerals Council South Africa; Mine Health and Safety Council (MHSC), and Mining Qualifications Authority (MQA). Participants were invited based on their interest in and relevance to the project topic. Different stakeholders participated in different phases of the study, and possibly in more than one component, with participation remaining anonymous for some of the tools used.

An initial stakeholder workshop was held with over 30 attendees, including Mandela Mining Precinct Programme Managers, researchers, consultants, technical experts, mining companies, organized labour, and OEM representatives. During this workshop, a short online questionnaire was presented. There were 11 attendees who responded to this questionnaire, of which four (36%) were mining companies' representatives, three (27%) union representatives, two (18%) represented the MHSC, one (9%) an industry expert, and one (9%) a researcher.

Discussions (one interview and three FGDs) were held with a total of eight individuals from stakeholder groupings including organized labour, research organizations and consultancies, developers, and industry. An online survey was distributed to OEMs, researchers, and industry partners. This survey was completed by 17 participants, of which 12 (71%) were from OEMs, three (18%) were researchers, one (6%) was an industry expert, and one (6%) a mine employee. Three stakeholder validation workshops were held, and approximately 18 participants, in addition to the project team members, attended these sessions.

Tools and procedures

The project took place from October 2020 to March 2021. Data collection was conducted online, on virtual platforms, to minimize risks associated with the COVID-19 pandemic. Interviews, FGDs, and workshop engagements were held using the Microsoft Teams platform, while surveys were completed on SurveyMonkey. Semi-structured questions were compiled to guide the discussions. During the discussions, which were facilitated by research team members, attendees were given a chance to discuss, name, and list their points to and beyond the questions asked. To avoid leading discussions and data gathering in a particular direction, the research team minimized their inputs to the discussions. The online survey questions were developed with the inputs from research partners and MEMSA, who assisted with ensuring brevity and clarity of the survey. The electronic questionnaires comprised mostly multiple-choice or 'tick-box' questions, while space was provided for open-ended responses for elaboration or comment. The main questions included in the tools are listed in Table II.

Table II

Themes discussed under results and discussion and questions asked during workshop, discussions, and online survey

Theme	Workshop questions	Discussions	Online survey
Approaches to equipment design and development	• What processes should be followed for equipment design and development?	• What is the usual process for equipment design and development (for use in the South African mining industry)? • What is the usual process for selection and implementation of equipment or technology?	• What is your stakeholder grouping?
Stakeholder, including worker, inclusion in equipment design and development	• Who do you think should lead and/or participate in the design and development of equipment for the mining and minerals sector in South Africa?	• Which stakeholders are usually included in the design and development of equipment for use in the South African mining industry? • Who do you think should be included in equipment design and development, and how should this be done? • In your understanding, are mine employees usually currently involved in equipment design and development?	• Inclusion of mine employees in the equipment design and development • Stakeholders to include in equipment design and development
Barriers to inclusion in equipment design and development	• What are the gaps relating to the inclusion of workers in equipment design and development?	• What are gaps in the current process for stakeholder, including mine employees', inclusion in equipment design and development? • What are barriers or shortcomings to the inclusion of stakeholders, including workers, in equipment design?	• Barriers to worker inclusion
Benefits of inclusion in equipment design and development		• What would be the value or benefit to original equipment manufacturers (OEMs), mining companies, and mine employees, with the inclusion of employees in equipment design and development?	• Benefits of worker inclusion in equipment design and development
Process for inclusion in equipment design and development		• what is the approach for inclusion of mine employees? • What do you think is a best practice model or approach for the inclusion of mine employees in equipment design and development? • What processes should be followed for mining companies, OEMs, and mine employees, to include employees in equipment design and development? (E.g. the step-by-step approach / model)	• Useful methods towards more people-centred equipment design and development
Critical factors in equipment design and development		• What methods can be used for the engagement with employees in equipment design and development? (E.g. interviews, workshops, prototyping)	• Critical factors in equipment design and development

Data analysis

The qualitative data was analysed using thematic analysis, and the quantitative data using descriptive statistical analyses on Excel software. The qualitative and quantitative data were triangulated to compare and confirm the project findings. Project validation took place through documentation review and workshops during which stakeholders were invited to review and comment on the findings.

