Another motivation for automation is clean working environment with less health and safety problems. The introduction of remotely managed systems provides direct benefits concerning occupational health and safe-ty since automation allows the same task management of processes physically away from potentially dangerous working places. In addition to health and safety benefits, compensations paid to labors due to accidents and workforce loss are eliminated with minimizing human factor in excavation areas with unmanned autonomous systems.

Reduction in human errors and growth in production quality is another item in automation motivation. Task complexity and stress on personnel for increased performance may cause human errors in production. Sensors and diagnostic tools with programmable monitoring services mounted on automated systems support production with high accuracy as well as minimized maintenance cost and downtime periods. (Entezari 2014)

3.2 Areas for Automation

As Roadheader provide many different functions, it is necessary to automate any single functionality. The challenges lies in the fact that the mining system has to fulfil a lot of different features, like cutting, loading, roof supporting, following a defined alignment or profile and keeping communication to many other under-ground components. A lot of information and many degrees of freedom have to be managed at the same time. The aim for the performance of the new automated system is to reach the operational cutting performance of an average machine operator, but to deliver stable performance without significant overloading of the system. This results in smoother machine loading and consequently in higher system reliability, less downtime and reduced operational costs as well as more comfort for the underground team.

Therefore, the technical improvement and automation of such machines is mainly focusing on the integration of features, which support the operator to make the mining and excavation process safer, more reliable and easier to be handled in order to ensure good and constant operating performance.

Some examples to improve the excavation on Roadheaders are:

- Positioning support

Positioning support to keep the desired orientation of the advance and to follow the predefined tunnel alignment or to keep the angle of inclination or declination for opening up the access tunnel. All these positioning activities are currently done by manual measurements of the mining and surveyor team. The ma-chine operator currently defines the size, position and individual shape of the profile to be cut by means of manual methods. An integrated guidance system that takes care about tunnel direction and shape of profile to be cut is beneficial.

- Automation of the cutting sequence

Currently, when the machine operator is cutting the face, he is controlling all the individual movements of the boom and the complete machine inclusive tracks, stabilizing cylinder, conveying system etc. This gives a lot of flexibility but it requests well skilled and experienced operator. The automation at least of some parts of the complete cutting cycle would provide a more reliable and more user-friendly system.

- Maintenance planner and diagnosis system

Automated and integrated planning and controlling of maintenance activities as well as an automatic check of the conditions of wearing components at such machines would result in an increase of the reliability and reduction of the downtime of the mining system. A diagnosis system would combine existing fault messages in order to find their original roots and causes and would give the machine operator some useful hints and information how to manage and prevent faults. (Kargl et al. 2010)

Most of the automation trends are coming out of the mining industry. However, some of the new technologies could be transferred to tunneling applications as well.

3.3 State-of-the-art Automation

3.3.1 Machine positioning and seam recognition

Before the machine operator is going to cut a face, he needs to define the position and shape of the area to be excavated in relation to the machine's position in order to perform suitable navigation. Therefore, one needs to know the expected layout of the tunnel and the position and orientation of the mining machine in-side the tunnel. The tunnel layout is usually defined by design of the underground construction and, especially in mining, influenced by the level of the mineral seam. To evaluate the exact position and orientation of a mining machine inside the tunnel separate equipment is needed, for instance theodolite-based navigation systems, which are quite commonly used at construction sites. In typical coal mining, such systems are not used for continuous position measurement and so there is much less online information available: typically, a single laser beam, which is positioned by the underground surveyor along the desired tunnel direction, provides information on heading orientation only. Normally there is no online information about the ma-chine position along the tunnel chainage available. Vertical navigation is usually defined by the actual level of the mineral seam in front of the miner rather than predetermined in detail by a planning process. (Kargl et al. 2010)

3.3.2 Roadheader Guidance System

Today's standard technology on Roadheaders include guidance systems, data logging and remote monitoring capabilities for networked machines.
The system is designed to periodically track the actual 3D position and orientation of a road header's cutter head during operation and to visualize this data together with the actual centerline and profile geometry on the on-board monitor of the operator cabin. The core component is a robotic total station serviced by the on-site surveying personnel communicating with the machine's control system.

The main features of the system are:

- Continuous determination of the absolute 3D machine position and orientation in the project coordinate system by automatic geodetic observations from the robotic total station
- Continuous determination of the absolute 3D cutter head position and orientation by means of above data and data of additional on-board sensors (2 inclinometers, 2 angular sensors, boom sensor for boom telescope position)
- 3D visualization of the actual cutter head position and orientation within the designed pro-file geometry and numerical display of all relevant guidance

parameters (station of tunnel face, horizontal and vertical distance from cutter head to profile line, etc.)

