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Models of simulation in the making of decisions in the mining operation

Modelos de simulación en la toma de decisiones en la operación minera

CASTILLO-SERRANO, Erika†, PÉREZ LUGO Myrna Urith, AVELINO-ROSAS, Roberto and RIVERA-MOJICA, Denisse Gabriela

Universidad Tecnológica de Tula - Tepeji,
Universidad Tecnológica de Tecamachalco
Universidad Tecnológica Paso del Norte

ID 1st Author: *Erika, Castillo-Serrano* / **ORC ID**: 0000-0001-8049-9902, **Researcher ID Thomson**: S-6714-2018, **CVU CONACYT ID**: 689775

ID 1st Coauthor: *Myrna Urith, Pérez-Lugo* / **ORC ID**: 0000-0002-4916-209x

ID 2nd Coauthor: *Roberto, Avelino-Rosas* / **ORC ID**: 0000-0002-1564-4302, **Researcher ID Thomson**: S-6538-2018, **CVU CONACYT ID**: 344859

ID 3rd Coauthor: *Denisse Gabriela, Rivera-Mojica* / **ORC ID**: 0000-0003-4382-2197 **CVU CONACYT ID**: 214879

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Abstract

In open pit mining, the loading, unloading and hauling system can represent a high percentage of the operating cost. The objective of this document is to provide an overview of the different approaches in the application of simulation models as an alternative applied to open pit mining operations that can help in decision making to optimize resources. It talks about the different types of simulation models that can be applied in mining operations such as stochastic, deterministic and discrete events. The underlying idea of this text is to highlight that with the increase in competitiveness, mining companies are in need of using simulation techniques to reduce costs, time and risks when making decisions, since simulation allows the creation of scenarios that approximate reality. In the end, the document concludes that simulation models are a tool to help in decision-making, for the optimization of resources, increased improvement and efficiency of the processes of loading, transport and unloading in open pit mines

Simulation, Models, Simulation Software

Resumen

En la minería cielo abierto el sistema de carga, descarga y acarreo puede representar un alto porcentaje del costo operativo. El objetivo de este documento es ofrecer un panorama sobre los distintos enfoques en la aplicación de los modelos de simulación como una alternativa aplicada a operaciones mineras a cielo abierto que pueden coadyuvar en la toma de decisiones para optimizar los recursos. Habla sobre los distintos tipos de modelos de simulación que pueden aplicarse en operaciones mineras como el estocástico, determinístico y de eventos discretos. La idea subyacente de este texto es resaltar que con el incremento de la competitividad las empresas mineras se ven en la necesidad de usar técnicas de simulación para la disminución de costos, tiempo y de riesgos a la hora de tomar decisiones ya que la simulación permite crear escenarios que se aproximan a la realidad. Al final, el documento concluye que los modelos de simulación son una herramienta de ayuda en la toma de decisiones, para la optimización de recursos, incremento de la mejora y la eficiencia de los procesos de carga, transporte y descarga en minas cielo abierto.

Simulación, Modelos, Softwares de simulación

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* Correspondence to Author (email: erika.castillo@ uttt.edu.mx)
† Researcher contributing first author

Introduction

Although it is true that in the past, business decisions were taken under intuition, nowadays the development and use of quantitative tools as well as simulation through information technologies have generated an advance in decision making, being this an essential part of the generation of business knowledge, which has created a degree of decisional maturity.

In order to make a correct and viable decision, organizations need observing how the system reacts to certain actions. To know this, pilot studies are carried out, in which variables such as costs, time, security, etc. are taken into account. As García Dunna, García Reyes, & Cárdeenas Barrón (2013) state, one of the techniques for conducting pilot studies, with fast results and at a relatively low cost, is based on modeling - which is known as simulation. Simulation has become a necessary tool for organizations since it is convenient to carry out simulations to predict the use and optimization of their resources. Simulation guides decision making under the representation of different scenarios and periods (Simon-Marmolejo, 2013).

