Key performance indicators — a tool to assess ICT applications in underground coal mines

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Synopsis

Implementing new technologies in industrial operations entails the challenge of measuring the improvements gained by the applied technology. Nevertheless, it is absolutely essential to assess the technical and economic benefits in objective and comprehensible numbers to create a platform for further management decisions. Underground coal mines are characterized by numerous, quite complex procedures which make it difficult to determine the specific economic benefit of a new machine, technique, or method. In the OPTI-MINE Project funded by the European Union's RFCS programme, five underground coal mines applied the latest information and communication technologies (ICTs) to improve efficiency, mine safety, occupational health, and environmental im-pacts. An integral part of the project is the assessment of these technologies by using key performance indicators (KPIs). The paper will describe some examples of the selected KPIs and the preliminary findings.

Keywords

key performance indicators, information and communication technology, ICT-applications, network infrastructure, material tracking, wireless communication.

Introduction

The key performance indicators (KPIs) described below are established within the framework of the project 'Demonstration of Process Optimization for Increasing the Efficiency and Safety by Integrating Leading Edge Electronic Information and Communication Technologies (ICT) in Coal Mines'. The EU Project OPTI-MINE, with a duration from July 2011 until June 2014, is subsidized by the European Union within the framework of 'Research Fund for Coal and Steel (RFCS)'.

'OPTI-MINE is a demonstration project, which aims at integrating, installing and operating the newest Information and Communication Technologies (ICT) applications at an industrial-scale and bringing together all the technical and economic data in order to make their European-wide implementation in the mining industry possible but at a minimum risk. Not only the new ICT applications themselves are being demonstrated, but by integrating the ICT systems into one common Ethernet (TCP-IP) based open network platform of high bandwidth and standardized configuration (internet technology), information can be exchanged between all applications and processes. Thus the processes as a whole can be optimised and the efficiency and safety of mines will increase considerably.

'The project covers leading edge ICT for underground mining processes including logistics, transport, personnel communication and information by voice and data, machine communication, staff localisation, guidance etc. Individual components developed within the project will be integrated into a comprehensive system where possible. The benefits demonstrated by this comprehensive optimisation of mining processes are related to considerable improvements of efficiency, mine safety, occupational safety and health and environmental impacts.' (OPTI-MINE, n.d.)

The participants are:

- Project coordinator:
  - Evonik Degussa GmbH (EVD) on behalf of RAG-A, Germany
- Academic partners:
  - Silesian University of Technology (SUT), Poland
  - Georg Agricola University of Applied Sciences (DMT-TFH), Germany
- Underground coal mines:
  - RAG Anthrazit Ibbenbüren GmbH (RAG-A), Germany
  - Premogovnik Velenje d.d. (PRV), Slovenia
  - Hulleras del Norte S.A. (HUNOSA), Spain
  - OKD a. s. (OKD), Czechia
  - Kompania Weglowa S.A. (KWSA), Poland
- Suppliers of the new technical equipment:
  - Minetronics GmbH (MT), Germany
  - Asoc. Inv. y Des. Ind. Rec. Nat. (AITEMIN), Spain.

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The proposed activities of the participating mines have been allocated to different clusters. Table I presents a map of the activity clusters with names of companies participating in each kind of activity. Because the backbone for any application is an adequate network infrastructure, a common field of interest for all mining companies is the development of modern network infrastructure (cluster c1). The other fields of interest are generally site-specific and reflect the areas that require improvement from the point of the view of management. These fields of interests have been gathered and identified in a group of activity clusters.

Key performance indicators

As stated in the Grant Agreement of the project, the introduction of KPIs is essential to evaluate the improvements created by new ICTs. KPIs are a set of selected parameters, designated to facilitate the ongoing assessment of an activity and its results. Due to the complex nature of an operational process, the parameters have to be selective. It is essential to select the most important factors to obtain a reliable and clear view of the operational process.

Implementing new ICT underground covers a multi-layered process and depends on many parameters with a dynamic behaviour. Additionally, the operational setting varies as coal mining is not always a steady, well-defined production process. Therefore the assessment of ICT implemented underground is quite a complex task and requires some simplifications.

Prior to the selection of the KPIs, the academic partners SUT and DMT-TFH had to determine the general requirements that suitable KPIs have to fulfil. These requirements are not limited to the coal mining sector; they are commonly agreed upon in the industry.