Ethics approval

Ethics approval for this project was granted by the CSIR Research Ethics Committee (REC) (reference number: 332/2020).

Results and discussion

This section describes the findings from the data gathered from various industry stakeholders through workshops, interviews, FGDs, and online survey. The questions used were drafted by the research team based on project aims, the outcomes of the literature review, and inputs from research partners and OEMs. The questions asked during the workshop, discussions and online survey are grouped per theme in Table II. The online survey used questions with either a Likert scale or multiple-choice options; the topics are included in Table II along with the themes under which the result are discussed. The study findings are described according to the main themes, which related to equipment design and development approaches, stakeholders, barriers, benefits, processes, and critical factors to consider. Due to the similarity of questions and the limited number of interviews conducted, the analysis and discussion from interviews and FGDs are combined.

Approaches to equipment design and development

Several approaches to equipment design and development were listed by study participants in the workshop questionnaire, discussions, and online survey:

➤ Iterative design
➤ Stakeholder participation from the start of the process
➤ Needs analysis through consultation with workers
➤ Proper change management
➤ Gap analysis
➤ Recognized system design and engineering.

The participants in the discussions noted that an important factor to consider in equipment design and development is that of 'market pull' *versus* 'market push'. Market pull refers to the case where equipment design and development would be initiated and driven by the industry as opposed to market push, which is the initiative of the OEMs, researchers, and/or designers. In market pull, the mine would normally identify the required equipment, which would likely mean the mine would identify the development house and provide other required resources, including its operators. In market push, the OEMs, researchers, and/or designers might have a challenge getting access to stakeholders such as operators and artisans whose daily work revolves around that equipment.

The study participants further noted that another important factor in the inclusion of some of the stakeholders is whether the equipment is being designed from scratch or upgraded incrementally to the next version of an existing piece of equipment. In the latter case (step change) the process is relatively straightforward, while the implementation of a new system (fundamental change) requires deeper analysis and change management.

The participants mentioned that approaches to inclusion in equipment design and development would need to consider several contextual factors, such as the type of mine, company, and technology or equipment. Another factor that should be considered for equipment design and development in the South African context is level of education and culture.

The discussion participants mentioned two approaches for equipment design and development. One approach is concurrent engineering, described by one of the participants as '*a process for involving every speciality from the start, so that all the downstream lifecycle phase requirements are accounted for upfront in the design*'. The second approach -is human-centred, described by the participant as '*a set of techniques for engaging with the non-designers and different types of users*'. For both approaches, early involvement of users and appropriate change management structure were recommended.

Stakeholder, including worker, inclusion in equipment design and development

Stakeholders from the workshop suggested that the following stakeholders should be part of the equipment design and development process. They further suggested that each stakeholder should be involved at the stage which required their expertise:

➤ Mining operations / company representatives, including:
  - Senior production personnel (such as production managers), senior mechanical, electrical, and even industrial engineers, occupational hygienists, and training officials
  - Atypical/nonconventional mine worker profiles, such as industrial engineers, business process people, data scientists/engineers, mechatronics engineers *etc*.
  - Workers or operators who are using current equipment and those who will be using the new equipment
➤ People who used to be employed as miners and shift bosses
➤ Contractors
➤ OEMs
➤ Design and development team experts
➤ Local service providers who are subject matter experts in the mining industry
➤ Service departments or specialists
➤ Unions/organized labour
➤ The Department of Mineral Resources and Energy (DMRE)
➤ Communities, in some cases.

Participants in the discussions stressed that OEMs do not get much stakeholder input into the design and development of equipment. Stakeholders involved in design/development would normally include management and/or small teams such as service teams, engineering staff, and procurement. Furthermore, engagements revealed that previously, mine operators were usually not meaningfully engaged in the equipment design and development process. Mine operators are usually included during the testing stage of equipment development. Examples were provided where the interactions in the prototype stage were limited to those in the research and development technical teams. On the other hand, organized labour was said to be involved as part of the new technology forums in the mines, which means they would be involved from inception until implementation.