To understand the behavior of a real-life system, it is necessary to translate it into a model that represents the system. The use of simulation models can be inferred to replace the performance of experiments in real systems and those projects that are still in the development phase. Nowadays competition, globalization, technology and innovation in the mining industry are forced to restructure their processes. It follows that an era has arrived in which manufacturing technologies and information technologies come together to create innovation in negotiations, manufacturing and management in order to optimize resources and generate value in the supply chain by achieving flexibility, efficiency, and effectiveness.

The development of computing has had in the simulation one of the most widely tested tools in different fields of application and with respect to manufacturing processes has not been the exception (Cantú González, Guardado García, & José Luis, 2016).

The lack of a simulation model for decision making in loading, unloading and hauling operations, is inferred could impact the costs of open-pit mines, so it is suggested to use simulation software such as Arena, Flexim, AweSim, GPSS/H, HAUSLIM, SIMULART, Promodel or SimMine as a possible alternative to assist in decision making in mining operations. The costs in the operations of the load and transport of minerals represent a considerable sum in the costs of production of the mineral. Therefore, the proper sizing of these operations is extremely important to reduce such costs. (Lins de Noroha, Cano Núñez, F. dos Reis, & Arroyo Ortiz, 2018)

Pinto & Saliby (1999) argue that open-pit mining is a high investment cost activity and the stochastic behavior of the system makes it more complex, as well as any decision making. The mining organizations fight for the optimization of their resources and to stay in the market to achieve it they must reduce their costs and minimize their risks, for this it is suggested to make use of the technology through simulation techniques, that allows them to experiment and to visualize variables and to be modifying in real-time limits that show them the statistical indicators respective to their processes or activities and this way the best and timely decisions are taken.

Systems and Simulation Models

System

For Jahansen Bertoglio (1991), a system is a group of interacting parts and objects that form a whole or are under the influence of forces in some defined relationship. On the other hand (Shannon, 1988) he defines a system as a set of objects or ideas that are interrelated as a unit for the achievement of an end.

Simulation

The simulation technique was born in 1940 during the Second World War, when scientists Von Neuman and Ulam, who worked on the Monte Carlo project, solved problems of nuclear reactions whose experimental solution would be too costly and the mathematical analysis too complex.

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Simulation is defined as a fictitious representation of a real situation determined through models whose results are applied in the context of the problem; thus, the greater the degree of approximation of the simulation to reality, the more useful it will be; therefore, as a prerequisite for correct simulation, an exhaustive knowledge of the system and its behavior is indispensable (Blanco Rivero & Fajardo Piedrahíta, 2003).

For Thomas H. Naylor, he defines simulation as a numerical technique for conducting experiments on a digital computer. These experiments involve certain types of mathematical and logical relationships, which are necessary to describe the behavior and structure of real-world systems over long periods.

Simulation is the process of designing a model of a real system and carrying out experiments with it, to assimilate the system's behavior or to evaluate various ones to understand the system's functioning (Sokolowsky, 2009).

Currently, several tools allow simulations and analysis of complex systems. Simulation is used to help optimize resources while anticipating undesired results in advance. Simulation allows companies to modify and redesign in order to meet goals and objectives at the lowest cost, in addition to being a fast and efficient tool that allows us to make adjustments to parameters and simulate as many times as necessary, which saves cost and time.

The simulation has applications in manufacturing processes (Bernal Loaiza, Cock Sarmiento, & Restrepo Correa, 2015), public transportation systems (Ortíz Treviño & Serrano Rivera, 2006), agriculture (Candelaria Martínez, et al, 2011), construction (Gómez cabrera & Morales Bocanegra, 2016), environmental impact (Tarshizi et al. 2015), business (Vázquez Fajardo & Fajardo Vaca, 2017), design (Lugo, Ponce, Molina, & Castro, 2014), education (Forero-Paz & A. Giraldo, 2016), equipment failure (Barros Leal & Martínez Espinosa, 2018), training (Carangui Cárdenas, Cajamarca Criollo, & Mantilla Crespo, 2017), health (Mendoza Casseres, González Conde, Corcho Martínez , & Berdugo Alonso, 2016), army (Debán Blanco, García Luque, & Castillo Chamorro, 2016).

