1-1-2010

Challenges and Opportunities for Simulation Modelling Integrating Mine Haulage and Truck Shop Operations

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10.1080/13895260412331326812
This is an Author's Accepted Manuscript of: Hodkiewicz, M., Richardson, S. J., & Durham, R. (2010). Challenges and opportunities for simulation modelling integrating mine haulage and truck shop operations. Proceedings of 2010 Australian Mining Technology Conference. (pp. 163-172). Perth, Western Australia. CRC Mining. Available here.

CHALLENGES AND OPPORTUNITIES FOR SIMULATION MODELLING INTEGRATING MINE HAULAGE AND TRUCK SHOP OPERATIONS

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ABSTRACT

Historically considerable work has been done to develop models that simulate truck haulage for both underground and open-pit operations. However, this work frequently simplifies or overlooks aspects such as the reliability of the trucks, priority setting and maintenance strategies in the truck shop, and resourcing of the repair facilities. This paper provides an overview of work in this area that is specific to the mining industry and also relevant work from other sectors that might inform how improvements can be made.

The paper proposes some specific projects that will assist in identifying technical issues. Initially, it is important to understand what questions should be asked, and justify why it is worth going to the trouble of building a simulation model. What are the potential benefits? How do we measure the performance of the whole system? Once these are resolved, what are the challenges in incorporating asset management strategy, condition and reliability related data into the truck haulage simulation model? These issues will be explored and suggestions for future projects presented with examples.

INTRODUCTION

As Niels Bohr said back in the early 1900s "*prediction is very difficult, especially about the future.*" In modern mining the ability to predict production numbers and then deliver on them is crucial for managers and stakeholders including the ever-watchful mining investment analysts. While there are many reasons why production numbers are not achieved one common reason is unavailability of mobile assets, and the major type of mobile assets within most surface mines are the trucks and shovels/excavators. Part of managing the uncertainty around future production plans is to actively explore it, asking the "what would happen if?" question. Simulation models are one of the tools that may be used. This paper describes the work done on simulation models for mobile mining assets and focuses on the need to reflect real situations in which the reliability of mobile assets influences mine production goals. This paper is aimed at operations and asset managers who are interested in understanding the cost-benefit factors involved in simulation projects.

OVERVIEW OF SIMULATION DEVELOPMENT PROCESS

Simulation is a tool for analysing anticipated performance, validating designs, demonstrating and visualising operations and performing many other analyses. It is widely used in military, manufacturing and scheduling, logistics, business process, risk management, construction engineering and project management applications, and also in education. Hundreds of articles and papers are produced annually providing application case studies across industries but there are only a handful of papers on the application of simulation to mining haulage or truck shop cases. Why is this and is this an issue for the mining industry?

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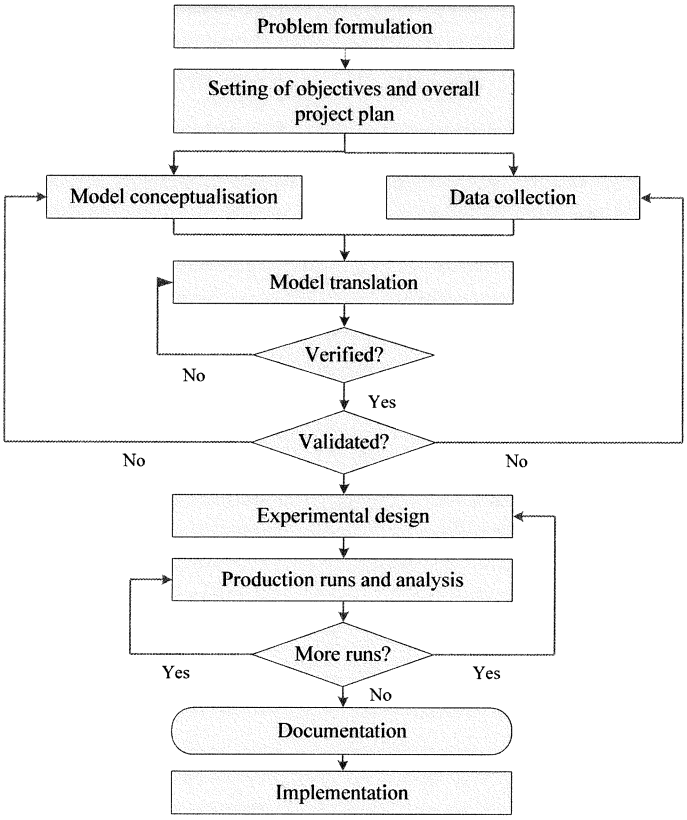

Figure 1: Steps in simulation study (Banks et al., 2005)

There are many excellent books on simulation and the interested reader is referred to (Sokolowski, 2009) and (Banks, 1998) as examples. The core of the discipline is based on an understanding that models can be approximations for the real–world and that simulation of these models can be used to study the behaviour of a real world system over a period of time. In particular, simulations can model the real world in an accelerated time frame, thus exploring in a few minutes the behaviour of systems over many hours, days or even years.