The stakeholders who are sometimes involved during the development stage are those that play a regulatory role such as the DMRE. It should be noted that these bodies usually become part of the process during the testing of the prototype, and only for consultation regarding issues such as health, safety, and risk. It is recommended that with modernization and 4IR taking place, these bodies should also be consulted regarding legal matters that might arise as a result, such as privacy issues relating to introduction of the internet of things (IoT).

The online survey results showed that the participants agreed that the inclusion of workers and other stakeholders would improve product quality, usability, and acceptance. Furthermore, 53% of participants mostly agreed, and 41% strongly agreed, that mine employees should be included in the equipment design and development procss. On the other hand, only 41% of online survey participants noted that mine employees were currently included in equipment design and development.

The online survey further sought to obtain inputs regarding the necessary level of involvement of stakeholders in equipment design and development. The survey showed that 94% of participants said OEMs should be involved throughout the process. Meanwhile, 88% of participants said mine employees should be involved in most if not all stages. Other stakeholders that should be frequently involved in the process include technology transfer facilitators, researchers and developers, mine management, suppliers, and training personnel. Study participants believed that stakeholders such as labour representatives, government, and mine communities should be involved at some stages when necessary. Study participants further noted that the stakeholders and their level of involvement will also depend on the technology being developed. The stakeholders that the participants thought should be involved in the equipment design and development process, as identified from the online survey, were in line with those identified in the workshop, discussions.

Barriers to inclusion in equipment design and development

During consultation with various mining industry stakeholders, it was noted that at times there are some factors that act as barriers to the inclusion of stakeholders in the equipment design and development process.

According to the findings from the discussions, one of the most common beliefs is that since most of the employees and/or operators do not have technical skills, they cannot meaningfully contribute to the equipment design and development process. Some of the stakeholders, however, noted that the role of operators, artisans and other workers is not necessarily technical, but their inputs are on the practicality of the design and technology. Workers or operators could give insight into the conditions and practices at the mine and be able to describe practical implications relating to the use of the equipment. One of the participants stated '*Speaking to the appropriate people throughout the design process, which should be an iterative process, will forestall any long-term risks for the implementation of that technology*'. Another participant stated, '*We are going to be the users of the machinery, so surely we should have a say in it*'. The lack of design skills was also identified as a barrier by the workshop participants, and by 63% of the participants in the online survey.

The discussions identified another barrier to the inclusion of employees in the equipment design and development process. Sometimes employees have a negative attitude towards the implementation of new technologies; and they resist change. Approximately 56% of the online survey participants also identified this as one of the possible reasons for not including employees in the equipment design and development process.

Organizational culture was also identified as one of the barriers to the inclusion of employees. This was also indicated by 63% of participants in the online survey.

Study participants in the workshop discussions noted that a lack of time for mine workers to be involved in the equipment design and development process was a further challenge. Factors such as production demands make it difficult to get operators away from their production-related key responsibilities areas. Taking operators from the mine would mean loss of production. Study participants also noted that funding for research and development was among the barriers.

Other barriers to inclusion listed by study participants during discussions include:

- ➤ OEMs are removed (far) from the mines. Logistical matters, such as the distance to travel, getting necessary clearances, including medicals, and the time involved, can make it difficult to test equipment in a mine
- ➤ Lack of buy-in from the mines, *i.e.* technology push *versus* technology pull
- ➤ Having too many people involved in the decision-making process can lead to process delays
- ➤ At the introduction of new technologies, sometimes efficiencies can be low, thus making it difficult to realize the benefits and leading to lack of buy-in
- ➤ Involvement in the equipment design and development process might require certain levels of clearances due to intellectual property issues.

Study participants from the online survey further indicated their level of agreement with the following list of barriers to equipment design and development, where the percentages of participants who agreed on each of the barriers are shown in parentheses.

- ➤ Lack of resources (*e.g.* time, materials, and personnel) (81%)
- ➤ Inadequate communication (75%)
- ➤ Lack of a systematic plan or approach (75%)
- ➤ Production requirements (63%)
- ➤ Inadequate leadership (44%)
- ➤ Poor working relations (38%)
- ➤ Lack of support for the intervention (38%).