Investment projects (Bermúdez Correa & Carreño owners, 2011), mining (Bórquez Dönicke & Ramis Lanyon, 2017) and its use has increased thanks to information technologies and is part of operations research. The experts agree that simulation processes are a tool that allows the promotion of technological development and sustainability; through them, it is possible to strengthen and generate new capacities and actions that improve efficiency in the use of existing resources, with a connotation of social, economic and environmental sense (Bernal & Bernal Pérez, 2015).

The types of simulation are stochastic, deterministic, static, dynamic, continuous or discrete.

Model

Using a model, we can simulate the way a real-life system works. Understanding as a system a set of objects or ideas that are interrelated with each other as a unit to achieve an end (Shannon, 1988). To start studying a particular system, it is necessary to create a model. As they say (Rosenblueth & N., 1945) no substantial part of the universe is so simple, that it can be controlled without abstraction. The abstraction consists of replacing the part of the universe, under consideration, by a model, of similar, but simple structure. Models are a central necessity of scientific procedure.

A model is useful only if it allows us to experiment under certain favorable conditions that simulate the real system and that can represent the system under study. The best model is one that is simple and represents realism. For Chase & Jacobs (2011) the first step in the elaboration of a simulation model is to determine the properties of the real system that should be fixed, called parameters, and which should be allowed to vary during the execution of the simulation, called variables. Simulation models show a sensitivity analysis of the different variables by diversifying the parameters and provide performance indicators in service or manufacturing.

A model showing the behavior of a system is required before simulation. Modeling is a method for understanding and representing system complexity.

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A simulation model is a set of equations that represents processes, variables, and relationships between variables of a real-world phenomenon and that provides approximate indications of its behavior under different management of its variables (Perez et al., 2006). A simulation model acts as a tool the objective of which is to understand the functioning of the system and, based on this, to be able to predict and produce results in advance and thus control the system under study. There are models according to their function, magnitude, purpose or level of abstraction. The types of existing simulation models are Physical Models, Mathematical Logical Models, and Computational Simulation Models.

Use of simulation software in mining

In the market, we can find different simulation software, the most known are Witness, Slam 2, Simul 8, Promodel, Flexsim, Automod and Arena, GPSS/H; which use object-oriented programming languages for discrete models.

The simulation software has had a great advance and currently there is 3D animated technology that makes them more friendly and efficient. These allow companies to transfer from a virtual context to a physical context considering people, machinery and products by programming virtually in advance and then implementing what we will be part of the 4.0 industry or fourth transformation. Industry 4.0 is a term that was first used by the German government and describes an organization of production processes based on technology and devices that communicate with each other autonomously along the value chain (Smit, Kreutzer, Moeller, & Carberg, 2016).

The new era in which machines, people, internet and technologies such as simulation software and others are handcuffed to be in communication upstream-downstream in the value chain to interact and prevent errors. Industry 4.0 is the era in which digital and the physical world are merging.

Mining

Mining is the process of extracting naturally occurring ore from the crust for economic benefit (Newman et al., 2002).

The mining industry contributes significantly to the growth of the world economy since, in addition to providing materials for the development of other industrial sectors, it is also an important source of employment generation and monetary resources for the governments of countries where mining activity is relevant, as is the case of Mexico (Cámara de Minería de México, LXXXI Asamblea General Ordinaria., 2018).

According to INEGI data, mining in Mexico contributes to society and has provided outstanding results and is a support for Mexico's economic growth. In 2017, the mining-metallurgical sector in our country represented 8.3% of the Industrial GDP and 2.5% of the National GDP (3.3% considering the expanded mining) according to INEGI data.

Mining simulation models

A simulation model can stage the context of the haulage, loading and unloading system in which the variability in the times of the activities is taken into account to later give results in the tonnage of material per defined time, as well as the number of units necessary for the haulage. There are current models on which mining planning is defined in the main companies that extract mineral resources in the world: The first is the deterministic or classic mining planning model. The second is the model of mining planning as a function of money. And thirdly, the stochastic mine planning model. (Branch Bedoya, Jaramillo Alvarez, & Franco Sepúlveda, 2012). The fourth model of discrete events.

