Towards an Evolving Software Ecosystem in the Mining Industry

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***Abstract*— How will the data provider and consumer come together? Towards a mining 4.0, research is being conducted on innovative technologies for digitalization and automation. In addition to data transport on the technical infrastructure level, there are many challenges in the area of integration of different sensor and actuator data sets, as well as already existing isolated applications from different stakeholders. The defined goal is to reduce the gap between the existing system boundaries, on a technical level as well as among the involved persons.**

Keywords Digital-Ecosystems; cloud-based Systems; Data-driven architectures; Software Engineering approaches for ecosystems and Services; Ecosystem Architecture

I. INTRODUCTION

The sector of the primary resources industry and especially the sub-sector of raw material extraction is subject to a technological change in a facsimile to Industry 4.0 - Mining 4.0. This also includes, with regard to mining, new social demands on this sector of industry [16] and [18]. Thus, technology transfer and implementation not only lead to problems in dealing with existing interfaces aimed at process optimization and thus increasing economic efficiency, but also to the desire for more transparency, sustainability and security [16] and [18]. These two trends must progress harmoniously, and can be supported by flexible, innovative and modern technologies and IT solutions. High-level architectures enable a new type of software design, which is described by the approach of development and IT operations (DevOps), and enable the use of new tools for the optimization of software solutions [14] and [19].

In order to implement these trends, a new role model for the use of platform-based cloud solutions was developed. For this purpose, in Section II an underground mining system is roughly transferred into an ecosystem. In doing so, rudimentary aspects of underground mining and the special features of this use case and its rough structures are also described. In particular, in Section III, the belt conveyor is explained and presented as a subsystem of an entire mining ecosystem. In Section IV is exemplarily described what challenges can influence the implementation of new models in the mining industry, in order to go into the utilization structures of the data generated in the subsystem in Section V. These data utilization structures are extended by the introduction of cloud-based platforms. Based on this, Section VI presents the role and process model developed to reduce or overcome dynamically existing system boundaries. Section VII summarizes the findings and gives an outlook on future next steps and work

II. THE MINE AS IT ECOSYSTEM

The increasing complexity of software-intensive systems has led to the fact that the classical approaches of software engineering have shown difficulties with scalability. Software-intensive systems are systems, in which software development and/or integration are dominant considerations, which includes computer-based systems ranging from individual software applications, information systems, embedded systems, software product lines and product families and systems-of-systems. Consequently, software systems should no longer be considered in isolation due to their high degree of interconnectedness, as otherwise the exchange of information and thus the synchronization, actuality and consistency between the systems is inhibited. Instead, they should be designed as part of a larger IT ecosystem [13].

In analogy to biological ecosystems, IT ecosystems are based on the balance between individuals (autonomy) and rules (control) that define equilibria within an IT ecosystem. The maintenance and continuous development of IT ecosystems requires a deep understanding of this balance [8] and [26]. In addition to these aspects, the mixture of interdisciplinarity and technology and non-technology-driven perspectives plays an important role [7]. The aim of an IT ecosystem is therefore to establish and ensure a balance between autonomous subprocesses and systems for greater controllability and optimization of the overall system by gaining a better understanding of the influencing components and actors [10] and [11].

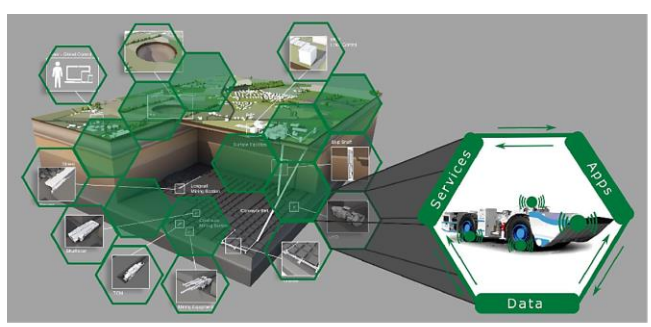

Figure1. Exemplary elements, based on an underground mining ecosystem.

Analogous to the term IT ecosystem, economic industrial companies/mines can also be described as ecosystems [7].

A. Short introduction to underground mining

The term mining infers development and extraction of valuable primary mineral resources from natural deposits. In particular, the underground mine, shown here in Figure 1, describes the development and extraction via shafts and extensive drift systems. Based on the geological conditions, there may be a difference in the implementation of the respective mining method. Due to the different possibilities of the mining method, different technologies and machines can be used. Nevertheless, underground mines are subject to difficult conditions, a constant change of position of machines due to the progress of the mining site, the influence of dust, temperature, limited access to the machines in use and often long distances, to name but a small number of influencing factors. Due to the constant increase in size and a frequently very long working time, different machines from different manufacturers with different state of the art technology are often used, which makes it difficult to overcome the interfaces between the machines.

