Industrie 4.0 – The Industrial Internet of Things Hidden Champion

Highly automated Systems in Underground Mining Operations

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Apart from classical fields of application associated with the name Industrie 4.0 (Industrial Internet of Things) such as production and mobility, underground mining is increasingly developing into a hidden champion in this respect. Spurred on by falling prices for raw materials tied to ever increasing demands on humanisation of work the branch soon resorted to approaches to solutions described under "Industrie 4.0". Fully integrated systems with "part-automated machines, which move through environments without human guidance and make their own decisions, are already reality in mining nowadays. The industry has already succeeded in applying "Mining 4.0".

Mining • Supply industry • Internet of things • Mining 4.0 • Innovation • Shearer loader • Rail haulage

This report presents two examples of applications by the Eickhoff Group from different sectors of the mining process chain: longwall mining by the cutting winning method as well as haulage by rail in ore mining. The Eickhoff Group has been one of the technological leaders in the further development of mechanised mining thanks to its innovative methods tailored to the customer. In this connection, automation of the group's own products beyond the machine limits actually forms a focal point for its current research and development activities.

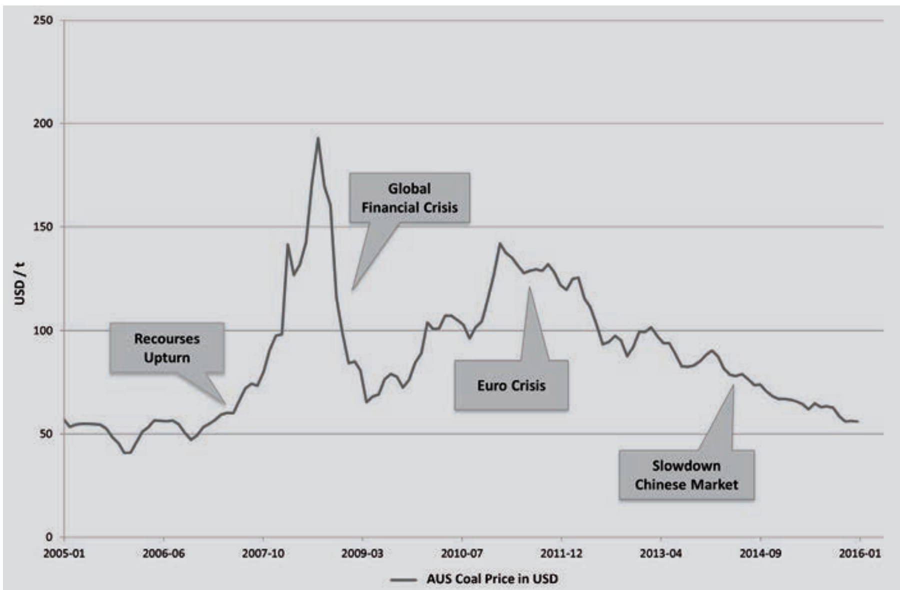
Market Expectations and Challenges

Optimisation of the mining process represents the key to economically successful mining: the costs per tonne of mined valuable mineral largely depend on the performance and the costs of the equipment used, quite apart from its availability and the amount of resources applied in terms of energy and manpower. Should these factors be optimised this is directly reflected in the production costs per tonne of valuable mineral; an increase in operating point concentration thanks to a more efficient production chain reduces the costs for the underground infrastructure. Requirements relating to quality control and productivity along with automation resulting from this motivation continue to grow. Mechanical engineering calls for constant further development; the utilisation of innovative technologies becomes ever more important.

The ever growing awareness of safety standards causes further major aspects of research and development activities – the Australian market deserves mention here. The warding off and prevention of acute potential dangers as well as avoiding substantial impacts on manpower and the environment are becoming of ever increasing significance in mining throughout the world. Efficient solutions are expected from equipment suppliers in order to prevent occupational diseases and to protect man and machine in holistic terms. Thus for example the legal emission standards are hard to reach in combatting dust in spite of all the research efforts and progress achieved and silicosis has still not been conquered.

At the same time, the industry currently has a number of other challenges to contend with. Following the general fall in prices on the raw materials market (**Fig. 1**) mining companies are pursuing the strategy of increasing productivity without further increasing investment costs. This exerts a direct effect on machine manufacturers and suppliers. Recent predictions indicate that this trend will continue in the short to medium term. Ever growing competition and market pressure promote increasing production rates while at the same

Fig. 1: Development of the coal price
Source: index mundi



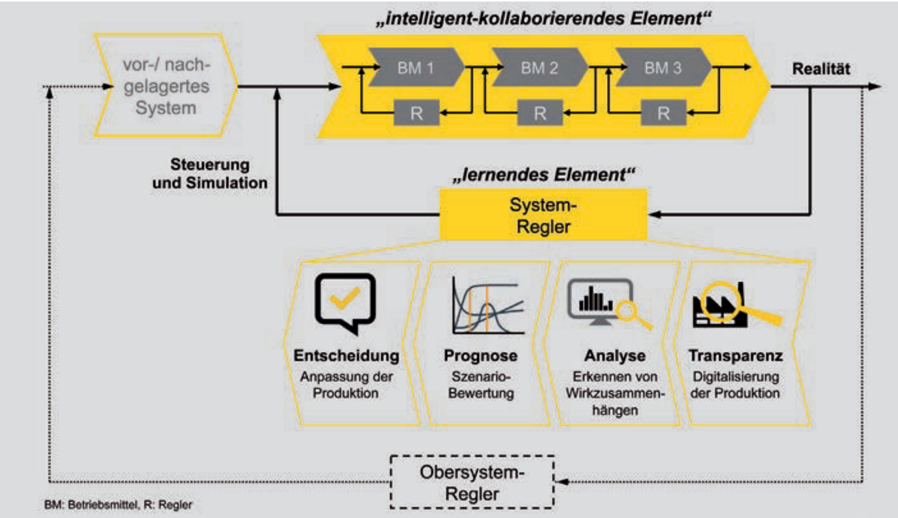


Fig. 2: Mining 4.0 – basic understanding of the interrelationships and objectives

time the haulage costs per tonne are minimized. This objective is not easy to accomplish in view of the ever more complex extraction of available resources and the related working conditions.

