Benefits of Discrete Event Simulation in Modeling Mining Processes

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ABSTRACT

Discrete event simulation is a stochastic mathematical modeling tool. In modern mining operations maximizing productivity by effective decision making is essential. Discrete event simulation is used to conduct "what if" analysis supporting mining engineers and management in decision making. This paper discusses benefits of discrete event simulation compared to other analysis techniques like spreadsheet analysis. Discrete event simulation can model uncertainty and time changing events. It can be used to model complex systems. A case study example of a stochastic framework for equipment selection is presented to elaborate an example of the applicability of discrete event simulation in modeling and optimizing mining processes. A summary of the results is presented.

1. Introduction

Our modern lifestyle is based on the consumption of mineral resources. From cradle to grave we are surrounded by consumer products created out of stones and rocks. A growing world population, economic growth in developing and emerging countries and a constant need for further innovation increases the demand for mineral resources. The constant optimization of mining operations is vital to cope with the global challenges linked to the rising demand for mineral resources. This paper introduces the concept of Discrete Event Simulation and its application in modeling and optimizing processes in the mining industry. Recent literature is reviewed to acknowledge the variety of applications of Discrete Event Simulation. The analysis of Discrete Event Simulation models is compared to traditional spreadsheet analysis. Advantages and disadvantages of Discrete Event Simulation are evaluated. A brief case study of the application of Discrete Event Simulation in the gypsum quarry industry is presented. Recent limitations of Discrete Event Simulation applied in the mining industry are outlined. Further topics of research are suggested.

2. Benefits of Discrete Event Simulation

Discrete Event Simulation has evolved as a powerful decision making tool after the appearance of fast and inexpensive computing capacity. (Upadhyay et al. 2015) Discrete event simulation enables the study of systems which are discrete, dynamic and stochastic. Discrete Event Simulation models are dynamic simulation models. Time evolvement plays an important role in the analyzed system. Stochastic simulation models are run several times to generate a distribution of outcomes that can be analyzed. (Law, 2015) Additional literature about the utilization of Discrete Event Simulation in the mining industry includes but is not limited to (Ben-Awuah et al., 2010), Paravarzar et al. (2018), Moradi-Afrapoli & Askari-Nasab (2020), Moradi-Afrapoli & Askari-Nasab (2022), Noriega & Pourrahimian (2022) and Hazrathosseini & Moradi-Afrapoli (2023).

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Discrete Event Simulations are typically used to analyze queuing problems. Although it fits many applications in mining, the optimization of the load-haul-dump cycle, both above and underground, is most critical for achieving higher efficiency and cost reduction. Fluctuating cycle times represent the queuing behavior and performance is measured in delay, waiting time, throughput and resource utilization. (Coronado & Tenorio 2015) (Fishman 2001, p.6)

Discrete Event Simulations have been used for a number of purposes in optimizing mine haulage management. The purposes include but are not limited to: the improvement of equipment utilization, reducing waiting and queuing time, to evaluate cost reduction ideas, to minimize the effects of breakdowns, to understand the impact of mixed fleet interactions.

The scope of each Discrete Event simulation model analysis is defined prior to designing the simulation model. (Price, 2014) All methods of successful performance of discrete event simulation include quality control. Procedures of quality control include verification (checking whether the simulation model works as intended) and validation (checking whether the simulation model reflects the real system adequately). (Rabe et al., 2008)

A summary of the most important benefits of Discrete Event Simulation models is given below:

- In a capital intensive industry the possibility to perform what if analysis by the means of simulation and evaluate systems before they are introduced is an essential benefit. Mining engineers are able to study the behavior of systems in order to evaluate design alternatives, improvements or to justify costs. Every aspect of the system can be tested without committing resources for the acquisition of for example new equipment. (Both, 2015)
- Various levels of detail and complexity can be modeled according to the grade of accuracy and detail needed for the decision-making process. According to Price 2014: “Discrete Event simulation models are very useful when components of systems change […] at discrete points in time as a result of specific events. For example, the state of a truck will normally change at discrete points during a haulage cycle.” (Price, 2014)
- Uncertainties and dynamic (time-changing) behavior of the real system can be modeled. Stochastic variables that influence haulage fleet management are for example: waiting times, loading time, spotting time and the haulage time. These factors will vary depending on the road conditions, the type of material loaded, the skills of the operators, the weather and other uncontrollable and sometimes different to predict conditions. (Price, 2014)
- Phenomena can be sped up or slowed down in the simulation. An entire shift can be analyzed in minutes. (Dindarloo et al., 2016)
- The question why a phenomenon occurs in a real system is often asked by managers. Reconstructing the scene with a simulation and analyzing the system microscopically can answer why a phenomenon occurs. (Dindarloo et al., 2016)
- New policies and different operating procedures or new methods can be analyzed in the simulation model. Meanwhile the real system is not disrupted by experiments. The system is modified on the computer rather than modifying the real system. (Dindarloo et al., 2016)
- The simulation model can be used to train new staff. The new operators make their decisions in the simulation model to learn and gain experience before operating the real system. When they make mistakes they can learn from this experience while the real system is not disrupted. (Dindarloo et al., 2016)
- Simple haulage models used to estimate fleet requirements make a large number of assumptions and can not model complex systems. Decisions made based on these simple models do not represent accurate solutions for complex models. Inaccuracies in the haulage models and under-optimized haulage systems is a severe consequence. (Price, 2014)

