Mining Technology
Transactions of the Institutions of Mining and Metallurgy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ymnt21

Training of load haul dump (LHD) machine operators: a case study at LKAB's Kiirunavaara mine

Muhammad Tariq, Anna Gustafson & Håkan Schunnesson

To cite this article: Muhammad Tariq, Anna Gustafson & Håkan Schunnesson (2023) Training of load haul dump (LHD) machine operators: a case study at LKAB's Kiirunavaara mine, Mining Technology, 132:4, 237-252, DOI: 10.1080/25726668.2023.2217669

To link to this article: https://doi.org/10.1080/25726668.2023.2217669

Published online: 05 Jun 2023.

MINING TECHNOLOGY
2023, VOL. 132, NO. 4, 237–252
https://doi.org/10.1080/25726668.2023.2217669

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Training of load haul dump (LHD) machine operators: a case study at LKAB's Kiirunavaara mine

Muhammad Tariq, Anna Gustafson and Håkan Schunnesson

Division of Mining and Geotechnical Engineering, Luleå University of Technology, Luleå, Sweden

ABSTRACT
Mining is a high-risk industry, so efficiency and safety are key priorities. Technological advancements, such as digitisation, digitalisation, and automation have made mines safer. These developments have also highlighted the need for operators with updated skills and improved education programs. This study analysed the training of semi-autonomous and manual Load Haul Dump (LHD) operators' at LKAB's Kiirunavaara mine, focusing on operators' training, perspective and integration of more recent tool such as simulator training. The survey questionnaire was sent to all 120 LHD operators. 86 answers were received, giving response rate of 70%. Results showed that operators generally were satisfied with how the training was structured, organised, and delivered. However, they wanted to add more topics, including practical loading, spending time with departments of other sub-processes, etc. In addition, 36% of the operators, including 20% of those operating semi-autonomous LHDs, and 80% of those operating manual LHDs, found simulator training difficult.

ARTICLE HISTORY
Received 21 March 2023
Revised 3 May 2023
Accepted 19 May 2023

KEYWORDS
Training; Underground; Simulators; Mining education; LHD; Training method; Underground mining equipment; Operator training

Introduction

Mining, in general, and underground mining in particular, has always been associated with risk, which has placed high demands on safety and efficiency. Technological improvements and the recent exponential growth of digitalisation in the mining industry have made modern mines safer and more efficient (Rogers et al. 2019). Despite this technological advancement, humans had not yet been completely removed from the system. Their role remains critical, and they continue to have the highest impact on the system (Rogers et al. 2019). As the industry moves toward digitalisation and digitisation, operators' skills must be updated and supported through training and learning (Maxwell 2002). This calls for effective training and detailed instructions Standard Operating Procedures (SOP).

Training has a long tradition in the mining industry and has transformed over the years, the change, in the nature of the work, has broadened the training objectives beyond improving efficiency and safety to adding new skills (Bell et al. 2017). In addition, training methods have evolved; methods used include lectures/classes, on-the-job training (OJT), technology-based learning, coaching/mentoring, playing games, outdoor training, group discussions, tutorials, case studies, and simulators.

In an underground operation, mobile mining equipment is critical to the production (Gustafson et al. 2011), and Load Haul Dump (LHD) machines are the backbone of many modern production systems (Gustafson et al. 2017). The tasks performed by these machines are central to many mines in terms of economy and safety (Gustafson et al. 2017).

As an example, the effect of the operator practice on the performance of surface digging equipment such as shovel's energy efficiency has been highlighted (Patnayak et al. 2008) and statistically evaluated (Oskouei and Awuah-Offei 2014) in various investigations. Although other factors affect operational efficiency, the operator's skill is a key factor that easily can be improved through training (Oskouei and Awuah-Offei 2016). The literature has generally emphasised the importance of operators' training (Oskouei and Awuah-Offei 2016) and particularly the training of LHD operators (Gustafson et al. 2017). Training is critical in inherently highly risky, complicated, and time-dependent working conditions that requires decision-makers to handle imperfect and incomplete information (Aronsson et al. 2021). Loading in sublevel caving is a good example, as it is a complex, time-critical operation involving high risk and relies on operator decisions.

CONTACT Muhammad Tariq muhammad.tariq@ltu.se Division of Mining and Geotechnical Engineering, Luleå University of Technology, Luleå, Sweden; Luleå University of Technology Laboratorievägen 14SE-971 87 LULEÅ Sweden

The literature on mine training in general and LHD and/or simulator training, in particular, is quite limited compared to other fields such as defence, military, aviation, and health. However, studies have been done including multi-disciplinary research projects such as 'Handbook of Simulation-Based Training' (Farmer et al. 2017) to provide guidelines or common frame of reference to design simulator training. Aronsson et al. (2021) used a qualitative approach to analyse how simulator training is designed, carried out, and evaluated in dynamic decision-making work situations, based on existing methods and frameworks, such as Analysis-Design-Development-Evaluation (ADDIE) (Branson et al. 1975), 'training need analysis' (Goldstein and Ford 1993), and 'task and work analysis' (Wilson et al. 2013). LHD operation falls into the group, dynamic decision-making, as the operator is required to make a series of decisions that are not independent and must be made in real-time. Moreover, the state changes both autonomously and as a result of the operator's actions.

The purpose with this study is to analyse how the training for LHD operators is currently structured, delivered, and evaluated at Loussavaara-Kiirunavaara AB's (LKAB) Kiirunavaara mine. The mine has 120 operators of semi-autonomous and manually operated LHDs and runs a 10–11 weeks training programme for both types of operators, including the use of a simulator.

Regulations

For manual operated LHDs, the countries with regulations that govern LHD operators' training in vocational institutes and mines (in public and private organisations and companies) are summarised in Table 1. The specific outcomes and the assessment criteria are listed in the table. Table 2 shows the same information for remotely operated LHDs. The choice of training methods is not uniform in the mining industry because of the complexity and diversity of the global mining sector. However, since LHDs are common mobile mining equipment in underground operations, these regulations provide a good framework for mines to develop a training programme and cross-validate their training content.

Simulators used in training

This study included a review of the training simulators for LHDs offered by various simulator or equipment manufacturers. Simulators use various scenarios, such as control familiarisation, brake testing, hazard avoidance, truck loading, etc. The focus areas covered by these simulators or training programmes are compared and summarised in Table 3.

The simulator curriculum varies from mine to mine, and while some perfectly integrate the system into their training programme, others do not. Various companies were contacted to see how they recommend to use the simulator training, but only Thoroughtec was part of this study; others did not respond or had confidentiality issues.

Thoroughtec offers both generic and customised products based on customer demands (Mendes 2022). The generic models are cheaper than customised products; the latter include mine-specific scenarios, layouts, safety rules, etc. Thoroughtec's simulators investigate three main areas: safety, machine abuse, and productivity (also known as the three pillars). They track 150 metrics and give feedback when an operator operates the machine (Mendes 2022). According to Mendes (2022) a simulator can only replace part of what can be achieved by training on a real machine. Although a simulator does not represent all loading scenarios as real machine, it addresses diverse training needs, including advanced emergency situations such as brake failures, engine fires, burst tyres, etc. Therefore, it is recommended by Thoroughtec that an operator spends around 90 h training on the simulator (Mendes 2022).

Methodology

The research approach initially included a literature review on regulations and training methods for LHDs. The study then took a qualitative approach to build a baseline mapping of LHD operators' training at LKAB's Kiirunavaara mine by interviewing instructors in the training programme, and a qualitative and quantitative approach to capture the operators' perspective and satisfaction by a survey questionnaire sent to all current LHD operators. In addition, the research included mine visits and interviews, and discussions with commercial companies.

Effectiveness is the measure of whether the training goals have been achieved (Ravikanth et al. 2018). Surveys, questionnaires, ratings, checklists, and performance measurements of the operator are a few ways to assess training (Ravikanth et al. 2018). The traditionally used Kirkpatrick model includes four levels: reaction, learning, behaviour, and results (Kirkpatrick 1986). The first two parts of the model, 'reaction' and 'learning' was used as a basis for several questions. 'Reaction' serves as a measure to evaluate whether the respondents have found the training relevant to their work. 'Learning' is a measure to see if the respondent has acquired the right knowledge and skills matching the aim of the training.

Once a baseline for the training at the mine was determined, a survey questionnaire was sent to all LHD operators at Kiirunavaara mine, asking about their training. The original survey was conducted in Swedish using the online platform Survey Monkey®.

Table 1. Summary of regulations specific to manual LHD operators.

