Production System Modelling Methodologies of an Open Pit Mine

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ABSTRACT
Open pit mines experience several challenges and constraints in the management of mining operations and processes. The heterogeneity of the infrastructures and the complexity of the physical and managerial systems highlight these various challenges. The creation of a generic system that can drive but at the same time models in a dynamic logic all these constraints and elements assume a major complexity. In addition, the modelling allows the implementation of real-time decision-making components and increases the responsiveness of the system. This paper presents six modelling methodologies of the production system, namely Open System Architecture for Computer Integrated Manufacturing, GRAI Integrated Methodology, Purdue Enterprise Reference Architecture, Generalized Enterprise Reference Architecture and Methodology, Zachman and Model Based System Engineering. Based on the multi-criteria analysis, we have shown that the Modelling Based System Engineering is the most adapted methodology in the case of open pit mines but this method knows a lack of agility in the system. Our system will use a methodology based on Model Based System Engineering and will consider the agility of the system.

Keywords: *Industrial control system, Manufacturing execution system, Production system, Modelling methodologies, Multi-criteria analysis.*

1. INTRODUCTION

With the rise of industrial and technological development, today's industrial companies must ensure efficient production management at both operational and strategic levels in order to maintain a competitive position on the market. At the strategic level companies have to reduce delays and ensure resources efficiency. At the operational level production systems have to be flexible in order to manage orders interchangeability and hazards occurrence. One of the most relevant solutions to reach these objectives is the piloting of industrial facilities. The latter has as a main purpose which is the creation of synergy between actions and planning on the short term and strategic decision making on the long term.

Piloting system is a vague term and knows different definitions and meanings in the literature. APICS proposes a general definition in the broad sense which summarizes these definitions: piloting system or control system is the process of orienting and allocating work to be carried out in production units and actions to be done related to suppliers management. Shop floor management involves the principles, methods and techniques necessary to plan, monitor measure and assess the efficiency of production operations.

Manufacturing Execution System (MES), which are in charge of the control system, ensure the management of the data flow exchange between the physical production system and management system [1]. Indeed, manufacturing execution is a complex task because of the non-linear nature of the production system, the production processes and the environmental uncertainties. In the field of the mining industry, the main problem of MES is integration: namely the heterogeneity of the processes (extraction, physical and chemical treatment) and the heterogeneity of materials.

The purpose of this article is to present the production control system with its different modelling methodologies present in the literature that can be applied to an open pit mine and make a synthesis in order to choose the most suitable method for our case. The paper is structured as follow Section 2 describes the different modelling methodologies of production system. Section 3 proposes a comparison of its different methods using the multi-criteria analysis and explains the modelling methodology chosen and adapted to an open pit mine. Section 4 ends with conclusion and perspectives.

2. PRODUCTION SYSTEM MODELLING METHODOLOGIES

Senechal [2] defines the production system as consisting of a set of human, technical and financial resources; placed in a natural, economic, social and political environment; functioning for its own sustainability, for the good of its members, its users and society in general; realizing products of goods or services; implementing different processes (design, production, management, marketing ...) and whose composition, organization and activities evolve.

In general, the management of a production system has two levels [3] :

- Management planning: it ensures the anticipation and programming of a set of actions or decisions.
- Real-time management: it develops decisions and actions that are carried out in real time and are triggered by a set of events related to the current state of the production system. The capacity of computers to analyse the amount of data in real time is an essential criterion in real-time management [4].

There are various modelling methodologies in a production system; the methods explained below do not present an exhaustive list:

2.1. CIM-OSA (Open System Architecture for Computer Integrated Manufacturing)

CIM-OSA is such an Open Systems Architecture for CIM being developed by the ESPRIT Consortium AMICE. CIM-OSA caters for support throughout the CIM system life cycle. It is architecture for analyzing integrated production systems [5]. It has a methodological approach for a coherent modelling of the company since the precise expression of the needs until the description of the implementation by using the process approach for the integration of the functions of the company. The CIMOSA cube is shown in figure 1.