- Key performance indicators must reflect the operational goals
- Key performance indicators must be quantifiable by numbers
- Key performance indicators must be free of authoritative judgements
- Key performance indicators must depend on data that is reasonably easy to obtain.

With regard to their scientific and industrial experience, the academic partners designed a number of KPIs applicable for the new ICTs and fulfilling the above requirements. These KPIs covered technical issues of the technology, parameters of the monitored machinery, data concerning the logistics underground, and process-related figures. Due to the specific ICT installations, the varying operational objectives, and the local conditions for each mine, individual KPIs have been designed. After an intensive discussion with project partners, some of the drafted KPIs were altered in accordance with the recommendations of the mining companies. There was a general commitment that the selected KPIs should describe the status before and after implementing the new technology. At the end, it was commonly agreed that each mine should adopt at least three indicators that should cover the essential process improvements gained by the new ICTs.

The determination of KPIs requires a number of operational data. The basic requirements for data collection were set as follows:

- In general, data collection consists of two measuring periods, one before and one after implementing ICT
- Between the two periods, a sufficient testing and troubleshooting time for implementing the technology has to be considered
- With regard to the time frame of the project, a third period of data collection should take place six month after the second period. The sustainability of the improvements will be the focus of this activity
- A minimum number of 10 data-sets are required for each KPI
- The data-sets must cover at least one month
- The partners must check whether operational deviations regarding the KPIs have occurred. If so, a differential treatment of the raised data and the calculation of concerned KPIs must be carried out.

Table I

Activities of the mining companies in the OPTI-MINE Project

Cluster	RAG-A	HUN	PRV	OKD	KWSA
c1: network infrastructure	x	x	x	x	x
c2: material logistic	x	x		x	
c3: personnel communication & information	x	x	x		
c4: personal tracking		x	x	x	x
c5: environment monitoring		x	x		
c6: machine communication				x	
c7: conveyor monitoring	x	x			

KPIs applied by RAG Anthrazit Ibbenbüren GmbH (RAG-A), Germany

Figure 1 outlines the system structure that RAG-A has applied in the cluster 'Material logistics'.

The technology in this cluster consists of a network structure expansion with fibre optic cables (FOCs) in the production area 'Beustfeld'. In addition to 5000 m of FOC and 20 FOC distributers, 15 industrial-grade PCs (IPCs) and 9 mining infrastructure computers (MICs) have been installed. (Mueller, C. and Hübner, R.) The MICs equipped with RFID

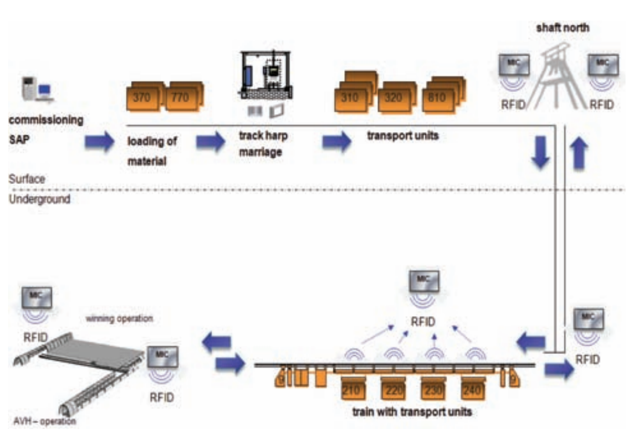

Figure 1—Process for tracking transport units and attached material at RAG-A (Kuschel and Misz, 2013)

readers are able to detect and utilize the passive tags. The RFID tags are affixed to the transport units to enable their location to be tracked.

The informative link between the transport unit, for example the number '370', and the loaded material is executed with an additional barcode label attached to the transport unit. The information from these two different labels is interconnected (marriage) before the transport unit arrives at the shaft.

One KPI is called 'Specific transport performance indicator (TPI)' and is aimed at indicating the productivity of the workforce engaged in the transport of the material units.