Consequences for Suppliers

How can suppliers react to market expectations? In the near future, there will be no essential changes in the technical processes in mining: the valuable mineral will usually be recovered underground from the rock face at places in the world, which are unfavourable in infrastructural terms, mined as selectively as possible so that worthless wall rock is eliminated from further processing. The broken material is loaded at the point of recovery and hauled to the surface, where it is prepared at great cost to obtain a marketable product. The greatest potential for innovations can be ascribed to the information technology sector within this technology chain. The fields of sensorics, data analysis and the development of continuous communication systems afford numerous opportunities for innovative, substantial improvements.

New technologies and a holistic approach can enhance productivity and flexibility in a sustainable manner and place the topic of automation at a new level. The vision of the unmanned hard coal mining operation (longwall) in which man concentrates on aid and monitoring functions from a safe master display represents an important target in this connection. Continuous technical advancement of production facilities and the implementation of innovative technologies combined with the concentration of data have already led to a high degree of automation and control.

Mining 4.0

This transformation of the (sub-)systems used underground – extraction, loading and haulage – summed up under the concept of Mining 4.0 – is aimed at mastering complexity. New Information Communications Technology (ICT) will influence the operational performance rate in existing structures – by avoiding non-productive times and increasing output. The approaches being pursued, initially present an extremely heterogeneous picture. The control circuit principle is suited for structuring these approaches and clarifying interrelationships (**Fig. 2**):

The controlled system in this case is formed by the direct and indirect processes within the sub-systems along the mining process chain (extraction, loading, haulage). The cutting extraction method in longwall mining represents one sub-system for instance. The shearer loader, means of conveyance and support are integrated in this case. Haulage by rail comprising the processes loading, transport and unloading represents a system that can be optimised. By making use of the increasing opportunities afforded by information and communication technology as well as networking, it is possible to optimise collaboration within this controlled system. It can also be regarded as an "intelligent collaborative" element of a future Mining 4.0 infrastructure. The objective is to increase flexibility and efficiency in existing models.

The controller on the other hand has the task of influencing or rather altering these existing models. He can thus be seen as the "learning" element of a future Mining 4.0 infrastructure. He causes the revolutionary character of Industrie 4.0 to appear. After all, the regulating of sub-systems in mining is only made possible by the consistent horizontal and vertical networking of people, machinery, objects and ICT systems. The output parameters (data) of the controlled system, in other words the core processes extraction, loading and haulage, form the starting point. The basic prerequisite for controlling is in this case digitalization. The creation of transparency, i.e. making these data available and the possibility of processing them further are defining for the "learning process". Subsequently it is then possible to identify interrelationships at further stages, whose modelling for its part permits prognoses, on the basis of which decisions can be made. The contentual sequence of transparency, analysis, prognosis and decision in this case corresponds to the chronological process in implementing these "learning" structures in the sub-systems. In this connection, this logic is not simply confined to the given sub-systems; it can also be expanded to the complete mining process chain.

Mining 4.0 in Longwalling

The key to an "intelligent-collaborative" infrastructure is to be found in networking the mining machine's sensor technology and the totality of all the face components involved. In this connection, a high degree of coordination and comprehension in dealing with special data is essential; the change of technology in mining normally takes a relatively long time. The reasons for this are high financial risks should the performance even fail marginally due to unexpected effects while changing the system. High demands on approving new technologies for underground use as well as