Benefits of inclusion in equipment design and development

Potential benefits of inclusion in the equipment design and development process that were listed by participants during the online survey and discussions are summarized as follows:

- ➤ Improved product quality
- ➤ Improved productivity, efficiency, profitability, and ergonomics
- ➤ Improved health and safety
- ➤ Improved understanding of pain points and practicality of design
- ➤ Increased insight into the context of use
- ➤ Competitive advantage
- ➤ Fewer design iterations and early identification and detection of problems
- ➤ Getting to market faster
- ➤ Improved acceptance, ownership, and uptake
- ➤ Increased skills
- ➤ Reduced downtime
- ➤ Improved morale, commitment of workers, and organizational culture.

Additional benefits of inclusion in equipment design and development, and the percentages of participants from the online survey that agree on them, were:

- ➤ Improved trust between stakeholders (75%)
- ➤ Improved product quality and design (75%)
- ➤ Increased accessibility of a wider range of people and capabilities (69%)
- ➤ Reduced training and support costs as equipment is easier to understand and use (63%).

Process for inclusion in equipment design and development

The commonly followed process of inclusion in equipment design and development, as described by participants during discussions, comprises various phases. Those phases relate to product specifications, concept design, design and development, prototyping and trialling, verification and validation, and implementation or commercialization. It was noted that the process followed during equipment design and development would vary based on the context. For example, it would depend on whether the eqipment was new or an upgrade, as well as the type of equipment/technology. In either case, it was highly recommended that the process should be systematic and involve all relevant stakeholders.

Critical factors in equipment design and development

In the online survey, participants identified the factors they deemed critical in the equipment design and development processes:

- ➤ Evaluation, feedback, and redesign
- ➤ Addressing the whole user experience
- ➤ Skills development
- ➤ Understanding of the users, tasks, and environment
- ➤ Multidisciplinary skills and perspectives in the design team
- ➤ Specifying the user and organizational requirements
- ➤ Systematic, step-by-step approach
- ➤ Employee involvement throughout design and development
- ➤ Change management.

Development of a guideline

A guideline for the inclusion of stakeholders in equipment design was required as one of the study outputs. The guideline was developed from the findings in the various engagement sessions and should be viewed as a practical handbook to the inclusion process. The guideline includes a five-step process, with each step title supported by a title description. The various steps in the process are underpinned by activities which support the practical application of the guideline. The guideline further includes suggested methodologies to support the underpinning activities. Lastly, the guideline also identifies possible stakeholders that need to be included for each step.

As a departure point to stakeholder inclusion it was necessary to define who constitutes stakeholders. For the purposes of this guideline, a stakeholder is a party that has an interest in a mining company and can either affect or be affected by the business (mining operations). At a typical mining operation, stakeholders include the board of directors, all management levels, frontline supervisors, all employees (workers), organized labour (unions), contractors, service providers, government (particularly the DMRE), other mining companies, communities surrounding the mine, non-governmental organizations, and local authorities. The developed guideline is appropriate for a 'market pull' position where there is drive behind equipment design and manufacturing from an operations perspective. Once equipment is required by an operation there will be operational interaction and management drive. Even during this 'market pull' scenario it was evident that workers are usually only involved when the equipment is being rolled out or trialled at the mine.

In the development of the guideline, it was necessary to understand who the various stakeholders would be during equipment design. The following groups were identified:

- ➤ OEMs
- ➤ Researchers, designers, and developers
- ➤ Mining company management or representatives, such as senior production personnel, technical services, engineers (mechanical, electrical, mining, industrial, and mechatronics), business process personnel, data scientists, human resources (HR), finance, procurement, occupational hygienists, and training officials
- ➤ Contractors and local service providers
- ➤ Workers or operators (end-users of the equipment)
- ➤ Frontline supervisors (foremen), miners, and shift bosses
- ➤ Unions
- ➤ The DMRE, or legislation and policy writers
- ➤ Communities, in some cases.