The deterministic model is related when randomness does not intervene, that is, the variables of the system are perfectly defined. This model is generated from inputs that are fundamentally made up of: geological models (resources and reserves); infrastructure (limitations and opportunities); finances (investments; prices and costs); operating scenarios (reserves; cut-off grades, and levels of extraction or exploitation); operating data (sterile/mineral ratio; endowments and equipment - machinery), which result in outputs from mining planning and which comprise pit limits, the tonnage-law curve (in the case of the exploitation of a metallic deposit), the life of the mine, the cash flow of the mining project, among others. (Franco Sepulveda, 2017).

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The cash-based mining planning model from Martinez & McKibben (2010) is based on the simultaneous optimization of the extraction-processing-refining (production) chain that leads to an increase in the Net Present Value (NPV) of the mining business, taking into account the entire value chain of the mining business, from the definition of the resources and mining reserves (which are part of the inputs), until finally reaching the market (which is part of the outputs). (Franco Sepulveda, 2017). The VPN consists of determining for a future state and the net present value to be greater than other alternatives, that is, the plans will be modified.
The Stochastic Model is a system that performs randomly and integrates the uncertainty in one or more of its parameters and changes its value randomly at a certain time. From the observation of the different systems, data are taken and accumulated to later represent them in probability distributions or probability density curves. The mining operation is characterized by the fact that its inputs have a certain degree of uncertainty, which generates risk at the same time. For Damghani K. (2009) the problems under risk are somewhere between the probabilistic and deterministic. Considering risk as the unknown or changing, as the variables are discovered or resolved the risk decreases. Sometimes risk can remain constant while uncertainty increases over time (Mun2006).

Discrete Event Modeling: A Discrete event simulation is a tool used in the field of mine engineering to evaluate the performance of complex mining systems, both in open-pit and underground mines. These systems are not limited merely to the evaluation of production in material handling systems, but also integrate the coexistence of development, preparation, and production of mining systems (Manriquez, 2016).

Application of the simulation in mining

The increase in competitiveness in mining companies has created uncertainty regarding their performance, which makes important to know how to make the best decisions to help optimize the available resources. Giubergia, Gil Costa, Mansilla, & Narvaez (2016) comment that a production process can be evaluated before its execution by simulating it in a model that allows introducing changes to analyze alternatives, optimizing effectiveness and efficiency.

In mining, simulation techniques can be used as stipulated by Sepulveda, Branch Bedoya, & Jaramillo Alvarez (2012) with which, based on known data, a certain number of hypotheses are generated, which are then analyzed, and the work begins. The importance of the use of simulation techniques in mining is framed by the fact that a reduction of costs and time can be achieved in some activities, the reduction of risks at the time of decision making and the possibility of developing a simulation model that can approximate reality.

Simulation has been widely used to examine open-pit and underground mining problems (Newman, et al 2010). Ortiz S., Canchari S., Iglesias L., & Gonzales T. (2007) also comment that through deterministic and/or probabilistic simulation the excavation and haulage cycle of the material handling system of a surface mining operation can be modeled. Knowing the cycle, the required fleet or equipment is calculated at minimum unit cost and/or maximum production in the unit of time.

For (Sepulveda, Branch Bedoya, & Jaramillo Alvarez, 2010) the optimization of mining operations is carried out, in most cases, through simulation as a controlled statistical sampling technique to calculate the performance of complex deterministic and probabilistic systems, it is applied when the analytical models are not sufficient to explain a phenomenon or it is very complex.

Giubergia, Gil Costa, Mansilla, & Narvaez (2016) conducted a simulation of a mining process composed of storage hoppers and transport equipment, to determine the optimal number and capacity of trucks and hoppers.

Gomez M. & Correa E. (2011) indicate that the use of discrete simulation in the analysis of transport and distribution in mining allows us to represent, analyze the current performance and support the identification of improvement opportunities. Lins de Noroha, Cano Núñez, F. dos Reis, & Arroyo Ortiz (2018) predict through a simulation model the behavior of the loading and transport system of materials in a mine and analyze the use of the equipment to objectively determine the size of the fleet that meets the required production requirements.