In principle, underground mining can be divided into several processes for simplified presentation. The Extraction of Raw Materials refers to the extraction of valuable mineral resources and waste rocks from the natural deposit. Following this, the Haulage and Transportation of the dissolved materials takes place. This is done by underground logistics and the various machines required for this. The aim of loading and transport logistics is to transfer the extracted rocks to the Mineral Processing. In mineral processing the concentration of the targeted valuable minerals should be enriched by separating from the waste rocks. The supply of sufficient fresh air must be ensured in order to guarantee the work in underground mining. This section is grouped together in the Ventilation work area. These fields of work are supported by other fields of work, such as Safety, Maintenance and Logistics and several others, which will not be discussed further here [22].

When transferring the ecosystem understanding to a mining company, the individual supply and process chains play an important and specific role in order to ensure optimized mining operations. The independently acting subsystems extend along these chains and thus define very clear system boundaries with a defined goal and set of rules. As shown schematically in Figure 1, a section can consist of participating subsystems, actors and mutually influencing dependencies. The real representation of a mining ecosystem depends on the underlying implementation of an operation and is not subject to a superordinate definition or delimitation.

An entire operational ecosystem is made up of many interactive or parallel systems, which system boundaries are characterized by great dynamics. Nevertheless, an attempt can be made to idealize these individual systems and to delimit them by "virtual" system boundaries into their areas of activity, such as extraction, haulage and transportation, processing and ventilation.

These systems are further subdivided into subsystems, which can be defined within system boundaries in analogy to the previous description. In transport logistics, for example, these are subsystems, such as Load Haul Dump Vehicles (LHD) and conveyor belts. These subsystems provide data obtained by sensor technologies in different ways, which can be used in the higher-level systems to gain new information about the underlying processes by recombining these collected data with the aim of building virtual sensors. The entire system structure and hierarchy is shown as an example in Figure 2. The macrosystems in the third level of the system structure cluster the sensor technologies used on the acting machines according to their data technological end-use. Depending on the configuration, these respective macrosystems are composed of many microsystems. Representatives for these microsystems are the individual sensor technologies.

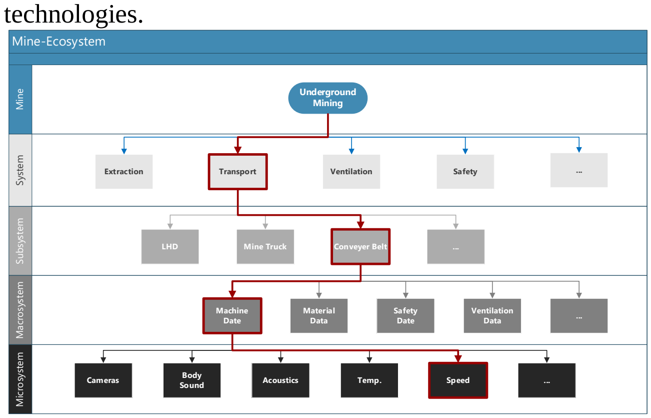

Figure 2. Exemplary representation of a mining system structure.

III. SUBSYSTEM BELT CONVEYER

As described in the previous Sections, the overall ecosystem of a mine is made up of subordinate systems and these in turn are made up of many subsystems. From the system of haulage and transport, the belt conveyor (Figure 3) was chosen as a consistent example to illustrate the system structural complexity [5].

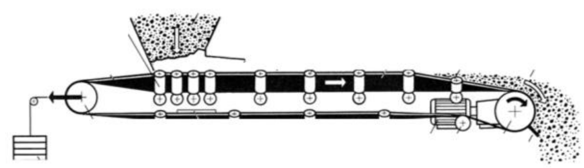

Figure 3. Exemplary sketch of a belt conveyor.

The conveyor belt is a central component of underground mining and combines extraction with further processing steps like hoisting or mineral processing. It supports the haulage and transport of the rock extracted during the mining process. The distances to be conveyed from extraction to mineral processing can range from a few hundred meters to several kilometers. Due to this central location in a mine, uninterrupted operation of this subsystem is essential [1]. The subsystem conveyor belt can be seen as a Cyber-Physical System [26].