While inclusion has been shown to improve aspects such as product quality and buy-in, there is a lack of inclusion of workers or employees (end-users) throughout the design and development process in the South African mining sector. Since this is the case, why do product developers not include employees in equipment design? The following are some of the major barriers to worker inclusion in equipment design and development:

- ➤ A knowledge gap between the designers or manufacturers and the end-users
- ➤ A lack of resources (*e.g.* time, budget, materials, and personnel)
- ➤ Challenges releasing workers (mining industry employees) for inclusion in equipment design and development
- ➤ Logistical constraints
- ➤ Challenges managing requirements of numerous stakeholders
- ➤ Lack of a systematic plan or approach
- ➤ Lack of integrated systems thinking
- ➤ Lack of technical and design skills
- ➤ Inadequate communication
- ➤ Intellectual property (IP) and legislative concerns
- ➤ Organizational culture or climate
- ➤ Attitudes or mindsets of mines, OEMs, and workers
- ➤ Lack of acceptance (resistance to change)
- ➤ Dealing with perceptions and engaging people to obtain buy-in at all levels
- ➤ Concerns about the impact (*e.g.* job losses and skills requirements)
- ➤ Lack of appropriate change management strategy.

From the above it is evident that there was the need to identify essential elements of the design and development process to ensure that the guideline addresses the needs of the sector. The following essential elements for an effective design and development process were identified.

- ➤ Understanding of the users, tasks, and environment (system context)
- ➤ Addressing the whole user experience
- ➤ Specifications of user and organizational requirements
- ➤ Needs analysis (through consultation)
- ➤ Cost-benefit analysis
- ➤ Stakeholder participation early and throughout the design and development process
- ➤ Multidisciplinary skills and perspectives
- ➤ Equipment designed to be easy to use, fit for purpose, and fit to the user
- ➤ Understanding of regulations or legislative framework
- ➤ Iterative design feedback, evaluation, and redesign)
- ➤ Systematic, step-by-step design process
- ➤ Systems mapping and integration
- ➤ Skills development
- ➤ Effective change management.

Based on the above, a basic process model was developed to serve as a framework. highlighting process stages where workers can be incorporated in the equipment design and development process. The process model is depicted in Figure 1. The backward-pointing arrows refer to examples of loops to reflect on whether the requirements of previous steps have been adequately met. This type of verification should take place for each step in the guideline.

Five basic stages are proposed in the recommended guideline, and are listed below.