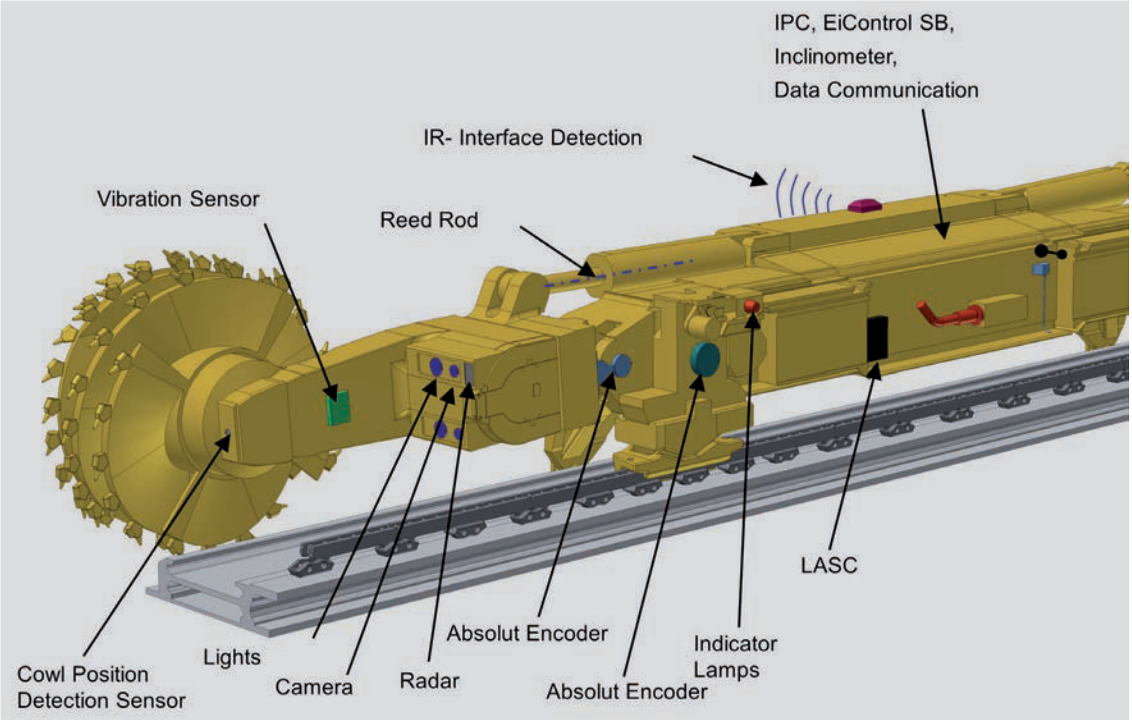


Fig. 3: Sensorics and shearer loader

the constantly changing environmental conditions and the need to succeed in practice make more difficult the establishment of automation systems, which are already state-of-the-art in other branches of industry.

Since the Eickhoff shearer loader was introduced in 1954, the company has implemented a series of technically significant further developments such as e.g. radio remote control in 1966, industrial PCs (IPC) in 2001, the EiControl control concept in 2005, the EiControlPlus with extended sensor technology in 2007 and finally the parameterized control system EiControl SB in 2008. Since 2010, the further development of the shearer loader has increasingly focused on a mechatronical discipline in which mechanical engineering, electrical engineering and software are intermeshed with each other. This is first and foremost in evidence from the increasing proportion of sensors and software involved in the machines as well as a future-oriented data and communication structure [1].

Nowadays the shearer loader is fitted with numerous sensors, which redundantly take over various tasks and ideally pursue a different functioning principle (**Fig. 3**). Sensors to determine relative and absolute positions as well as for navigation supply for example a detailed presentation of the longwall profile. In conjunction with highly complex control algorithmics this permits the extraction process to be steered accurately to within a few millimetres. Further sensors for identifying the geological environment improve accuracy for mining and adhering to the field limits when cutting. Sensors for assessing the geometric environment identify potential sources of danger in advance and prevent the machine colliding with the support for example. Sensors that determine the mechanical status and performance register and evaluate the external and internal environment of the machines. The sensor technology is rounded off by a diagnosis system to identify errors quickly and make maintenance straightforward. Data and historical events allow to derive status-oriented servicing plans. The shearer loader is furthermore in the position to carry out its own diagnoses of its status and workload as well as plausibility tests.

Video monitoring systems enable the roadway to be monitored and remote controlled. Further graphic digital displays afford access to sensors, acoustic transducers and input units. The flow of communication between man and machine is substantially improved as a consequence. The further development of sensor technology plays an outstanding role in this respect for the more autonomous the technical application is, the more information it requires about its physical environment and about itself. It represents "the key for all efforts to design machines and systems autonomously". Sensor components that are already integrated for registering the environment are refined by a real-time capable processing logic circuit and increasing built-in intelligence. These optimised systems are in the position to work almost faultlessly in the most dynamic and extreme underground conditions, to adapt autonomously to the environment they are deployed in and take over self-controlling functions (**Fig. 4**) [1, 2].

Example: The Shearer Loader at the Centre of Mining 4.0

If one examines the complete longwall system then the shearer loader represents the central, collaborating ele-