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IV. Particular Challenges Exemplified by Data Quality and Model Validation

In an extensive industrial ecosystem, a large number of systems act and react in a network to guarantee cross-process and process-specific functionality. In the Section described above, an infinitesimal part of a hierarchy in a mine is shown and divided into several levels according to the data and communication hierarchy. This Section briefly outlines the increased requirements and demands placed on a subsystem (see Figure 2) if the operated machines are compared to the target concept of the digital mine.

A basic prerequisite for the vertical integration of processes into a higher architecture is the digitalization and automation of the machines used within the specific processes [16]. The operational requirements of the target system, i.e., stable system states to ensure a link to the equilibrium of an ecosystem, must never be ignored [16]. For process-central systems, such as a logistics system (belt conveyor) within a mine, permanent availability, efficiency and no loss of work quality must be guaranteed [16]. When a belt conveyor system stops, the upstream processes are also interrupted [17]. This has a corresponding effect on the downstream process steps in the mine like for example, that without a mineral processing no further processing steps of the targeted value mineral to a product are possible. This strategically important role of a belt conveyor can only be maintained by applying robust machines that can operate in a constantly changing environment. In addition, due to the frequent local changes in the mining industry, digitalization measures specializing in a particular application must be recalibrated again and again in order to ensure that the quality of the new application does not deteriorate [16]. The resulting constantly changing environmental conditions mean that systems can rarely be mirrored or flexibly transferred to “similar” applications. This is made even more difficult by the fact that the systems are not always up to date and combined with the fact that with an increasing number of different suppliers, the number of different systems also increases. The evolution of such long-living cyber-physical systems should be performed in a managed way. A formal description technique for modelling long-living cyber-physical systems is described in [24] and [25], which guarantees the consistency between the system evolution requirements and system implementation.

This general importance of logistic systems in mining also led to the specific content of the Use Case design in the EIT Raw Materials funded project Maintained Mine and Machine (MaMMa)[21]. Here, an interface-neutral, cloud-based MaMMa platform for the optimization of maintenance cycles is to be developed using a belt conveyor in an underground mine as a use case. In order to optimize individual sub-areas, such as a belt conveyor, of a superordinate operational system, such as an underground mine. For this purpose, the data producer and usage structure of such a described subsystem had to be analyzed [21].

V. Data Use and Role Structure of a Subysytem In Mining

The current state of data usage and the role structure are presented in the following. For this purpose, a subsystem is divided into the respective macro and micro systems.

A. Collected Sensor Data of a Subsystem (Belt Conveyer) Divided into Macrosystems

As previously described mining operations are characterized by versatility and variability. Therefore, a lot of data can be generated to describe processes and their environment [2] and [6]. These possibilities include not only extensive machine data sets, which can be derived from the belt conveyer usage alone, but also a large number of other microsystems, which are conducive to transparency of the subsystem. This leads to the fact that a target horizon of data collection and thus the data consumer of the different sensor data has been divided into different macrosystems.

When considering the data technology environment of a machine-related subsystem, the available sensors and data sets can be divided into two categories. On the one hand, the existing machine data and those included in the machines are to be used. The advantage of these data is that they can be acquired in real time without any sensor-technical extension. On the other hand, the sensor-technical acquisition of machine data, as described in the previous Section, is possible by means of additional sensors that are specifically applied to the machine environment. In addition, there are further sensor-technical investigations that are active in the periphery of the subsystem under consideration and address different data sets and data consumers as their main goal. These data can be used, for example, for quality control, control engineering, safety engineering, ventilation engineering and process optimization. This multitude of generated data sets is supplemented by the number of data sets of the upstream and downstream machines and systems for the respective subsystem. The belt conveyor, as a single system is separated from the overall process by system boundaries, is shown in Figure 3. In their technical use the described possibilities of sensor-technical data collection, which are grouped into individual macrosystems in different cases of data collection, are very dependent on the respective degree of technology, the conveyor system, the machine manufacturer and the mine operator. Even within one company there can be different degrees of technology or fixed physical system boundaries. Irrespective of this, the data collected in the subsystem belt conveyor should be made available for process analysis. The complexity of the process analysis can be shown more completely by an increased information density.

Figure 4 refers to the singular data usage according to the respective thematic macrosystem. The different sensor data collected are used by the respective data specialist for process optimization or maintenance. Often, coordinated systems and structures are used for this purpose. An exchange of information within the system structure between the data usage paths is neither planned nor made possible. Thus, a change in the system structure of data use aims at enabling flexible data and information exchange [3].