What is involved? In a classic simulation study, the first step is a statement of the problem. The problem drives the development of the model and each model should start with a problem statement that is defined from a business need. Another question that needs to be answered before the simulation can be built is “What are the output parameters (metrics) by which the performance of the system will be measured?” Data from the system provide the input to the model. The availability and form of the data help to specify the model boundaries and details. The role of the modeller is to build the model in accordance with the problem statement and the available system data usually following steps as described in Figure 1. The outputs from the model support decisions required to address the problem (Pritsker, 1998).

Some specific simulation projects on mobile mining assets are described in the following section.

SIMULATION OF MOBILE MINING ASSETS – A REVIEW

A recent review paper of Operations Research in mine planning provides a history of developments using simulation and optimisation approaches to open pit and underground mine design, long- and short-term production scheduling, equipment selection, and dispatching (Newman et al., 2010). It is interesting to note that there is little focus in any of the papers reviewed on asset (truck, shovel, load-haul-dump units etc) maintenance or reliability and how these issues can influence asset availability and production schedules.

The 129 simulation and optimisation papers reviewed in this journal article either omit mention of asset availability or assume it is constant. The need to maintain trucks and shovels, the potential impact of maintenance strategy, adherence to the maintenance schedule, maintenance quality, are not discussed and the potential influence of mobile asset unavailability on system performance and production is not actively considered. This is not intended as a criticism of these works, in many cases the focus of the research papers reviewed in (Newman et al., 2010) is elsewhere. However even papers that look specifically at modelling underground haulage operations using simulation such as (Roberts, 2002, Gamache et al., 2004) do not incorporate any data on unscheduled stoppages, such as vehicle breakdowns.

What work has looked at the impact of mobile asset reliability on mine production from other perspective, outside those of the operations research community?

There have been a number of studies reporting the results of reliability analysis on mobile plant underground (Hall et al., 1998, Hall and Daneshmend, 2003) and in the open pit (Lhorebte et al., 2004). The analysis process described in (Hall et al., 1998) using Pareto analysis of failure, repair and cost data coupled with statistical analysis, which was still the domain of a few highly qualified personnel back in 1998, has since been democratised. The major mining groups now capture asset data as a matter of course and have access to in-house and commercial software for processing and a growing army of reliability analysts. One example of how this data can be deployed to look at potential production delays is provided by (Hall and Daneshmend, 2003) for a decision concerning the opening of a new face for production using various combinations of loaders and trucks. (Louit and Knights, 2001) deploy simulation to quantify the effect of various management initiatives aimed at remedying low equipment availability, a high proportion of unplanned maintenance and non-compliance with preventive maintenance programmes for a mobile mining fleet. This paper provides a useful framework for future projects considering how to set up a discrete event simulation model for a truck shop.

(Vayenas and Yuriy, 2005) applied genetic algorithms to the reliability assessment of mining equipment to predict future TBF and TTR data from an initial population of machine failures. This data is also used in discrete event simulation models for different underground mobile assets (jumbo drill, LHD, and roof bolter) to simulate operation during a development cycle (Vayenas and Xiangxi, 2009). Of particular interest is simulation of the impact of LHD failures on the production cycle. As expected the model demonstrated a significant impact on average tonnage when LHD failures are included as well as lower equipment utilization for the other types of machinery because of longer waiting periods waiting for the LHD to become available. (Sharma et al., 2009) use a Bayesian approach to predict and update production probability distributions. These distributions are influenced by inputs including the historical delays and downtime experienced by the assets. These papers implicitly consider the impact of equipment failures on a mine's throughput using a predictive approach but do not look further back at the maintenance strategies and truck shop processes that might have influenced the reliability of the asset.

