Understanding social collaboration between actors and technology in an automated and digitised deep mining environment

M.-A. Sanda, J. Johansson, B. Johansson & L. Abrahamsson

Division of Industrial Work Environment, Centre of Advanced Mining and Metallurgy (CAMM), Department of Business Administration, Technology and Social Sciences, Luleå University of Technology, SE-97187, Luleå, Sweden

Available online: 06 Oct 2011

To cite this article: M.-A. Sanda, J. Johansson, B. Johansson & L. Abrahamsson (2011): Understanding social collaboration between actors and technology in an automated and digitised deep mining environment, Ergonomics, 54:10, 904-916

To link to this article: http://dx.doi.org/10.1080/00140139.2011.606922

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Understanding social collaboration between actors and technology in an automated and digitised deep mining environment

M.-A. Sanda*, J. Johansson, B. Johansson and L. Abrahamsson

Division of Industrial Work Environment, Centre of Advanced Mining and Metallurgy (CAMM), Department of Business Administration, Technology and Social Sciences, Luleå University of Technology, SE-97187 Luleå, Sweden

(Received 7 March 2011; final version received 10 June 2011)

The purpose of this article is to develop knowledge and learning on the best way to automate organisational activities in deep mines that could lead to the creation of harmony between the human, technical and the social system, towards increased productivity. The findings showed that though the introduction of high-level technological tools in the work environment disrupted the social relations developed over time amongst the employees in most situations, the technological tools themselves became substitute social collaborative partners to the employees. It is concluded that, in developing a digitised mining production system, knowledge of the social collaboration between the humans (miners) and the technology they use for their work must be developed. By implication, knowledge of the human’s subject-oriented and object-oriented activities should be considered as an important integral resource for developing a better technological, organisational and human interactive subsystem when designing the intelligent automation and digitisation systems for deep mines.

Statement of Relevance: This study focused on understanding the social collaboration between humans and the technologies they use to work in underground mines. The learning provides an added knowledge in designing technologies and work organisations that could better enhance the human–technology interactive and collaborative system in the automation and digitisation of underground mines.

Keywords: human’s subject-oriented activity; psychosocial environment; social collaboration; automated and digitised deep mine

1. Introduction

There is an ongoing need amongst firms involved in underground mining to explore deeper the earth to exploit the metal ore deposits that abound there. This need has also brought in its wake the desire by these firms to replace significant number of humans (miners) with machines at all levels in the value chain. In working towards the realisation of this desire, a rapid increase of automation and integration of various processes and unit operations must occur to enhance the firm’s economic viability and competitiveness. Nevertheless, there is the notion that increased automation, combined with global competition, will lead large industrial companies to rely on a lean production with smaller multi-skilled workers capable managing multiple areas of the business. Johansson et al. (2010) observed that the use of smaller workforce with expanded role responsibilities could create the risk of losing operational and business knowledge. Abrahamsen et al. (2009) have proposed that future mining will involve lot of automation and digitisation with an increased focus on human work in automated systems compared with the present situation. This proposition has necessitated the need for understanding the psychosocial aspects of human (miners) work and the socio-technical characteristics of the various processes in automated and digitised underground mining to enable the optimisation of the mine’s organisational activity system design. In this regard, new key factors for monitoring the automated and digitised work environment will be needed to enable new goals for the work environment to be formulated for the design of the systems. By implication, there is a need for the creation of new learning that includes generic theoretical knowledge for creating flexibility in the production systems of underground mines on the basis of the work schedules that embraces safety, work motivation and miners’ social requirements. This need, therefore, represents the object of this study. It brings to the fore the importance of studying and understanding the psychosocial characteristics of the human activity

*Corresponding author. Email: mohami@ltu.se
system in the highly automated and digitised underground mining environment. It also raises the issue of how such learning could be used to improve the psychosocial aspect of miners’ activity in the future work design of digitised deep mine production system that could result in increased productivity, improved quality of work life, positive negotiation of tasks and the capturing of tacit knowledge. In this context, and in line with the object of this study outlined above, the human (i.e. miners’) activity is viewed as a representation of a work system that consists of heterogeneous structural elements (Bedny and Karwowski 2007). These structural elements, each of which also contains different units, allow for the use of models to describe the miners’ activities.

In tackling the issue raised above and its corresponding challenges, answers to the following questions were explored in this study. (i) What effect will the automation and digitisation of mine work have on individuals’ object-oriented activity, which entails human physical interaction with technological tools, and mental interaction with communication models? (ii) What effect will the automation and digitisation of mine work have on individuals’ subject-oriented activity, which entails social interaction and collaboration between the human self and communication models? (iii) Does the simultaneous use of technology as a mediating tool in object-oriented activity, and also as a socialising tool in subject-oriented activity, affect the motivation of individuals engage in the activity? (iv) What learning can be derived from the dynamics of automated and digitised deep mine activity that can be used to design a digitised human work environment to enhance productivity, quality of work life, positive negotiation of tasks and the capturing of tacit knowledge.