- Discrete Event simulation models model how complex real systems actually operate. They include the variability, interactions and dependencies of the real system. Thus, decisions such as to invest in new infrastructure or equipment can be made with more certainty. (Price, 2014)

Major shortcomings of Discrete Event Simulations are:

- Discrete Event Simulation can only be applied if the simulation model can replicate the reality to a sufficient extent. (Upadhyay et al. 2015)
- Stochastic skills and an adequate level of experience and knowledge is needed for the creation of a simulation model. This time consuming simulation approach is therefore limited to larger mining companies that have the financial capacities to invest in simulation. (Basu, 1999)
- It is difficult to keep mine models up to date due to the highly dynamic nature of mining. For example, does the design of haul road networks change almost daily. If mine simulation models are not managed by the mine planning team of the mining company onsite but are prepared externally the mine simulation models will become out of date soon. (Price, 2014)
- Like numerical mathematical models and traditional spreadsheet analysis, Discrete Event Simulation only provides estimations for the model outcomes. (Price, 2015)

More areas in mining operations and mineral processing that can be modeled with Discrete Event Simulation need further research. (Dindarloo et al., 2016) There is no comprehensive Discrete Event Simulation program adjusted for mining applications available on the market. Further research should focus on the development of low-cost simulation tools with an easy usable User-interface.

3. Case Study Castellina Gypsum Quarry

For the work presented in this case study the Discrete Event Simulation software Plant Simulation, a product developed by Siemens was used. The software was adapted to develop a simulation tool that can be used on a cross-project basis in the mining industry. The development of the Discrete Event Simulation model followed the general procedure adapted from the Association of German Engineers (VDI), which is shown in Figure 1. (Both, 2016)

Objective of the case study was the optimization of ore transport in the Castellina Marittima gypsum quarry operation. The quarry is located in the south-west of the Italian province of Pisa. The ore is mined by drilling and blasting. At the time of raw data collection for the case study four levels were in operation. The mining equipment in operation included two 3.2 m3 shovels and two articulated dump trucks with a capacity of 27 and 23 tonnes. (Both, 2016)

In the case study the benefit of stockpiling is analyzed in comparison to conventional ore transport. Aim of the case study is to find the most cost effective transportation setup comparing a stockpiling and non-stockpiling scenario with varying equipment. The daily operating costs are used as key performance indicators (KPI). The results of the Discrete Event Simulation model are verified and compared to a deterministic spreadsheet calculation of the same problems. Figure 2 gives an overview of the complexity of the topographical network layer for the simulation model of the case study. (Both, 2016)

