Model-Based operational analysis for complex systems : A case study for an integrated control system in a mining industry

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A case study for an integrated control system in a mining industry

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Abstract

As many manufacturing processes, the mining industry falls within the traditional organization setup, in which the operations are executed in different locations but managed from one master place. This centralized management is ensured by integrated control and monitoring systems. In the literature, some conceptual models have been proposed for different manufacturing processes. However, few works were dedicated to mining operations. Hence, we investigated a conceptual model-based on complex system engineering approach for integrating control and monitoring tools in mining industries. The proposed approach was based on the ISA 95 standard and adapted to specific needs of mining industry by relying on existing business process. This model was applied on a real case study from a mining phosphate company.

1°) Introduction

In order to maintain their leadership and follow ambitious development strategy, mining companies enhance their productivity by the digital transformation. Therefore, they require new strategic models for making their processes smarter, including full integration from sensors to planning.

The fourth industrial revolution focuses on intelligent products and production processes [BRE 2014], it is characterised by the cyber physical systems (CPS) deployment, the Internet Of Things and cloud computing [IND 2013]. Hermann et al. [HER 2016] characterized the industry 4.0 by transforming centrally controlled production processes into decentralised ones. They presented six design principals: (a) interoperability, (b) visualization, (c) decentralization, (d) real-time capability, (e) service orientation, and (f) modularity. The main novelty of this tendency is, in one hand, the implementation of a modular and fully integrated plant where all productive resources (physical and personal, internal and external) with collaborative activities are interconnected and able to exchange real time data. In the other hand, decentralized decisions are taken as autonomously as possible. From this perspective, the complex systems engineering approach based on conceptual modelling can be useful for integrating the different plants since it provides a formal description of all the components of the system [IND 2013].

The integrated control system for mining operations management is considered as the first step toward the complete digital transformation of a mining company. Given its complexity, the development requires a preliminary phase in which experts use systems engineering philosophy with the aim of defining a holistic approach for a complete design [DOU 2014]. Wherefore, in this work, we studied the integration of different functionalities in one fully connected informational system by specifying communication interfaces between them and adding new data interchanging possibilities.

The paper is structured as follows. First, we propose a state of the art based on the standard ISA 95 and the tools used to model the system. On the other hand, some related works were cited to highlight the importance of the proposed approach. Then, we present the overall approach with a case study from mining industry.

2°) State of the art

Standard: ISA 95

The main objective of the ISA-95 or IEC 62264-3 is to define a standard for data modelling and exchange of information between management systems (ERP) and control systems (SCADA: Supervisory and Control Data Acquisition, MES). It deals on one side with the management of the exploitation of industrial systems (MOM: Manufacturing Operations management, and MES: Manufacturing execution systems) by presenting a multidimensional functional infrastructure that defines the functions of the control system, and on data flow definition for interoperability [SCH 2007]. In addition, this standard reduces the cost, risk and errors related to the business to-manufacturing integration since it well defines and formalise data from heterogenous components [IEC 2003].

Formally, the ISA-95 standard consists of five parts. In this study, we focused on parts one and three. The part 1 named "***Enterprise-Control System Integration Part 1: Models and terminology***", presents the models and the terminologies of the system hierarchy and information exchange. Part three named "***Enterprise-Control System Integration Part 3: Activity Models of Manufacturing Operations Management***" focuses on the activities and the related data for MES level [IEC 2003].

In order to define the boundaries and the exchange model between the MES and the ERP, ISA 95 used the CIM pyramid [WIL 92] levels (Figure 1) to place the MES in the third layer. It represents the control domain with time horizon of days, hours, minutes, seconds, and the ERP in the fourth layer, the enterprise domain where activities are followed by years, months, weeks and days [IEC 2003].

