OPEN-PIT TRUCK/SHOVEL HAULAGE SYSTEM SIMULATION

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

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This thesis is aimed at studying the open pit truck- shovel haulage systems using computer simulation approach. The main goal of the study is to enhance the analysis and comparison of heuristic truck dispatching policies currently available and search for an adaptive rule applicable to open pit mines. For this purpose, a stochastic truck dispatching and production simulation program is developed for a medium size open pit mine consisting of several production faces and a single dump site using GPSS/H software. Eight basic rules are modeled in separate program files. The program considers all components of truck cycle and normal distribution is used to model all these variables. The program asks the user to enter the number of trucks initially assigned to each shovel site.

Full-factorial simulation experiments are made to investigate the effects of several factors including the dispatching rules, the number of trucks operating, the number of shovels operating, the variability in truck loading, hauling and return times, the distance between shovels and dump site, and availability of shovel and truck resources. The breakdown of shovel and trucks are modeled using exponential distribution. Three performance measures are selected as truck production, overall shovel utilization and overall truck utilizations. Statistical analysis of the simulation experiments is done using ANOVA method with Minitab software. Regression analysis gives coefficient of determination values, R^2, of 56.7 %, 84.1 %, and 79.6 % for the three performance measures, respectively. Also, Tukey's method of mean comparison test is carried out to compare the basic dispatching rules. From the results of statistical analysis, it is concluded that the effects of basic truck dispatching rules on the system performance are not significant. But, the main factors affecting the performances are the number of trucks, the number of shovels, the distance between the shovels and dump site, finally the availability of shovel and truck resources. Also, there are significant interaction effects between these main factors. Finally, an adaptive rule using the standardized utilization of shovels and trucks is developed.

Keywords: Open Pit Truck-Shovel Haulage systems, Truck Dispatching, Heuristic Rules, Discrete-Event System Simulation Approach, and GPSS/H Software.

ÖZ

AÇIK OCAK KAMYON/EKSKAVATÖR TAŞIMA SİSTEMLERİN SİMÜLASYONU

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Bu çalışma, bilgisayar simülasyonu yöntemi kullanılarak açık ocak kamyon – Ekskavatör sisteminin araştırılmasını amaçlamaktadır.Çalışmanın temel amacı, mevcut olan hüristik kamyon atama kurallarının analizi ve karşılaştırılmalarını incelemektir.Bu amaçla, birkaç üretim panosu ve bir tek döküm sahasından oluşan orta ölçekli bir maden için GPSS/H simulasyon paket programı kullanılarak olasılıklı bir kamyon atama ve üretim modeli geliştirilmiştir. Sekiz değişik hüristik kural, ayrı ayrı programlar olarak kodlanmıştır. Program kamyon devir sürelerinin bileşenlerinin tamamını içermektedir. Normal dağılım fonksiyonu bütün devir bileşenlerinin modellemesinde kullanılmıştır. Program kullanıcıya, her bir ekskavatöre başlangıçta yapılan kamyon sayılarını sormaktadır.

Tam faktörlü simülasyon deneyleri sekiz ayrı faktörün araştırılması için yapılmıştır. Bu faktörler, kamyon atama kuralı, kullanılan kamyon sayısı, kullanılan ekskavatör sayısı, kamyon yükleme, taşıma ve geri dönüş sürelerindeki değişim, ekskavatör ile döküm sahası arasındakı mesafe, ve kamyon ve ekskavatörlerin kullanım randımanlarıdır. Kamyon ve ekskavatörlerin arızaları üstel dağılım fonksiyonu kullanılarak modellenmiştir. Performans ölçütleri olarak ta, kamyon üretim miktarı, toplam ekskavatör kullanma oranı ve toplam kamyon kullanma oranları alınmıştır.Simülasyon deneyleri sonuçları, ANOVA metodu ile Minitab paket programı kullanılarak istatistiksel olarak analiz edilmiştir. Regrasyon analizleri sonucunda bu üç performans ölçüsü için R^2- degerleri sirasıyla, 56.7 %, 84.1 % ve 79.6 % olarak hesaplanmıştır. Tukey testi ile de bu temel kamyon atama kuralları istatistıksel olarak karşılaştırılmıştır. Yapılan analizler sonucunda, temel kamyon atama kurallarının performans ölçütlerini fazla etkilemedikleri sonucuna varılmıştır. Fakat, performasları etkileyen ana faktörlerin, kullanılan kamyon sayısı, kullanılan ekskavatör sayısı, döküm sahasına olan mesafe ve ekipmanların kullanma randımanlarını olduğu sonucuna varılmıştır. Ayrıca, bu etkileyen temel faktörler arasında da oldukça ikili etkileşmenin olduğu gözlemlenmiştir. Son olarak, kamyon ve ekskavatörlerin standartlaştırılmış kullanma oranları kullanılarak yeni bir adaptif kamyon atama kuralı geliştirilmiştir.