- Due to the integration of machine data with geodetic machine position information georeferenced machine data reporting becomes available. This in turn enables the following advanced features:
  - Accurate cut volume reporting
  - Calculation of specific energy requirements
  - Specific pick consumption monitoring (manual input of pick changed necessary)

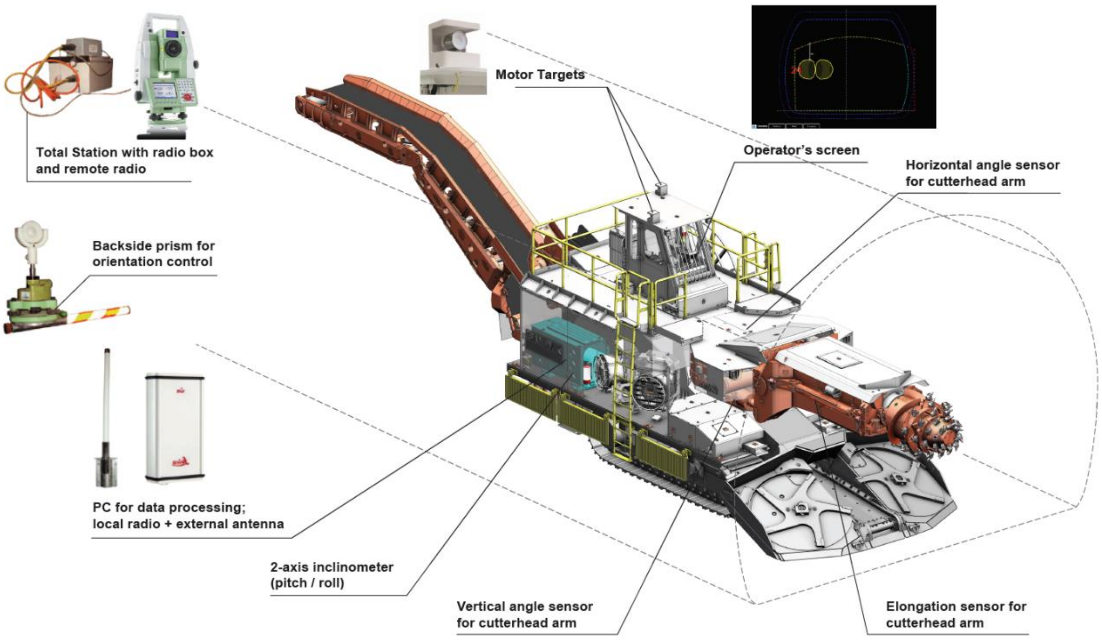

Fig. 1 Layout of Sandvik Geodata Roadheader guidance system

3.3.3 Automatic Cutting Cycle

The development of the automated cutting cycle is a complete new approach aiming to improving the central task of the machine. Similar to the machine concept itself a balance has to be found between several key requirements on the system. On the one hand, a high amount of flexibility is necessary in order to cope with various and often changing boundary conditions such as excavation geometries, rock hardness and support requirements. On the other hand, the ultimate demand of the customer obviously is production and every automated system that targets the core process has to perform at least as well as an averagely skilled ma-chine operator solely on his own hand. Here it has to be pointed out that the aim of such a system has never been to replace the operator. In a similar way that a cruise control of a car is not designed to replace its driver, this system aims at relieving the operator of the normally rather dull task of controlling the individual back and forth movements of the arm but still keep him in control of the governing parameters. Therefore, the machine operator still has the full control and responsibility over the entire machine operation.

One challenge of the design was to minimize this number of governing cutting parameters the operator has to keep track of.

For cutting automation of a Roadheader in principle, three degrees of freedom have to be taken into account: one horizontal, one vertical swing axis and the telescoping boom.

One further aspect has been to introduce a certain kind of learning behavior into the system, by keeping track of and analyzing key feedback parameters, such as the resulting cutter motor current, and thereby optimizing cutting performance for instance by calculating the optimum cutting height for every single cut.

The automatic cutting cycle is handled in the way that the machine operator plans the path by the online visualization component, whereby minimal configuration is necessary and the machine operator can define the cutting parameters if necessary. The planned cutting paths are visually checked by the operator and it is finally transmitted to the PLC system before executed by the equipment.