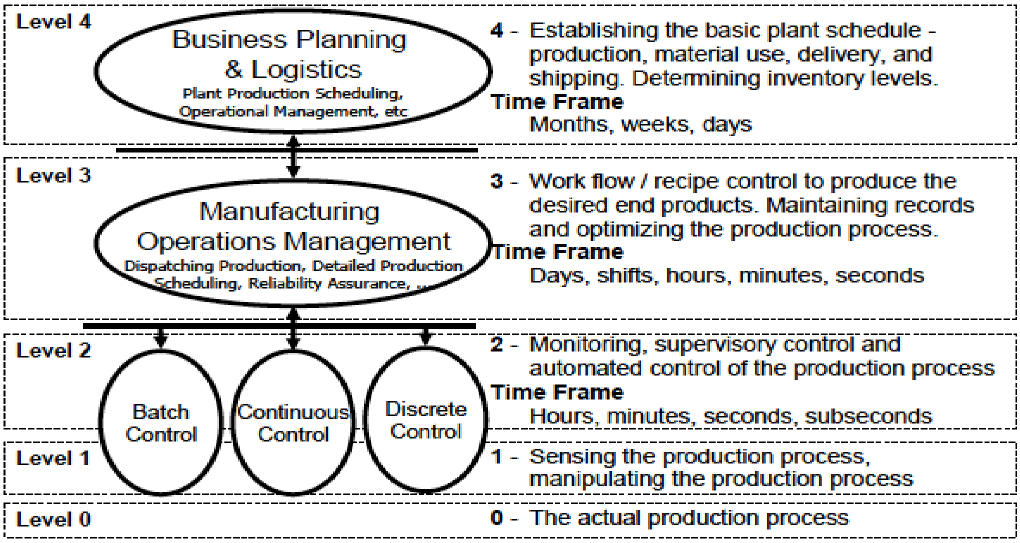

Figure 1: The functional hierarchy model ISA-95 / IEC 62264 [IEC 2003]

In the third level, the Manufacturing Operations Management Model consists of placing the production control in the center and then defining its relations with the other activities. The ISA 95 standard provides a clear division of the activities within the four areas of control (Production, maintenance, quality and inventory) and defined in a detailed way all the exchanges between them.

MOM for mine activities:

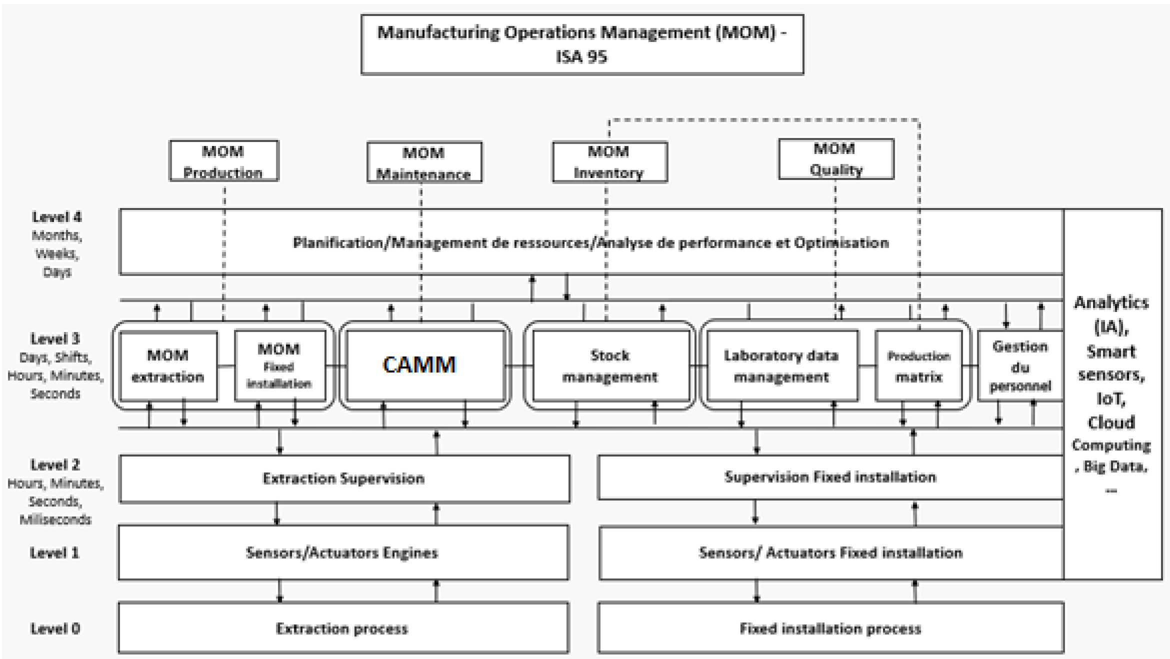

Figure 2: Manufacturing operations management model adapted to the mine industry

Projecting the ISA 95 model on the mine structure gave us the model above, it classifies the mine activities in the four areas of the standard: production, maintenance, quality and inventory.

Complex Systems Engineering

According to INCOSE, complex systems engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. The practice started first in the military sector (e.g. the DodAF and MODAF framework), then aeronautics (NASA) and now it is emerging in the automotive sector and many other industries [BEN 2016].