To provide context in the exploration of answers to the questions outlined above, the notion of object-oriented activity is used to refer to a miner’s activity that entails his/her physical transformation and classification of objects according to the required goal and work criteria in the digitised mine. In other words, the object-oriented activity is performed by a worker using tools on a material object. With the individual having the capacity to change his/her own behaviour or activity according to his/her objective environment, ‘his/her object-oriented activity may also include the transformation of elements of the context within which he/she performs his/her task’ (Bedny and Karwowski 2007, p. 24). The notion of subject-oriented activity is also interpreted as the activity performed by the individuals in accordance with the conscious goals and tasks embedded in their works. In other words, subject-oriented activity (social interaction involving two or more workers) is constituted through information exchange, personal interactions and mutual understanding at the workplace. The worker, as an individual, is viewed as an agent with accumulated historical and social experience who, through his/her acting transforms or changes the object according to the goal of activity, ‘emerges as a subject who reflects transformed reality in his/her consciousness, and based on this reflection regulates his/her activity in relation to others for whom he/she is a persona’ (Bedny and Karwowski 2007, pp. 22–23).

The purpose of this article, therefore, is to develop an understanding of the social collaboration between employees who work in underground mines and the state-of-the-art technologies (automated and digitised tools) that they use in their work. The objective is to develop knowledge and learning on the best way to digitise organisational activities in deep mines that could lead to the creation of harmony between the human, technical and the social system, towards increased productivity. In other words, it is to develop the requisite knowledge in automating and digitising the underground mine work environment that allows for open collaboration between human (miners) activity and technological functions through the use of social networking technologies in the production systems of future mines that could make the optimisation of cross value chain a reality.

1.1. Human work in automated and digitised deep mines

There is a prevailing argument to the effect that a modern mine, by virtue of it being so technically advanced, would experience a significant decrease in its requirement of unskilled human labour (Abrahamsson and Johansson 2006, Bassan et al. 2008, Johansson et al. 2010). The rationale for such significant decrease is that, in the modern mine, the humans might not be required to operate in a difficult work environment, irrespective of whether their work tasks have become simpler or even remained as complex as before. In this regard, Abrahamsson and Johansson (2006) have explained that the aura of job secrets will disappear because of the formalisation and codification of what was once the minersworkers’ tacit knowledge (Polanyi 1967) into automated routines and digitised programs. This modernisation of the mine industry entailed what Johansson et al. (2010) referred to as the contradictory movement of upskilling in which the rapidly changing skill demands more theoretical and comprehensive tasks, and also the contradictory movement of deskilling in which there is a fragmentation of individual craft knowledge and whole tasks.

According to Bassan et al. (2008), the shortage of skills has compelled firms in the mine industry to
increase workers’ productivity by introducing automation and remote operation technologies in their value chain. These technologies included the use of smart mining systems to automate business processes and operational decisions. It also included the improved application of remote and automation technologies to plant and equipment to make work tasks much simpler. Widzyk-Capehart and Duff (2007) viewed the following as important human factor indices that need consideration in the operation of remote and automation technologies: (i) situation awareness, performance and workload, (ii) vigilance, (iii) automation bias, (iv) task automation and operator feedback and (v) operators’ feedback and usability testing. These indices are reflective of the intensive and extensive interaction required between humans and technology in the work environment of a digitised mine. In this regard, human work in the automated and digitised mine environment must incorporate high situational awareness that supports complex emergency situations and also stimulates good performance. As a result, the future work environment of automated and digitised mines will consist of flat organisational structures that are driven by necessity and enabled by technology. This imply the re-orientation of the traditional mine firms into leaner and technology-oriented entities with cross-skilled and technology-assisted workers able to perform two or more traditional job roles. The consequence of this re-orientation is that tasks will be fully automated and digitised with the number of employees (i.e. miners) becoming smaller with less supervisory roles. Therefore, with the automated and digitised mine firms requiring both humans and technologies for the accomplishment of work, it is important that the interrelation between humans and the technology is understood. This is because in the pursuit of organisational activities in an organisation, it is the technology that structures the transactions between human roles (Hendrick and Kleiner 2001) and, by doing so, affects social relations amongst employees.

Social interaction, or subject-oriented interactions, involves two more subjects (employees). Like object-oriented interaction, social interaction begins with a subject’s goal orientation in a situation. Bedny and Karwowski (2007) characterised social interaction to entail an understanding of partners, predictions of their activity, evaluation of partners’ goals, their abilities, past experience, personal features, possible strategies and actions in response to one’s own. Thus, social interactions are constituted by three sets of phenomena. These include the exchange of information, personal interactions and mutual understanding (Bedny and Karwowski 2007). The first phenomenon includes both verbal and non-verbal communication.