Fig. 4: Environment detection systems on the shearer loader

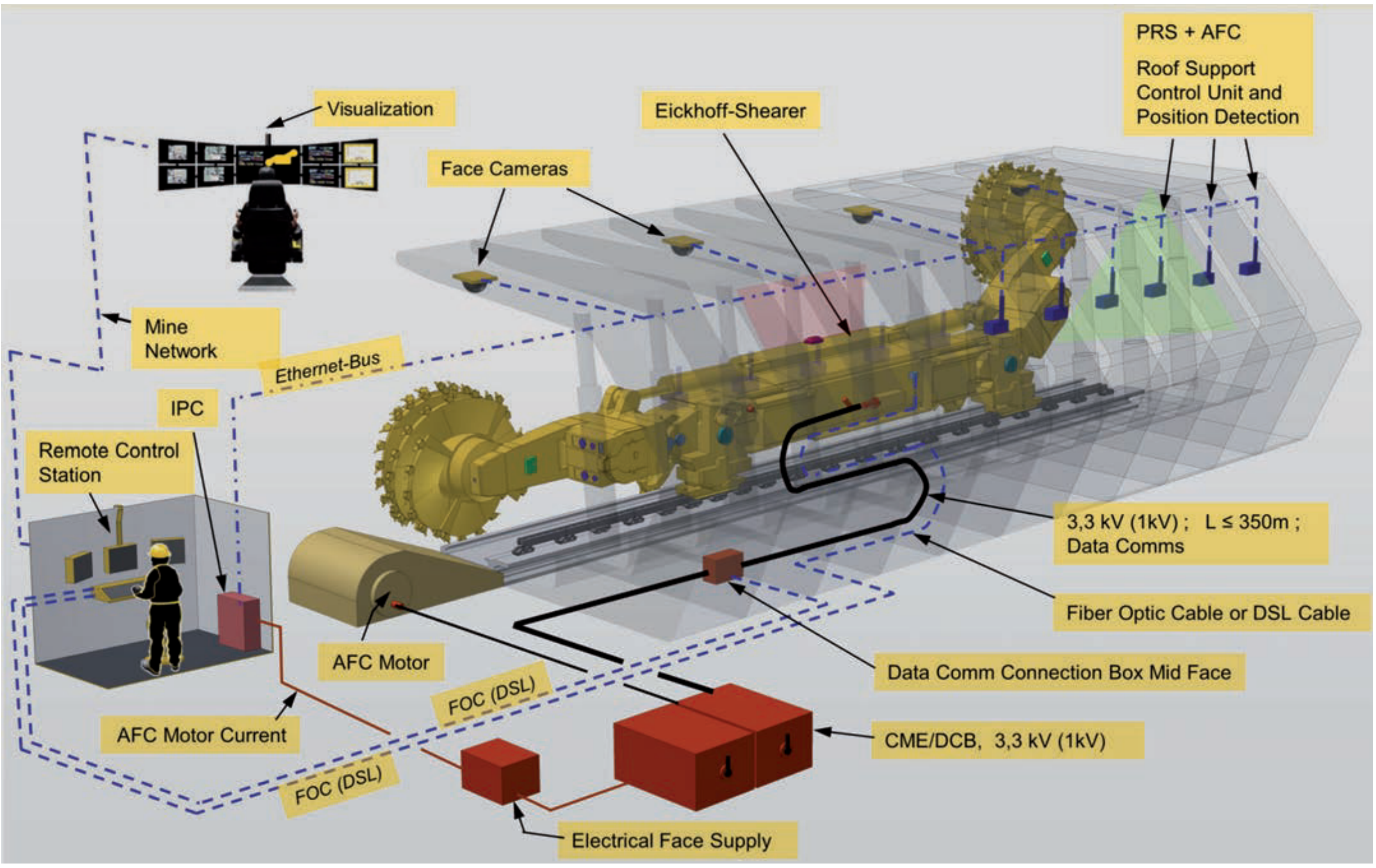


Fig. 5: The shearer loader as a central element in the longwall

ment. It continuously communicates with the support and haulage systems (**Fig. 5**). Information such as haulage load, location of the shearer loader, active identification of collision hazards and other application and process data are exchanged and sent to the control station and to the control centre on the surface. After the shearer loader has passed through, the shields are set by fully automatic means and the conveyance system advances. The conveyor drives and the chain tensioning device are controlled after determining the conveyance system load and the load situation affecting the drives. Should irregularities in the process be observed – as for instance a support that has been too deeply set – the situation is evaluated and corresponding measures resorted to. For example, the shearer loader is stopped by a warning signal and the maintenance crew underground and on the surface informed.

In this case this hinges on efficient and reliable communication systems. The systems currently applied in mining comply with all established industrial standards. They are designed redundantly, can be connected with power lines or are also based on DSL, light wave conductors (LWC) or WLAN. Internally the shearer loader is interconnected by a bus system, which includes the sensor technology. Internal communication, with the control station and the control centre is executed via Ethernet. Towards this end, various protocols for transferring data are used. All signals are sent either completely fail-safe or encapsulated.

The State-Based Automatic EiControl SB controls the process. It represents the core of the shearer loader control system and divides the cutting process methodically into different, independent steps. The so-called states are clearly defined and form a closed cycle. The predefined process can, however, be changed as desired by the user, expanded and thus adapted to extreme requirements at any time. The sequential processing of the desired values on the status table depends on the ongoing process: the machine reacts automatically and as required to changing conditions. The machine operator can for his part supervise, correct and alter the process either on-the-spot or from a distant control centre.