KPI: '*TPI*' Specific transport performance indicator in 1/MS (Man Shift)

$$TPI = \frac{n_{TU}}{n_{MS}} \quad [1]$$

TPI: Specific **T**ransport **P**erformance **I**ndicator [-]
n_{TU}: **N**umber of delivered **T**ransport-**U**nits per month [-]
n_{MS}: **N**umber of required **M**an-**S**hifts per month [-]

Preliminary findings

The objective of the improved process is increased productivity, *i.e.* the maximization of *TPI*. The coal mine RAG-A Ibbenbüren has collected the relevant data for the new mining area, the 'Beustfeld' (Figure 2), which has been equipped with the new ICT system. Additionally, this data has been recorded for the mine in total (Figure 3).

As shown in Figure 3, the specific transport performance indicator for the mine in total comes to about 2.3, *i.e.* each worker employed for transport (monorail driver, handling people *etc.*) moves 2.3 transport units per shift. In the Beustfeld area (Figure 2), which is completely equipped with the new technology, this indicator ranges around 3. The performance in the Beustfeld is thus about 30% higher than in general. Despite some other parameters that may have an influence, this is a clear indication that the new ICT system makes a valuable contribution to the productivity of the workforce underground.

Another applied KPI refers to the amount of information the new technology is providing to the operator. The parameter for this KPI is the location of the transport unit, and the aim is to know the actual position of each unit at every time.

KPI: 'I_{ITU}' Average Increase of the level of information about locations of Transport-Units in percent:

$$I_{ITU} = \frac{n_{TUa} - n_{TUb}}{n_{TUb}}.100\% \quad [2]$$

I_{ITU}: Average **I**ncrease of the level of **I**nformation about the locations of **T**ransport **U**nits underground [%]
n_{TUa}: Mean **N**umber of known locations of **T**ransport **U**nits, referred to the specific mining area, **a**fter implementation of new ICT
n_{TUb}: Mean **N**umber of known locations of **T**ransport-**U**nits, referred to the specific mining area, **b**efore implementation of new ICT

Preliminary findings

The objective of optimization is a positive I_{ITU} as this indicates an improved level of information about the location of the transport units underground. Table II represents the recorded data, starting in May 2012 when the new technology was not yet in place. In this month the operator received in average of 2.17 known locations of a transport unit underground. After implementing the new ICT technology in the Beustfeld area, this figure ranged between 3.01 in February 2013 and 5.14 in August 2013.

The I_{ITU} (column 5 of Table II) shows the operator receives on average 60% more information about the location of the transport units. This is a very welcome improvement. A widely branched coal mine is often called a 'black hole' due to the fact that knowledge about numbers of units, their location, and content is often very limited. Less information leads to failed, missed, or dispensable transports. Furthermore, it will reduce the productivity of monorails and operators, as their capacity is not properly matched by the dispatching system.

The recorded increase in the level of information is very well in line with the findings of the previously described KPI 'TPI' (Specific Transport Performance Indicator). It is a strong indication that the new technology leads to significant improvements to the operational process of material logistics.

Cost saving, not a KPI, but most important for mining companies

Another parameter, which was not selected initially, should be mentioned. Owing to the new ICT, it is possible to locate the IPC necessary for the control of the longwall faces on surface. In consequence a flame-proof version is not required and maintenance *etc.* is less complex. The Ibbenbüren coal mine started in 2010 with four IPCs under-ground at an expenditure of 159.124 Euro (Table III). In 2013 all these underground IPCs were replaced by IPCs on surface. These

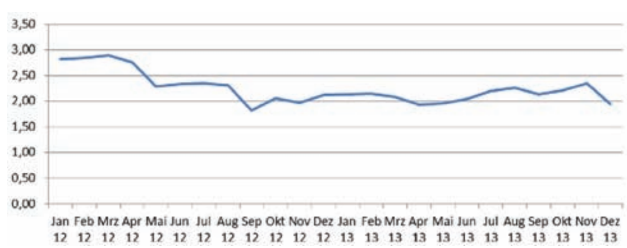

Figure 2—Specific transport performance indicator TPI for the Beustfeld area (Kuschel and Misz, 2013)

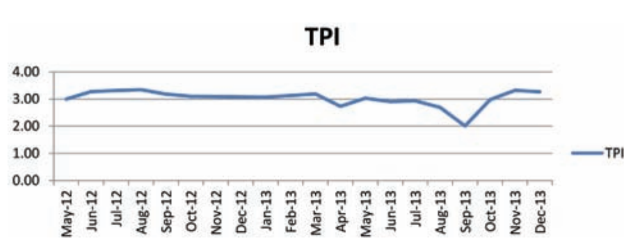

Figure 3—Specific transport performance indicator TPI for the mine in total (Kuschel and Misz, 2013)