The second phenomenon concerns the coordination of actions amongst individuals, role definitions, development social norms, standards and values. The phenomenon subsumes mutual understanding, comprehension of one another’s inner experience, motives, goals and feelings. In general, many aspects of social interaction are distinct from object-oriented activity. Object-oriented activity and subject-oriented activity during job performance interact and continually transform into one another (Bradley 1989, Bedny and Karwowski 2007). Therefore, firms involved in underground mining might need to be provided with new mental images of their work environment based on the new technologies supported by a modern work organisation that supports high productivity as well as good working and social conditions, for example, a work environment in which the mining firms see themselves playing the roles of management coordinators by organising subcontractors to undertake the mining work activity underground, and also relating to equipment producers who sell technological services (such as drill hole metres) instead of physical products (such as drilling jumbos).

1.2. Penetrating the situated and localised nature of practice

Arguing along the lines of Jarzabkowski (2003), workers in underground mines could be viewed as having shared meanings of their local and situated organisational practices which could be understood by finding out how they systematically interpret unique circumstances in their work environment. Hence, to understand human practices in an automated and digitised deep mine, it is important to penetrate the situated and localised nature of such practices in the automated and digitised work environment. The importance of such penetration is underscored by Bradley’s (2002) observation to the effect that sometimes employees hide behind their computer screens (technology) to avoid conflicts or difficult meetings with other persons. This is because in the process of transforming a work practice, the workplace culture and identities are affected which, in turn, also challenge the old behaviours and attitudes of workers.

Johansson et al. (2010) have proposed some lessons which could be used to enhance the penetration of the situated and localised nature of work practices in automated and digitised underground mines. The lessons concerned the need for (i) all control at the workplace being exercised by the group (as an operative unit) and not by the individual, with all employees having control over their own work cycle, (ii) general/generic knowledge being included in
learning at the workplace to enhance the competence development and professional roles of both employers and employees and (ii) broad work roles in which many other work assignments are integrated as additions to work tasks, such as machine maintenance performed by operators. Such broad work roles, according to Johansson et al. (2010), must come along with it the demand for increased flexibility in the production system. The consequence of these lessons is that, in the move towards lean mining production, technology and work will have to be built around autonomation, whereby people and machines cooperate. Thus, firms in the mine industry face a number of psychosocial work environment challenges which must be addressed from the sociotechnical and organisational perspectives (Abrahamsson and Johansson 2008, Sanda et al. 2010). This is because the psychosocial work environment signifies the process that occurs when objective factors in the work environment are reflected in the individual’s perception of work and its underlying conditions (Bradley 2002).

2. Theoretical framework

The evolution of the practice research approach in management literature, as Jarzabskowski (2003) argued, is motivated by the need to understand the gap between the conceptions of what people do, and what people actually do, when they interact with the social and physical features of context in their daily activities or practices. Thus, in studying the automated and digitised mine environment, a guiding theory with a framework to provide a dynamic view of work practices in the mine environment and their role in organisational continuity or change is required. Leontiev (1974) has argued that a theory has value if it is able to shape the object of study and highlight issues that are relevant, and not whether it provides an objective representation of reality. This view has been grounded in several practice researches (Bardram 1998, Barthelmess and Anderson 2002, Halverson 2002, Sanda 2006) amongst many others. Barthelmess and Anderson (2002) have argued that a classification scheme for a theory is only useful to the point that it provides relevant insights about the objects it is applied to. On the basis of this perspective, Halverson (2002) argued that, by taking a pragmatic view of theory, four attributes for evaluating its relevance to a study could be identified. The first attribute is the theory’s descriptive power (i.e. its ability to provide a conceptual framework that could help in making sense of and describing the world). The second attribute is the theory’s rhetorical power (i.e. its ability to help talk about the world by naming important aspects of the conceptual structure and how it maps to the real world). The third attribute is the theory’s inferential power (i.e. its ability to aid in making references). The fourth attribute is the theory’s application (i.e. how it can be applied to the real world for essentially pragmatic reasons).

As Aldrich (2008) said, the theorisation of organisations as activity systems has the tendency to bias thinking towards a concern for processes, many of which are goal directed and boundary maintaining. To alleviate the tendency to bias thinking towards processes in this study, the systemic-structural activity theory (Bedny and Karwowski 2004, 2007) is used as the theoretical framework. In line with the research purpose, this theory has the descriptive, rhetorical, inferential and application powers to enhance the development of knowledge in an automated and digitised mining activity. Arguing along the lines of Halverson (2002), the systemic-structural activity theory (a modern synthesis within activity theory) has the rhetorical power to bring to the fore, conceptual and analytical constructions to facilitate the understanding of the dynamics in an activity system. As Bedny and Karwowski (2007) argued, there is a current trend whereby most of the works within activity theory are restricted to the sociocultural approach to activity study, with the individual-psychological approaches to activity study, which are basic to the study of human work, usually not discussed. The individual-psychological analysis of activity includes the informational (cognitive), the morphological, the functional and the parametrical methods of activity analyses (Bedny et al. 2001). All these methods are considered interdependent in systemic-structural activity theory. They are logically organised into stages and levels of the activity analysis to allow the researcher to tie together the obtained data into a holistic system (Bedny and Karwowski 2007). Bedny and Karwowski (2007) highlighted the need for expressing psychological units of analysis in ways that will permit identification in real work processes. They also suggested the combination of activity descriptions with quantities measures as a way of enhancing the prognosis of the efficiency of the performance. In this regard, ‘the description of activity should be performed in such a way to allow us to make an inference or prediction as to how we can increase the efficiency of performance’ (Bedny and Karwowski 2007, p. 41). Expressing actions, which may be formulated in terms of the object of action, the tools and the subject of an action, as units of analysis satisfy these requirements (Bedny and Karwowski 2007).