The goal of CIM-OSA is to provide an Open System reference architecture which supports derivation and definition of a consistent architecture for a particular enterprise. Such architecture will define the explicit structure of the enterprise operation and will identify all its information requirements. It thereby allows to model, to simulate and to control in real time all internal and external information needs of the total enterprise (including its relations to suppliers, customers, government agencies, financial services, etc.)

The phases of CIMOSA [6]:

Step 1: Requirements specifications that users deem necessary at the enterprise level.

Step 2: the conceptual specification including the implementation consisting of the choice of several techniques in order to test the performance of the model (simulation, analysis etc.).

Step 3: the specification of the actual implementation that describes the way in the use and control of the execution of operations in the enterprise.

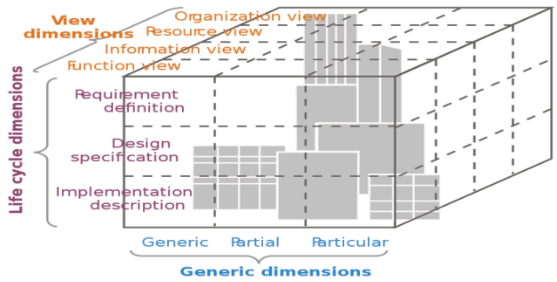

Figure 1 CIMOSA cube [7].

View dimensions: It consists of four views forming a coherent modelling framework: The functional view, the informational view, the resources view and the organizational view.

Generic dimensions: It is composed of three levels: first the generic level which contains the basic generic modelling elements, then the partial level which contains the partial models with predefined, reusable and applicable structures for a particular domain and finally the particular level which corresponds to the specific models of particular enterprises constructed from the partial models.

Life cycle dimensions: It includes: Requirement definition starting with business needs, Design specification that allows you to specify and analyze solutions that meet the expressed needs, and implementation description for the description of the complete CIM system with the implementation of all the elements as well as the solutions chosen.

2.2. GIM (GRAI Integrated Methodology)

GIM was born from the GRAI extension (Result Graph and Inter-related Activities). It is based on the GRAI technique with its different modelling languages, which offers a user-oriented approach, transforming the user needs into specifications in terms of functions, information, decisions and resources and a second technology-oriented approach to transform the specifications as well as generated in other purely technical specifications [8]. The GIM methodology models the company into three subsystems[9]. GIM modelling framework is shown in figure 2.

- The physical system through which pass the physical flows processed by resources to the delivery of products.
- The decision system that transmits commands to the physical system after treatment of the information or decision making according to the levels and periods.
- The information system which collects, distributes and stores information useful to the decision system for transmitting orders to the physical system.

	Information view	Decisional view	Physical view	Functional view
Conceptual level	**Modelling Framework: A user-oriented part**			
Structural level	**Modelling Framework: A technical oriented part**			
Achievement level	Organizational view		Technological view of the information	Production technology view

Figure 2 GIM modelling framework [9].

2.3. PERA (Purdue Enterprise Reference Architecture)

It is a complete engineering methodology indicating in detail the modelling activities regardless of formalism that are left to the choice of users [10]. In PERA, the description of the tasks and functions of the company is broken down into two separate systems: the information system that includes the decision and control system, and then the production system.

The modelling framework consists of only two axes that include the life cycle and the modelling views.

The production and information views give rise to an organizational view from the functional design phase that defines the activities by human resources and the organizational relationships between these resources. The life cycle integration project phases contained in PERA's master plan show an approach that takes into account the real application aspects of the methodology. The Purdue Enterprise Reference Architecture is shown in figure 3.

The life cycle phases of PERA are described below [11]:

Phase 1- Identification: Identification of the company: activities, limits, feasibility, and delimitation of the field of study.