In the literature, Issad et al. [ISS 2016] applied the SE approach in the specification and analysis of a railway system using a scenario-oriented language. In their work, they showed the utility of the scenarios in representing the interactions between the components of a system. The approach is simple and effective and allowed the stakeholders to detect some systematic errors and missing information. To show the importance of the SysML language in global SE approach, Valeo studied the case of embedded automotive systems and developed a modelling methodology [AND 2010]. Yeonhwan [YEO 2017] applied the SE approach to investigate the limitation of the conventional Operational Mode Summary/Mission Profile (OMS/MP) for weapon systems acquisition and proposed a new one. The approach proved its efficiency since conceptual model was successfully implemented in the Harbor Underwater Surveil System.

CESAMES Systems Architecting Method (CESAM)

CESAM is a systems designing & modelling framework, developed since 2003 in close interaction with many industrial leading companies. It is dedicated to the working systems architects, engineers [CES 2017]. According to the CESAM approach, each integrated system S can be completely analyzed from three different and complementary perspectives that give rise to three generic architectural views: operational, functional and organic views, each grouping together different types of systemic models, as defined as the following:

- Operational view: strictly speaking, the operational view groups only the models of the environment of S - and not of S itself - that imply S. Such operational models thus describe the interactions of S with its environment.

- Functional view: the functional view groups all the models at the system level describing the input / output dynamics of S, without referring to its concrete components. Such functional models thus abstractly model the behaviors of S.

- Organic view: The organic view groups the S models of the natural system built by the composition of the lower level models associated with its components. Such building models thus describe the structure of S.

3°) Case Study: integrated control system of a phosphate mine

In this section, we present the case study of the integrated control system model using the System Engineering approach. The objective is to support the mine projects of control rooms and control towers. It represents an excellent opportunity for all mining operations (Mines, Processing, and Chemistry) to take advantage of new technologies that allow a real-time connection between all entities.

Our work is to model the real-time data flow to define interfaces between third-party systems and eliminate redundancy. On the other hand, we formalized the scenarios and develop standard specific to mine control and supervision projects.

The proposed approach includes all the appropriate activities to design, develop and verify a system that provides a cost-effective and efficient solution to the mining companies needs while satisfying the stakeholders.

However, we focus on an operational analysis through some examples. To follow a SE in our study, we used the CESAMES approach explained above that gave us guidance and rules for building the models of our case study.

Operational analysis:

As explained previously, the first part of the methodology is the operational study. In this phase, we describe the static mission of the system, the needs and the context as well as the use cases. Then, we analyze dynamically the interactions between the external systems using scenario diagrams.

The centralized control room represents the interlocutor between the rising data flow of the automated production sites and the MES, which provides the information and the decisions necessary for the optimization of the production activities. In this context, the mining company is building a centralized control room that will allow global visibility on the production chain and centralization of data.

- **Needs analysis**

For this analysis we used the ISA 95 standard for integrated control systems. As the activity diagram of Part 3 explains, there is four groups of activities (Maintenance, production, quality and inventory) that we must take in consideration while designing the integrated control system.

Needs	Details
Define the data flow to report	Define Maintenance data flow
	Define inventory data flow
	Define Production data flow
	Define quality data flow
Define key performance indicators	Maintenance KPIs
	Inventory KPIs
	Production KPIs
	Quality KPIs

Automate the manual data exchange	Define the outputs and the inputs of every sub-system
	Design a map of the data exchange
Help to decision making	Optimize Operations planning and scheduling
…	

Figure 3: Example of system's needs

The general needs from ISA 95 shown in Figure 3 can be translated into requirements and presented by the requirement diagram. It allows describing the hierarchy and the different relations between the system requirements. Figure 3 shows an example of a containment (composite requirement) relation between the head requirement and its derivatives using the requirement diagram, this diagram can be used for describing all requirement of the entire system. Other requirement relationships can be described such as: Derive relationship, refine relationship, satisfy relationship …