The systemic-structural activity theory framework entailed the conceptual application of both organisational activity and macroergonomics, in that it
brings together the cultural-historical and system-structural strands of the activity theory tradition with findings and methods from human factors and cognitive psychology. Bardram (1997) has characterised an activity to consist of several actions with each action also consisting of several operations. This implies that an underground mining activity could be divided into the activity level, the action level and the operation level. In other words, an activity consists of actions (or chains of actions) and the actions also consist of operations (or chains of operations). Actions can be further divided into unconscious operations, the actual nature of which is determined by the concrete conditions under which activity takes place (Bedny and Karwowski 2007). Using this reasoning, ‘the structure of an activity during task performance becomes a logically organized system of motor and mental actions’ (Bedny and Karwowski 2007, p. 41) that is made up of operations, with the ‘operations and actions transforming mutually one into another’ (Blunden 2010, p. 10). An action is, therefore, a discrete element of activity that fulfils an intermediate, conscious goal of the activity and, as such, emerges as the primary unit for the morphological analysis of activity (Bedny and Karwowski 2007). An activity, therefore, determines the specificity interaction of conscious subjects with the external world, and during which the human cognitive mental processes evolve as a result of the external activities of subjects mediated by intersubjective relations (Bedny and Karwowski 2007). Human activity is, therefore, an object-oriented, artefact-mediated and socially formed system in which artificial objects deemed as necessary precondition for the development of internal cognitive processes are created by humans (Bedny and Karwowski 2007).

Macroergonomics is also concerned with human–organisation interface with technology. It is conceptually defined as a top-down socio-technical systems approach to the design of work systems, and the carry-through of the overall work system design to the design of the human–job, human–machine and human–software interfaces (Hendrick 1997, Hendrick and Kleiner 2001). Two primary types or aspects of activity are outlined by the systemic-structural activity theory framework. These are the object-oriented activity (performed by a worker using tools on a material) and the subject-oriented activity (social interaction involving two or more workers constituted through information exchange, personal interactions and mutual understanding). During task performance, the object-oriented and subject-oriented aspects of activity continuously transform into one another. In any analysis of object-oriented activity, intersubjective relationships must always be considered (Bedny and Karwowski 2004, 2007, Sanda 2011). Therefore, the units of analysis, viewed within the Vygotskian perspective, are the unified cognitive and behavioural actions that constitute the respective components of the human object-oriented and subject-oriented activities (Zinchenko 1985, Bedny and Karwowski 2007). These action components of human activity are considered as whole entities and are divided for the purposes of studying their components and the integration of these components into a dynamic whole (Zinchenko 1985). A sense of this theoretical representation as applied in the automated and digitised mine work environment is shown in Figure 1.

The systemic-structural activity theory framework could, therefore, be used to provide dynamic view of human practices in transforming organisations, such as in the automation and digitisation of deep mines. The importance of such dynamic view is projected by Lave and Wenger’s (1991) argument that, in a community of practice, individual thought is essentially social and is developed in interaction with the practical activities of a community through living and participating in its experiences over time. By implication, human practices in an organisation could be viewed as local and situated practices that enhance the creation of work identity. Jarzabkowski (2003) explained that such local and situated practices arise from the daily interactions amongst employees’ themselves and also between employees and their work environments. As such, the individual’s actions and identity formation can be variously affected by the organisational structures and/or the symbols characteristic of the production system in different ways. In this respect, Abrahamsson and Johansson (2008) have explained that the process of work identity creation by employees must involve figuring out the identities to enact and how to enact them. This figuring action can be understood as acts of socialisation and learning, which is part of the process of becoming a full member of an organisation or a community of practice (Wenger 1998, Salminen-Karlsson 2003). In this context, Fenwick (2006) emphasised that a critical element of employees’ identity is formed by their sense of their own knowledge in work and the skills valued by the groups to which they are members. Therefore, the identity aspects of work, together with the more formal structural aspects at the workplace (i.e. technology, organisational structure and qualification demands) and the symbolic aspects of work (i.e. stories, myths, ideas and perceptions of what a ‘real’ worker is like), form four organisational processes that also influence employees’ identity (Acker 2006).
3. Method