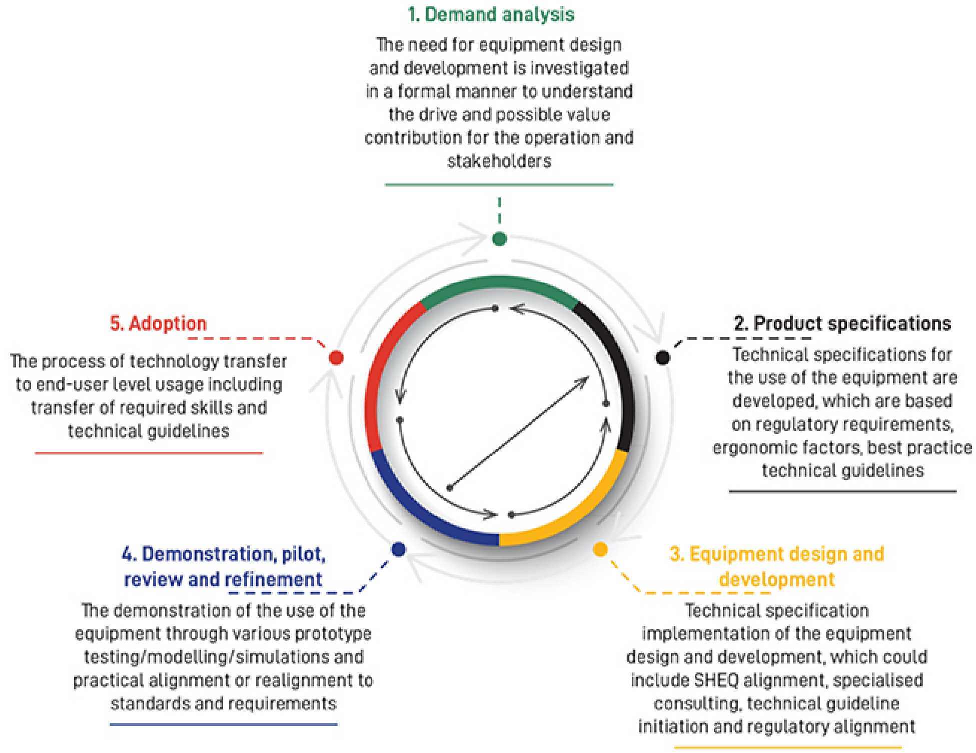

Figure 1—Process flow model for stakeholder inclusion in the equipment design and development process

- *Demand analysis*: The guideline is initiated by various changes/drives in the environment (regulatory requirements, best practice developments, production methodology changes, *etc.*)
- *Product specifications*: This stage focuses on technical specifications that need to align to best practice, regulatory requirements, safety, health, environment, and quality (SHEQ) specifications and other technical requirements around human-centred design
- *Equipment design and development*: There is a focus on the development of a technical guideline for users which is aligned to best practice and the development of a prototype;
- *Demonstration, piloting, review, and refinement*: User interaction is evaluated and ergonomics factors evaluated in the use of the equipment. Digital/physical interfaces are evaluated during this step
- *Adoption*: Would be either per operation (if economically viable), per company, per commodity, or for the sector as a whole. Business cases would have had to be used as a basis for this (see step 1).

The descriptions, sub-processes, and potential methods for each step are indicated in Table III. Factors underpinning the guideline are also incorporated, and include the need for loop learning, and change management throughout the process. Loop learning serves as a continuous improvement tool where gaps and lessons learnt are identified at each stage of the process, for subsequent development and implementation of an action plan to close the identified gaps. Loop learning within the guideline refers to the theory of organizational learning that takes place. Loop learning also closely relates to project management success and contributes to greater success in project implementation (McClory, Read, and Labib, 2017). Loop learning theory thus applies to the project management approach to equipment design.

The guideline is designed as an iterative process, linking back to the theory of loop learning, and utilizes project management as a foundation to the implementation. The 'golden threads' of the guideline are stakeholder engagement, change management, and feedback (monitoring and evaluation) structures.

The guideline is contained in five steps, with descriptions of each step. There are process underpins that outline what is required within each step. These can also be referred to as sub-steps. The guideline also provides methodologies for the implementation of each of the steps. Further to this, the guideline also provides a list of the stakeholders to be engaged/involved within each step. Lastly, the underpinning factors outline the essential factors across all the steps in the guideline.

Research limitations

Successful execution of the project scope was susceptible to potential risks and limitations. The research depended on the participation and buy-in from stakeholders. Assistance from the Mandela Mining Precinct and early engagements with stakeholders assisted in facilitating this involvement. Potential risks resulting from the COVID-19 pandemic were mitigated using online platforms for engagement, and adherence to related health and safety protocols. Pre-identified themes used for the questions in the data collection tools could be a potential source of bias in the data gathered. Open communication, feedback, and collaboration were sought to optimize the co-creation outcomes of this project.

Conclusion and recommendations

A people-centric technology design and development approach is reccomended to facilitate successful implementation and adoption of technology in the South African mining sector. The study identified several economic and social benefits of early inclusion of stakeholders in the technology design and development process.