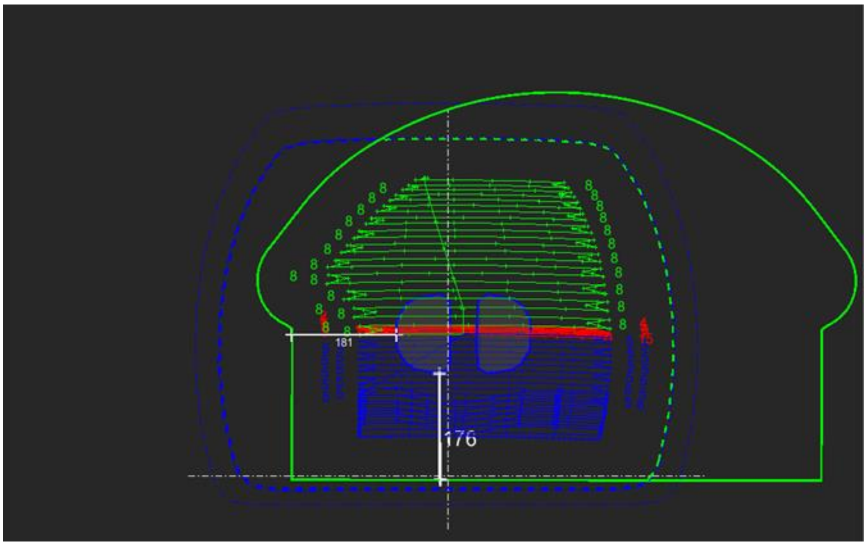

Fig. 2 Automated cutting cycle in large profile

4. TELE-REMOTE TECHNOLOGY

Tele-remote operation is a new way to explore the full potential of automated mechanical cutting equipment while achieving the benefits of increased productivity, safety, and cost-efficiency in mining and tunneling operations. Tele-Remote is the entry-level solution from Sandvik to its industry-leading AutoMine™ offering.

Currently, machines are operated from a cabin or via radio remote control from a nearby position. Operators are exposed to hazards such as dust, noise and to moving equipment in confined space. Furthermore, immediate working area close to unsupported ground. The target of the tele-remote operation is to operate machines from a secured area in a remote position, e.g. from surface. The ultimate aim at the end of the day is, to operate machines completely autonomous

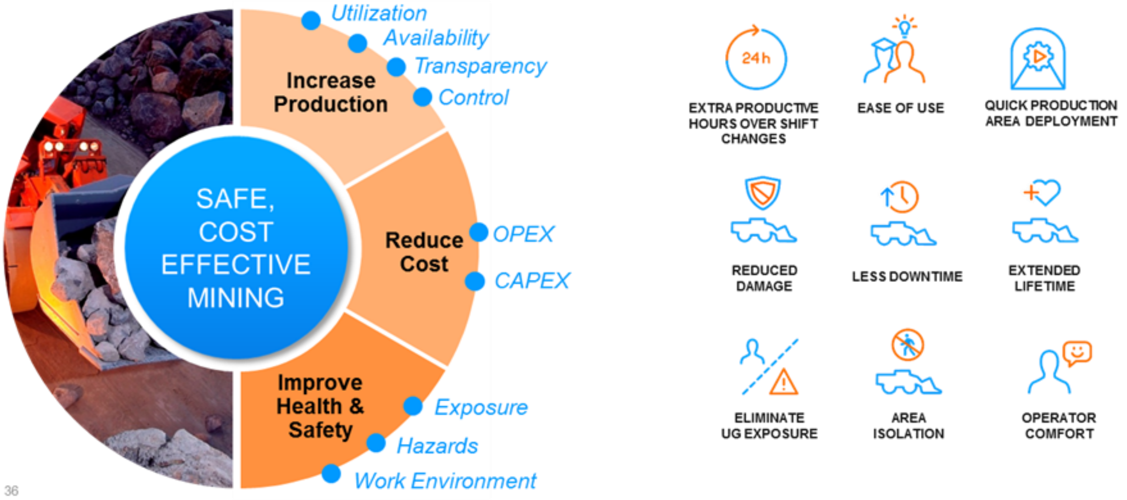

Fig. 3 Value proposition of tele-remote operation

4.1 Guidelines and standards

However, it is necessary to consider certain prerequisites for a tele-remote operation of a Roadheader via a distributed control system (DCS). Standards and guidelines to consider in Europe are the “Machine guideline 2006/42/EG (control system and actuators)” and “Standard for Safety for Machines DIN EN ISO 13849 (ma-chine safety)”. One part or the machine guideline EN13849 is the risk assessment to evaluate the safety risks ensuing from a machine. If a risk is evaluated as too high, design actions need to reduce the risk to an acceptable residual risk.