Other developments include the trend to fewer, larger capacity mobile assets and greater automation (Roman and Daneshmend, 2000, Bozorgebrahimi et al., 2005). The haul capacity of the largest trucks operating in 1980 increased by 70% over 1960, and again by 112% in the next 20 years from 1980 to 2000 (Roman and Daneshmend, 2000). Driven by a focus on improved production efficiency these developments have also resulted in a greater exposure to production losses from an unplanned asset failure. In the past, the unplanned failure of a single asset may have had minimal effect on production due to the flexibility of reassigning a similar mobile asset from elsewhere in the fleet. The loss of production caused by the unavailability of a single truck is often insignificant with a large fleet of small trucks, but can be very significant with a small fleet of large trucks. The trade off between production costs and reduced flexibility for larger capacity assets is explored in a simulation case study by (Roman and Daneshmend, 2000). The resulting model is sensitive to the 'mean time to repair' distributions and the authors warn of the risks in assumptions around unproven reliability and maintenance characteristics of higher capacity equipment. Both of these issues could be explored with simulation.

The section above demonstrates that relatively little research work has been published on the effects of truck shop configuration and performance, and mobile asset maintenance strategies on production. Does this gap reflect real-life? (Roman and Daneshmend, 2001) in making a case for improved communication and coordination between operations and maintenance to improve mine effectiveness provide the following description of the mine planning process. "Traditionally, overall mine planning is driven by production targets with emphasis on production planning. Based on production schedules, personnel and equipment resources, annual monthly, weekly and production plans are created. In developing these plans, production planners typically assume some level of equipment availability along with utilization factors. They may or may not consult the maintenance department about these values. In most cases the predictions are based on historical data and experience. The availability targets for the equipment become constraints on the maintenance organisation since failure to meet the assumed targets will result in a drop in production. Some allowances are made for unscheduled maintenance should unforeseen failures occur. This activity is difficult to plan for and often throws off the preventative maintenance schedule as resources are diverted to make the urgent repairs that are holding up production. Unfortunately, this priority adjustment has a multiplier effect since the neglected or delayed preventative maintenance is likely to lead to future unscheduled or failure maintenance and a vicious circle can result".

The paragraph above describes why a holistic approach to production and maintenance is important. Progress has been made through changes in reporting responsibilities, assigning metrics across departments (maintenance management is assessed on some production metrics and vice-versa), making visible maintenance metrics to general managers, and so on. There is now a greater awareness at the tactical level but incorporating long-term maintenance plans for mobile assets into long-term production planning remains a challenge.

An integrated TRUCK SHOP and PRoduction model

What questions do general managers have around the capacity and performance of their truck shops? How do they explore options around alternate resourcing options, additional/ reduced bay capacity, prioritisation, changes in maintenance strategy?

These questions lend themselves to simulation. However simulating the truck shop alone to develop answers is seldom sufficient. While a truck shop only model may deliver indicative cost values, a more significant benefit may come from the impact on production. Hence, it is a necessary next step to demonstrate the possible influence of improvements in truck shop operation on production. As described earlier, there are very few examples in the literature to show how this can best be done. Models tend to be done for the asset, the truck shop, or the mine production process, each is separate. This paper postulates that there are potential benefits in integrating the models. These benefits accrue from the ability to explore the impact of truck shop strategy and performance on mine production and hence the value chain. This exploration assists in the development of business cases for truck shop and maintenance improvement projects and in the identification and proactive management of risk.

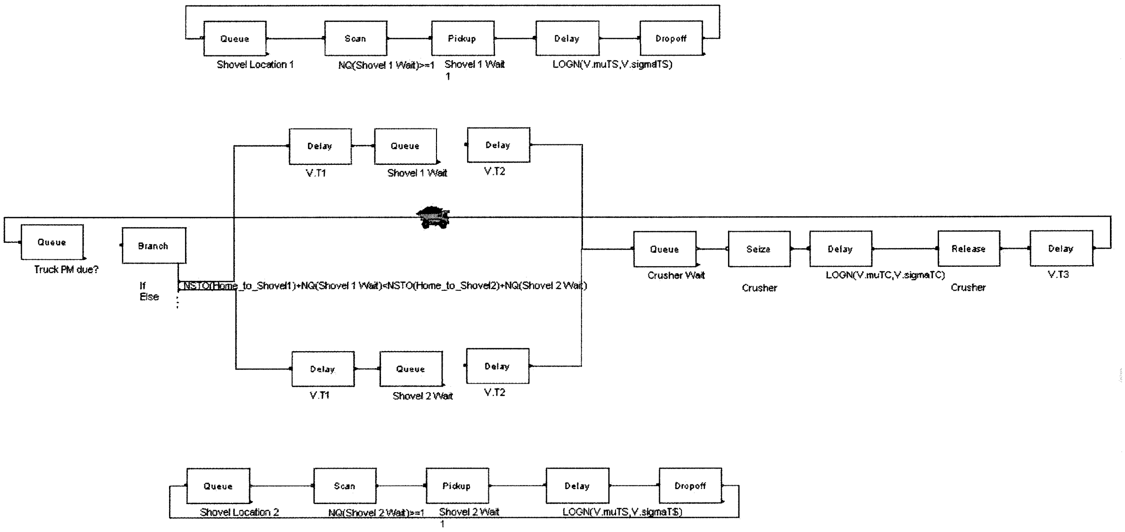

Figure 2: Screen shot of part of a simple simulation model

The following section demonstrates how a simple simulation model (shown in Figure 2) can be used to analyse the impact of priority setting and the quantity of repair resources available on the production tons and the availability of the mobile assets.