Country (reference)	Specific outcomes	Assessment criteria
South Africa (SAQA 2018a)	Specific requirements pertaining to the transfer of broken rock	Operational requirements (idling time, hazards, towing and speed limits, traffic control systems, environmental conditions, and refuelling). Emergencies (brake failure, fire to equipment, fall of ground, and collision). Importance of compliance and consequences of incompliance.
	Prepare to transfer broken rock	Personal protective equipment, area examination for any potential hazards, selection, examination, and transporting of tools, material, and equipment, and pre-use and after-start inspection.
	Transfer broken rock	Environmental conditions, ground conditions, and roadway conditions, correct use of tools and equipment, preparing the muck-pile for the safe loading, filling the bucket to allowable capacity, manipulation of control, and sequence of loading. Dumping includes bins, dump trucks, conveyer systems, ore passes, and spillage prevention. Interpersonal communication and teamwork. Consequences of non-adherence to safety, occupational health, and production.
	Perform post-transferring activities	Preparation and storage of tools and equipment, completing and submitting forms, checklists, reports, parking, securing, and locking out procedures. Consequences of non-adherence to the compliances of safety, occupational health, and production.
Australia (Australian Government 2022a)	Plan and prepare for operations	Compliance documentation, pre-start checks, hazard identification, environmental issues, adherence to emergency procedures, a site inspection for scaling, ventilation check, and erection of safety provisions.
	Operate LHD	Communication with other operators, equipment safety, equipment performance management, and end-of-shift information exchange.
	Load, haul, and dump material	Dust suppression, scaling down loose material, identifying misfires, safe storage, bogging according to plan, and road clearance. Confirm the type of material and bucket position, manage spillages, maintain the haulage site, and distribute dump material as required.
	Clean up the job site	Scaling, and cleaning the site.
	Carry out operator maintenance	Shutdown procedures and service.
	Carry out housekeeping activities	Cleaning equipment, cleaning and storing auxiliary service equipment, and maintaining a safe working environment by managing or reporting a hazard.
India (NSQF 2022)	Prepare Side Discharge Loader (SDL)/LHD/other loading machines for operation	Pre-operation checks and record details (logbook, shift handover).
	Carry out SDL/ LHD Operations	Start/ stop and drive the machine to the work area. SDL/LHD operation.
	Perform routine maintenance and troubleshooting on the SDL/LHD	Preventive maintenance, basic diagnostics, and troubleshooting,
	Follow health, safety, and environmental guidelines	Follow work-site health and safety measures, environmental guidelines, mine vocational training rules, and mine rescue rules.
New Zealand (NZQA 2018)	Describe the operational characteristics and performance of an LHD machine in an underground operation	Safety features, instruments, controls, operating procedures, attachments, and powered attachments.
	Describe safe work practices and conditions for operating an LHD machine in an underground operation	Gradient, speed, lighting, accessibility, ventilation, roadway conditions, roof, and rib security, compressed air, water, and electrical services.
	Check readiness and operate an LHD machine in an underground operation	Availability, capacity, walk-around checks, pre-start checks, post-start checks, documentation, Identify and report defects. The machine is operated based on job and machine specifications, manoeuvring, loading, lifting, carrying, dumping, grade surface, position objects, attachments, powered attachments
	Unload and shutdown an LHD machine	Following industry best practices and company procedures: the machine is unloaded, shut down and parked, identified defects, and reported; documentation is completed

The language was kept simple, with the mine-specific technical words used to avoid any misunderstanding. The information from respondents was kept confidential, and the survey was accessible on multiple platforms, such as computers, tablets, and mobile phones, to encourage maximum participation.

LKAB's Kiirunavaara mine has a diverse fleet of LHD machines consisting of both manual and autonomous LHDs. However, in this study, autonomous loading refers to semi-automatic LHDs with manual bucket loading and autonomous tramming and dumping. The operator controls the semi-autonomous LHDs from a control station underground using a joystick and control panel during the loading of the bucket, while tramming and dumping are fully autonomous. These machines can also be operated manually if needed.

Participants

The survey questionnaire was sent to all LHD operators at the Kiirunavaara mine, totally 120 operators. 86 completed questionnaires were received, giving a response rate of 70%. Currently, the mine has 34 operators assigned to autonomous loading and 86 to manual loading. 22 out of 34 operators of semi-autonomous LHDs took part (65%), and 64 out of 86 operators of manual LHDs participated (74%). In terms of the gender distribution at the mine, 35 (29%) of the 120 LHD operators are female. Among

Table 2. Summary of regulations specific to remote LHD operators.

Country (reference)	Specific outcomes	Assessment criteria
South Africa (SAQA 2018b)	Specific requirements pertaining to the transfer of broken rock by means of remote-controlled LHD	Operational requirements (remote panel, hazards, towing and speed limits, traffic control systems, environment conditions, emergency procedures (brake failure, fire in equipment, ground failure, collisions, and power failures), the importance of compliance and consequences of non-adherence.
	Prepare broken rock	Personal protective equipment, examination of the remote panel, area examination for any potential hazards, selection, availability of required tools and equipment, pre-use and after-start inspection, and consequences of non-adherence.
	Transfer broken rock	Environmental conditions, ground conditions, and roadway conditions. Correct use of tools and equipment. Preparing the muck-pile for safe loading, filling the bucket to allowable capacity, manipulation of control, and the loading sequence. Dumping and including bins, dump trucks, conveyer systems, ore passes, and spillage prevention. Interpersonal communication and teamwork. Consequences of non-adherence to safety, occupational health, and production.
	Perform post-transferring activities	Preparation and storage of tools and equipment, completion and submission of forms, checklists, reports, parking, securing, locking out procedures consequences of non-adherence to the compliance of safety, occupational health, and production.
Australia (Australian Government 2022b)	Set up tele-remote operation	Check transmitter functions, cameras, and receiver are installed, ensure communication, confirm visible warning lights, and ensure proximity device or barrier is operational.
	Conduct tele-remote operation	Monitor control room indicators for equipment and environment and feedback, constant control of remote equipment, assess ground conditions, pass on an end-of-shift operation to an oncoming shift, and proximity sensors.
	Carry out operator maintenance	Operator maintenance, park up and shut down procedures, service, and adjustment of equipment, visual inspection of equipment, and report faults.
	Conduct housekeeping activities	Cleaning equipment, cleaning and storing auxiliary service equipment, completing documentation and result
Canada (MTCU 2012)	Operate Scoop Tram-Remote Control	Identifying workplace hazards and responding to them; inspecting and scaling the workplace; performing pre-operational checks; starting up; conducting operational checks; performing preoperational checks on the scoop tram in remote control mode; operating, hauling, loading and dumping the scoop tram in remote control mode; shutting down the scoop tram in remote control mode.

them, 24 (20%) of the operators are assigned to manual loading and 11 (9%) to autonomous loading.

Demographics

The demographic information obtained via the survey included the operators' LHD experience (Figure 1a), LHD type (manual or semi-autonomous) (Figure 1b), training year, and the inclusion of simulator training. The purpose of including the demographic information was to identify those attributes that significantly affect the operators' education. Questions on machine type (Figure 1c,d) were added, assuming that education and operation differ for operators assigned to manual and semi-autonomous LHDs; therefore, the responses might vary. Experience is also the only tool used to measure performance at the mine. Therefore, it was added as a variable to see if the training differs based on experience. Similarly, simulator training was added to see if it changed the operators' perspectives about the training content.

Baseline mapping of LHD operators' training

The initial part of the baseline mapping included interviews, visits, and meetings with managers to assess how the training is structured, how it has changed over the years, and how it has been performed recently. The selected interviewees were responsible for the training of LHD operators.

Training structure

Today the LHD operators' training at the mine usually lasts for 10–11 weeks. The training is divided into several parts, summarised in Figure 2. Typically, 6–8 operators start their training at the same time. A theoretical part of the training lasts for about a half to a full 8-hour shift, followed by an initial visit to sub-process departments, i.e. production control, autonomous loading, scaling, and blasting, where the operator spends a single shift per department to get an overview of the operation. However, this practice was not followed during the pandemic (2020–2021). Following the initial visit to sub-processes, the operator starts practical training using a Sandvik simulator. This training lasts for about 8 h but is not always continuous.

After simulator training, the operator is sent to a special training area where he or she works under the supervision of a senior operator for 1–2 weeks. The senior operator can either be inside the cabin during operation or loading close by in the same area.

Table 3. Simulator training offered by commercial companies and OEMs of LHDs as per references.

	Mining equipment simulator providers (reference)					
Focus areas	Immersive technologies (Immersive Technologies 2022)	5DT technologies (5DT 2019)	Thoroughtec (CyberMine) (Thoroughtec 2022)	Sandvik (digital trainer) (Sandvik 2019)	Epiroc (RCS) (Epiroc 2022)	CAT simulators (Simscholars 2022)
Supported OEMs/models	*Caterpillar, Komatsu, Sandvik*	*NA**	*Epiroc Caterpillar Joy MTI Sandvik*	*LH517i and LH621i*	*ST7, ST14 and ST18*	*NA**
Control familiarisation	✓	✓	✓	✓	✓	✓
Hazard avoidance	✓	✓	✓			✓
Brake testing procedure	✓	✓	✓	✓	✓	✓
Engine management	✓	✓	✓	✓	✓	✓
Operator productivity	✓	✓	✓	✓	✓	✓
Site safety procedures	✓	✓	✓	✓	✓	✓
Minimising unscheduled maintenance	✓		✓	✓	✓	✓
Truck loading		✓	✓			✓
Crusher dumping			✓			✓
Artificially intelligent traffic		✓	✓			
Scenarios (rockslides, water pool and rubble spillages etc)			✓			
Operator evaluation (feedback)	✓	✓	✓	✓	✓	✓

NA* Information not available.

After completion of training under supervision, the operator is sent to the loading group, where he or she is assigned a mentor. Mentors are experienced (>3 years) operators who voluntarily become part of the training programme. They assist and supervise the operators during the shift, and are either working in the same area or communicating with their mentees during coffee and lunch breaks to answer any trainees' questions. Finally, the operators are evaluated on their performance based on tonnage output. Operators are assisted in reaching the target if necessary.

Training content

This part covers information gathered during the baseline mapping, discussed in Section 5, and the training materials used by the instructors for the LHD operators' training, at the mine.