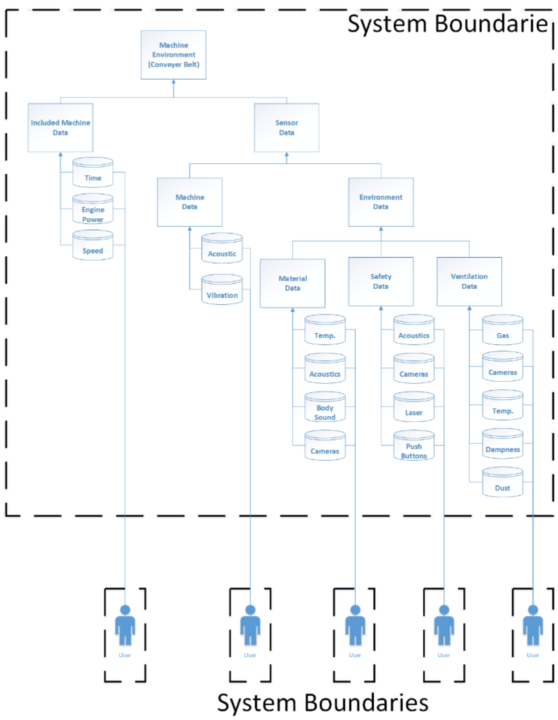

Figure 4. Example of a reduced data hierarchy of a subsystem.

B. Introduction of a Cloud and Service Based Platform – MaMMa

Figure 5 picks up the data usage structure defined in Section V-A. Based on this, a comprehensive data usage string is derived. As an example, for the presentation of the structural change and problem definition, the data input is shown singularly for one sensor from the structural points - machine data / material data / system data. Here, the data usage is extended by the individual acting roles in the development of IT solutions for sensor technical data collection.

The **Sensor Specialist** is responsible for the configuration and design of the sensor technologies used. He has a deep understanding of the domain and detailed knowledge of the microsystem.

The **Data Analyst** is a specialist for processing and evaluating data. He has a high level of domain knowledge. He interacts with the sensor specialist, to increase or optimize data quality. The data analyst does not work directly with sensor data, but with the data provided by any kind of infrastructure. If the data analysis has reached a stage where these findings should be made available to the user or third parties, the data analyst passes these findings on to the Software Developer.

The **Software (SW) Developer** is an IT specialist and developer, who implements new Services or Applications to make data or processed data available. For this he only needs a rudimentary domain understanding, but a very high IT understanding.

The **User** is the person who uses the product, which was created during the development.

Over the entire data value chain, which was described by means of the acting roles, a data point reduction is carried out with each processing step. In each step, information is lost, perhaps unimportant for the end-user in this context, but presumably important in another context. The introduction of platform-based cloud solutions and the resulting expansion of system boundaries means that extended, flexible and extensive data use can be enabled. The system boundaries between developer and user (or between data supplier and consumer) are softened and/or dissolved. By feeding existing and newly developed products into a platform-based system, new possibilities for their use arise. This enables the development of virtual sensors by deriving the final products and the information included for new applications and information bases [3].

The presented open system is a tool for a comprehensive high-level architecture. Not only the linear feeding and provision of pre-processed data or the combined provision of different end products, related to the macrosystems, shall be enabled in this way. Interaction of the user with the platform for flexible retrieval of the different analyzed data sets and end products via flexible/interactive dashboards is used to create an increased value of the existing data. This should lead to a more comprehensive process analysis to improve process optimization and also maintenance [4].