Table II

Number of known locations of transport units in the Beustfeld area (Kuschel and Misz, 2013)

	Reference value 2012 May				
	Sum	Sum	n_{TUb}		
	Locations AP 13/12 AP > 30	Recorded tags			
May-12	941	433	2.17		
	Sum	Sum	n_{TUa}	I_{ITU} (%)	Remarks
	Locations AP 12/15 AP > 30	Recorded tags			
Nov-12	328	154	2.13	-1.99	Software update
Dec-12	973	378	2.57	18.45	Test
Jan-13	1740	613	2.84	30.61	Commissioning and test
Feb-13	1799	597	3.01	38.66	AP12: antenna does not send
Mar-13	2019	601	3.36	54.58	AP12: antenna does not send
Apr-13	2267	591	3.84	76.51	AP: 70 added
May-13	1962	552	3.55	63.55	
Jun-13	2924	684	4.27	96.71	
Jul-13	2657	718	3.70	70.28	
Aug-13	3576	696	5.14	136.42	
Sep-13	3272	701	4.67	114.78	
Oct-13	2522	690	3.66	68.19	AP: 35 added
Nov-13	3244	702	4.62	112.64	
Dec-13	2782	606	4.59	111.24	Optimization shaft entry
Jan-14	2718	765	3.55	63.49	State 30.01.2014

Table III

Expenditure for IPC underground and on surface (Kuschel and Misz, 2013)

	Number of IPC underground	Number of IPC on surface	Expenses IPC underground	Expenses IPC on surface	Expenses IPC before ICT-Inst.	Expenses IPC after ICT-Inst.
2010	4	0	39.781 €	5.849 €	159.124 €	159.124 €
2011	3	1	43.987 €	5.908 €	159.124 €	137.869 €
2012	2	2	43.987 €	5.944 €	159.124 €	99.862 €
2013	0	4	43.987 €	5.944 €	159.124 €	23.776 €

IPCs come to 5944 Euro each, which is about 15% of the price of an IPC underground. Consequently, a cost saving indicator, SIPC, was introduced, which indicates a saving of 85%. That does not take into account the reduced effort for installation, maintenance, and the improved reliability.

KPIs applied by Hulleras del Norte S.A. (HUNOSA), Spain

HUNOSA expects that the new ICT system will have an influence on the performance of extraction functions, including secondary/auxiliary ventilation and haulage of coal by belt conveyors. The main reasons for production or haulage disturbances are breakdowns resulting from mechanical or control systems failures. The new ICT system should improve extraction, conveying, and lead to better use of time during production shifts. The new network infrastructure for communication and information is shown in Figure 4.

HUNOSA stated that KPIs should be related to the average time required to rectify a breakdown affecting the extraction process or the horizontal conveying, *i.e.* mean time to repair (MTTR). The introduction of the new ICT system will deliver a level of information at the control room which is more accurate in time and more detailed than previously. It is expected that this will facilitate remote diagnostics, which in combination with better communication will reduce the MTTR.

KPI: 'D_{MTTR}' Decrease of *MTTR* (Mean Time to Repair), caused by breakdowns, either mechanical or due to a failure of the control systems

$$D_{MTTR} = \left(1 - \frac{MTTR_a}{MTTR_b}\right).100\% \quad [3]$$

D_{MTTR} Decrease of *MTTR* after implementation of the new ICT [%]
$MTTR_a$ *MTTR* after implementation of new ICT [h]
$MTTR_b$ *MTTR* before implementation of new ICT [h]

MTTR represents the average time required to repair a failed device. The data sampling refers always to one month.

$$MTTR = \frac{\text{Total corrective maintenance time}}{\text{Total number of maintenance actions}} \quad [4]$$