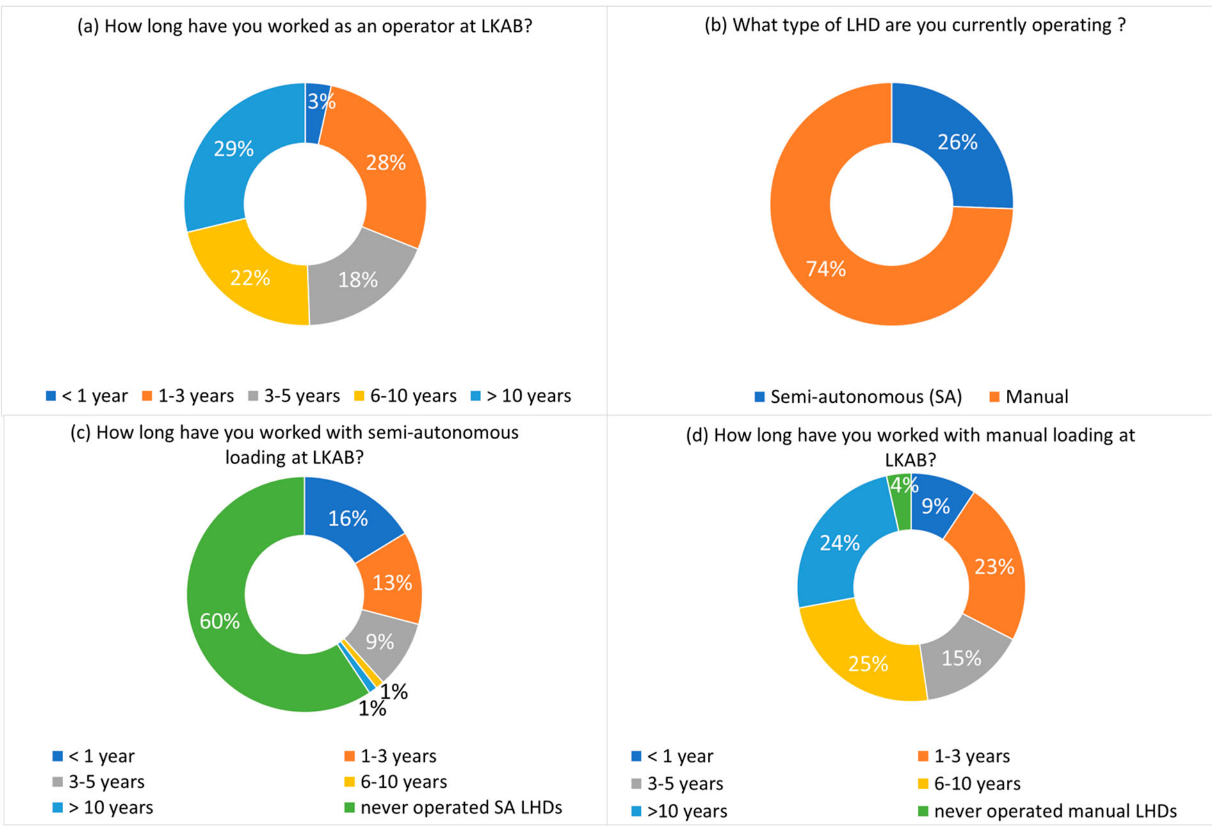

Figure 1. (a) Operator experience with loading at LKAB; (b) machine type; (c) semi-autonomous loading (SA); (d) manual loading. Images are available in colour online.

Theory

The theoretical part of the training for the LHD operators consists of approximately 4–8 h and include 11 different modules. These modules cover a wide range of topics, including organisational structure, mining method, mining operations (drilling, charging, blasting, and reinforcement), driving techniques, daily inspection, safety measures such as securing the work area, protecting cables, knowledge of the instrument, and loading techniques, that has a significant impact on the dilution and ore recovery, in caving operations. Schematic diagrams or real images explain how to open a ring and handle issues such as boulders, hang-ups and roof left (meaning that the top or bottom part of the production ring does not come down). The decision to close a ring should be taken in cooperation with Production Control. Also, guidelines on securing the machine during blasting, for example parking the machine far from the face, with the bucket raised and the tip of the bucket downwards to protect the windows.

The theoretical part puts extra emphasis on the importance of loading and the demands placed on the operator in terms of role and competence, but the operators' responsibilities are defined beyond loading, mucking, and dumping operations and also includes driving style, maintenance, and loading economy, etc.

The duration of the theory section in the mine's operators' training is quite different from what is observed in some of the regulations. For example, the South African Qualification Authority (SAQA) has a compulsory 12 h of classroom-based teaching for diesel, electric, and remote LHDs. Similarly, the National Skills Qualification authority (NSQA) in India regulates a compulsory 110 h of theoretical classroom-based learning, not including the prerequisite courses related to underground safety, etc.

Visit to sub-processes

After completing the theoretical part, the operator is sent to various sub-processes to better understand the overall operation. Each operator spends a single shift in each department. The sub-processes include production control, blasting, scaling, autonomous loading, maintenance, etc.

Practical training

Simulator training. Simulator training was added during 2020 to the LHD operators' training at the mine. The simulator is based on the Sandvik LH621 diesel and represents a completely authentic operator's cabin with similar controls but with a graphic representing a surface mining operation. In responses to the survey, 17% of the operators said their training included simulator training.

The importance of simulator-based training as a tool to develop competence has increased over the years (Nortje 2020; Bergamo et al. 2022). Simulators and virtual reality will optimise learning by providing repetitive tasks, giving clear instructions, and offering immediate feedback (Nortje 2020). In addition, they help trainees visualise some practical applications (Parker 2021). The positive effect of mine simulation training on retention and acquisition of knowledge has been highlighted by Zhang et al. (2010). However, the level of acquisition and retention of knowledge from this training relies on state of art and evidence-based instructional methods (Bennett et al. 2010).

A qualitative and quantitative approach was used to assess how the simulator is integrated into the practical part of the training programme (i.e. the survey questionnaire).

Special training area. After completing simulator training, the operator is sent to a special training area, where he or she practices loading under the supervision of an experienced operator. The experienced operator is either in the cabin or close by in the same area using radio communication to stay in touch with the trainee. The operators' perspectives on loading under supervision were gained by asking qualitative questions (the survey).

Production loading (autonomous and manual loading). Semi-autonomous loading and manual loading are currently seen as two different operations at the Kiirunavaara mine. The mine has a fleet of 19 Sandvik manual LHD machines, including twelve 25 tonnes (LH625), two 25 tonnes (LH625iE), four 21 tonnes (LH621), and one 21 tonnes (LH621iE). There are also 11 semi-autonomous LHD machines, including four 21 tonnes (Sandvik LH621s), three 21 tonnes (Sandvik LH621i), one 25 tonnes (Sandvik LH621iE) and three 18 tonnes (Epiroc ST18s). The semi-autonomous LHDs are operated from one control room with six control stations: five operate the Sandvik machines, and one operates the Epiroc machines.

The training programmes for semi-autonomous and manual LHDs are the same for most of the training, but after one to two weeks training in the special training area underground, the operators are assigned mentors and sent either to the manual or to the autonomous loading group for the remaining seven to eight weeks of training.

Evaluation

At the moment, the operators are not required to pass any form of examination. Overall, the sole performance criterion for an operator is tonnage. The tonnage difference between a senior operator and a new operator can range from 2000 to 2500 tonnes per shift.