In conceptualising this model the following individual components have been identified, 8 trucks, and 2 shovels (or excavators), truck shop and crusher. The shovels operate at fixed locations, and load trucks from an (assumed) unlimited pile of ore. The trucks transport ore from the shovel(s) to a single crusher location. The shovels and crusher can only deal with one truck at a time, so queuing is necessary. With the exception of undergoing maintenance (either preventive or corrective) the trucks and shovels operate continuously (i.e. shift changes and crib breaks are ignored). Table 1 shows typical inputs for a model and some initial assumptions.

Example Inputs	*Notation*	*Assumption*
Travel time (between truck shop and shovel)	T_1	Constant value
Travel time (between shovel and crusher/ and return)	T_2	Constant value
Normal Travel time (between crusher and truck shop)	T_3	Constant value
Additional travel time between crusher and truck shop after an unplanned failure		Log Normal (μ_{fT}, σ_{fT})
Loading time at shovel		Log Normal (μ_{TS}, σ_{TS})
Unloading time at crusher		Log Normal (μ_{TC}, σ_{TC})
Failure distribution for each truck		Weibull (β_T, η_T)
Failure distribution for each shovel		Weibull (β_S, η_S)
Truck repair time distribution for scheduled work		Log Normal (μ_{rT}, σ_{rT})
Shovel repair time distribution for scheduled work		Log Normal (μ_{rS}, σ_{rS})
PM Inspection interval (for each truck)	t_T	Constant value
PM Inspection interval (for each shovel)	t_S	Constant value
Repair time penalty factor for unscheduled work (truck)	α_T	Constant value
Repair time penalty factor for unscheduled work (shovel)	σ_S	Constant value

Table 1: Typical inputs for a simulation model

Developing the model requires an understanding of what causes interruptions to the truck cycle between shovel and crusher (for simplicity shovel to waste has been ignored), how often they occur, and what the impact is. In this simple example, we assume that each mobile asset may become unavailable due to planned maintenance inspections (PMs) and corrective maintenance (unplanned failure). Major repairs are not included but could be if desired. We assume that when an asset fails that repairs return the asset to "as good as new" condition. PMs are scheduled and when a PM is due the asset completes its current task before presenting at the truck shop (even if there is already a queue). The frequency of unplanned failure and the time to repair are represented by distributions, the parameters of which can be adjusted.

The penalty for allowing a truck failure to occur is a loss of availability due to the additional time to get the truck to the shop and the time to perform the repair. Assumptions can be made to represent additional time taken to complete an unplanned repair when compared to a planned job. In reality a truck failure in the pit may or may not result in a loss of production depending on the production plan and its flexibility.

The truck shop may be represented as a (variable) number of repair resources. Each resource may include a physical space such as a truck bay and associated labour and tool team. Trucks arriving at the shop are attended to immediately if at least one of the repair resources is available, and will wait in a queue if they are all busy. When shovels need maintenance, the resources generally travel to the shovel site. When there are multiple assets waiting for maintenance they will be attended to in order based on specified priority logic (e.g. first in first served, or shovel before trucks etc).

The model was run for a 100 times over 100 days and results are shown in Table 2. There has been no attempt to validate the model as it is based on generic data and a conceptual site.

Number of repair resources	*Shovel has Priority*	*Average Production (number of loads)*	*Average Truck Availability (%)*	*Average Shovel Availability (%)*
1	No	11134	76.6	75.1
1	Yes	11744 (+5.5%)	73.3 (-4.3%)	83.4 (+11.1%)
2	No	14631	87.6	86.9
2	Yes	14713 (+0.6%)	87.5 (-0.1%)	87.5 (+0.7%)
3	No	15005	88.5	88.4
3	Yes	14991 (-0.1%)	88.5 (+0.0%)	88.4 (+0.0%)
4	No	15015	88.6	88.4
4	Yes	15012 (-0.0%)	88.6 (+0.0%)	88.4 (+0.0%)

Table 2: Results of simulation example for mine-truck shop over 100 days

The results illustrate the following.