Anahtar Kelimeler: Açık Ocak Kamyon- Ekskavatör Sistemi, Kamyon Atama, Hüristik Kurallar, Kesik-Olaylı Sistem Simülasyon Metodu, GPSS/H Simülasyon Programı

To My Parents and My Dear Grand Mother Dudu ELMAS

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SYMBOLS

GPSS	General Purpose Simulation System
ANOVA	Analysis of Variance
TP	Total Production
SU	Shovel Utilization
TU	Truck Utilization
DR	Dispatching Rule
NT	Number of Operating Trucks
S	Number of Operating Shovels
LT	Truck Loading Time
HT	Truck Hauling Time
RT	Truck Returning Time
SDD	Distance Between Shovels and Dumping Point
A	Shovel and Truck Availability
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
FTA	Fixed Truck Assignment
MSPR	Minimizing Shovel Production Requirement
MTWT	Minimizing Truck Waiting Time
MSWT	Minimizing Shovel Waiting Time
MTCT	Minimizing Truck Cycle Time

MSC	Minimizing Shovel Coverage
ELS	Earliest Loading Shovel
LWS	Longest Waiting Shovel
AR	Adaptive Rule
K	Shovel Number to Which Truck is Assigned
TNOW	Time Elapsed from Start of Shift
TSHIFT	Total Shift Time
P_i	Actual Shovel Production at Current Time
PO_i	Shovel Target Production
SR_i	Ready Time of Shovel for Loading This Truck
TR_i	Ready Time for The Truck to Be Loaded by The Shovel
TCT	Truck Cycle Time
TT	Mean Truck Travel Time from Dispatching Point to Shovel
STU	Standardized Truck Utilization
TU_{cur}	Current Truck Utilization
TU_{mean}	Mean Truck Utilization
SDTU	Standard Deviation of Truck Utilization
SSU	Standardized Shovel Utilization
SU_{cur}	Current Shovel Utilization
SU_{mean}	Mean Shovel Utilization
SDSU	Standard Deviation of Shovel Utilization

CHAPTER 1

INTRODUCTION

Surface mining involves the basic procedures of topsoil removal, drilling and blasting, ore and waste loading, hauling and dumping and various other auxiliary operations. Loading of ore and waste is carried out simultaneously at several different locations in the pit and often in several different pits. Shovels and frond-end loaders of various sizes are used to load material onto trucks. Hauling material from the shovel production faces to the dumping sites must be accomplished through a network of haul roads of various length and grades. Haul roads can be extremely complex, cover large surface areas and pass through extreme elevation changes. Loading times of shovels depends on shovel capacity, digging conditions, and the truck capacity. Queues often will form at the shovels since trucks of various sizes may be used at individual shovels. Thus, allocation of trucks to haul specific material from a specific pit or shovel becomes a complex problem. Obviously, efficient mining operations are strongly dependent on proper allocation of trucks to shovels and the respective allocation of trucks along the appropriate haul roads and dump sites. The number and type of trucks and shovels are two important factors in determining the optimum design parameters of an open-pit mining system. Also, the characteristics of truck's arrival and loading times at shovels determine the performance measures (i.e. total production) of truck-shovel system. The assumptions of identical truck travel and loading times may result in underestimating or overestimating the performance of these systems.

The ability to assess the performance of a truck-shovel system in open-pit mines accurately would be a very useful device for mining companies. Any marginal improvement in the performance would save a significant amount of money in most modern open-pit mining operations where very large capital investments are required to purchase and replace the necessary equipment. Accurate assessment of the system performance is not so easy because of the complexity of the system. However, with some simplifying assumptions one can obtain fairly accurate results using computer simulation techniques for all practical purposes.