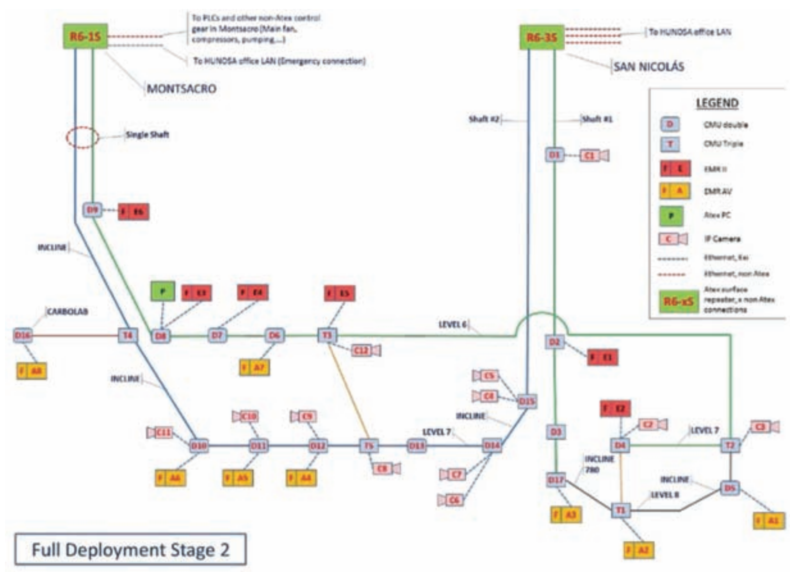

Figure 4—Network infrastructure at the Hunosa Mines, Shaft Montsacro and San Nicolas (Garcia José, González Ruisánchez, and Rodri-guez, 2013)

Preliminary findings

- ➤ $MTTR_b$ ranges between 3 and 7 hours (when expert staff necessary must go on the next shift to resolve a problem), with an average of 5 hours
- ➤ $MTTR_a$ ranges between 2 and 5 hours (when expert staff help to resolve a problem during the shift with the help of ICT technologies), with an average of 3.5 hours
- ➤ D_{MTTR} ranges between 33% and 28%, with an average of 30%.

The objective is the maximization of D_{MTTR}, as this indicates a decrease of the mean time required to repair a failed device. The calculated value of the KPI shows the positive impact of the ICT for a failure-reduced operation.

KPIs applied by Premogovnik Velenje d.d. (PRV), Slovenia

At the current stage of implementing the new ICT infrastructure at the Velenje mine, a LAN/WLAN infrastructure has been installed in one longwall area. The specific objective is to facilitate wireless communication between workforce and staff at all important places at the longwall, at the head- and tailgate, and in the surrounding workings. Some details of this network are shown in Figure 5. Improved personal communication methods are expected to improve transport performance (in terms of increased efficiency or reduce labour consumption) and reduce downtimes as a result of faster response time.

The following described KPI is aimed at measuring the decrease in time required to reach a person.

KPI: 'D_{RT}' Average decrease of time to reach a person, %:

$$D_{RT} = \frac{t_{RTb} - t_{RTa}}{t_{RTb}} .100\% \qquad [5]$$

D_{RT} Average decrease of time to reach a person [%]

t_{RTb} Mean time to reach a person before implementation of new ICT [min]

t_{RTa} Mean time to reach a person after implementation of new ICT [min.

- ➤ Explanation:
  - – Mean values should be determined by two test series, one for the day shift and one for the afternoon shift
  - – The central control room should make about 10 attempts to contact a fitter or an electrician
  - – The time from the first request until reaching the person is to be captured. Both tests should cover a period of 5 days minimum.

Preliminary findings

Figure 6 shows the measured response times for two different coal faces:

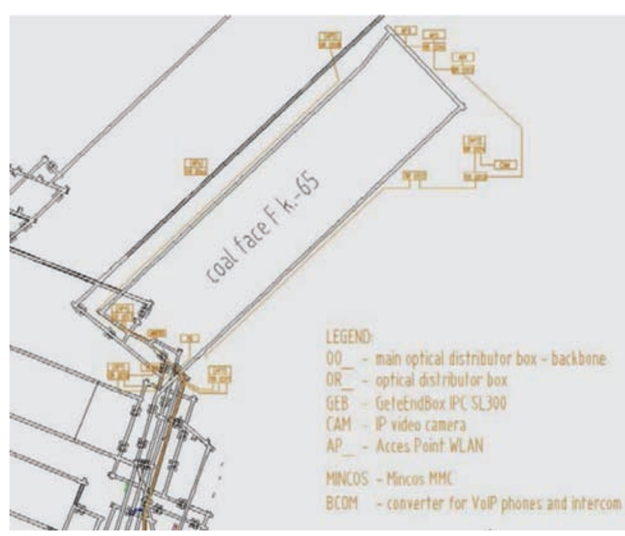

Figure 5—Network infrastructure at the face Fk.-65, Velenje Mine (Krenker and Skarja, 2013)