Phase 2- Concept: Definition of mission, vision, values, operational policies, strategies, key success factors.

Phase 3- Definition of the project: Identification of needs and constraints, tasks, modules of functions required for the execution of the missions and objectives of the company, construction of flow diagrams or other models of the entity of the "business.

Phase 4- Project specification or preliminary design: Identification of human tasks, specification of human organization and identification of information equipment, control, processes etc.

Phase 5- Detailed design for the construction phase: Detailed specification of the components, processes, equipment, products, and service elements of the company.

Phase 6- Construction and installation: Construction activities, installation, control, proficiency testing, selection of operations etc.

Phase 7- Operation: Continuous improvement of production processes, their maintenance, organization, skills, information systems etc.

Phase 8 - Dissolution and reprocessing: Revision activities of the concepts of definition of the company. Decision to resume the activity or dissolve the business.

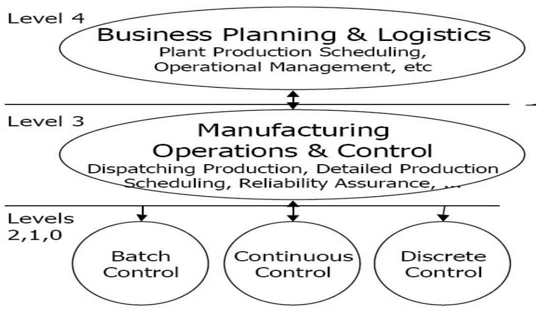

Figure 3 Purdue Enterprise Reference Architecture [12].

2.4. GERAM (Generalized Enterprise Reference Architecture and Methodology)

GERAM is the result of synthesis of the concepts coming from CIMOSA, GIM and PERA to have a modelling reference architecture that can be applied to all kinds of companies[13].

The framework of GERAM consists of 3 dimensions based on the life cycle as in PERA, on the modelling views and on the genericity. This framework is shown in figure 4.

Modelling views are constituted by:

Entity Model Contents views: functional, informational, organizational and resource views.

Entity Purpose Views: Product View, Customer Service, Control and Management.

Entity Implementation Views: Human Tasks View, Automated Tasks.

Entity Physical Manifestation Views: resource view (software and hardware), hardware resources.

The genericity concerns the partial models in a project of engineering of particular companies.

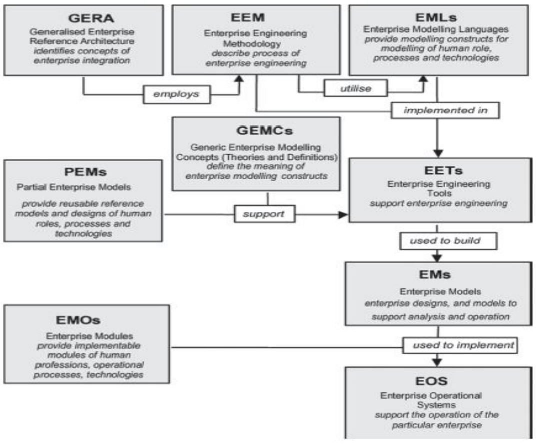

Figure 4 Generalized Enterprise Reference Architecture and Methodology [14].

2.5. Zachman

In 1987 John A. Zachman, an IBM researcher, proposed what is now popularly called the Zachman Framework, a way of conceptualizing what is involved in any information system architecture [15]. The Zachman Framework is an analytic model or classification scheme that organizes descriptive representations. It does not describe an implementation process and is independent of specific methodologies [16].

Zachman states that "The Framework for Enterprise Architecture is a two dimensional classification scheme for descriptive representations of an Enterprise: Perspectives and Abstraction [17]. The conceptual framework is described by a matrix of 36 cells that cover the company's points of view that the author calls "abstraction levels" represented by the questions "What, How, Where, Who, When, Why". Also the perspectives called "levels of detail" constituted by" the Scope, Business model, System model, Technology model, Representation, Function". The lines represent the different perspectives (views) apprehended in relation to the points of view of the stakeholders, which may be quite diversified according to the system and the columns that are constituted by the modelling views.