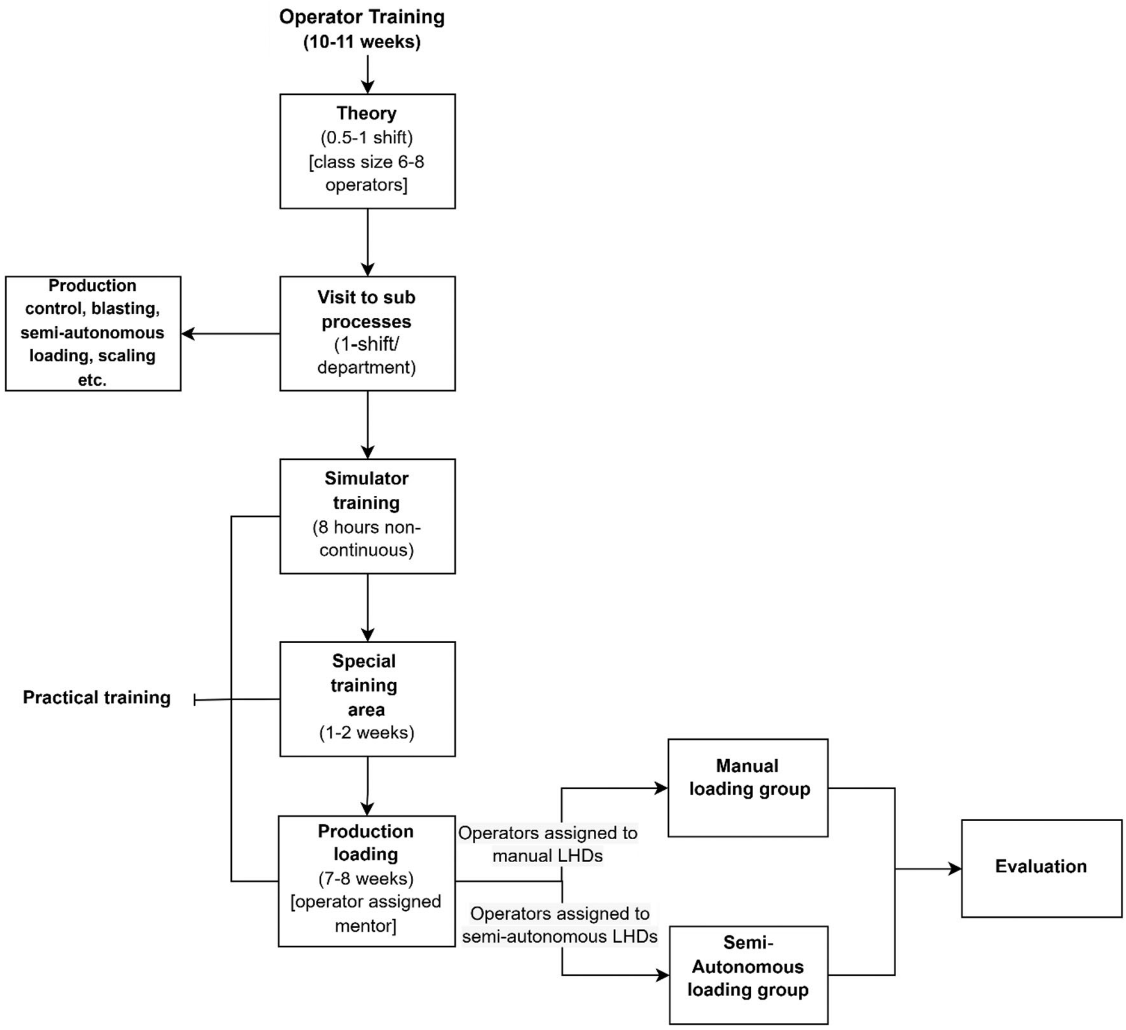

Figure 2. Training structure at LKAB's Kiirunavaara mine. Images are available in colour online.

Results of the questionnaire and discussion

Training structure

The operators' responses to the survey also showed the overall training structure. The respondents could choose multiple options to indicate what was included in their training programme. The responses were compared based on when the operators had taken the training (Figure 3). It was observed that over the years, the training was consistent in including basic theory and loading with an experienced operator in the cabin or in a nearby area. However, simulators were recently added which can be seen in Figure 3. Autonomous loading was not part of the training five to six years ago, but some operators who took the training more than six years ago had autonomous loading included in the training. The gap seen here could be explained by the fact that autonomous loading was not used for several years but restarted about 7–8 years ago.

Training content

Theory

The study compared the duration of the theory section of the programme across various training years (Figure 4). Most of the respondents (51%) said training lasted two to five days. The responses were inconsistent with the information gathered during baseline mapping, as the interviewees specified 4–8 h. The operators might have included the visits to sub-processes, such as autonomous loading, production control, scaling, and blasting, as part of the theory section. However, all the respondents whose training did not include a theoretical part or who had theoretical training for more than 10 days received their training more than six years ago. Overall, the duration (0.5–1 day) of the theoretical training described in the baseline mapping seems inconsistent with the operators' responses (2–5 days for the majority), as shown in Figure 4, and greatly depends on when the training occurred.

Simulator training

Simulator training is the initial part of the practical training, where the operator becomes familiarised with the controls of the machine. This was introduced recently (<3 years ago). Therefore, only 16% of the operators had used simulators in their training. The operators who took simulator training were asked

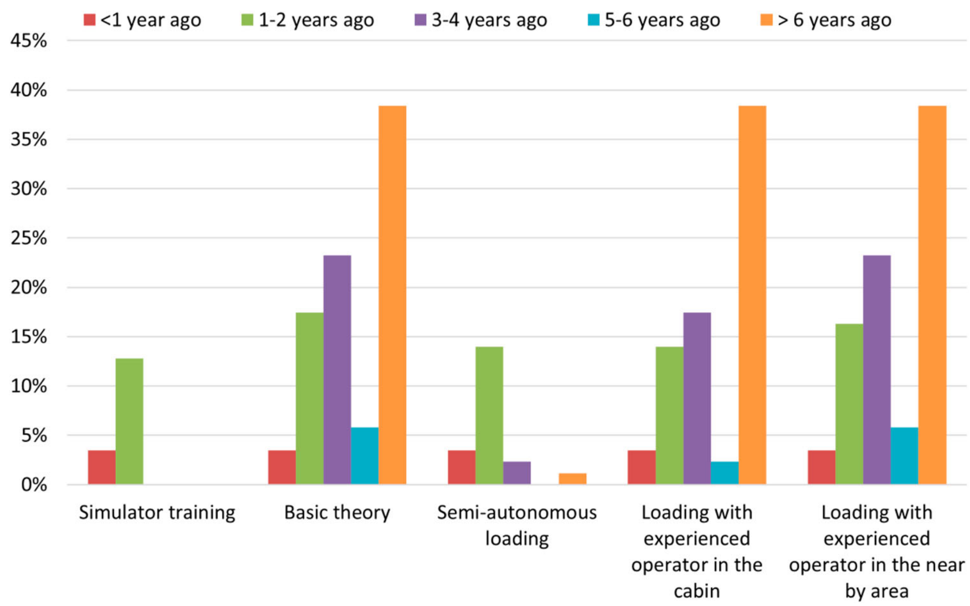

Figure 3. What parts were included in the LHD operators' training that you received? Images are available in colour online.

which parts they found difficult in training. They could choose from multiple options. Interestingly, 36% found simulator training difficult (Figure 5). This could be explained by poorly developed instructional design and cognitive overload. As cognitive overload can hinder learning and retention of knowledge (Bennett et al. 2010). Arguably, the simulator graphic represents a surface operation and does not have enough realistic situations to depict loading underground. The reported difficulty also varied depending on the machine type that the operator was assigned to. More specifically, out of the 36% that found simulator training difficult, the majority (80%) were operators of manual LHDs, while only 20% were operators of semi-autonomous LHDs.

The operators' perspectives on simulator training were analysed using a 5-point Likert scale, where 1 represented 'Strongly agree', 2 'Agree', 3 'Neutral, 4 'Disagree', and 5 'Strongly disagree'. The operators' experience with simulator training (see Figure 6) can be summarised as:

- The majority (86%) of the respondents found the simulator part of the training very useful.
- The operators agreed there was sufficient time on the simulator for training, and there were enough scenarios.
- The respondents were more divided on whether the simulator offered realistic situations to resemble underground loading: 36% disagreed, and 14% were neutral.
- Similarly, responses on whether the graphic in the simulator resembled underground conditions moved towards disagreement: only 14% of the operators agreed with the statement.

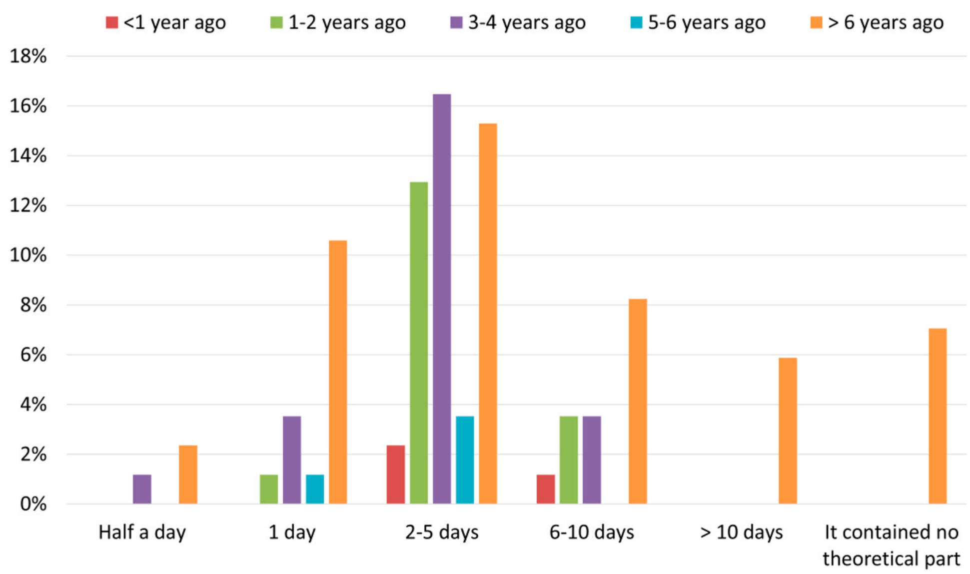

Figure 4. How long was the theoretical (classroom-like) part of the training? Images are available in colour online.

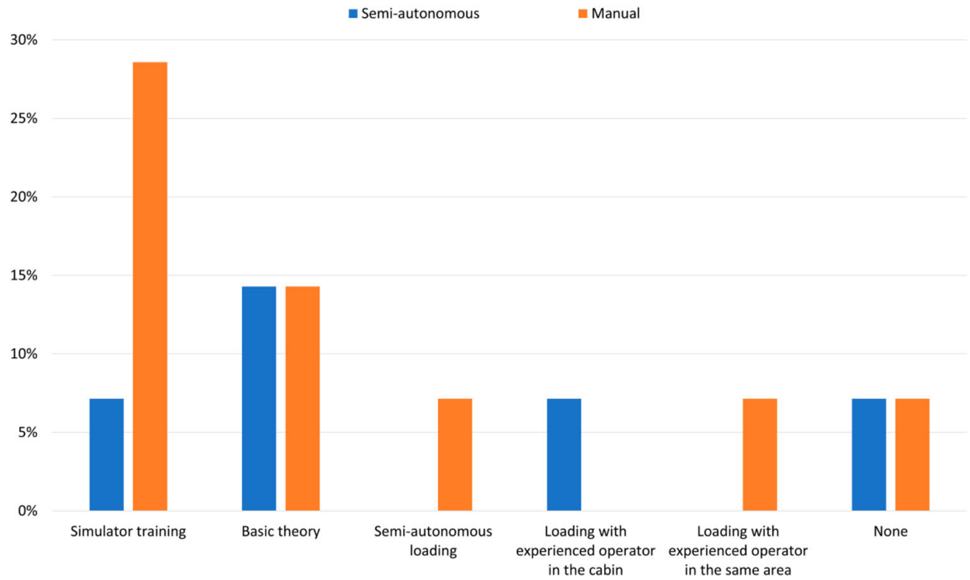

Figure 5. What part of the operators' training was difficult? Images are available in colour online.