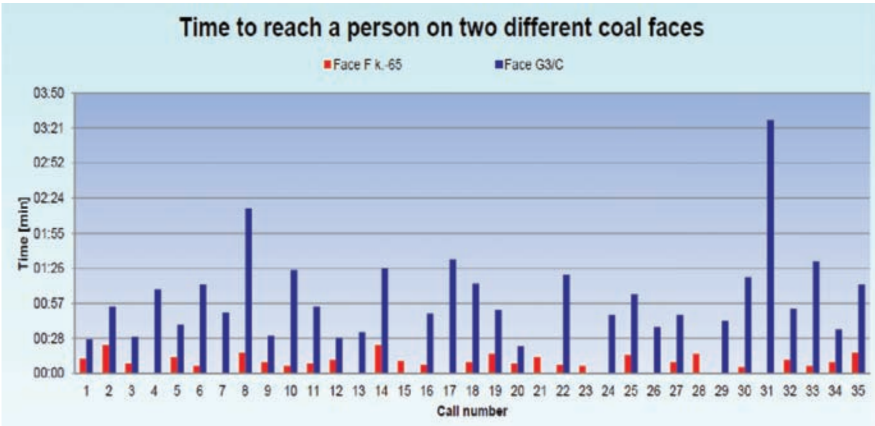

Figure 6—Time to reach a person at two different coal faces, Velenje Mine (Krenker and Skarja, 2013)

- Coal face 'G3/C' without ICT—Face length was 177 m, total length 675 m, average seam thickness 5.14 m, average efficiency (productivity) was 145 t per man and shift
- Coal face 'Fk.-65' with ICT, Face width was 154 m, length 480 m, average thickness 6.20 m, average efficiency (productivity) was 112 t per man and shift

The objective is the maximization of DRT, as this indicates the reduced time required to reach a craftsman in the longwall area. With regard to the successful attempts, the calculated value of DTR is 82%, which is a welcome improvement

Another KPI is aimed at measuring the ratio of successful call attempts. This should indicate the range of the WLAN network in the face area and the reliability of the installed devices.

KPI: 'R_{SC}' Average ratio of successful call attempts to a person equipped with VoIP phone or smartphone when within the range of the wireless communication network

$$R_{SC} = \frac{n_{SC}}{n_{TC}} \times 100\% \quad [6]$$

R_{SC} Average ratio of successful call attempts [%]
n_{SC} Number of successful call attempts
n_{TC} Total number of call attempts.

Voice communication within the range of wireless network should in principle allow immediate contact to a person equipped with a VoIP phone or smartphone. In real conditions, some gaps may occur and a connection may not be established at some moments. This factor is incomparable with the state-of-the-art before and after implementation, but describes the reliability of the system and also reflects coverage failures of the wireless network. Measuring this factor could also help to determine areas where the system efficiency is low and requires, for instance, a denser node net.

Preliminary findings

The objective is the maximization of R_{FC}. The collected data indicates a R_{FC} of 77%, which shows the positive impact of the ICT on the time required to reach a person but also indicates that there is room for improvement.

Summary and outlook

In the demonstration project OPTI-MINE, funded by the European Union's RFCS programme, five underground coal mines have applied the latest information and communication technologies (ICTs) to improve efficiency, mine safety, occupational health, and environmental impacts of their operations. The improvements set by these technologies have been assessed with key performance indicators. Some of the KPIs cover transport performance, the increase of the level of information, the decrease of mean time to repair, the average decrease of time to call a person, and cost savings. The preliminary results give clear evidence that the new enhanced ICT will positively impact mine productivity and mine safety.

The research leading to these results was supported by the European Unions's Research Fund for Coal and Steel (RFCS) research programme under grant agreement No. RFCP-CT-2011-00001. (Malesza, A. and Szarafinski, M. and Strozik, G.)

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