After the execution of a risk assessment, safety system with according performance levels need to be implemented. In total, five performance levels a, b, c, d and e for safety systems describing the failure probability of a safety component related to the operating hours. (Haubmann 2013)

4.2 Communication and transmission technology

The communication between the operator’s location with the automated and tele-remote controlled machine is an aspect of utmost importance. The communication system layout is structured into a remote operator station with supervisory system functionality, a machine-onboard automation package including an integrated navigation system and control and monitoring capabilities. The installation of access control system barriers at the application area is used for safety isolation. Finally, the communication between remote operator station and machine is essential.

Safety is an important topic in terms of the process data communication, which means, it needs to be determined if the communication line is interrupted. It is clearly defined that any dangerous operating condition must be avoided due to communication related situations.

Thus, it is clear that there are certain functional requirement demands to the field control system. Those requirements are, for example, real-time abilities, reliability, flexibility, high bit rate and finally yet importantly cost efficiency. Such control systems are process field bus (Profibus) or CAN bus (control area network).

A typical communication system is Ethernet or WLAN communication with fast bit rates of 10 to 100 Mbit/s. Also to the Ethernet network, certain requirements like reliability under industrial or even mining or tunneling environment or real-time ability are demanded.

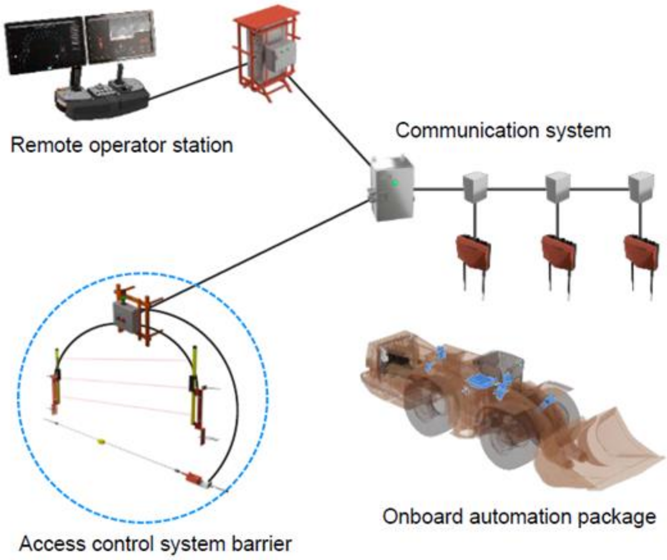

Fig. 4 Communication layout with machine safety concept

4.3 Machine concept

A potential machine concept for a tele-remote controlled Roadheader in a tunneling application requires certain prerequisites, especially safety relevant installations and protective functions defined by any applicable guideline or standard. Additionally, it is necessary to establish a reliable communication network between control station and machine. The most important aspect is to have a safe operation of the mine mitigating any kind of risk for humans and machines.

To have a distinct operation mode it is necessary to implement an “operation-mode-selector-switch” to re-lease the tele-operation modus. On the one hand, maintenance and repairs works can be conducted at the machine; on the other hand, a tele-remote modus can only be achieved with the right position of the mode selector switch.
In the so-called maintenance mode, the machine can be operated by a line-by-sight radio remote control, if necessary. This is already a passive safety mechanism for a safe operation. The operation mode selection is an additional feature to clear danger zone.

Especially, for dangerous equipment like tele-remotely controlled machines, it is appropriate to install additional safety barriers in the danger zones. If a person or another equipment approximates the danger zone, a dangerous movement of the machine must stop. A big challenge is to detect a movement as harmless or potentially dangerous for the operational action. The system needs to decide automatically, if the machine operation must stop or proceed. However, it necessary to have other equipment or machines entering the danger zone for haulage, rock support and other necessary operational activities. This is already an evidence how difficult it is to have an operation automated.