3.1. Data collection

Data was gathered at the Renström underground mine in Boliden, Sweden. Cut-and-fill and sub-level stoping are the basic methods used in underground mining. In applications of the cut-and-fill method, the void left by the mined ore is filled with tailings from the concentrator or with natural sand. Sub-level stoping is a large-scale method. The ore is mined using 10- to 20-m-long vertical drill holes and the void after mining is filled with waste rock. Actual mining operations consist of drilling, charging, blasting, scaling and mucking. In addition to miners, other personnel include maintenance crew, machine fitters, electricians and transport and storage personnel. Transport between different levels and the mine stopes is via a ramp, an irregularly twisting path. The ramp can be used for rapid transport of machines, materials and personnel between different stopes on the same level and between different levels and the surface. A reflection of the work environment in which the data was gathered is shown in Figure 2 with the miner inside the safe cabin of a high technology rock-drilling machine.

The source of data in this regard was the miners who were engaged in activities such as rock drilling, roof scaling and bolting using easily operated drilling and scaling/bolting machines. Roof scaling and bolting is one of the most important aspects of mining operations in which the workplace is secured against falling rock from the walls and roof. The activity involves the removal of loosely embedded stones from the walls and roof after which the rock structure is reinforced by grouting with long steel bolts and wires. In some cases, shotcreting is used. As an improvement to the work environment, the use of heavy manual work by the miners in carrying these activities has been reduced by the use of large new automated machines which provide better protection for the miners. In the past several years, the drilling activity was conducted using electrohydraulic machines.

Data was collected through recorded interviews with the miners and also by observing and video recording them as they carry out their activities. In the data collection procedure, four separate visits (shifts) were made to the mine work environment 1.3 km underground in the company of four different mineworkers engaged in rock-drilling as well as roof-bolting activities using the automated drilling and bolting machines. Each visit lasted seven hours which is the work duration for each shift.

3.2. Data analysis

In large firms, such as the deep mines, different phases of organisational activities (i.e. mining) are undertaken
to extract the requisite minerals or other geological materials from underground, i.e. the earth. These activities include the development work and mining. Each of these mining activities entails a series of actions, with each action consisting of several operations undertaken by different persons or groups, and/or mechanisation process, which together constitute a complex collective system (Sanda et al. 2011). For such complex system, techniques for both qualitative and quantitative descriptions of work activity guided by the systemic-structural activity theory have been developed by Bedny and Karwowski (2007). The design-oriented analysis is focused on the interrelationship between the structure and self-regulation of work activity and the configuration of its material components. The systemic-structural activity theory framework is specifically oriented towards the analysis and design of the basic elements of human work activity. These elements include tasks, tools, methods, objects and results, as well as the skills, experiences and abilities of the actors involved in the activity. Thus, in analysing organisational activity, it is important to give consideration to who the actors in the activity are, what their intentions, goals and motives are as well as what type of activity they are involved in. This is because activity analysis highlights how the often unrecognised inconsistencies that develop within activity systems provide major opportunities for review and re-conceptualisation, and how new challenges may trigger new learning (Engeström 2000).

In the activity analysis, person(s) engaged in an activity, what their intentions, goals and motives are and what type of activity they are involved in, are considered important. In this respect, two aspects of the automated and digitised mining activity are analysed. These are the sociocultural aspects and the individual-psychological aspects. The units of analysis (previously discussed in Section 2), viewed within the Vygotskian perspective (Zinchenko 1985, Bedny and Karwowski 2007), are the cognitive and behavioural actions that constitute the components of the miners’ object-oriented and subject-oriented activities. The cognitive and behavioural actions in the object-oriented activity are analysed from the perspective of the individual miner using technological tools in production work (drilling and breaking rocks) to achieve results. The cognitive and behavioural actions in the subject-oriented activity (i.e. social interaction), which involves two or more actors engaged in information exchange, personal interactions and mutual understanding, are analysed from the perspective of the individual miner using technology for production work as social tools to enhance self-engagement with the work environment.

Figure 2. A reflection of the work environment in which the data was gathered with the miner inside the safe cabin of a high technology rock-drilling machine.
4. Results

4.1. Operators’ subject-oriented activity

The subject-oriented activity entailed social collaboration between the operators’ physical activity (i.e. production drilling operations) and mental activity (i.e. the simultaneous observation of the production drilling work and listening to communication models). In this activity, the subject (i.e. the individual operator) was observed to be engaged simultaneously in physical activity through the manipulation of digitised computer technology to programme robotic work tasks, as well as in mental activity by using digitised communication gadgets to listen to background music, receive radio transmission from the mine control centres, and/or from colleagues approaching or leaving areas close to the individual’s activity location inside the deep mine. A representation of the observed workplace interface between the miners and their technological tools is shown in Figure 3.