In the years since he wrote his original article, Zachman has worked to refine and elaborate his framework and it is shown in table 2 [18].

Perspective lines:

Scope / Context: These are views that correspond to the point of view of investors. It describes the system's vision, mission, context, boundaries, architecture and constraints, feasibility, etc.

Business model: This is the modelling of the company or system from the perspective of the owner following solutions proposed by the designer. This line corresponds to the definition of the objectives, goals, strategies, structure and processes necessary to maintain the mission of the system. It can be matched to the "concept "stage.

System model: it concerns the views of the architect or the designer of the functional system. It defines the needs, objects, activities and functions to make the * business model work. This is the step that corresponds to "Logic ".

Technology model: It is the builder's perspective that defines in detail the technological constraints such as human resource constraints, tools, technologies and materials. This is the "Physical "stage.

Detailed representation: It consists of the perfectly detailed concrete components provided by the subcontractors.

Real system: this is the real functional system.

Table 2. The Zachman Enterprise Architecture Framework [18]

Abstractions (Columns)

The Zachman Framework	**DATA What (Things)**	**FUNCTION How (Process)**	**NETWORK Where (Location)**	**PEOPLE Who (People)**	**TIME When (Time)**	**MOTIVATION Why (Motivation)**
SCOPE (Contextual) Planner	List of things important to the business	List of processes the business performs	List of Locations in which the business operates	List of Organizations Important to the Business	List of Events Significant to the Business	List of Business Goals/Strategies
BUSINESS MODEL (Conceptual)	Semantic Model	Business Process	Business Logistics	Work Flow Model	Master Schedule	Business Plan

Perspectives (Rows)

Owner		Model	System			
SYSTEM MODEL (Logical) Designer	Logical Data Model	Application Architecture	Distributed System Architecture	Human Interface Architecture	Processing Structure	Business Rule Model
TECHNOLOGY MODEL (Physical) Builder	Physical Data Model	System Design	Technology Architecture	Presentation Architecture	Control Structure	Rule Design
DETAILED REPRESENTATIONS (Out-of-Context) Sub-Contractor	Data Definition	Program	Network Architecture	Security Architecture	Timing Definition	Rule Specification
FUNCTIONING ENTERPRISE	Actual Business Data	Actual Application Code	Actual Physical Networks	Actual Business Organization	Actual Business Schedule	Actual Business Strategy

Modelling views:

Data view (what): which describes the entities considered important for the company from each perspective. It models the data and their relationship in the company.

Function view (How): which focuses on the transformation of objects. It can be likened to the functional view of CIMOSA. It defines the functions, the activities of the company.

Network view (where): which shows the geographical positions and the interconnections between the internal activities of the company. It also concerns enterprise networks.

People view (who): who models the human resources and their organization (capacity and performance, responsibility, authority). This column also corresponds to the man-machine interfaces, between the people and the works that they execute.

Time (when) view: which describes the time required and the scheduling of the activity control.

Motivation view (why): which describes the motivations of people. It reveals the objectives, the operational goals, the operational policies, the organization of the company, the reasons for the decision-making, the work, and also the justification of the strategies and the objectives.

Unlike GIM and CIMOSA, The Zachman framework does not propose any modelling languages [19].

2.6. MBSE (Model Based System Engineering)

The term MBSE was first introduced by Wymore[20]. MBSE promises to be a more rigorous and effective means for developing complex systems [21]. The value of MBSE stems from the fact that all system-related information is stored in a central repository. This characteristic enables the interconnection of model elements and the ability to effectively retrieve desired information and reason about the system [22]. MBSE provides an underlying layer that links data items to each other. Objectives link to requirements, which then link to functions, functions to physical architecture items, and so on, as far down as projects want to model [23]. Multiple benefits are advocated by MBSE practitioners, such as managing complexity, ensuring consistency and completeness, improving communications [24].