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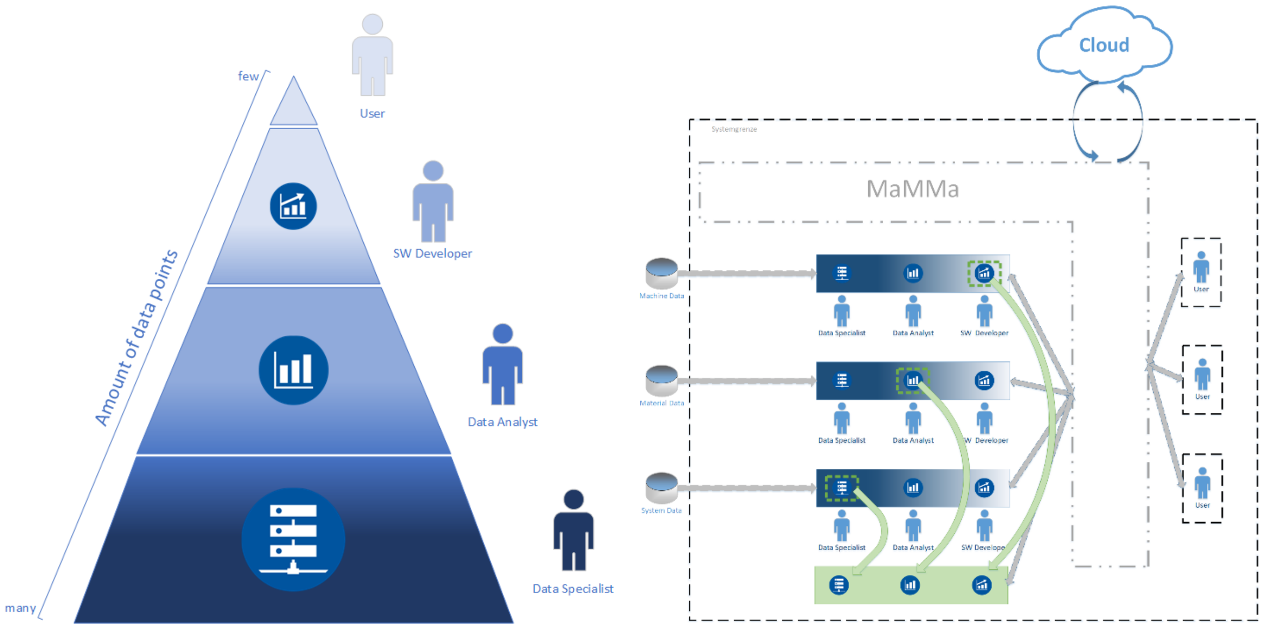

Figure 5. MaMMa-Solution and data reduction.

VI. Structural Development of Software for IT Ecosystems

Based on the stringent and linear data usage and the associated role structure derived from the current state of practice, the benefits of platform-based systems to bridge the technical gapwas demonstrated. In the following, a new concept for a role structure enabled in this way is presented.

A. *Overall Approach*

The innovation of a cloud-based platform in contrast to the classical monolithic IT concepts is the shift of the system boundaries from a closed to an open one, as shown in Figure 5. The solution presented here not only allows to combine already existing products, but also to break the described linear paths of usage. However, this can only be done in a managed way and process. An IT ecosystem in the mining industry is subject to clearly structured processes and operational limitations on the one hand, but must also ensure creative, flexible and fast changes in the process structure on the other hand. The visualization of the described transformation process is shown in Figure 6. Here, a clear role model is used to define responsibilities in relation to processes, data, applications and the goals pursued. To achieve this, clear communication channels must be created across the existing system boundaries and limiting interfaces.

This model can be used as a blueprint for all software-intensive processes regardless of their complexity and level of abstraction (see Figure 2). Scalability and implementation are discussed in detail in the following Section VI-B. In contrast to common process models, the one presented does not have a defined sequence of execution. The interaction is rather to be interpreted as synchronization points, where the arrow direction describes the initiation of synchronization. For this purpose, the roles already introduced in previous Sections are extended by the roles Operator and Integrator.

The **Operator** has a very high understanding of the IT infrastructure, its use and design. He interacts indirectly with every other role through the data and services he manages. During the interaction / communication between the other roles involved, the operator has a special position. If the role of the operator does not coincide with another role, the interaction takes place only via the integrator. From the complexity level onwards, where this role is occupied as an independent role, the topic of infrastructure will also be cross-sectional and concern more than one usage path.

The **Integrator** has a superordinate understanding of all areas and controls the cooperation of all roles. Furthermore, he is responsible for integration beyond the system boundaries, i.e., both on the same hierarchical level and between different usage threads.