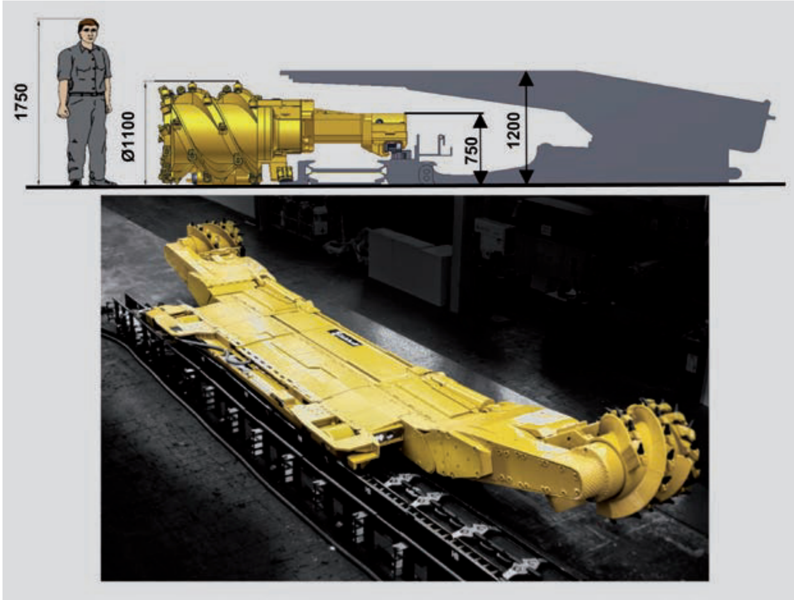
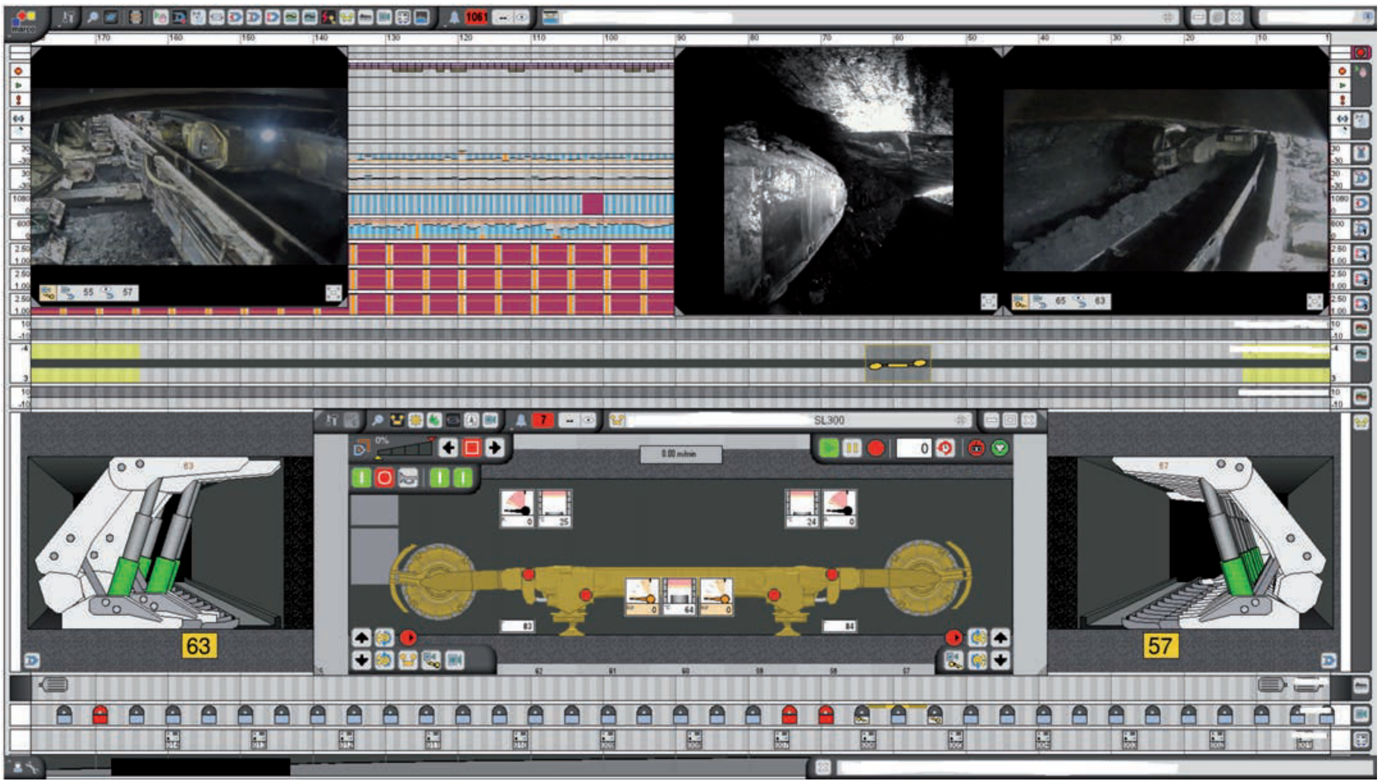


Fig. 6: Compact shearer loader SL 300L – face thickness 1.2 - 1.8 m

More Possibilities: from Remote Control to Full Automation

The withdrawal of the labour force from the danger zone is a main advantage of increasing automation. Furthermore, deposits can be exploited more efficiently – particularly in very thin seams of up to 1.2 m, as no minimum extraction height is necessary for the longwall crew so that considerably less wall rock is pro-

Fig. 7: Integrated face control Type MARCO with Eickhoff shearer loader



duced. This can only be accomplished by means of full automation and/or remote control involving all the sub-systems (**Fig. 6**).

The operator can for his part control and monitor the entire process from the control centre with the help of face cameras, sensors and positioning software. The control station is linked to the shearer loader via TCP/IP protocols, which are transferred via redundant powerline modem and fibre glass connections. The functions are carried out by joystick, handheld controller or semi-automated means via temporary manual intervention. In the latter case only corrections involving a minimum amount of intervention are undertaken. These aspects were consistently applied by Eickhoff when developing the new compact shearer loader SL300L (**Fig. 7**).