A comparison of the simulator training at Kiirunavaara mine with simulator training offered by commercial companies, indicated that the simulator training at the mine mainly focuses on control familiarisation and driving, while the commercial simulator providers also offer many other things. Furthermore, these simulator providers continuously improve and upgrade their systems to depict more realistic scenarios. However, none of these simulators has scenarios for tasks such as road maintenance, boulder handling, etc., tasks highlighted by some LHD operators as difficult to learn.

Special training area

Learning from experienced operators is a main part of the training programme at the mine. In the special training area, the operator trains with an experienced operator in the cabin or in a nearby area. It was observed that the time with an experienced operator in the cabin depended on the year of training (see Figure 7). Just over a third (37%) of the respondents had not driven with another operator in the cabin. According to Robert-Sauvé Research Institute for Occupational Health and Safety (IRSST) referred in Bellehumeur and Marquis (2016) the limited space in the cabin is an obstacle to the transmission of knowledge, as it prevents experienced workers from always accompanying new operators. Some of the operators' responses affirmed this: 17% found driving with another person in the cabin difficult, and only 9% thought driving with another person in the nearby area was difficult.

Autonomous loading

According to the baseline mapping, the training following the loading in a 'special training area', differs for semi-autonomous and manual LHD operators. Therefore, the operators who answered that the training included both manual and semi-autonomous loading (26% of the respondents) were asked about

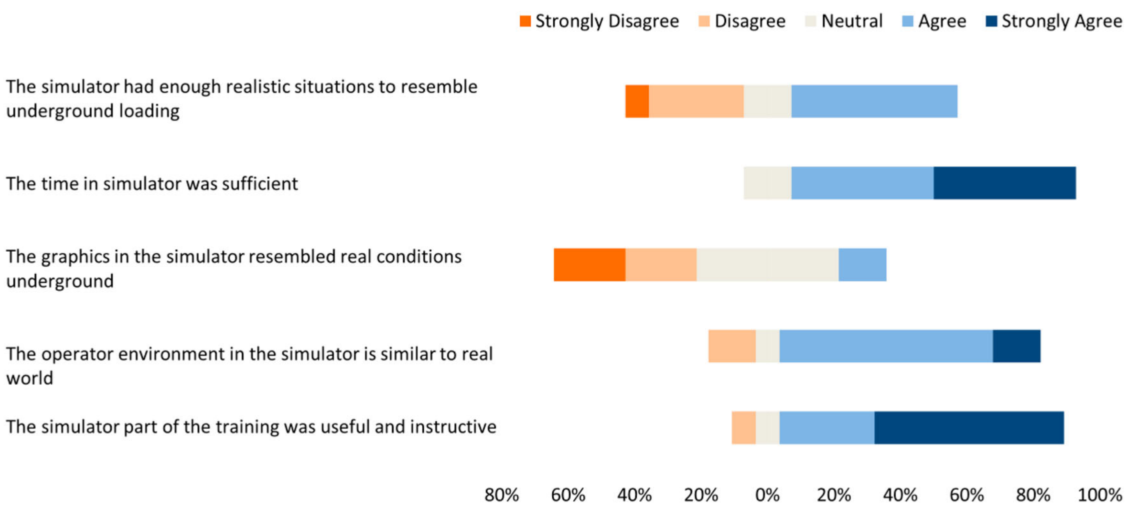

Figure 6. Operators' satisfaction with simulator training. Images are available in colour online.

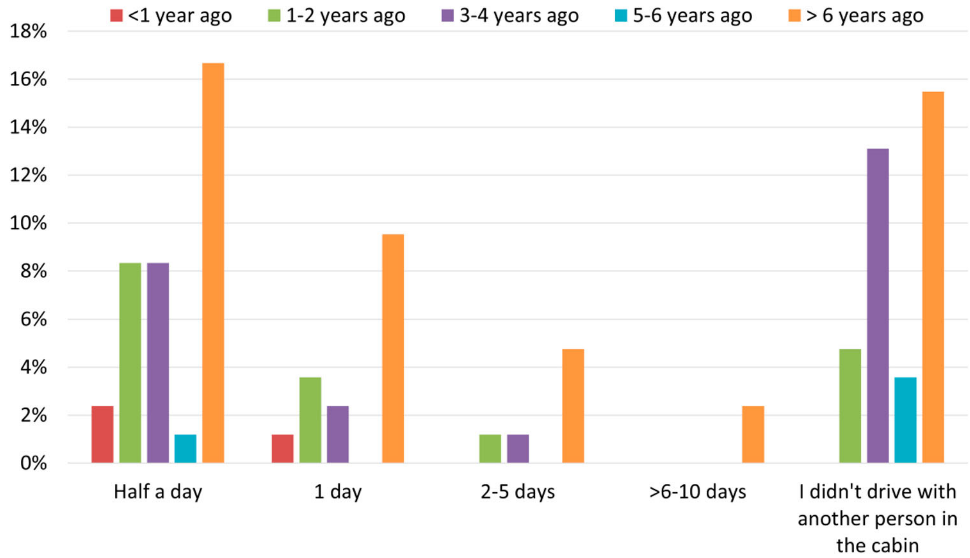

Figure 7. For how long did you drive with another person in the cabin? Images are available in colour online.

the differences in training (see Figure 8). It can be seen that the different activities vary depending on, when the training took part, and the largest difference was the amount of time spent practising autonomous loading. However, 23% of the operators said everything was the same. A comparison of the results to regulations from South Africa, Australia, and Canada indicates the standards and learning outcomes are different for remote loading operators in different countries. In addition, skills training offered by semi-autonomous system providers such as RCT includes modules specific to remote operations that last for three days.

The operators were asked what they think is difficult to learn with autonomous loading (Figure 9). The operators could choose among multiple options. 48% of the respondents answered the question and almost half (49%) of them found road maintenance to be the most difficult task to learn. This was followed by bucket filling (43%), keeping track of traffic and people in the area assigned to autonomous operations (28%), and boulder handling (21%). No one found dumping difficult to learn. The operators could also specify other options: 6% thought the semi-autonomous system and control station part was hard to learn, and 6% thought everything was easy.

The answers from Figure 9 were then analysed based on when the respondents took the training (Figure 10). It can be seen that the activities that are found difficult vary with when the training took part. The reason for this could be the differences in the training content depending on the year of training. E.g. only operators who had received training of more than three or four years previously found loading

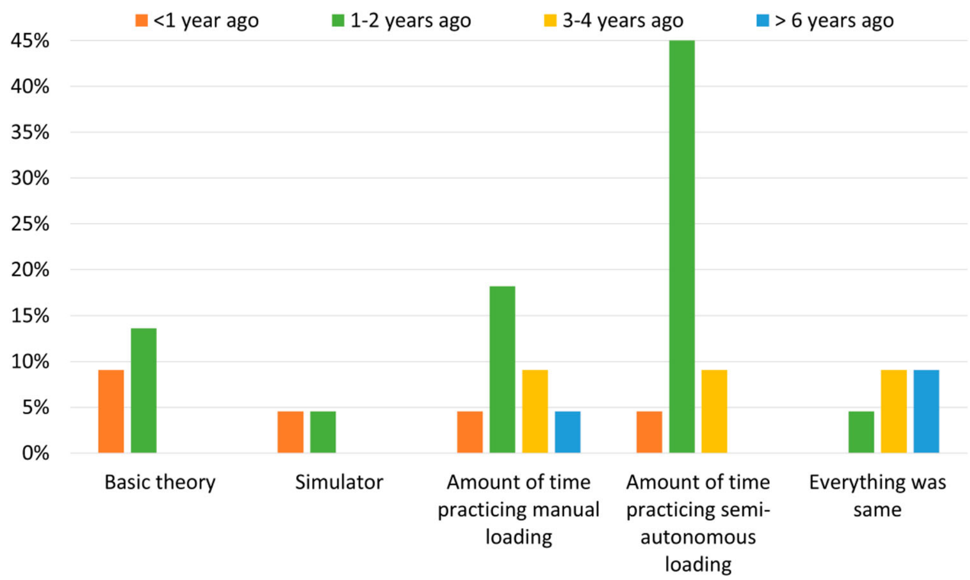

Figure 8. What parts of the training were different for semi-autonomous and manual loading? Images are available in colour online.