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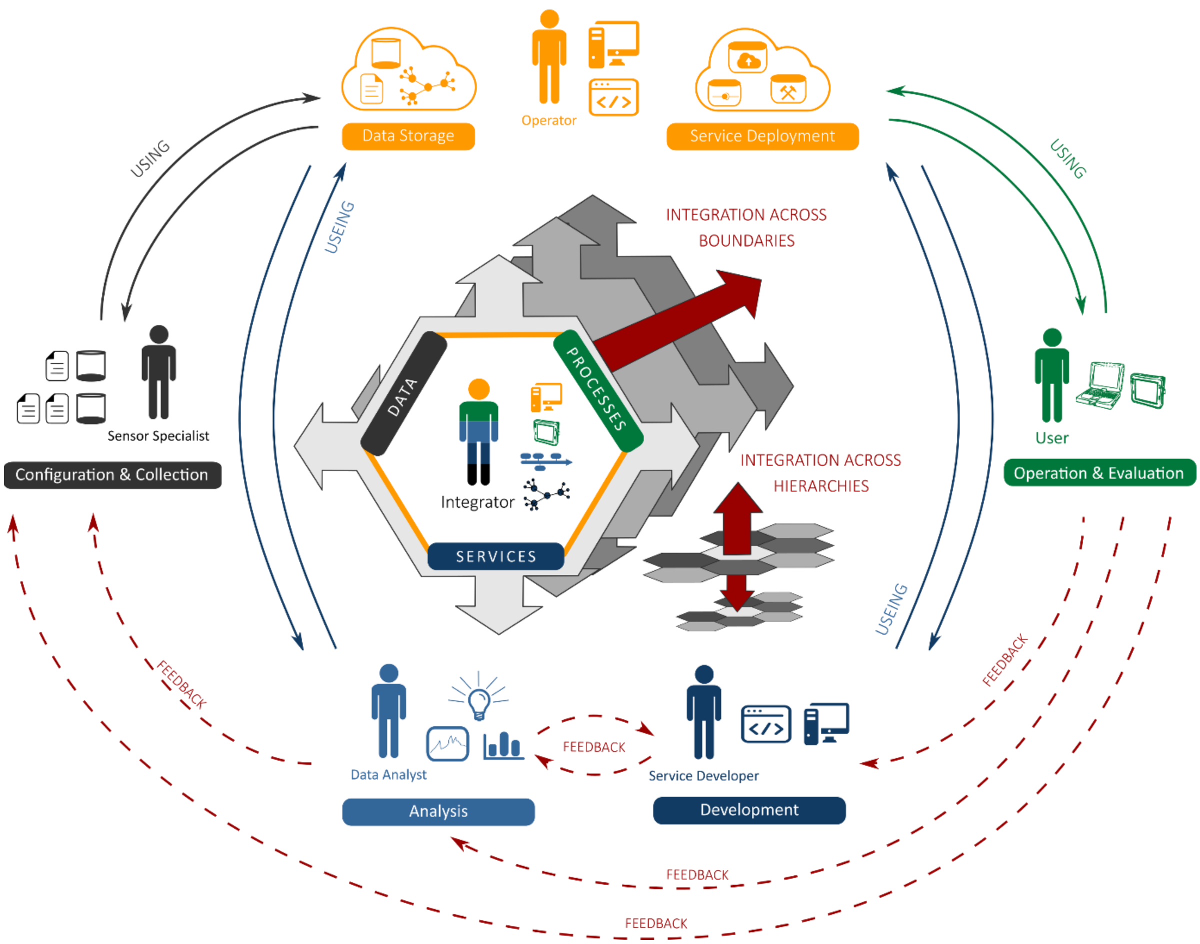

Figure 6. Role- and process model.

His role is not only to be regarded as a technical integrator, but also as a mediator, since he is the one who brings together the triad of data, service and process.

Basically, there are three types of interaction,

i.) the mediation and integration within the system, between systems and between hierarchy and abstraction level is responsible through the role of the integrator.

ii.) usage relationships with the infrastructure as a central element.

iii.) feedback channels that allow iterative and incremental development. The interaction / communication is either directly through the cycles implied by the feedback channels or through the integrator.

The following Section will deal with this role and process model can be adapted to the different needs in a mining ecosystem.

B. Scalability and Mapping to Software Engineering Processes

Considering a macrosystem and its usage paths as shown in Figure 2, such software-intensive systems can be modelled very well to proven and classical waterfall models [9] and classical concepts of software engineering. The disadvantage resulting from these process models are the long project durations, which are predominant due to the placing of orders. By developing cloud and service-based technologies a technical infrastructure is created, which allows integrating systems or components in different ways. However, this results in new challenges in the context of an ecosystem that requires new methodologies, concepts and mechanisms on higher levels of abstraction [9] [15].