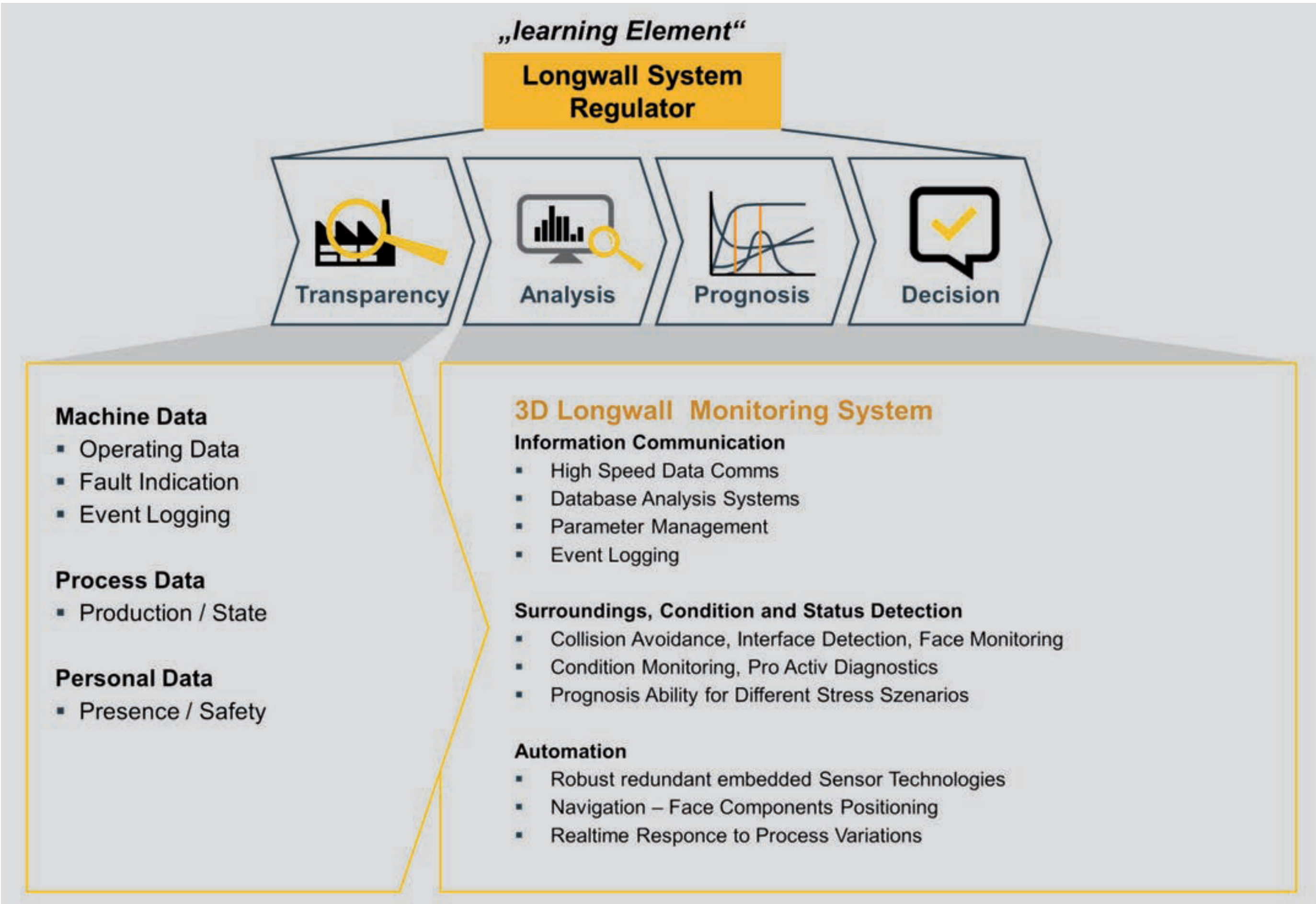
The next level is the complete networking of all sub-systems involved. All face elements have to be further developed in this direction for full automation. The creation of interdisciplinary transparency represents the prerequisite for further analyses, the derivation of prognoses and options for resultant decisions. After all, systems that support decision-making can only be effectively applied after thorough registration and provision of all relevant data.

Intelligent mining thus implements information technology throughout the entire chain: from exploring the deposit, geological modelling, planning and executing the mining operations right up to the infrastructural functional areas accompanying extraction as for example transport and logistics. By means of Mining 4.0 and innovative communication technologies it is possible to progress from remote control to complete autonomous operation. Shearer loader, support system, haulage, crusher and conveyor belt system are integrated in a superordinated 3D face control system. In this way, all relevant data are obtained and made generally available.

In this connection, the challenge is evaluating big data. Millions of sensor data must be analysed and interpreted. Highly efficient analytical systems make big data transparent in the process: they recognize interrelationships and facilitate proactive communication of all sub-systems (**Fig. 8**).

Permanent availability, analysis and correlation of all personal, machine and process data represent the basis of Mining 4.0. Continuous event logging in this case enables maximum well-founded fault diagnoses. The system enhances the capacity to predict and permits reactions and process deviations in real time. In addition, extensive parameter management provides the system with the necessary flexibility. It enables the implementation of further system elements that extend the functions – as for instance, environment and status evaluation systems.

Fig. 8: Method of functioning of the face controller



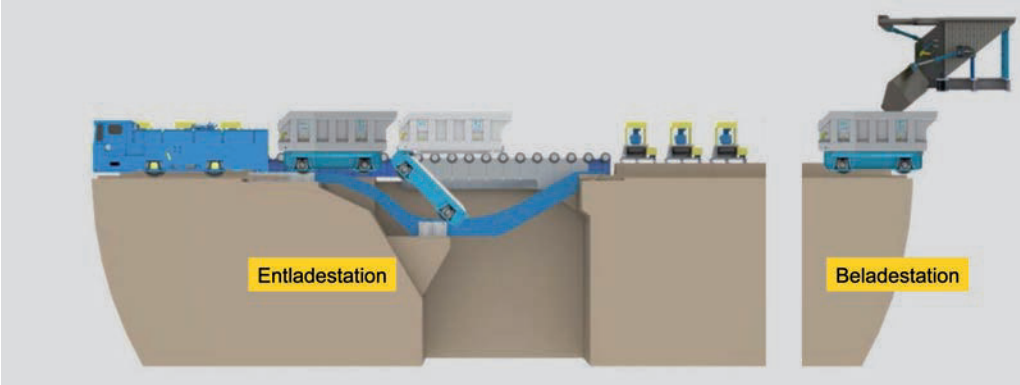


Fig. 9: Collaboration in train haulage system

The 3D face control system, which operates at various hierarchical and communication levels, provides control instructions for all face elements involved. In this connection, the greatest possible autarchy and redundancy – from sensor technology right up to the totality of the local sub-systems cater for maximum operating safety of the system.