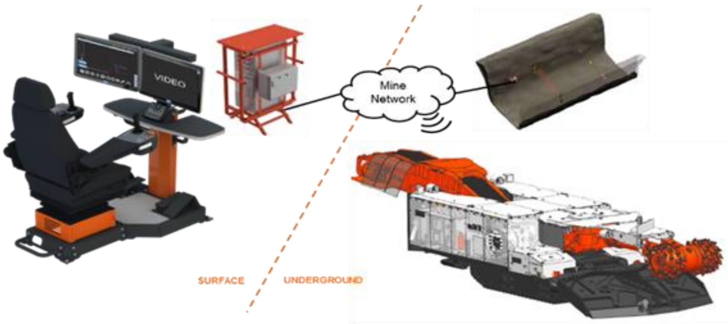

Fig. 5 Machine concept for a tele-remote operation

It is necessary to implement a safety barrier in dangerous operating areas. There are few different technologies for safety barriers like contactless safety concepts. It is necessary to not exceed the required distances between the sensors defining a working area. The concept design with minimum distances of contactless sensors is to protect humans against risky approximation to a danger zone. Potential threats like, crushing, cutting, shearing, collision, puncture hazard etc. are considered according to international standards. (Gräf 2003)

The protection of danger zones can be established also with emergency stops. However, an emergency stop is not a substitute to safety design requirements of the machine and an emergency stop is not allowed to cause another unsafe condition during activation. When activated a machine must stop and an independent restart must be avoided. Those emergency stops must be marked with right colors on a Roadheader. (Gräf 2003)

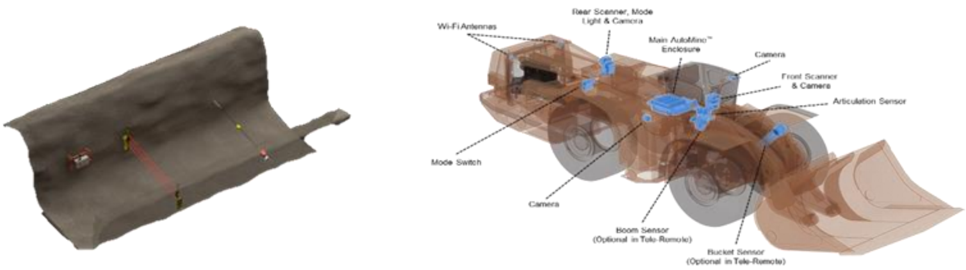

Fig. 6 Safety barriers and machine sensor for tele-remote operation of a loader

Laser scanner are some other contactless safety barriers applied in tunneling and mining applications. This optical control system is scanning relevant danger zones. If an external individual or a machine not allocated to the operating area enters, the tele-remotely controlled machine must stop. A big advantage of the scanner is the potential to define three different ranges – measurement field, warning field and safety field. This gives the opportunity of a pre-warning before a deactivation takes place. (Gräf 2003)

Light barrier and light grids are the next level of safety barriers. Those safety systems must be installed neither in the way that it is not possible to bypass them laterally nor underneath. Those systems must avoid the stay between safety field and danger zone. (Haubmann 2013)

5. CONCLUSIONS

Considering today's developments in automation, it can be stated that a tele-remote and semi-automated operation of a tunneling machinery is possible. Automated equipment is already state-of-the art technology and applied in many applications. The safety concept, which needs to be implemented into the machine control system, is essential for securing the operational areas and to protect miners from hazards arising from machine operations. At any time, no harm to humans and to machines are acceptable. Corresponding monitoring and emergency stop mechanisms must be implemented in the conceptual design. A reliable data connection together with a safe data protocol between machine and control station is very important.

Such a tele-remote operation protect miners as they control equipment from remote and safe places without hazardous and tough working conditions like dust, heat, noise, vibration humidity, etc. The ergonomic situation of the operator is another advantage of the tele-remote operation.

As personal is present only during maintenance and repair works at the dangerous underground location, the risk for geological and machine related hazards is minimized. The huge advantage of an autonomous machine application is in achieving much higher performances by eliminating the human influence on the operation. Furthermore, a new level of accuracy in tunneling with nearly no overprofile can be achieve which helps to save costs for, e.g. shotcrete. The lifetime of components will be increased due to the optimized utilization of the Roadheader.

Due to the technical implementation of tele-remote controlled Roadheaders, future mining and tunneling applications will be further optimized. A big advantage will be that from one control station several ma-chines can be controlled and operated. This will increase productivity, decrease the risk for injuries and counterbalance the lack of well-trained miners in mining and tunneling industry. However, today's technology is heading towards autonomous equipment working in underground applications with the ultimate goal to fully automate the complete mining process.

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