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Conclusions

The simulation models serve as a tool to help in the decision-making process since it is possible to experiment with different operational scenarios until the desired result is found and thus optimize the necessary resources in the process of loading, unloading and transporting material in an open-pit mine.

The simulation models properly evaluated and validated increase the improvement and efficiency of the processes of loading, unloading and hauling in open-pit mines and can generate value by reducing operating costs, generating timely deliveries both internally and externally.
The use of technologies and simulators can help solve problems quickly and reliably, as they are powerful tools that assist in decision making.

References

Barros Leal, J. A., & Martínez Espinosa, J. C. (2018). Modelo ára detección y simulacion de falla bajo la gestion de mantenimiento y proyectos. *Informador Técnico*, 11-25.

Bermúdez Correa, L. T., & Carreño dueñas, D. A. (2011). Hacie el uso de la simulación como herramienta para el análsis de proyectos de inversion. *Rev. Investig.Desarro. Y Inov*, 40-52.

Bernal Loaiza, M. E., Cock Sarmiento, G., & Restrepo Correa, J. H. (2015). Productividad en una celda de manufactura flexible simulada. *Revista Tecnura*, 133-144.

Bernal, J. V., & Bernal Pérez, M. B. (2015). La simulación como herramienta para la mejora en el uso de recursos empresariales. Caso pruebas destructivas de calidad. *Ciencia y Tecnología*, 41-54.

Blanco Rivero, L. E., & Fajardo Piedrahíta, I. D. (2003). *Simulación con promodel.* Bogota: Escuela Colombiana de Ingeniería.

Bórquez Dönicke, D., & Ramis Lanyon, F. (2017). Calculo del consumo de combustible y emisiones de CO2 de camiones mineros, mediante simulación discreta. *Revista Ingeniería Industrial*, 151-168.

Branch Bedoya, J., Jaramillo Alvarez, G. P., & Franco Sepúlveda, G. (2012). El planeamiento minero en colombia: Hacia lo estocástico. *Red de revistas cientificas de América Latina, el Caribe, España y Portugal*, 17-19.

Cámara de Minería de México, LXXXI asamblea General Ordinaria. (2018). *Informe anual 2018.*

Candelaria Martínez, B., Ruiz Rosado, O., Gallardo López, F., Pérez Hernández , P., Martínez Becerra, A., & Vargas Villamil, L. (2011). Aplicación de modelos de simulación en el estudio y planificación de la agricultura, una revisión. *Tropical and Subtropical Agroecosystems,*, 999-1010.

Cantú González, J. R., Guardado García, M. d., & José Luis, B. H. (2016). simulación de Procesos, una perspectiva en pro del desempeño operacional. *Revista Iberoamericana de Producción y Gestión Educativa*.

Carangui Cárdenas, L. R., Cajamarca Criollo, O. A., & Mantilla Crespo, X. A. (2017). Impacto del uso de simuladores en la enseñanza de la administración financiera . *Innovación Educativa*, 103-122.

Chase, R. B., & Jacobs, F. R. (2011). *Administración de Operaciones. Producción y Cadena de Suministros.* Mexico D.F.: Mc Graw Hill.

Debán Blanco, J., García Luque, A., & Castillo Chamorro, J. M. (2016). Optimización de despliegues militares sanitarios en. *Sanid mil*, 8-14.

Forero-Paz, Y., & A. Giraldo, J. (2016). Simulación de un Proceso de Fabricación de Bicicletas. *Formación universitaria*, 39-50.

Franco Sepúlveda, G. (2017). Modelo de optimización estocástica para explotaciones mineras a cielo abierto. Medellín Colombia.

García Dunna, E., García Reyes, H., & Cárdeenas Barrón, L. E. (2013). *Simulación y análisis de sistemas con Promodel.* Mexico: Pearson.

Giubergia, A. A., Gil Costa, V., Mansilla, Y., & Narvaez, D. (2016). Simulación aplicada al cálculo. *Minería y Geología*, 72.