Mining 4.0 for Haulage by Train

A further example from the Eickhoff Group is haulage by train underground as performed in hard rock mining by the Schalker Eisenhütte that belongs to the group. In this case, mainly horizontal transport is concerned in conjunction with the block caving and sub-level caving mining methods: in this case the material is transferred by loaders (LHDs) on the extraction level into ore passes, at the lower ends of which, the haulage level, the locomotives are loaded. Transportation reverts at the transfer point to vertical haulage, i. e. to the surface (**Fig. 9**).

Together with its partners, Nordic Minesteel (loading and unloading, cars with bottom discharge) and Bombardier Transportation (train automation), the Schalker Eisenhütte has developed a fully-automatic, driverless solution for high-performance mines. The El Teniente (Codelco), Kiruna (LKAB) and Grasberg (Freeport) mines are already using this system with success. A considerably higher frequency and in turn, an increase in productivity can be achieved especially when several locomotives are in operation. At the same time, it is possible to do without a round circuit and resort to back-and-forth operations. The costs for driving roadways can thus be substantially reduced [3].

The controlled system in this case consists of the collaboration of loading, train haulage and unloading. In similar fashion to the longwall system in coal mining the individual elements of the controlled system are equipped with a large number of sensors and control elements. These enable the elements to optimize themselves; at the same time, however, they also allow them to begin interacting with one another.

Expressed simply, self-regulation for the element locomotive is as follows: traction forces, power consumption and temperatures are collated continuously via the applied sensor technology in order to control the train system – comprising locomotive and cars in keeping with the system parameters [4].

As far as the collaboration of the individual elements with each other is concerned, the unloading process in particular requires a large degree of coordination – in this case between the train (locomotive and cars) and the bottom discharge system. In the case of this unloading system, external propulsion units take over operating the train at the unloading point. The locomotive and cars are directed over the unloading station; the floors of the cars open downwards – guided by a rail (**Fig. 10**). The dynamic loads on the train system caused by each individual car being emptied must be compensated for by intelligent control processes of the tractive drum system so that the train can pass the area at constant speed and the locomotive can then subsequently take over the train composition's further journey [5].

Controlling as such – and in turn the "learning element" of the 4.0 architecture – becomes evident at the level of the overall system of train haulage. Full automation of the system as well as the controlling algorithms concealed behind it enable the integration of both status-oriented as well as historic data; the system is correspondingly capable of prognosis: the trains do not travel to the unloading stations in keeping with a prescribed schedule but instead react to states in the controlled