It is observed that the operators were apparently happy with the communication models they were using in their work environment. They have background music to transcend them into a state of relaxation. They also received information relayed from the mine control centre through portable wireless transmitter handsets, carried by each operator, as a way of keeping them in a state of alertness. For these operators, listening to familiar voices on these communication gadgets provide them with perceptual senses of closeness to other colleagues in distant workstations, even though they, at times, find the continuous flow of such communication irritating. In this regard, there was a sense of these operators socialising with the technologies’ objects with which they work. An example in this case is the use of pen drives loaded with music and connected to the music player fitted in the cabins of the tractors. Operators listened to the music in their tractor cabins whilst they work.

In the mines, you always work alone. You only meet others at lunch. Sometimes two of us work on the main ramp here, but on different sides. So there are consequences when you work down here and you do not have to think so much about it. When it is time for lunch, you go up. When you finish lunch, you are back to work. What I miss down here is the chance to listen to live transmission of my favourite radio station which plays nice music around the time I am working. So I listen to music inside the cabin all the time. I always carry along with me a pen drive loaded with music which I play when working. It is nice to work and listen to your favourite songs.

The interviewees viewed as comforting the listening of music despite the challenge of having to concentrate on their objective tasks and also trying to listen to information transmission from their communication gadgets.

Here in the mines, you cannot have a bad day. You must be sharp all the time. If all of a sudden you feel

Figure 3. Observed human (miner)-technology relationship in the digitised deep mine.
like you are not in a good working mood, you listen to music. The harmonics help to calm you down, and put you in the mood to work hard.

Though such brain activity was perceived by the interviewees as overload, they were able to accommodate it. In this regard, they socialise with a technology-oriented object, as it is shown in Figure 4 with an operator turning on his music device inside the machine cabin in the course of work.

There was the feeling amongst the interviewees that though the provision of new technology has made it easier for operators to work longer hours without the machines needing repairs, it also minimised the level of social interaction that the frequent breakdown of machines used to enhance amongst the operators.

Now let us look at the old machines. You work with them for a couple of hours and they get broken. So you end up repairing them all the time. When you are repairing them, your friends will be there to provide you support. In the course of the repair, you can turn round and discuss ice hockey or share a joke with your friends. Now look at the way it is today. Things have changed with these new and technology machines. Because they do not break down easily, you are always down here working alone. It always makes you feel like this technology change has taken something away from you. Though it was difficult in the old days, you could always turn and see a friend by your side.

According to most of the interviewees, they view the technology for the object-oriented activities as tools for work only and not for play.

I am happy with the work environment. I have also developed enormous knowledge on manipulating the technology to make my work activity easier, but which knowledge I do not share. I socialize with the technology that I use in carrying out my work. This takes away the feeling of working alone down here which is about one kilometre below the earth.

The operators were of the view that their quality of work life will be enhanced if each operator is to have access to an operational car underground. Additionally, operators think the expansion of toilet facilities to get them closer to operators’ working areas will add to their comfort. The possibility of using mobile phones underground is also a welcomed idea to the operators. The operators viewed that the provision of a compartment in the tractor cabins for the storage of drinking water will be a welcomed idea, because this will alleviate the thirst situation that the operators most often encounter because of the heat condition underground. The operators also wished for improvement in the workstation design in the tractor cabins.

4.2. Operators’ object-oriented activity

On the basis of the observations and video recordings of the miners at work, it is found that their individual object-oriented activity consisted of both physical and mental activities. The underlined work observed in this activity included rock-drilling and roof-bolting operations. As it is shown in Figure 5, the object of the operators’ physical activity is production drilling operations. The object of the operators’ mental activity is the simultaneous observation of the production drilling work, and listening to communication models, as it is shown in Figure 6.

The operators viewed that the use of tractor technology with multi-boomers (i.e. robotic arms) for production drilling tasks is excessive for one operator.

Figure 4. An operator turning on his music stereo (digitised device) inside the machine cabin.

Figure 5. Miner engaged in physical activity during production drilling using rock-drilling machine (with 2 boomer) in the digitised deep mine.
to handle. This is because of the difficulty the operator encounters in his/her ability to focus on the computerised programming command for the automated rock drilling using the multi-boomers. This view was supported with the situational fact that, with the existing technology that has two boomers, the operators have to stretch their necks to get clearer view of drilling spots on walls because of view blockage by the metal guards, resulting in the development of neck pains. The operators also engaged in shifting their upper bodies whilst sitting in attempts to widen their view of the operational performances of the two boomers and, in the process, developed musculoskeletal pains in the back. Operators also use lens spectacles to obtain a clearer view of marked spots for either production drilling or bolting. The operators possessed also tacit knowledge developed overtime on various objective activities, but which remained shared. This tacit knowledge is used by the operators to negotiate technology-based standardised task patterns in bids to overcome task repetitiveness and also to increase their productive capacities. The development of the tacit knowledge was to cater for the operators’ observations that the technologies they used in their task undertakings do not always get it right. Operators were of the view that, even in deep mines where robotic loaders, controlled by remote technology from safe distances, are used for loading task, the guide cameras used to manipulate the robots’ movements do not guide the loading operations in the same efficient way as the eyes of the operator when on site. As such, the operators, based on acquired experiences, mostly find ways to guide the technology for optimum performance. In some instances, in the bolting operations, operators negotiate tasks to make them move faster. For example, in a roof-bolting activity, instead of operator following the sequential roof-bolting pattern of firstly drilling a hole, followed by pumping cement in the drilled hole and then inserting bolted rod in the cement-filled hole to complete task, the operator negotiate this pattern by firstly drilling as many holes as possible before pumping cement and the inserting bolted rod in each of the drilled holes. This self-developed task negotiation remained tacit knowledge. The operators were also observed to engage in frequent disembarking from their cabins to load bolted rods on the boomers, and also to wash the cement compartment of the machines.