Murray [25] describes MBSE as a generic term that describes an approach to System Engineering that:

- defines a model of system architecture,
- combines the best practices of Traditional System Engineering with rigorous visual modelling techniques,
- generally uses the SysML language as a standard visual modelling language.

The V model [26] also known as the 'verification and validation model' is a graphical representation of the development life cycle of a system. Coming from the world of industry, the 'V' cycle has become a standard in the software industry since the 1980s; it summarizes the general steps that must be taken to develop a system. The 'V' represents the sequence of steps in the development life cycle of a project or system. It describes the activities that must be performed and the results that must be provided during system development. The left part of the cycle (descending part) represents the decomposition of requirements, and the creation of system specifications. The right part of the cycle (ascending part) represents the integration of the different parts of the system (components, subsystem) and their validation. The V model is shown in figure 5.The verification of the system or its components is always performed in relation to the requirements (technical requirements). On the other hand, the validation of the system or one of its components is always accomplished with respect to the needs of the users (functioning in a real environment). The 'V' model guides the planning and implementation of systems. The objectives of this model are the simplicity, the minimization of project risks, the improvement and quality assurance, the reduction of the cost over the whole life cycle of the project and the system and the improvement of communication between the stakeholders.

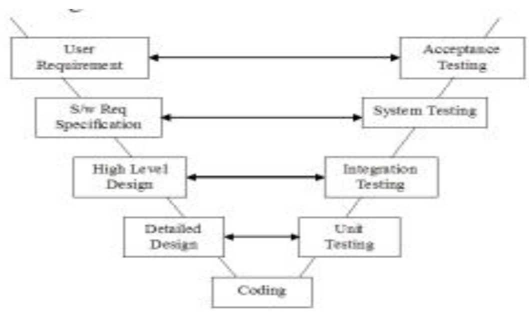

Figure 4 The 'V' Model [27].

The different phases are as follows:

User requirement: Identify and document key stakeholder needs, overall system capabilities, roles and responsibilities, and performance metrics for system validation at the end of the project.

System requirement specification: draw up a list describing the verifiable technical characteristics and meeting the needs of the stakeholders defined during the previous stage.

High-level design: Design a high-level system architecture that meets technical requirements and enables maintenance, upgrades, and integration with other systems.

Detailed design: Detail design to component level and allocate requirements to this level. The components will be identified in such a way as to allow their development or purchase within the original budget.

Coding: choose the right technology. Develop the hardware and software identified in detailed design.

Unit Testing: Test components individually and verify their proper operation based on detailed design requirements.

Integration testing: Integrate software and hardware components into subsystems. Test and verify each subsystem based on high level requirements.

System testing: Integrate subsystems and test the entire system based on requirements. Verify that all interfaces have been correctly implemented and that all requirements and constraints have been met.

Acceptance testing: check that the system meets the requirements and achieves the objectives set.

MBSE allows:

- Improved communication between development actors (e.g. customers, managers, system engineers, physical and logical party developers, testers, and other specialized engineering disciplines).
- Increased ability to manage the complexity of the system by allowing multiple views of the system model, and to analyze the impact of changes.
- Improved system quality by providing a unique and accurate model of the system that can be evaluated for consistency, accuracy and completeness.
- Improved knowledge acquisition and reuse of information by capturing information in a more standardized way and exploiting it in the abstraction mechanisms inherent in model-driven approaches. This can result in reduced cycle times and low maintenance costs to change the design.
- Improved ability to teach and learn the fundamentals of IS by providing a clear and unambiguous representation of concepts.