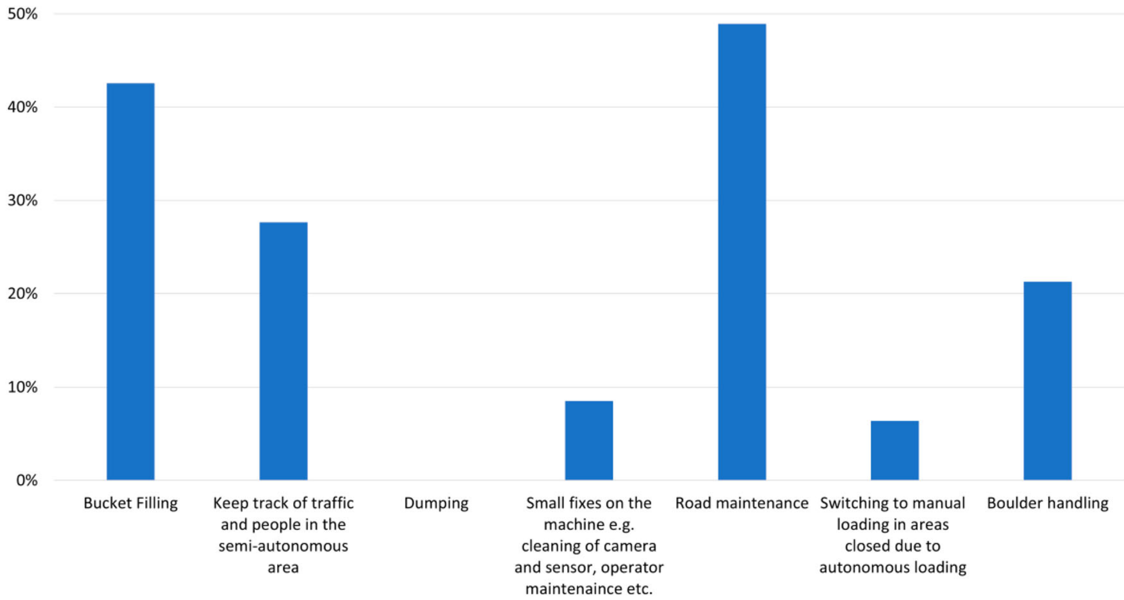

Figure 9. What is difficult to learn with semi-autonomous loading? Images are available in colour online.

boulders difficult to learn. Switching between manual and autonomous loading and handling small fixing on the machine was also dependent on when the training took part.

Training evaluation

Currently, as mentioned above, no traditional evaluation method is used to measure operators' response to the training or performance at the mine. However, the operators' responses suggested that there used to be some form of evaluation: 68% answered there was no evaluation, while 32% responded there were some form of evaluation, i.e. 24% theoretical, 7% practical, and 2% oral tests. Most operators who had some form of evaluation completed their training more than six years ago (Figure 11). In the United States and India, evaluation is mandatory. India has a compulsory examination that includes written, practical, and oral evaluation. Similarly, operators are evaluated and given feedback in training programmes offered by OEMs or commercial simulator companies (Table 3).

Refresher training

The need for retraining upon job rotation has been highlighted (Stothard and Swadling 2010) to retrain and retain knowledge that could be at risk of being

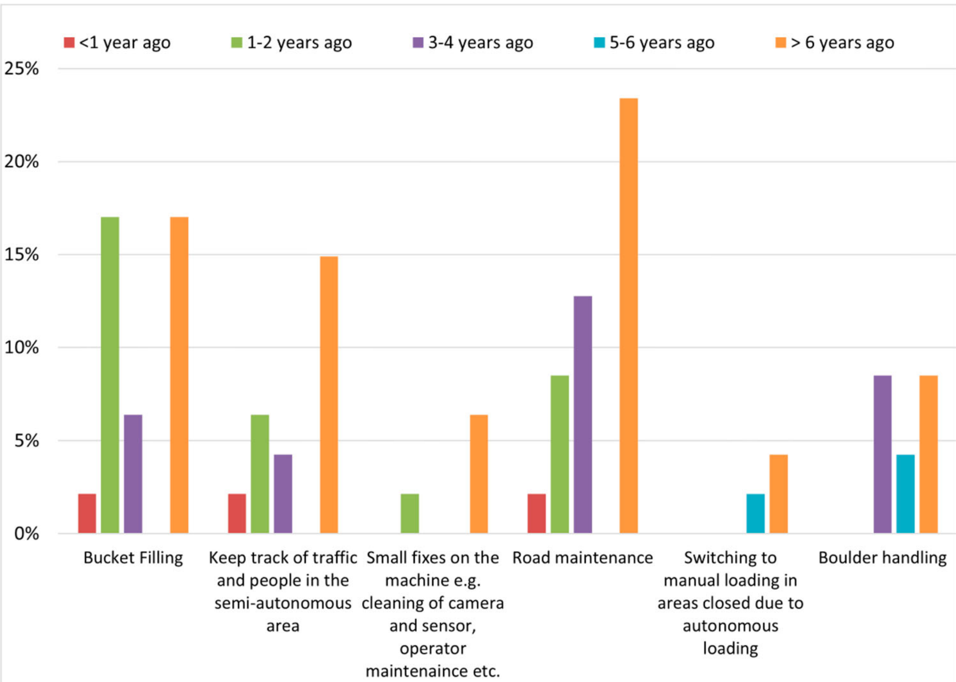

Figure 10. What is difficult to learn about autonomous loading (based on training year)? Images are available in colour online.

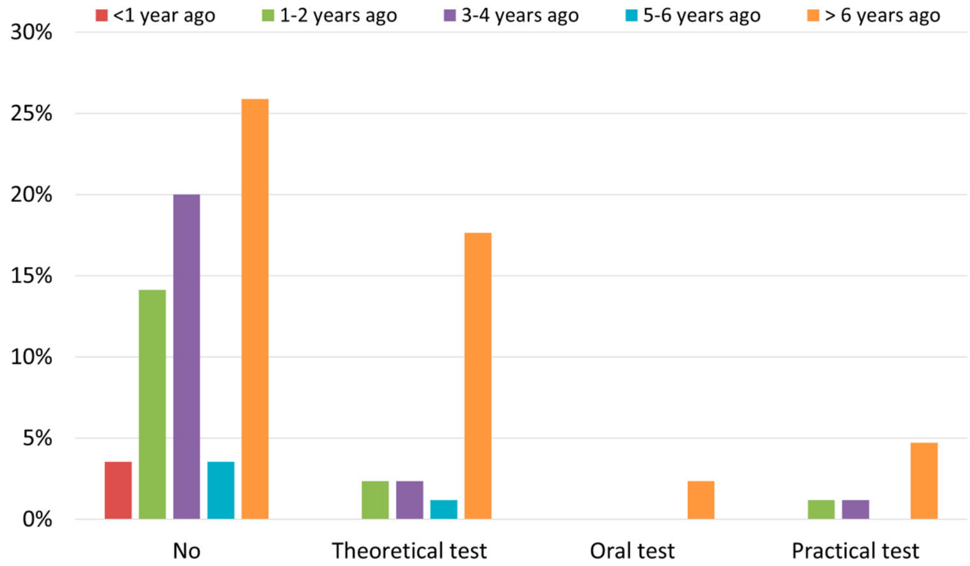

Figure 11. Did you pass an exam when you completed your training? Images are available in colour online.

lost. In the United States, it is mandatory to receive refresher training, and recommendations of a final report on mine health, safety, and prevention in Ontario, Canada, highlight the need for refresher training to ensure operators are up to date with new skills and changing technology (Gritziotis 2022). There is no refresher training in place at the mine, but operators receive additional training whenever new technique, or a new machine is added to the fleet. Survey responses showed that 27% of the operators had received some form of additional training and that 91% of them would like to receive such training.

Operators' perspective

To capture the operators' perspectives on training, both quantitative and qualitative approaches were used. To measure perspective, a 5-point Likert scale was used, where 1 represented 'Strongly agree', 2 'Agree', 3 'Neutral, 4 'Disagree', and 5 'Strongly disagree'. More than 95% responded to statements on the training's organisation, length, class size, duration, etc. The operators strongly agreed they had enough opportunities to learn from experienced operators, and the majority agreed with all statements (see Figure 12). However, some disagreed on whether training was well organised or covered everything needed to load underground. This is highlighted in the open-ended questions discussed later in this section.

A qualitative approach was used to determine whether operators wanted to remove any part of the training (Figure 13). Again, they could choose from multiple options. The response rate was 92%. Most of them (81%) did not want to remove anything, while 6% wanted to remove the theoretical part, and 6% wanted to remove the simulator training. Finally, 4% wanted to remove driving with another person in the cabin.

Similarly, a qualitative approach was used to get operators' perspectives on what is missing in the training and needs to be added. This was an open-ended question, and 49% of the operators responded. The responses were categorised into themes summarised

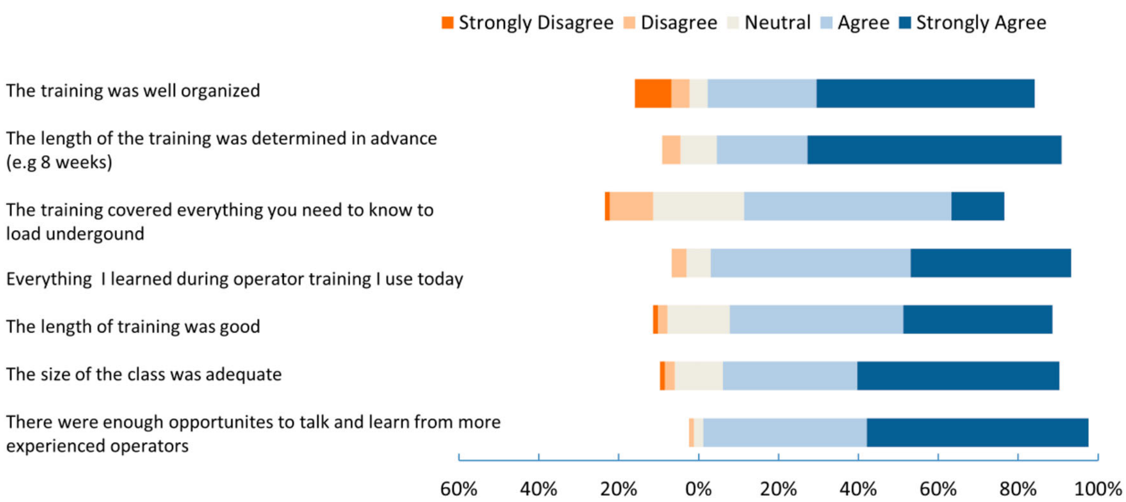

Figure 12. Operators' satisfaction with overall training in general. Images are available in colour online.