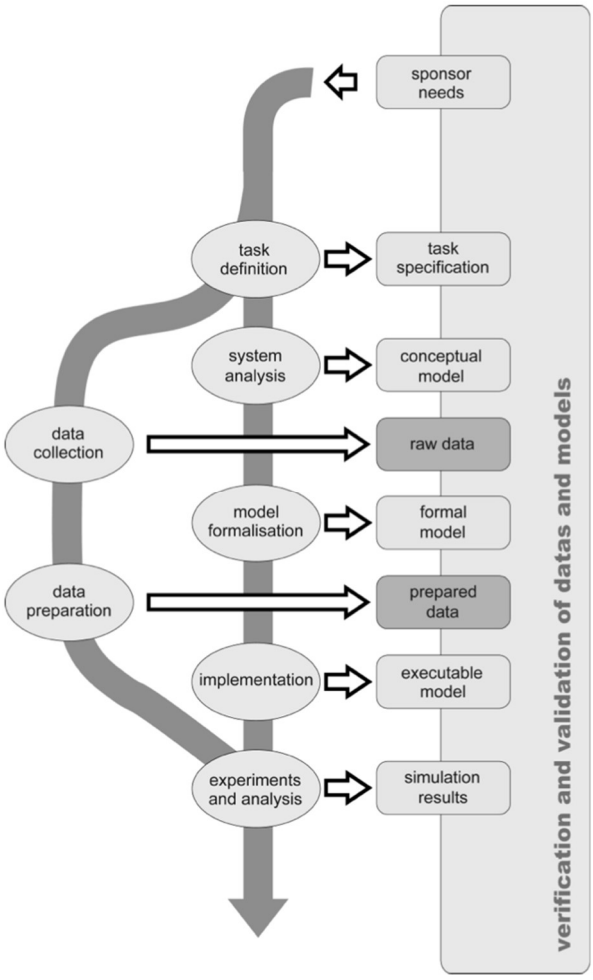

Figure 1. Procedure model for Discrete Event Simulations of VDI, translated to English by (Both, 2016).

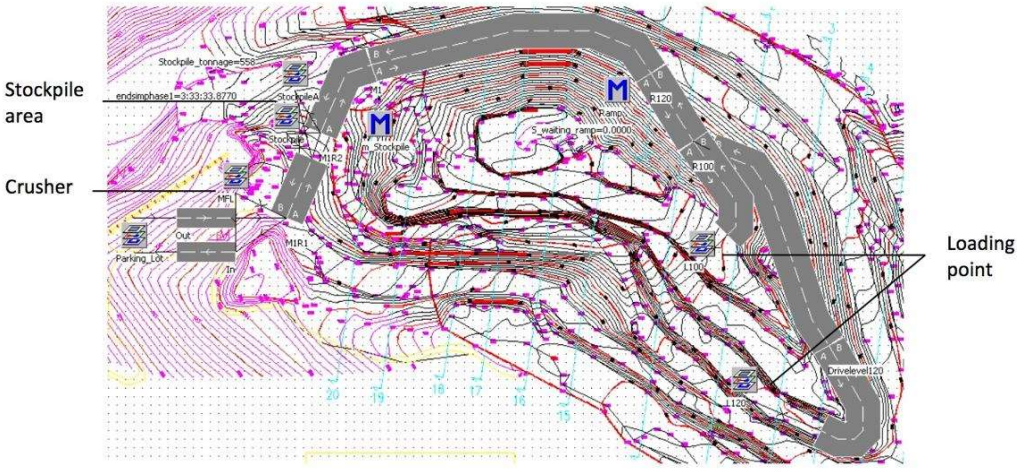

Figure 2. Topographical network layer for the simulation model of the case study (Both, 2016).

In summary, the assessment of the case study results showed that the Discrete Event simulation approach is superior to the deterministic spreadsheet calculation if the case study includes unpredictable interactions of equipment. (Both, 2016) One example stated by Both (2016) is “the

basic examination of stockpile profitability using different equipment combinations in the [] case study. While the exact amount of ore placed on the stockpile was difficult to determine by spreadsheet calculation, the Discrete Event Simulation model could benefit from decision-making based on the filling level of the crusher bunker, which reproduces the behavior of the real transport system."

4. Conclusion

Discrete Event simulation is a powerful decision making tool. Discrete Event Simulation enables the study of systems that are discrete, dynamic and stochastic. Discrete Event Simulation is ideal to optimize mine haulage management. Major benefits of Discrete Event Simulation include but are not limited to: a flexible and varying level of detail and complexity of the simulation model. As well as the possibility to model uncertainties and the dynamic behavior of the real system. What if analysis of different scenarios and training of new staff can be performed on the simulation model without disrupting the real system and committing resources for the acquisition of for example new equipment. In a capital intensive industry this is an essential benefit. New policies and new operating procedures can be tested at low cost.

To achieve this the Discrete Event Simulation model must replicate the real system to a sufficient extent. Effort is necessary to keep the mine models up to date and the simulation model validated. The application of Discrete Event Simulation is still limited to larger mining companies that have the necessary financial capacities. Further research should focus on the development of low-cost simulation tools with an easy usable User-interface adjusted to the mining industry to open up the possibility of Discrete Event Simulation to smaller companies. The comparison of the case study results achieved by simulation to the deterministic spreadsheet approach shows that simulation is beneficial when the interaction of the equipment pieces is hard to predict and the real system depends on dynamic processes. More areas in mining operations that can be modeled with Discrete Event Simulation in addition to haulage fleet management need further research.

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