3. METHOD IMPLEMENTATION

These modelling methods are used in many industrial sectors; Table 3 presents some applications of these methods:

Table 3. Method's applications

Methods	Implementation
CIMOSA	- Improvement of Preventive Maintenance Process Effectiveness in Insourcing and Outsourcing Scheme is be analyzed with House of Risk (HOR) method approach and supported by CIMOSA process-based function modelling for identification method and Supply Chain Risk Identification System (SCRIS) risk structure identification used for mapping problem, root cause, and its relation. [30] - Classify business process for mapping in the firms using CIMOSA. [31]
GIM	- Grai combined with IDEF-Simulation are applied to an electric motor manufacturing company to meet the requirements of manufacturing system analysis and design. It enables a system analyst and designer to build system models from the basic functional specifications to the sub-activity dynamic simulation level. [32]

	- GIM's application in the reengineering of an assembly shop in term of both physical and control aspects. [33]
PERA	- The application of the PERA method to a global engineering, procurement and construction management company, Worley Parsons Company, to have new enterprise architecture. the People-Centric Enterprise Architecture that not only focuses on human dimension in modern enterprises as the central thread, but also includes more business characteristics of the enterprise other than engineering. [34] - The adoption of the Purdue Enterprise Reference Architecture (PERA) for building a human-centred automation reference architecture that can structure and guide efforts to engineer Next Generation Balanced Automation Systems. [35]
GERAM	- The analysis of the US Department of Defense (DoD) Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) AF uses the GERAM meta-model as a roadmap. The analysis seeks to identify components of the C4ISR AF and map them according to GERAM structure. [36] - It is applied to the analysis of the virtual enterprise of a naval maintenance consortium, the naval alliance ANZAC. Specific models have been created according to GERAM to support projects in a timely manner as the virtual enterprise grows. [37]
ZACHMAN	- The design selling batik application based on cloud with the Zachman framework approach and the design's mapping in the Zachman framework matrix. [38] - The Zachman Framework is combined with management ideas to build the Network Attack and Defensive Framework (NADF). The framework provides a structured way for any attack and defense to acquire the necessary knowledge and is useful for security measurement in enterprises or organizations. [39]
MBSE	- It is applied in four application areas to functional avionics: organization modeling; early functional validation; communication and consistency; and temperature plate model framework development. It helps in investigating where the current issues with the existing systems engineering processes lie, and where an MBSE may be able to help, from the perspective of engineers working on spacecraft functional avionics in Airbus. [40] - MBSE is proposed to manage the complexity of an organization as a system to inform workforce decision making by applying a structured, model-centric methodology to understand how people interface within the organization and contribute to organizational objectives. This will then inform decisions on managing people as complex, changing beings. [41]

4. COMPARISON OF MODELLING METHODOLOGIES

The mine is a complex multidisciplinary field which includes chemistry, process engineering, electrical engineering, mechanical engineering, etc. In order to design and model a production system in a very complex and uncertain environment, we will evaluate the methodologies described above according to the following evaluation criteria: *the functional view* describes what the system does in relation to its environment; *the operational view* describes who drives the system; *the organizational view* describes the organizational structure and required human skills, responsibilities, functions, etc.; *the system life cycle* provides a comprehensive and understandable vision of the system. It also helps establish a framework to meet the needs of stake-holders; *the resource view* describes the resources and means necessary to implement to carry out the company's functions, their responsibility, their role, their task, their management method, etc.; *the information view* describes the objects of the company as they are perceived by the users concerning their relationships, their states etc. and *the evaluation and validation phase* allows testing and validating each phase before proceeding to the next phase.

The comparison between the different modelling methodologies of the production system is made by multi-criteria analysis and it is inspired by[42].

Multi-criteria analysis relies on a set of procedures to detail a decision problem involving complex situations. In the multi-criteria analysis, we look for a resolution domain that can take into account all the criteria likely to influence the decision [43]. The criterion is defined as a factor to be considered in evaluating a given scenario or in appreciating an opportunity for action [44], [45]. Table 4 presents the comparison of modelling methods according to the above criteria.