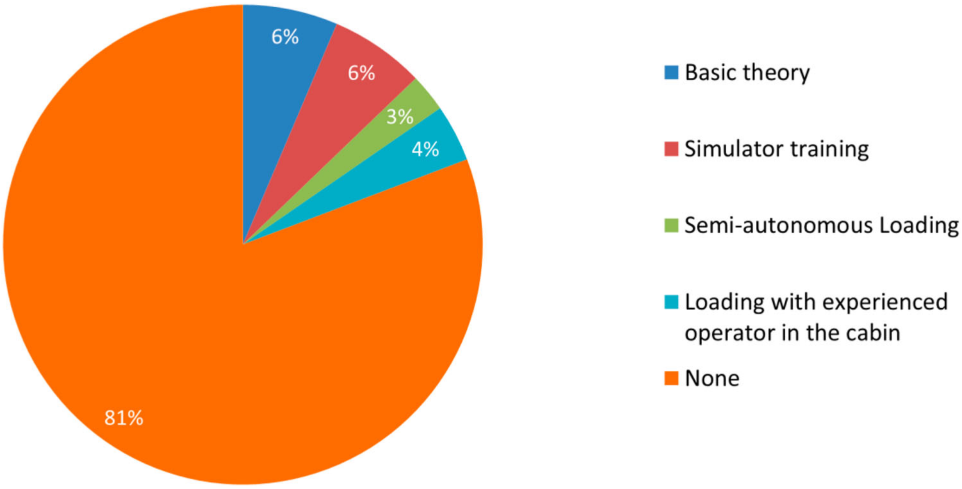

Figure 13. If you had to remove something from the training, what would it be? Images are available in colour online.

in Figure 14. The most frequently mentioned addition to the training was practical loading, with 28% of the respondents asking for more practical loading; 17% suggested adding visits to external departments (sub-processes); 14% wanted to learn more about rock mechanics, and 11% wanted to add truck loading and road maintenance. A bit less than 10% of the operators wanted to add more theory, machine maintenance, software, machine knowledge, scaling, software, geology, documentation, and debriefing tools. There were also comments about adding some form of examination and certification at the end of training.

During the pandemic (2020–2021), operators were not allowed to visit other departments, and this may explain why they wanted to add more visits to the sub-processes in the training programme. Some operators said it is overwhelming to have so much theory at the start of the training and to visit other departments so early on. Therefore, a recommended change is to have a mix of theory and practical training and to postpone visits to external departments to later in the training.

Conclusion

The main findings from this study are as follows.

- The training at LKAB's Kiirunavaara mine is quite comprehensive and focuses on practical training, giving enough learning opportunities for trainees to learn from experienced operators.

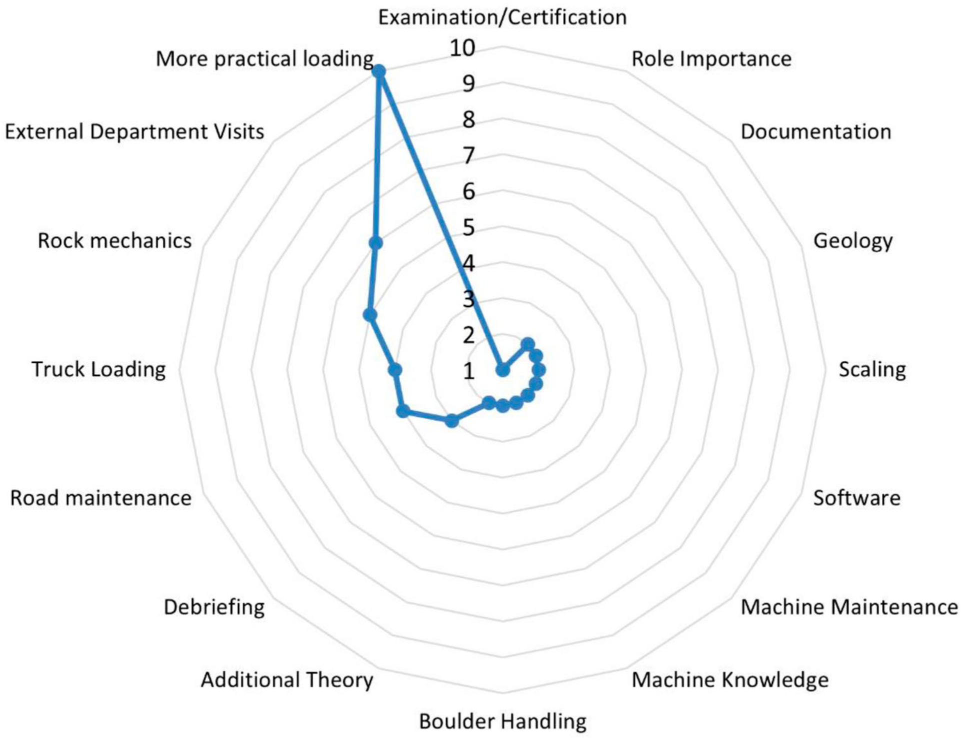

Figure 14. If you could add something to the operators' training that is missing today, what would that be? Images are available in colour online.

- The theoretical part of the training covers a wide subject area but needs better structuring and organisation, as the current module lacks the pedagogical principles required to develop the curriculum.
- The simulator training at the mine lacks integration and needs more efficient utilisation. This highlights that the inclusion of technologies alone is not sufficient for efficient training.
- Similarly, there is no assessment procedure in place except tonnage; it is the only performance-measuring criterion.
- Overall, LHD operators see the training programme as significantly useful and instructive, but they want to add more things to the training, such as road maintenance, truck loading, etc.
- The operators' responses showed that the training programme was affected during COVID, as operators were not able to visit each other.

In summary, the LHD operators' training programme at the mine needs to redefine some of its goals, clarify the learning outcomes, and introduce some form of evaluation and refresher training for its operators. In addition, the simulator training needs to be less generic and more customised to better integrate into the current system. Overall, to keep the training up to date and consistent, the mine needs to bring in more standards and guidelines for its instructors and get continuous feedback from the stakeholders involved in the training programme.

Recommendations

Based on the findings, the following areas are recommended for improvement.

Theoretical part

The theoretical part of the training needs improvement in terms of organising the content based on pedagogical principles. The use of other tools, such as animations, videos, or VR-based modules, could improve this part of the training and make the theory more interesting. The duration of the theoretical part also needs reconsideration. Regulations and courses designed by commercial companies such as Simformation^{TM} from Caterpillar and product skill training from RCT, could serve as references for improvement. Moreover, the content of the training should be revised on a regular basis. It is also recommended that loading strategies and loading control tools such as 'dynamic loading control' is included in the training.

Simulator training

The importance of simulators has been highlighted in recent years. But not all mines are able to integrate these systems into their training programmes (Mendes 2022). Simulators require capital investment, and their efficiency and sustainability will rely on how they are integrated into the existing training system. The simulator training at the mine needs improvement to be better integrated into the training programme. The following recommendations are made:

- The goal of the simulator training needs to be widened; for example, it could be used for evaluation or to practice emergency situations, such as brake failures, engine fires, burst tyres, etc.
- As recommended by Bennet et al. (2010) it is important to design simulator training programmes that minimise cognitive load by presenting information in a clear and concise manner. Using visual aids and interactive features to engage learners, and gradually increasing the complexity of the simulation as learners become more proficient (Zhang et al. 2010).
- The minimum time spent on the simulator should be defined; for example, commercial companies spend around 20–90 hrs on simulator training, excluding the theoretical part.
- Currently, the simulator software uses graphic representing surface operation, it should be upgraded to include more scenarios representing real underground operations, as well as truck loading, boulder handling, etc.
- The simulator training should include modules based on individualised professional development (Bellehumeur and Marquis 2016) focusing on areas identified as difficult by operators, such as bucket filling, road maintenance, loading boulders, etc.
- The training should encourage more collaboration among trainees as it enhances engagement, active learning and transfer of knowledge (Zhang et al. 2010).
- Simulator training should not only be assigned to new operators taking the training. It could involve all operators for refresher training or training specific situations.

Autonomous loading

Semi-autonomous loading with LHD machines is seen as a separate operation in mining regulations and also in the training offered by commercial companies. The focus areas of remote LHD operations are different from those of manual LHD operations. Therefore, the theoretical part of training should contain a separate module covering autonomous loading; not enough content is currently covered in mines LHD operators' training. The survey responses also highlighted that the semi-autonomous LHD operators find some tasks more difficult to learn than others. Therefore, the training programme needs to identify and focus on these tasks.

Training evaluation

Evaluation is considered an important measure of training effectiveness. The effectiveness of the training programme would increase if there were improved instruments to measure the competencies of trainees once they have completed the training (Gritziotis 2022). Some form of evaluation is recommended to assess how well operators have met the learning goals of the training, thus enabling continuous improvement of the training programme.

Refresher training

Regulations in the United States and Canada highlight the need for refresher training. The mine should include refresher training to ensure operators are kept up to date. Refresher training would also increase the confidence and improve the safety of operators who are returning to work after holidays or who are experiencing organisational change.