These challenges not only result in a change regarding the role of the data specialist, the analyst and also the developer in the context of a mining operation but also, to a greater emphasis on agile development methodologies [12], so that shorter release cycles can be achieved and smaller projects can be established in a quick and dynamic way. Furthermore, the user comes as an essential part of an IT ecosystem comes to the fore. The IT ecosystem must represent a benefit for the user. Otherwise, the role of the user or the development must be questioned at this point. The proposed approach also allows flexibility regarding fusion roles to be combined in one person. This can be done depending on the complexity or the involved usage paths. This can range from the extreme case that all roles are combined in one person, which can be the example in the case of experimental proto-

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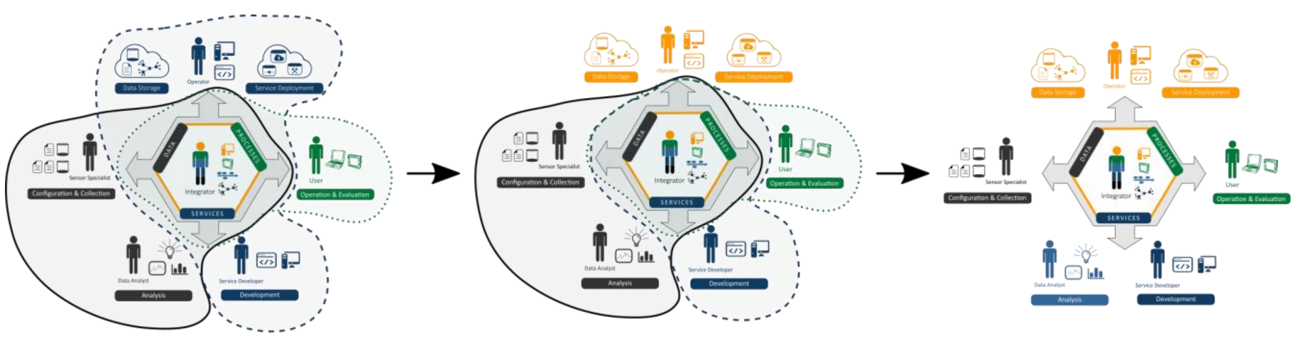
type development and testing, to a distribution of all roles even beyond the company borders. Figure 5 shows how such a dynamic adaptation of roles and thus a scaling of the approach across several abstraction levels and system boundaries can be designed.

Looking at the utilization path in Figure 2, the scenario shown in Figure 7 case i. could represent the development and installation of the speed sensor in the belt conveyor engine. This can also be done by or at the manufacturer. In this case the sensor is only used to control the drive of the machine. Therefore, the roles of developer and operator coincide, since the deployment is carried out on the control system of the machine itself. The roles of sensor specialist and analyst also coincide here, since the generated data output is designed for this special application and is therefore used for automated control. In this case, the user would be synonymous with the client, or the designer of the machine, and would thus implicitly represent the role of the integrator. However, the role of the integrator can also be fulfilled by the other two people/roles depending on the focus of the use case.

Case ii. of Figure 7 represents the scenario of making data available via a cloud infrastructure. Previously this data was only used for controlling the machine. This means that the role of the operator is occupied independently, since a central infrastructure is now accessed. In addition, the role of the developer will be newly occupied in person, because now it is no longer a question of developing a piece of software in an embedded system, but of writing a new service for the infrastructure. This leads to a new profile of the role of the developer. Also, in case ii), depending on the interpretation, the role of the integrator can be performed by one of the other roles. The integrator now has a special responsibility, as he is responsible for ensuring that added value is created through cloud integration. This does not have to be done in person by the integrator of the cloud integration project but can also be done by an integrator from the material analysis path of use, who could initiate case iii). Based on his/her domain expertise and the active exchange with the integrators of other utilization paths, it can be determined, that a virtual scale can be realized through the now available speed values, so that the original sensor data of the machine can now also be used for the utilization path of the material analysis. As shown in Figure 7 iii), each role is now the responsibility of a separate person, with the role of the analyst being more dominant over the sensor specialist, in contrast to cases i) and ii).

In summary, there is no single profile for the roles, nor for the combination of individual roles. This depends rather on the level of abstraction, the required domain and expertise and the context in the ecosystem. It is crucial that in every project the role affiliation and thus the responsibility is made explicit, and that the integrator can spread impulses and best practices through an active exchange across usage paths.



i.) ii.) iii.)

Figure 7. Dynamic role decomposition.

VII. Conclusion, Future Challenges and Further Work

In this article a case study was considered, which gives an impression of the existing complexity and at the same time that this complexity is still detectable and hand-able. Exemplary the data collection possibilities and usage structures were worked out. Therefore, the cyber-physical subsystem conveyer belt was used as a case study. By introducing a cloud-based platform, data usage could be made more flexible and extensive for the whole IT ecosystems. The described approach offers an important technical basis and reduces the hurdle to carry out small, agile and user-oriented software development projects.