Table III

A guideline to the inclusion of stakeholders in equipment design

Step title	1. Demand analysis	2. Product specifications	3. Equipment design and development	4. Demonstration, pilot, review and refinement	5. Adoption
Description	The need for equipment design and development is investigated in a formal manner to understand the drive and possible value contribution of the operation and stakeholders	Technical specifications for the use of the equipment are developed, based on regulatory requirements, ergonomic factors, best practice technical guidelines	Technical specification implementation of the equipment design and development, which could include SHEQ alignment, specialised consulting, technical guideline initiation and regulatory alignment	The demonstration of the use of the equipment through various prototype testing/modelling/simulations and practical alignment or realignment to standards and requirements	The process of technology transfer to end-user level usage including transfer of required skills and technical guidelines
Process underpins	• Business case • Context of use definitions (scenarios of use), which include the technical, physical, social, cultural, and organisational environments • Stakeholder identification • SHEQ Analysis • Organisational impact assessment	• Technical specification determination • Regulatory analysis • Environmental analysis • Ergonomic factor analysis • Best practice benchmarking	• Concept development • Technical specification analysis • SHEQ requirement inclusion • Specialised technical development and inputs • Projections and modelling	• Prototyping and organisation practical testing (mock-up trials) • User testing, feedback and alignment (if required) • Further technical guideline development • Verification and validation	• Skills transfer • Technology transfer to user • Application / commissioning and review
Methodology (Examples)	• Brainstorming • Benchmarking best practice • Idea generation methods • Surveys • Observations • Technical steering committee establishment and inputs provided • Environmental analysis • Cost-benefit analysis • Role play • Context diagram	• Benchmarking • OEM specification • Regulatory specifications • Ergonomic guidelines • Focus group discussions • Surveys • Desktop study	• Organisational prototyping • Design guidelines and standards • Virtual reality (VR) design and projections • Lead user analysis • National/international modelling	• Model run • Broader simulations • Projections (scenario, production, financial, other) • Physical demonstration (prototype concept and site/mock-up demonstration) • VR and simulations	• Skills transfer • User and technical guideline distribution and implementation • Standard operating procedures implemented • Post-delivery support • Refer to change guideline • Communication strategies rolled out
Possible stakeholder involvement	• Driver: industry / mine management • Lead: OEMs • Mine technical services (e.g. engineering, safety, production) • Support services at mines (e.g. ICT, training, HR, OHS, finance, procurement, legal) • External consultants (e.g. SHEQ, technical designer, programmers) • Indirect input from the workforce from all job grades (e.g. operators, artisans, supervisors, miners, shift bosses) • Labour representatives (if relevant) • Regulator (if relevant) • Etc.	• Industry / mine management, including technical and support services • OEMs • External consultants • Suppliers (if relevant) • Labour representatives • Workforce • Regulator (if relevant) • Etc.	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers • Labour representatives • Workforce (direct participation) • Regulator (if relevant) • Etc.	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers (if relevant) • Labour representatives • Workforce (direct participation) • Regulator • Communities • Etc.	• OEMs • Industry / mine management, including technical and support services • External consultants (if relevant) • Suppliers (if relevant) • Labour representatives • Workforce (direct participation) • Regulator • Communities • Etc.
Underpinning factors	Loop Learning (single, double and triple loop), including hazard analysis Change Management (monitoring and evaluation – communication strategies) Impact on Jobs and Skills Requirements				

The benefits include improved product quality, OHS, productivity, and acceptance. In the context of the South African mining sector, the timeous and adequate inclusion of stakeholders in the technology design and development process has been obstructed by factors such as lack of resources (human resources, time, and funds), difficulty accessing mines, organizational culture, and inadequate communication. The barriers have resulted in the development of equipment that was not fit-for purpose and have constrained progressive modernization of the mining industry.

Recommendations arising from this project, include the following.

➤ Involvement of all stakeholders, including end-users, in the early stages and throughout the technology design and development process is critical for successful introduction of technology in the South African mining sector. Identified critical enablers of the technology design and development process include the use of an effective two-way communication strategy (with timeous feedback), use of a structured change management process, development and implementation of a skills development plan to support the design, development, and implementation of the new technology, and continuous monitoring and evaluation of the process. It is also important to assess the organizational impacts of the technology, including the effect on jobs, skills, and SHEQ.The mining industry is advised to consider using the guideline for the inclusion of stakeholders in equipment design (Table II) to develop a site-specific and customized process for stakeholder inclusion in the design and development of equipment. The process should be customized to suit a particular context of use, taking cognisance of factors such as target end-users, tasks, technology and environment. To enhance buy-in and ownership, efforts should also be made to solicit inputs from all key stakeholders during the customization of the guideline.