Debriefing

Debriefing is considered critical for the learning process, both for the individual and the team or group involved (Aronsson et al. 2021). One operator thought that there should be a small theoretical part at the end of the training to reflect on what has been achieved. The mine should consider using more debriefing tools in its training programme to enable reflection on the overall results of training.

Supervisor training

The role of the trainer is crucial for training effectiveness (Bellehumeur and Marquis 2016), and from the instructor's perspective, maintaining and advancing one's pedagogical and subject matter expertise is important (Aronsson et al. 2021). Therefore, the mine should also put some form of standardised training in place for supervisors and mentors. The trainers should be provided with an instructor's guide to standardise the training for all operators. As Aronsson et al. (2021) highlighted, the training programme should not depend on a few individuals to conduct the training. Therefore, it is recommended that senior operators become involved in the training programme.

Continuous improvement

According to Gritziotis (2022), the main challenges to provide high-quality training are maintaining the relevance of training programme material and ensuring training is delivered uniformly across all sites. The mine needs to revise its training content on a regular basis, as the current theoretical part was last revised in 2012. It also needs to critically analyse the training programme and define measurable goals for its continuous improvement.

Operator feedback

An effective training effort should constantly aspire to receive constructive criticism to improve the forms and procedures to achieve its training objectives, including ways of using the same resource (Aronsson et al. 2021). Therefore, the mines training programme should encourage feedback from operators and other stakeholders to improve training and make the programme more effective.

Acknowledgements

The authors acknowledge the financial support from Luossavaara-Kiirunavaara AB (LKAB), Sweden, through the SUM (Sustainable Underground Mining) Academy programme, and the Next Generation Carbon Neutral Pilots for Smart Intelligent Mining Systems (NEXGEN SIMS) funded by the European Union's Horizon 2020 research and innovation programme. The staff and management at the Kiirunavaara mine are also acknowledged, especially all LHD operators and managers who voluntarily participated in the survey and interviews, as well as Robert Larsson and Åke Andersson who gave valuable input and support.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Luossavaara-Kiirunavaara AB (LKAB), Sweden, through the SUM (Sustainable Underground Mining) Academy Programme; Next Generation Carbon Neutral Pilots for Smart Intelligent Mining Systems (NEXGEN SIMS) through the European Union's Horizon 2020 Research and Innovation Programme under agreement number 101003591.

ORCID

Muhammad Tariq http://orcid.org/0000-0002-6133-3357

References

5DT. 2019. Mining simulators [online]. *5DT Technologies*. [accessed 2022 Nov 15]. https://5dt.com/scoops-lhds/.

Aronsson S, Artman H, Brynielsson J, Lindquist S, Ramberg R. 2021. Design of simulator training: a comparative study of Swedish dynamic decision-making training facilities. Cogn Technol Work. 23(1):117–130.

Australian Government. 2022a. *RIIMPO333D - conduct underground load haul dump operations (Release 3)*. training.gov.au. Australia: training.gov.au.

Australian Government. 2022b. *RIIUND307D - conduct tele-remote operations (Release 2)*. training.gov.au. Australia: training.gov.au.

Bell BS, Tannenbaum SI, Kevin Ford J, Noe RA, Kraiger K. 2017. 100 years of training and development research: what we know and where we should go. J Appl Psychol. 102(3):305–323.

Bellehumeur V, Marquis R. 2016. *POUR UNE IMPLANTATION RÉUSSIE DE LA FORMATION PAR SIMULATEUR D'ENGINS MINIERS AU QUÉBEC*. Quebec.

Bennett L, Stothard P, Kehoe J. 2010. SimTecT 2010 : Conference Proceedings : Simulation – Improving Capability and Reducing the Cost of Ownership. In: Leigh Elyssebeth, editor. Simtect 2010. Brisbane, Australia: Simulation Industry Association of Australia.

Bergamo PAdS, Streng ES, de Carvalho MA, Rosenkranz J, Ghorbani Y. 2022. Simulation-based training and learning: A review on technology-enhanced education for the minerals industry. Miner Eng. 175:107272. doi:10.1016/j.mineng.2021.107272.

Branson RK, Rayner GT, Cox JL, Furman JP, King FJ. 1975. *Interservice procedures for instructional systems development. Executive summary and model*. Virginia.

Epiroc. 2022. Scooptram RCS simulator [online]. *Epiroc*. [accessed 2022 Dec 21]. https://www.epiroc.com/sv-se/products/parts-and-services/training-products/simulators/scooptram-rcs-simulator.

Farmer E, van Rooij J, Riemersma J, Jorna P. 2017. Handbook of simulator-based training. England: Routledge Taylor and Francis Group. ISBN 0754611876.

Goldstein IL, Ford JK. 1993. Training in organizations: needs assessment, development, and evaluation. 3rd ed. Belmont (CA): Thomson Brooks/Cole Publishing Co.

Gritziotis G. 2022. *Final report: mining health, safety and prevention review*. Ministry of Labour, Immigration, Training and Skills Development. Toronto.

Gustafson A, Paraszczak J, Tuleau J, Schunnesson H. 2017. Impact of technical and operational factors on effectiveness of automatic load-haul-dump machines. Min Technol. 126(4):185–190.

Gustafson A, Schunnesson H, Galar D. 2011. TPM framework for underground mobile mining equipment: a case study. International Symposium on Mine Planning and Equipment Selection: 12/10/2011–14/10/2011; Almaty.

Immersive Technologies. 2022. Underground loader (LHD) training simulators [online]. Immersive Technologies. [accessed 2022 Dec 31]. https://www.immersivetechnologies.com/products/Underground-Loader-Training-Simulators.htm.

Kirkpatrick DL. 1986. Do training classes change attitudes. Personnel. 63(7):11–15.

Maxwell P. 2002. The evolution of employment, working time and training in the mining industry. Resour Policy. 28(1–2):77–78.

Mendes A. 2022. Simulator training. Personal communication [20 Apr 2022].

MTCU. 2012. U0020 Perform Trackless haulage-operate scoop tram remote control. Ministry of Training, Colleges and Universities Government of Ontario.

Nortje M. 2020. Service launched to analyse training needs, performance [online]. *Mining Weekly*. [accessed 2022 Dec 16]. https://www.miningweekly.com/article/service-launched-to-analyse-training-needs-performance-in-mining-sector-2020-04-22.

NSQF. 2022. *NSQF Qualification File*. National Skill Qualification Framework. India.

NZQA. 2018. 7151 *Operate a load haul dump machine with attachments in an underground operation*. New Zealand Qualification Authority. New Zealand.

Oskouei MA, Awuah-Offei K. 2014. Statistical methods for evaluating the effect of operators on energy efficiency of mining machines. Min Technol. 123(4):175–182.

Oskouei MA, Awuah-Offei K. 2016. A method for data-driven evaluation of operator impact on energy efficiency of digging machines. Energy Effic. 9(1):129–140.

Parker D. 2021. New training centre for diamond mine [online]. *Mining Weekly*. [accessed 2022 Dec 16]. https://www.miningweekly.com/article/service-launched-to-analyse-training-needs-performance-in-mining-sector-2020-04-22.

Patnayak S, Tannant DD, Parsons I, Del Valle V, Wong J. 2008. Operator and dipper tooth influence on electric shovel performance during oil sands mining. Int J Min Reclam Environ. 22(2):120–145.

Ravikanth K, Bahuguna PC, Glaser DC, Shivalkar S. 2018. Study of effectiveness of operator training simulators in the Oil and Gas industry. In: Øi E Lars, Komulainen Tiina, Bye T Robin, Nord O Lars, editors. *The 59th conference on simulation and modelling (SIMS 59)*. Oslo, Norway: Oslo Metropolitan University; p. 79–86.

Rogers WP, Kahraman MM, Drews FA, Powell K, Haight JM, Wang Y, Baxla K, Sobalkar M. 2019. Automation in the mining industry: review of technology, systems, human factors, and political risk. Mining Metall Explor. 36(4):607–631.

Sandvik. 2019. DIGITAL TRAINER LH LOADER SIMULATOR [online]. *Sandvik*. [accessed 2022 Dec 16]. https://www.rocktechnology.sandvik/en/download-center/technical-specifications/underground-loaders-and-trucks/digital-trainer-lh-loader-simulator/.

SAQA. 2018a. *10636-Transfer broken rock by means of a diesel-powered load haul dumper (LHD) in an underground mine*. South African Qualification Authority. South Africa.

SAQA. 2018b. *244467-Transfer broken rock by means of a remote-controlled Load Haul Dumper (LHD) in an underground mine*. South African Qualification Authority. South Africa.

Simscholars. 2022. Underground Load Haul Dump [online]. *Simformation*. [accessed 2022 Dec 16]. https://simscholars.com/courses/lhd/.

Stothard P, Swadling P. 2010. Assessment of maturity of mining industry simulation. Min Technol. 119(2):102–109.

Thoroughtec. 2022. CYBERMINE - underground loader simulators /LHD simulators [online]. *ThoroughTec Simulation (Pty)*. [accessed 2022 Dec 16]. https://www.thoroughtec.com/cybermine-lhd-simulators/.

Wilson MA, Bennett W, Gibson SG, Alliger GM. 2013. *The handbook of work analysis: methods, systems, applications and science of work measurement in organizations*. New York USA: Taylor & Francis.

Zhang S, Stothard PM, Kehoe J. 2010. SimTecT 2010 : Conference Proceedings : Simulation – Improving Capability and Reducing the Cost of Ownership. In: Leigh Elyssebeth, editor. Simtect 2010. Brisbane: Simulation Industry Association of Australia.