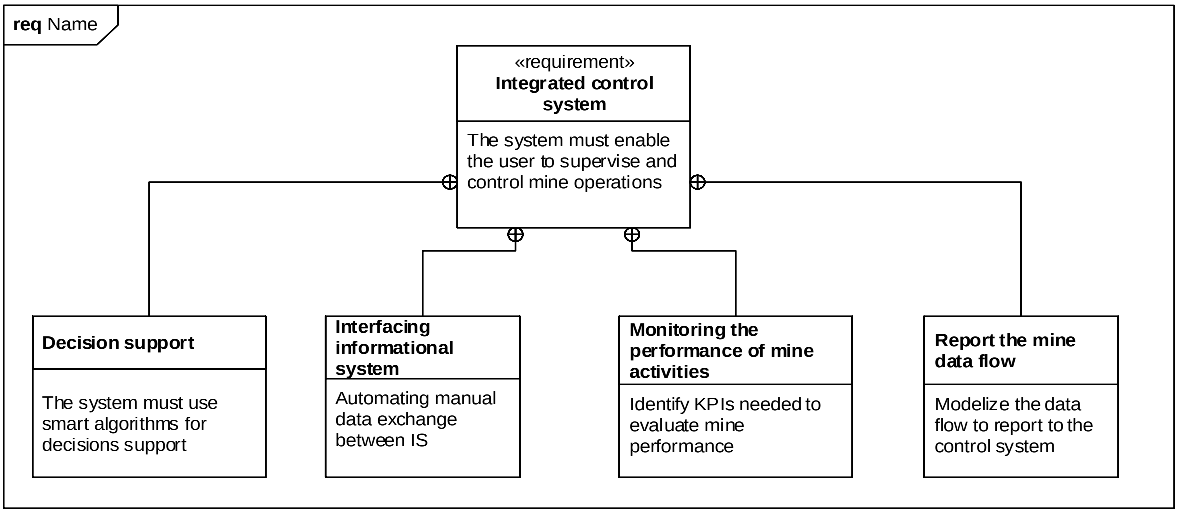

Figure 4: Requirements diagram

- **Stakeholder's definition**

It is a hierarchical exhaustive representation of all stakeholders or equivalently all external systems to that belong to the environment of the system in question (CESAMES Guide).

Figure 5 below provides an illustrative partial example of stakeholder hierarchy diagram for the integrated control system. A stakeholder or equivalently an external system being – classically –represented here by a graphic depicting a person when arrows – also quite classically – represent the inclusion or abstraction relationships on which this hierarchy relies.

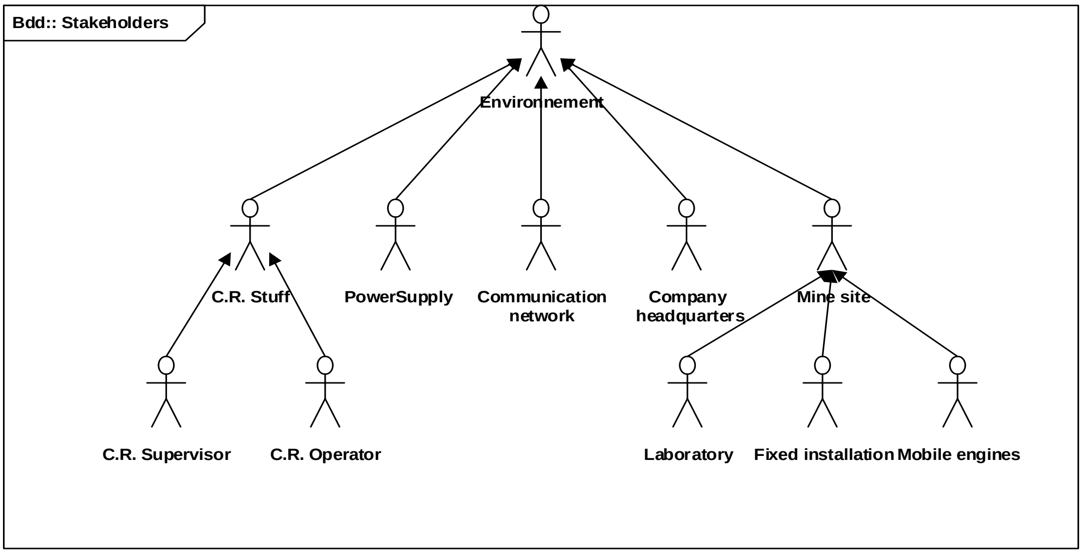

Figure 5: Example of a stakeholder hierarchy diagram for an integrated control system

The conceptual stakeholder's definition for mining activities will include:

- ✓ **C.R Stuff**: there will be several operators placed in the control room each responsible of monitoring an activity headed by a supervisor responsible in charge of coordinating between the activities.
- ✓ **Company Headquarter**: This is the main headquarter; it needs to have a view of the mine to make its strategic decisions.
- ✓ **Laboratory**: The laboratory in charge of the analyses of the phosphates qualities.
- ✓ **Fixed installations**: All the fixed installations of the mine: Stoning, screening and loading.
- ✓ **Mobile engines**: All the machines of the extraction activity.
- ✓ **PowerSupply**: Includes everything related to power supply.
- ✓ **Communication network**: all means of data transmission.