In a first step, the approach presented here has focused on modelling the actual state and the necessary changes in relation to the process and role model in to reduce existing barriers. The differentiation from existing technology solutions / technology stack was not considered in depth, as this is highly influenced by the existing solutions and could only be answered with the help of a comprehensive study.

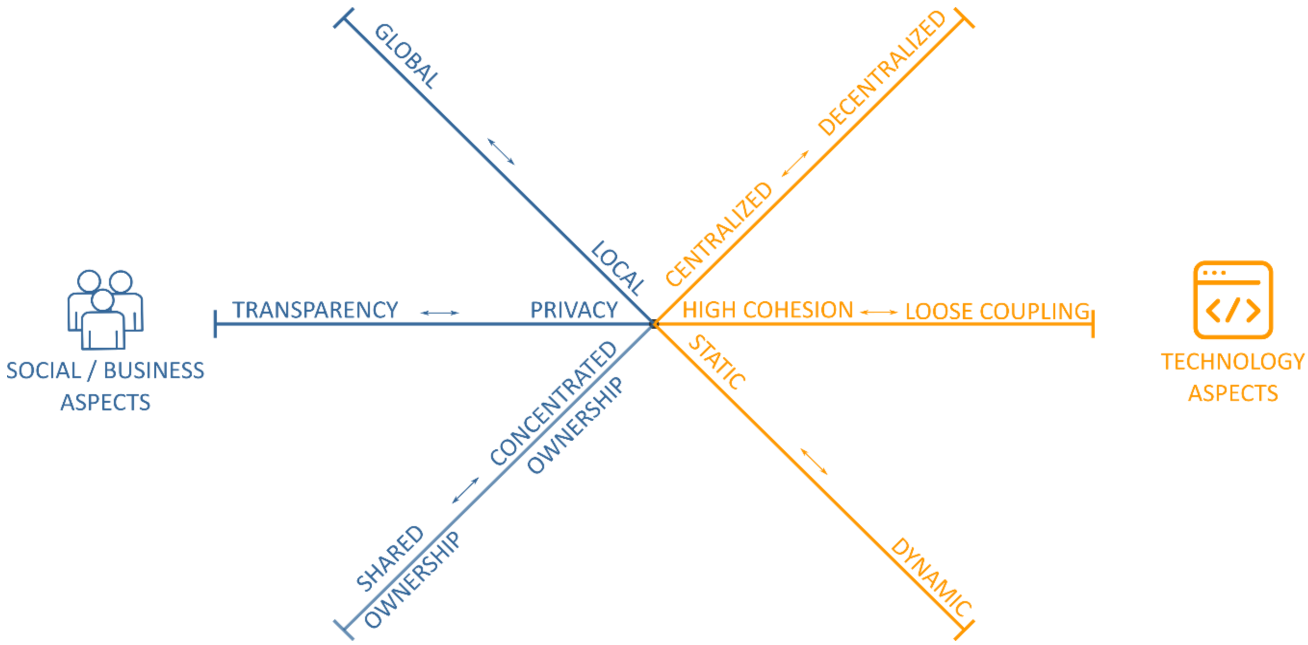


Figure 8. Classification of IT ecosystem.

Future research, necessary for integration into active mining operations may include following questions:

1) What role will employees play in future mining ecosystems?

2) What methodology and mechanisms can be used to create a balance for the social and business aspects, so that obstacles can be removed in this area as well?

In order to classify this challenge, systems can not only be classified into macro- or microsystems due to their complexity but can also be evaluated with regard to their technological, social and business aspects. Figure 8 describes six dimensions that can be used for this purpose. Also, from practical experience (reference to project MaMMa) it is known that the hurdles are not purely technical in nature. In order to create emergent system behavior, a high level of transparency and data availability beyond the system's own boundaries is necessary. The resulting areas of conflict cannot, however, be decided at a purely technical level, but the approach described here attempts to ensure a controlled process by introducing a specific role model and, in particular, the cross-cutting role of the integrator. The aim is to build and refine the necessary understanding between the individual actors and to contribute to the stability of the ecosystem. Another future challenge is the implementation of the model described to an active mining operation, since technological transformation must be accompanied by a cultural change in the company.

Furthermore, the specification of the individual activities, their initiation and their lifecycle will be part of further research. As shown in Figure 7, a comparison with the general definition of a DIN 69901 concept is obvious. The dynamic formation of teams pursuing a common goal fulfils the project character. But our approach goes one step further as we explicitly do not speak of a development project anymore. Hereby the evolution of the system and the shutdown or replacement of a system within the IT ecosystem is an integral part of this approach and had to be part of further research [20].

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