Fig. 10: Example of fully automatic Schalke train haulage system at LKAB

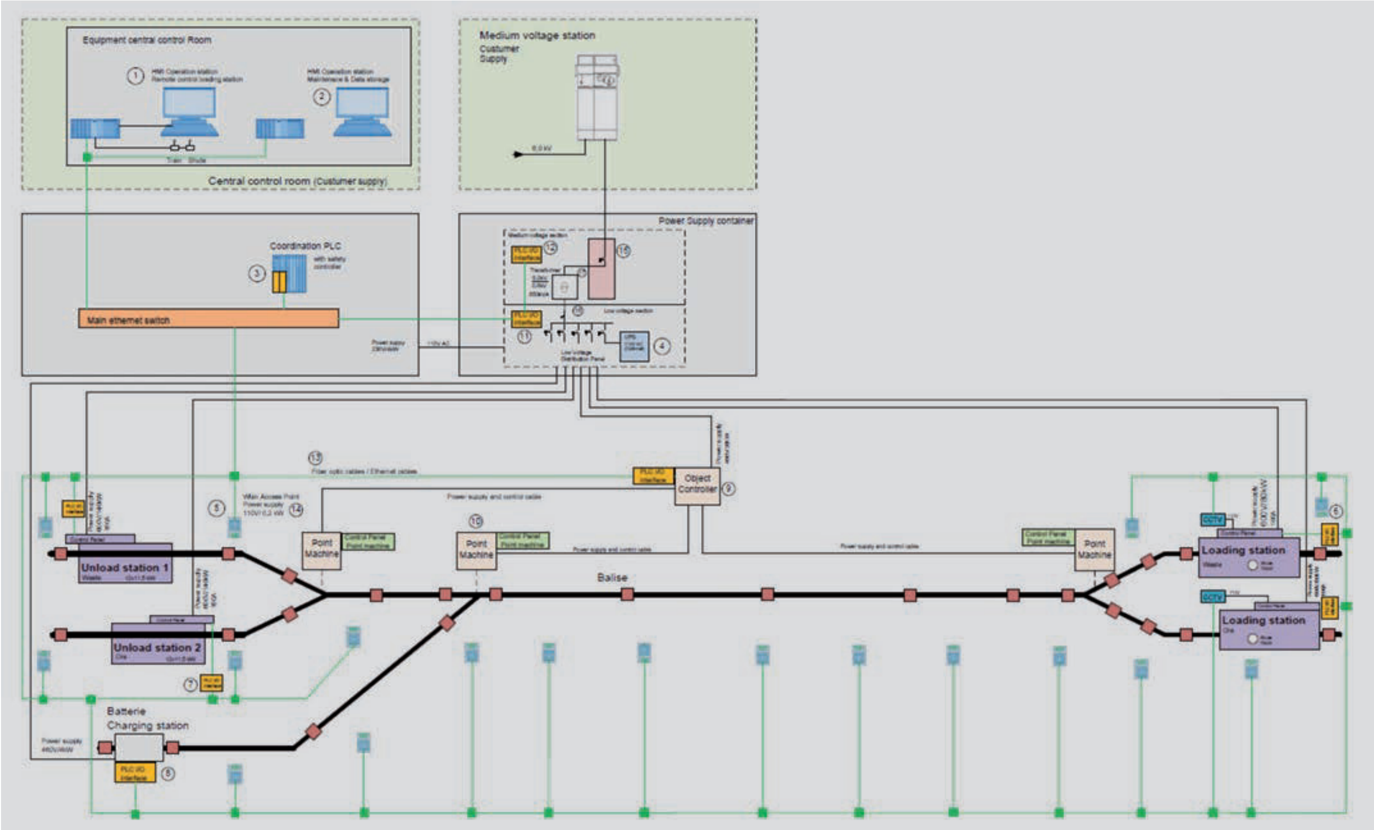


Fig. 11: Simplified example of a system architecture for a train haulage system

system (e.g. a queue at the unloading station) while at the same time optimising the transport cycles based on prognoses (the analysis does not simply concern which loading station is ready but also which loading station will be ready when the train arrives there).

An object controller in conjunction with a central train control centre forms the communication platform between the locomotive and the loading and unloading stations in this system. Control is effected via points or rather point machines and the signal system (**Fig. 11**). In this connection, the system controls the gaps between locomotives and observing the speed. Towards this end, the route is split into several sections, which adapt flexibly in accordance with speed, position and braking paths in order to provide the highest possible efficiency given the greatest possible safety.

In order to prevent collisions between trains, a programmable logic controller (PLC) of the train automation system monitors the gap between the locomotives. Towards this end, each train receives the positions of all the other trains via WLAN data transference. The software in the PLC continuously compares a train's position with the positions of the other locomotives. Should the predefined position be too small, the speed is reduced or the emergency brakes applied. The coordinating computer also carries out this monitoring process in parallel as the current position of every locomotive is stored there too.

Whereas an object controller regulates the collaboration of the system elements, a superordinated coordination PLC takes over the control of the overall system. The data of all those involved wind up here. Firstly, there are the classical status data:

- Where is which train located in which state?
- Which loading station is active?
- What is going on at the unloading stations?

Secondly the coordination computer also scans historical data: differences in the loading times per station as well as charging cycles for the batteries on the locomotives are taken into account when scheduling the trains. Furthermore, parameters, which so far have been rigidly lodged in the system, are included variably in the prognosis model depending on the given load situation (e.g. number of locomotives and loading stations being deployed) to improve the accuracy of the prognosis. Typical parameters here are transfer and waiting times.

Conclusion

The basic precondition for this example as well as in the case of other applications is a high degree of conversion for the controller prerequisites presented in the previous chapter: the creating of system transparency, i.e. the collation and storage of all data describing the system and states as well as their targeted evaluation with regard to correlation analyses. It is only possible to develop a more profound understanding of the system in this way, by means of which reserves in productivity can be exploited in the case of automated solutions as well.

The potentials for increasing performance while reducing costs at the same time and significantly increasing safety in mines represent the occasion and motivation to follow up this subject matter as an essential top technology of the future. Thanks to the presented systems and technologies, the Mining 4.0 concept has already been accomplished in efficient and tried-and-tested process and control technology for high-capacity production and haulage systems. The next step entails extensive networking of the complex underground systems as well as continuous optimisation of the performance and cost factors within the mining process chain extraction-loading-haulage.

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His professional career has always been marked by challenges posed by manufacturers: the application of lean thinking along the value chain, the creation of production and logistical structures as well as the introduction and further development of Industrie 4.0 applications in mechanical engineering/mining.

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References

Merchiers,A. ; Mavroudis, F. ; Pütz, M.: Industrie-4.0-Champion – Hoch automatisierte Systeme im untertägigen Bergbau. GeoResources Zeitschrift, Ausgabe 2-2016. GeoResources Verlag, Duisburg, 2016.

[1] Nienhaus, K.; Mavroudis, F.; Hackelbörger, B.: Walzenlader Automation und Kommunikation – Ein Leitfaden zum autonomen Walzenlader. Vortrag AIMS, RWTH Aachen, 2009.

[2] Bundesministerium für Wirtschaft und Technologie: Multimodale Sensorik-Konzepte der Umwelterkennung/-modellierung

[3] Bergstroem, R.; Sterner, T.; Nordstroem, T.: Heavy haul 1365 meter underground. IHHA meeting, Calgary, 2011.

[4] Merchiers, A.; Brudek, G.; Mackenzie, S.: The Renaissance of Underground Rail Haulage – Why upcoming Mining Projects focus on this Hidden Champion. In: Mineral Resources and Mine Development, Fifth Aachen International Mining Symposium, Aachen, 2015.

[5] Merchiers, A.; Brudek, G.; Dammers, M.: Advantages and Applications of Rail Haulage Systems in Underground Hard Rock Mining Operations. In: Glückauf Mining Report, Gesamtverband Steinkohle e. V., Herne, 2015.

[6] Merchiers, A.; Mavroudis, F.: Reaktion der Eickhoff-Gruppe auf die Anforderungen von Industrie 4.0. Vortrag, Forum Bergbau 4.0, RWTH Aachen, 2015.

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has around ten years' experience in the field of highly sophisticated capital-intensive machinery and equipment including automation.

After completing his engineering studies he worked at the military university in Hamburg Germany as a research assistant where he completed his Doctorate (Phd) in Engineering.

Gregor started his industry career as head of development at "Indunorm" and for the last five years has been working in different positions for "Schalke", a German specialist for tailor-made locomotives with the main focus on mining. In his current role as Executive Vice President, Gregor is responsible for sales and operations.

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