- **Use cases**

It is a static representation of the missions achieved through the collaboration between the system and the stakeholders. Figure 6 provides an example of the use case diagram. The square represents the system of interest where we use again the "person" representation to model its stakeholders. A mission is placed in the square when the system of interest contributes to it. In the same way, one puts a line between a stakeholder and a mission when the stakeholder contributes to such a mission. One also indicates by a rigid arrow when a mission contributes to another mission and by a dashed arrow when a given mission M1 is mandatory to manage another one M2. For example, the responsible of the control room inherits all the use cases of the operator and in addition he controls the mine activities, to do so, he needs to access to the mine data that will be transmitted by the network.

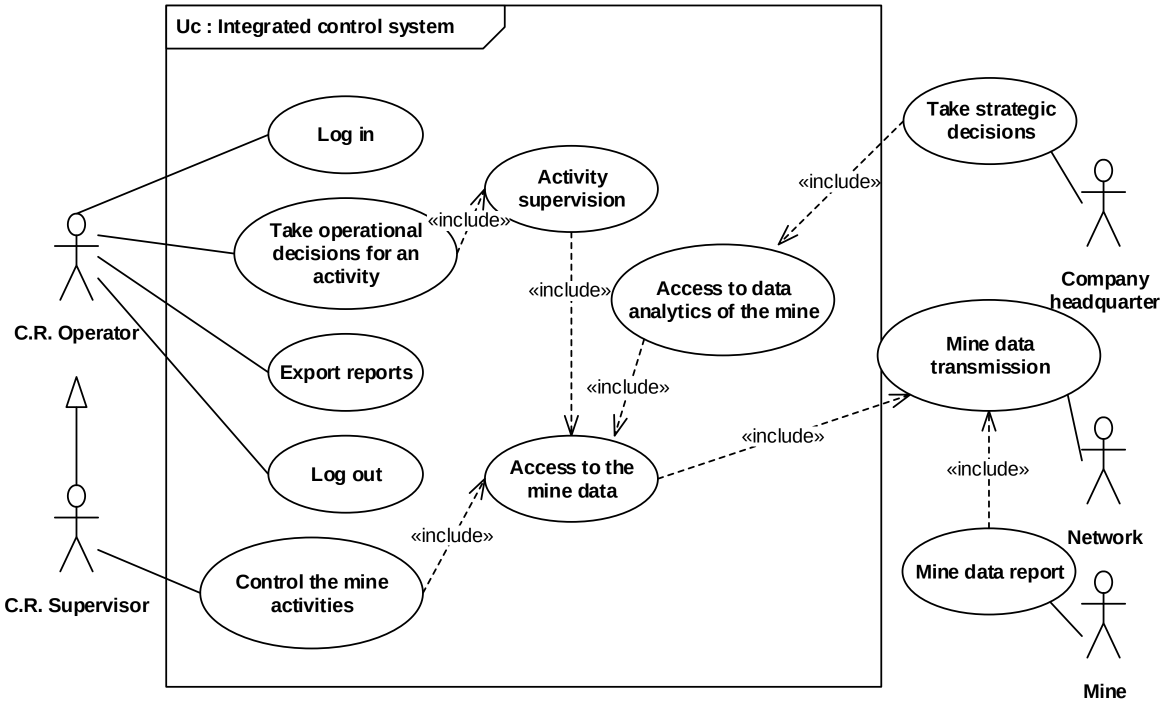

Figure 6: Use case of a control system

- **Operational scenario:**

An operational scenario diagram is a dynamic representation of the use cases, during the period of time, which is modeled, which explicitly specifies all interactions occurring between the system and the stakeholders – or equivalently the external systems – of its reference environment. In Figure 7 an example of operational scenario diagram is described, associated with the stakeholder "C.R. Operator". It describes the messages exchange between the stakeholder and the system in a sequence. Per example, when an operator wants to export an activity report, he must send a request to the system, of course after getting access to its dedicated session. Once the system receives the request, it asks the operator to specify the data fields wanted, the operator select the fields from an exhaustive list of all data the system can provide and then a Pdf or an excel report is exported.