➤ The mining industry should co-create innovative solutions to address some of the challenges that might hinder successful design, development, and implementation of new technology. Challenges include lack of research and development funding, unavailability of close to real-life test sites, and intellectual property and confidentiality issues.

Acknowledgements

This work was commissioned by the Mandela Mining Precinct. The Mandela Mining Precinct is a public-private partnership between the Department of Science and Innovation and the Minerals Council South Africa. The Precinct is co-hosted by the Council for Scientific and Industrial Research (CSIR) and the Minerals Council. We would like to thank the Mining Equipment Manufacturers of South Africa (MEMSA), for their support and assistance with the project survey. We would also like to thank Gillian Michalowski from Enterprises University of Pretoria for her assistance with conducting this research. Finally, we would like to express appreciation to each of the research participants and to all the stakeholders involved in the project workshops and validation.

References

EMESRT. 2012. Design Operability and Maintainability Analysis Technique – Design OMAT. Process and Skill Development Manual. Version 4. Earth Moving Equipment Safety Round Table, Queensland, Australia.

EMESRT. 2019. 2018 Annual Report. Earth Moving Equipment Safety Round Table, Queensland, Australia.

Fraser, P.D. 2017. What does "Modernisation" mean for South African Mines? *Proceedings of the 7th International Platinum Conference*, Polokwane, South Africa. Southern African Institute of Mining and Metallurgy, Johannesburg.

Horberry, T., Burgess-Limerick, R., and Steiner, L. 2015. Human centred design for mining equipment and new technology. *Proceedings of the 19th Triennial Congress of the IEA*, Melbourne 9-14 August 2015, pp. 1–6.

ISO 6385. 2016. Ergonomics principles in the design of work systems. International Standard, ISO 6385:2016(E).

ISO 9241-210. 2010. Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems. International Standard, ISO 9241-210:2010(E).

ISO 9241-210. 2019. Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems. International Standard, ISO 9241-210:2019(E).

ISO 9241:220. 2019. Ergonomics of human-system interaction – Part 220: Processes for enabling, executing and assessing human-centred design within organisations. International Standard, ISO 9241-220:2019(E).

Maguire, M. 2001. Methods to support human-centred design. *International Journal of Human-Computer Studies*, vol. 55. pp. 587–634.

Magweregwede, F., Mpofu, M., and Ngobese, S. 2019. Investigate blasting methodologies for underground narrow reef mines. Mandela Mining Precinct, Johannesburg.

McClory, S., Read, M., and Labib, A. 2017. Conceptualising the lessons-learned process in project management: Towards a triple-loop learning framework. *International Journal of Project Management*, vol. 35, no. 7. pp. 1322–1335.

Minerals Council South Africa. 2019. Modernisation: Towards the Mine of Tomorrow. https://www.mineralscouncil.org.za/industry-news/publications/fact-sheets [accessed 21 October 2020].

Minerals Council South Africa. 2020. Facts and figures pocketbook 2019. https://www.mineralscouncil.org.za/industry-news/publications/facts-and-figures [accessed 10 October 2020]

Pelders, J. Botha, W., Michalowski, G., Ngobese, S., Magweregwede, F., and Schutte, S. 2021. People-Centric Modernisation. Guideline to Include Stakeholders in Equipment Design and Development. SATCAP WP 3. Mandela Mining Precinct, Johannesburg.

Pelders, J., Murambadoro, M., Letsoalo, S., and Schutte, S. 2019. Globally Benchmarked Strategy for the Engagement of Workers in Original Equipment Manufacturer (OEM) Equipment Development Processes. Successful Application of Technology Centred Around People (SATCAP). Work Package 1.9. Mandela Mining Precinct, Johannesburg.

Pelders, J. and Schutte, S. 2021. Worker inclusion in equipment development processes in the modernizing minerals sector in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 121, no. 2: pp. 63–70.

Samaras, G.M. and Horst, R.L. 2005. A systems engineering perspective on the human-centred design of health information systems. *Journal of Biomedical Informatics*, vol. 38. pp. 61–74. ◆