ISSN 2531-2979

Gómez cabrera, A., & Morales Bocanegra, D. C. (2016). Análisis de la productividad en la construcción de Vivienda basada en Rendimientos de Mano de Obra. *INGE CUC*, 21-31.

Gómez M., R. A., & Correa E., A. A. (2011). Análisis del transporte y distribución de materiales de construcción utilizando simulación discreta en 3D. *Boletín de Ciencias de la Tierra*, 39-52.

Jahansen Bertoglio, O. (1991). *Introducción a la teoría general de sistemas.* Mexico: Limusa.

Lins de Noroha, O., Cano Núñez, A., F. dos Reis, A., & Arroyo Ortiz, C. (2018). Dimencionamiento de flota en las operaciones de carguío y transporte usando modelos de simulacion de sitemas. *Interfases*, 43-55.

Lugo, E., Ponce, P., Molina, A., & Castro, S. (2014). Co-simulación del Diseño Biomecánico para un Exoesqueleto Robótico Inferior. *Revista Mexicana de Ingeniería Biomédica*.

Manríquez, F. (13 de Septiembre de 2016). *Delphos*. Obtained from Laboratorio de Planificación Minera: http://delphoslab.cl/index.php/blogs/76-simulacion-de-eventos-discretos-como-herramientas-para-la-evaluacion-de-sistemas-mineros-complejos

Martínez, L., & McKibben, J. (2010). Understanding Real Options in Mine Project Valuation: A simple Perspective. Santiago, Chile.

Mendoza Casseres, D. A., González Conde, M., Corcho Martínez , R. A., & Berdugo Alonso, A. (2016). Aplicación de la simulación discreta en el área de urgencias de una institución prestadora de servicios para disminuir perdida de pacientes. *Ingeniare, Universidad Libre-Barranquilla,*, 55-71.

Newman, A. M., Rubio, E., Caro, R., Weintraub, A., & Eurek, K. (2010). A Review of Operations Research in Mine Planning. *Journal Interfaces*, 222-245.

Ortiz S., O., Canchari S., G., Iglesias L., S., & Gonzales T, M. (2007). Simulación determinística y estocástica para dimensionar,. *Revista del Instituto de Investigaciones FIGMMG*, 38-50.

Ortíz Treviño, J. E., & Serrano Rivera, L. (2006). Simulación de sistemas de transporte público masivo. *Ingeniería e Investigación*, 51-57.

Pinto, L. R., & Saliby, E. (1999). Sistema para simulación a eventos discretos utilizando Método Delphi. *III simposio de pesquisa operacional y Logística de Marina (SIMIN)*.

Rosenblueth, A., & N., W. (1945). The role of models in science. Chicago: The University of Chicago.

Sepúlveda, G. F., Branch Bedoya, J. W., & Jaramillo Álvarez, P. (2010). Una aproximación a la planeación minera a cielo abierto desde un enfoque basado en desiciones bajo incertidumbre. *Boletin de Ciencias de la Tierra*, 714.

Seúlveda, G. F., Branch Bedoya, J. W., & Jaramillo Alvarez, P. (2012). Planeamiento de minas a cielo abierto mediante optimización estocástica. *Boletín de ciencias de la tierra* , 107-113.

Shannon, R. E. (1988). *Simulación de Sistemas, diseño, desarrollo e implementación.* Mexico: Trillas.

Simón-Marmolejo, I. (2013). ProModel: Una herramienta alternativa al evaluar el rendimiento de la actividad industrial. *Iberoamerican Journal of Industrial Engineering*, 232-250.

Smit, J., Kreutzer, S., Moeller, C., & Carberg, M. (2016). Industry 4.0 Directorate General for Internal Policies. *European Parliament.* .

Sokolowsky, J. (2009). Principle of Modeling and Simulation: A Multidisciplinary Approach. *John Wile & Sons.*

Vázquez Fajardo, C. E., & Fajardo Vaca, L. M. (2017). La simulación de negocios como una herramienta de aprendizaje empresarial para desarrollar la competitividad. *Revista Atlante: Cuadernos de Educación y Desarrollo*.

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