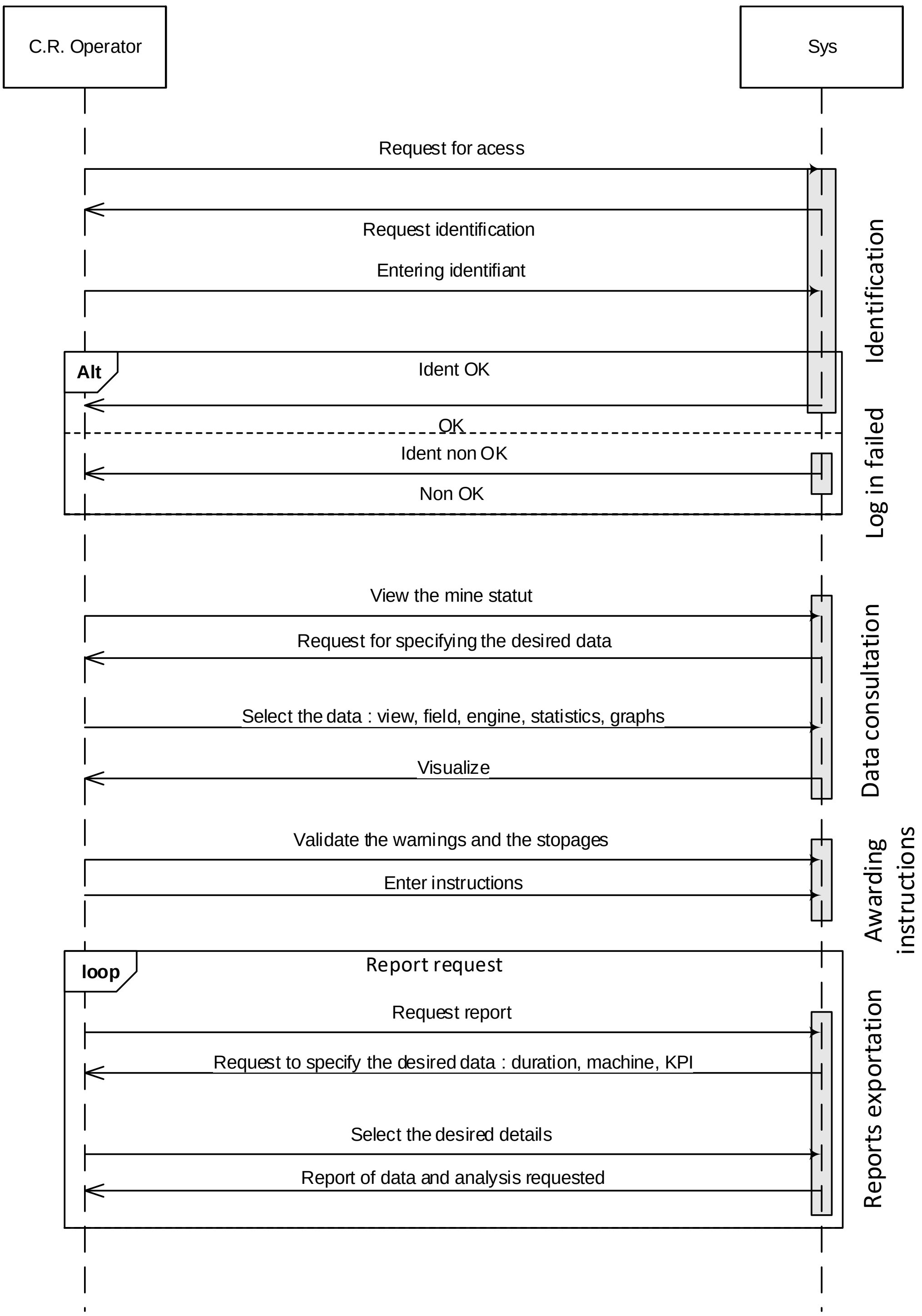

Figure 7: Example of an operational scenario for the C.R operator

4°) Conclusion

Few works have studied the integration of control and monitoring in mining environment. From this perspective, we propose to apply the complex system engineering approach in order to generate a preliminary conceptual model. This work was limited to the operational analysis of the integrated control system. In addition, the proposed study was based on ISA 95 standard directions and also a set of specifications given by our industrial partner. In order to show the efficiency of our model, we applied it on a real case study inspired by a mining phosphate company. For future work, we will extend the study to the functional analysis of the system. Furthermore, a detailed analysis for each sub-system of the overall integrated system will be investigated based on the four pillars of ISA 95 standard directions.

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