The technology does not always get it right. Most of the time, I use the experience I have acquired over the years to guide the technology for optimum performance. For example, I have come to realize that by washing the cement compartment in the machine immediately after task completion, I avoid cement caking. I have not been writing down the fascinating and/or intriguing discoveries I have made over the years on the best way to use equipment in carrying out my tasks, but I sometimes share my experiences with colleagues who use the same equipment. I have been imparting some of these knowledge to people I train over here. I explain things to them and hope that they pick it up gradually.

The tacit knowledge developed by the operators and used in task negotiation, aside it not being shared, is also not documented by the operators. Additionally, occurrences and/or experiences associated with the functionalities and/or use of the technologies that are viewed as intriguing by the operators are also not documented by them. Unlike the acquired tacit knowledge which are not shared, these intriguing occurrences and/or experiences are shared with colleagues who use the same technology.

5. Discussion

The results have shown that, in the automated and digitised mine work environment, the principal actor is the individual (operator) employee who simultaneously engages in two types of activities. One activity type is the individual’s engagement with physical task through the manipulation of digitised computer technology to programme robotic work tasks. The other activity type, which occurs simultaneously with the physical task, is the individual’s engagement with cognitive (mental) task through interaction with digitised communication models, such as listening to background music, information transmission from the mine control centres and information transmission from/to colleagues approaching or leaving the individual’s
activity location inside the deep mine. The implication from this result is that the operators’ objective and subjective activities are interdependent and regulated by the operators’ mechanisms of self-regulation. This interrelationship appeared to determine the operators’ physical activities and the successful application of their internal mental activities. As Bedny and Karwowski (2007) noted, this internal mental activity is a system of perceptual and imaginative decision making, and also other mental actions which have been developed through practice and social interaction. This is because of the increased level of technology and the consequent changes to the operator’s role in the technical subsystem and the relationship between the operator and the rock (Johansson et al. 2010). These changes also included changes not only in the operator’s qualifications, knowledge and skills but also in the forms of knowledge and skills they needed for undertaking the work tasks specific to the automated and digitised production processes.

As it was highlighted in the result, the operators make use of generic skills, such as flexibility, technical intelligence, perceptive ability, technical sensibility, a sense of responsibility, trustworthiness and independence (Abrahamsson and Johansson 2006) to enhance the interaction between object-oriented and subject-oriented activities. The result also showed that activity can be initiated by several motives (both conscious and unconscious) with varying priorities assigned to each influencing factor. For the operators, object-oriented activities could be said to be consciously motivated by the technology which had changed the role of the operator in the technical system as well as the relationship between the operator and the rock. Although there has always been direct relationship between the operator and the rock in traditional mining with a manually operating machine between them, the automation and digitisation of the work processes have resulted in the operator to have direct relationship with technology as a result of new types of work techniques which are carried using computers and digital devices. On the other hand, aspects of the operators’ subject-oriented activities could have been unconsciously motivated by the new technology, the new type of work tasks, the better work environment and the changes in qualifications, which together challenged the operators’ old behaviours and attitudes associated with the traditional mining. Arguing along the line of Bedny and Karwowski (2007), the totality of these motives could be viewed as determining the motivation of the operators activities in the deep mine. Motivation, therefore, encompasses more than the traditional study of motives (Sanda 2011). Thus, whenever there is a dynamic change in the work environment, as the work system changes dynamically, ‘it is essential that the actors within the system are able to recognise that a change has taken place, along with the implications for their behaviour and the behaviour of those with whom they are required to interact’ (Jenkins 2011, p. 118).