1. Priority setting impacts on production and availability.
2. Repair resource level impacts on production and availability.
3. There is a reduction in marginal benefit as repair resources are increased.

It should be noted that the apparent reduction in difference between the two priority strategies as the number of repair resources increases is due to the relatively small number of mobile assets compared to repair resources (i.e. competition for repair resources becomes insignificant and hence priority strategy has little impact).

This simple example has been used to explore two what-if scenarios, prioritisation and repair resources. There is considerable potential to explore more complex scenarios and explore alternative assumptions regarding model design. Some of the challenges include validation of the model for a specific site and determining when results show statistically significant differences in light of uncertainties in the assumptions.

Extensions to this work might consider the following

- How best to model 'penalties' associated with unplanned failures? These may include cost, time and schedule penalties as well as issues to do with what (component/ sub-system) has failed.
- How does major component replacement interval selection impact production?
- How does selection of maintenance strategy (usage based, condition based, run to failure) impact asset reliability and hence the probability of future unplanned failures?
- How to best represent the impact of deferring/ missing preventative maintenance inspections on asset reliability, unplanned failures and hence production targets?
- How to measure the extra cost/ benefit of increasing available repair resources?

ARE SIMULATION MODELS WORTHWHILE?

As exciting as the potential to look at some of these issues is, there is the question of cost/ benefit analysis. Many organisations have invested considerable time and resources to develop models, including simulation models that have not delivered on expectations. Jerry Banks (Banks, 1997), a prolific writer of books and articles on simulation developed a list of ten rules for when simulation is not appropriate.

1. The problem can be solved using common sense analysis
2. The problem can be solved analytically (as it is usually less expensive)
3. It is easier to change or perform direct experiments on the real system
4. The cost of the simulation exceeds possible savings
5. There aren't proper resources available for the project
6. There isn't enough time for the model results to be useful
7. There is no data – not even estimates
8. The model can't be verified or validated
9. Project expectations can't be met
10. The system behaviour is too complex or can't be defined.

As recently as five years ago the mining industry might have struggled with the data and proper resources issues mentioned above (items 5 and 7). However this is no longer the case. We have seen significant improvement in the collection and availability of failure and repair data, an increase in training for reliability analysts, and greater access to a wider variety of simulation software products. There is also a greater focus on data driven decision making necessitating a focus on use of prediction and other simulation work to support business case development.

There are benefits to model construction that extend beyond the generation of quantifiable values for decision-making. Model construction requires extensive communication across a number of groups resulting in knowledge exchange, and the process contributes to the capture and storage of maintenance, failure and operational knowledge within the organisation

(Hodkiewicz, 2008). Constructing a model has beneficial outcomes in terms of communication and knowledge management in addition to the value of producing a set of numbers that quantifies expected number of outages, total downtime and other metrics. As the foundation of 'good' models is an understanding of the structure and operating rules of the system, the process of constructing the model requires the engineer to communicate with a wide range of operational, engineering and maintenance personnel to obtain information (Robinson and Pidd, 1998). The model captures and codifies this knowledge. The consultation process can reveal issues about the operation of the asset or system that may not have been appreciated by all stakeholders; and the output of the model can challenge people's understanding of how they thought the process actually worked. In the situation under discussion in which there is a recognised lack of appreciation for the challenges experienced by production (in maintenance) and by maintenance (in production), this is a real benefit worth exploring.

There are organisational challenges for managers of simulation projects. Planning for the use of the model is important and discussions with stakeholders are vital to ensure the model results are used appropriately. It is a challenge for someone not familiar with the process to make the sort of valid simplifying assumptions that could result in a model being built that adequately represents the core of the problem. This is often best achieved by involving people familiar with the model construction process but it is difficult to do this unless they feel that the investment of their time is worthwhile (Sokilowski and Banks, 2009).

CONCLUSION

As Scott Adams said *"there are many methods for predicting the future. For example, you can read horoscopes, tea leaves, tarot cards, or crystal balls. Collectively, these methods are known as nutty methods. Or you can put well-researched facts into sophisticated computer models, more commonly referred to as a complete waste of time."* In this article we set out a case for use of simulation computer models, a sophisticated but accessible tool. We hope that this article will encourage operations and asset managers to consider when simulation may be an appropriate tool to explore how changes to truck shop operation and maintenance strategy will impact on mine production.

ACKNOWLEDGEMENTS

The authors wish to thank Widyo Hadiseputro and Christopher Vernon, both engineering honours students at UWA, for their contributions to this paper.

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