Table 4. Multi-criteria analysis of modelling methodologies

Evaluation Criteria / Methods	CIM-OSA	GIM	PERA	GERAM	Zachman	MBSE
Functional view	•	•	•	•	•	•
Organizational view	•		•	•	•	•

Operational view			•			•
Resource view	• Human	• Physical	• Human	• Human and physical	• Human	• Human and physical
Information view	•	•	•	•	•	•
System life cycle			•	•		•
Evaluation and validation phase						•
Minimization of project risks						•

All modelling methodologies described are oriented toward the approach of engineering complex systems. The life cycle phases are all respected in PERA, GERAM and MBSE, the other methods cover only a few parts of the cycle such as the needs, design and implementation aspects.

All methods take into account the functional view and so the complexity of the system. From an organizational and information point of view, almost all modelling methodologies consider them. GERAM and MBSE are the only methods who support both resources; human and physical views, the others take into consideration only one of the two. Only MBSE method takes into account minimizing project risk by improving project transparency and control by specifying standard approaches and describing the results corresponding to the roles of managers. This also makes the planning of the tests before the realization of the system which will reduce enormously the time of development and the cost. Defects are detected upstream during development, which will minimize the risks associated with these defects and prevent their spread. The CIMOSA method has problems with the integrating of infrastructure like [46]:

- It assumes synchronous operation, i.e., all systems involved in the communication must be up and running at the same time.
- It doesn't scale up well when the number of components to be interconnected becomes significant.

All the production system modelling methodologies follow the cascade model, only the MBSE method follows the V model. These models can support the design process at a very macroscopic level, but do not support either the usual collaboration required between different designers from different disciplines, nor the multi-domain integration, such as hardware-software integration [47].

Indeed, the cascade model is generally intended for projects where requirements, performance and processes are clearly defined and also for projects which do not require changes during development. If the requirements change during a late phase of the project, the product will not meet the requirements and solving this problem requires abandoning the development in progress and resuming from the ground up. The V model is not flexible, if changes occur in the middle of the cycle, the test documents and requirements documents must be updated. It does not allow having prototypes of the system at previous phases, it is necessary to wait for the phase of realization of the system itself [48].

The description of the different modelling methodologies used in the field of the production system, which are the most recognized and used in recent years and in addition of the comparison criteria make it possible to deduce that MBSE is the most appropriate modelling methodology. However, even if the MBSE approach presents a brilliant method of development of complete systems, this approach does not avoid system defects during or after the development process [49]. In other words, it doesn't take into account the agility of the system.

For the open pit mine context, we will use a methodology based on the MBSE that will consider the agility of the system.

Agile methods are based on an iterative, incremental and adaptive development cycle and must respect four fundamental values expressed in twelve principles from which stem a basis of practices, either common or complementary.

Agile methods promote four core values of the Agile Manifesto:

- Individuals and their interactions more than processes and tools;

- Operational software more than exhaustive documentation;
- Collaboration with clients more than contract negotiation;
- Adapting to change more than following a plan.

5. CONCLUSION

The response to competition in the manufacturing market is to adopt an efficient production strategy by setting up an interactive management system capable of providing the right information to the right people at the right time frame and offering a better quality of information. This will assert full and complete adoption of digitalization in the production.

In this paper, various modelling methodologies of the production control system are defined and presented, and which are based on systems engineering approach. Also, we performed a comparison of its different methods using multi-criteria analysis and deduced that the MBSE method is the most suitable for an open pit mine but it lacks agility.

In future, we will design in detail our modelling methodology of the mine production system that will be based on the Model Based System Engineering considering and integrating agility.

ACKNOWLEDGMENTS

This research was supported by The OCP Group. We thank our colleagues from Mohammed VI Polytechnic University who provided insight and expertise that greatly assisted the research. Work carried out within the framework of the Cooperation Agreement for technological and scientific development concluded between the UM6P and the FRDISI.

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