As it is indicative from the results, the goal of the operators’ object-oriented and subject-oriented activities was a conscious result of the operators’ own individual actions. In this regard, the physical efforts or the energetic component expended by the operators could be said to have been influenced by the motives behind their object-oriented activity. Similarly, the mental or cognitive efforts expended by the operators could be said to have been influenced by the goals that their object-oriented activity aimed to achieve. The importance of this dynamic view is projected by Lave and Wenger’s (1991) argument that, in a community of practice, individual thought is essentially social and is developed in interaction with the practical activities of a community through living and participating in its experiences over time. By implication, human practices in an automated and digitised underground mine could be viewed as local and situated practices that arise from the everyday interactions amongst the employees’ themselves, and also between the employees and their work environments. By virtue of such situatedness, the revolving dynamics of the miner’s identity as well as the miner’s projected sense-of-self and their relatedness to the symbolic aspects of underground mining work (especially, the perceptive description of who a ‘real’ mining worker is) should be understood alongside the technology-oriented structural changes at the underground mining workplace. As Abrahamsson and Johansson (2008) noted, creating work identity involves learning. For example, individuals need to figure out what identities to enact, how to enact them and how others perceive their identity. Individuals’ actions and identity formation at work will tend to be affected by the organisational structures and/or the symbols characteristic of the production system in different ways. This can be understood as both socialisation and learning, that is, as a part of the process of becoming a full member of an organisation or a community of practice (Wenger 1998).

Arguing from the perspectives of Fenwick (2006), the operators’ awareness of their tacit knowledge and utilising it to enhance the goal attainment of their object-oriented activities form a critical element of their identity. As Acker (2006) noted, this critical element, together with the more formal structural aspects of the workplace (i.e. technology, organisational structure and qualification demands), the identity aspects of work, the symbolic aspects of work (i.e. stories, myths, ideas and perceptions of what a ‘real’ worker is like) and relations forms four
organisational processes that also influence employees’ identity. Thus, employees need new mental images of themselves to be able to relate positively to their automated and digitised work environment. On the other hand, the work environment must also have work organisation that enhances employees’ object-oriented and subject-oriented activities, which supports high productivity as well as good working and social conditions. This is because, when technologies are used by employees to accomplish work in organisations, both their object-oriented and subject-oriented activities are influenced by the work system. Hendrick and Kleiner (2001) identified the source of this influence to be the technology which structures transactions between employees’ roles in the organisation and, thereby, affects the social relations amongst them.

The results showed that, in the digitised mine work, communication models could be used as functional tools by the miners for knowledge acquisition, socialisation, control and expression. Arguing along the line of Bradley (2002), technology can give more time for human contacts and, hence, enhance human emotional development if it is used in a proper way. By implication, technology could be used to provide insight into the value of meeting in person, and the importance of listening, trust, emotional support and safety associated with such meeting. But arguing along the lines of Somerville and Abrahamsson (2003), it is also important to understand individual work practices and interactions in the automated and digitised mines. This is because replacing the humans in the automated and digitised mine work would mean losing important organisational skills and knowledge. Thus, the interaction that emerges between the humans and the automated machines they control requires the creation of new human skills and knowledge to ensure productive collaboration. In this regard, skills and knowledge should not be seen as things that are simply static and accumulated by individuals, but rather as things that are created and changed in sociocultural contexts, through individual as well as collective processes.

6. Conclusion
The study has shown the need for understanding not only the socio-technical characteristics of the various processes in the automated and digitised mining but also the psychosocial characteristics of employees towards the optimisation of the mine’s organisational activity system design. In this regard, employees’ object-oriented and subject-oriented activities are identified as key indices whose understanding could be used to formulate new goals for the work environment, and also in designing of the digitised work systems. This, therefore, calls for the introduction of technologies that intelligently capture and transfer employee (miners) implicit knowledge towards increasing situational understanding of the automated and digitised mine.

It is, therefore, concluded that the functional efficiency and effectiveness of human work in the future automated and digitised deep mines could be increased by enhancing social collaboration between the humans (miners) and the technology they use for their work. By implication, understanding the human’s subject-oriented and object-oriented activities should be considered as an important integral resource for developing a better technological, organisational and human interactive subsystem when designing an intelligent automation and digitisation system for the deep mine.

The tacit knowledge of the miners, as it is identified in this study, and which is stored in their memories, is a valuable human-oriented resource that can be captured, nurtured and used in various ways. Presumably, two or more workers can have the same tacit knowledge about a task. Nevertheless, these workers may use such knowledge in different ways or may select different strategies in applying such knowledge in their work activities. These different employee strategies of using same tacit knowledge in their work activities need to be captured in a future research, using the systemic structural activity theory (SSAT) framework which offers the possibility of describing different strategies qualitatively (algorithmically), and the evaluation of performance time and errors, amongst others, leading to the selection of the most efficient strategy. The data to be associated with such efficient strategy (combine components of different strategies associated with employees’ use of same tacit knowledge) can be used for the purpose of improving training, reliability, safety and design, as well as in the evaluation of efficiency of innovations in the digitised deep mining environment.

Acknowledgements
The authors thank the management of Renström mines, Boliden, for their cooperation and also acknowledge the support of the Centre of Advanced Mining and Metallurgy (CAMM), Luleå University of Technology, Sweden.

References