One of the major issues in open-pit mining operations is the selection of trucks and shovels that would satisfy some economic and technical criteria optimally. This problem is faced at the design stage of the mine as well as during the operation of the mine where there may be a need to redesign for expansion purposes. The solution lies in efficient prediction of performance parameters for various combinations of trucks and shovels under realistic assumptions. These parameters could be used to determine the impact of different scenarios on the productivity of the operation and select the best promising alternative for actual design goals. Given the characteristics of the truck-fleet, dynamic routing of trucks to different service areas (i.e. loading and dumping) cannot be done arbitrarily since this would seriously affect the productivity of the mine. Therefore, it is very important for optimal operation that the design parameters should be determined accurately and applied at all stages of mining operation.

Efficient truck dispatching represents a traditional approach to improve production equipment utilization in open-pit mining operations. Increasing the equipment utilization can result in a greater increase in the profitability of operation and decrease in the truck-fleet size as well as increase in production. Truck haulage represents 50% or more of the total operating costs in most surface mines (Kennedy, 1990), and efforts have been made to reduce these high haulage costs. These include improving operating performance of the trucks resulting in higher efficiency and reliability, increasing the payload capacity of trucks, employing in-pit crushers and conveying systems with truck haulage, and using trolley-assisted trucks to reduce the truck cycle times. Another concept currently under development is the use of driver-less trucks since this approach has the potential to reduce the labor costs. These effort have focused on truck or haulage system designs. The same cost reduction goals can also be realized by more efficient utilization of trucks and shovel resources, which is primary objective of computer-based truck dispatching systems. With computer-based truck dispatching, one hopes either to increase production with existing truck and shovel resources or meet the desired production goals with reduced equipment requirements. This goal is achieved with careful consideration of assignment decisions that increase utilization of truck and shovel resources and reduce waiting times in the haulage network. Haulers are only productive when they are carrying a load and loaders are also only productive when loading material for haulage. Idle equipment times are the essence of non-productive equipment and they have to be minimized.

Truck dispatching issue is one of assigning trucks to shovels in a well-designed system on real-time basis so as to ensure the achievements of some goals or minimize the underachievement of such goals. The general problem solved by truck dispatching routines is to determine the shovel to which the current truck at the dispatching station should be assigned. The objective of computer-based truck dispatching is to improve the equipment utilization and increasing production subject to a variety of practical constrains. A computer truck dispatching system consists of two main components as hardware and software. Developments in hardware are concentrated on signal acquisition and transmission equipment and computer. Computational procedures are becoming relatively easier with the development of high-speed computers. Also, truck dispatching software presents many opportunities for improving the performance of open-pit mining systems.

Truck-shovel system is a complex mining system with respect to its stochastic features and interaction between system elements. It is naturally impossible to derive some global optimal solution algorithm for truck dispatching problem (Tan an Ramani, 1992). Therefore, every dispatching criterion is based on a consideration of local optimization. Various methods have been employed to model truck-shovel system. Some of these methods rely on empirical rules or trial and error and some are highly mathematical requiring significant computational effort. Analysis of open-pit truck-shovel system using computer simulation is a well-established procedure since it allows incorporating the inherent variability and complexity of the system.

This thesis is divided into six chapters including the introduction. A through literature review of truck dispatching systems and simulation models and the purpose of the thesis are presented in Chapter 2. The eight basic heuristic truck dispatching policies programmed together with the new adaptive rule are discussed in Chapter 3. Chapter 4 presents the input data sets and the basic assumptions made, and explains in detail the development and the general structure of the simulation model. The design of simulation experiments together with the statistical analysis performed over the results and discussions are presented in Chapter 5. Finally, the conclusions and the recommendations for further research made are given in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Problem Statement

The purpose of this research is to develop a stochastic truck dispatching and production simulation model program for a medium-sized open pit mine consisting of several production faces and a single dump location. We have used GPSS/H software to investigate the effects of several basic heuristic truck dispatching criteria currently available. The main objective of this research is to enhance the analysis and comparison of heuristic truck dispatching policies and search for a hybrid rule applicable to open pit mines.

Another aspect of this research is to develop animation of a truck dispatching system to aid users to observe dynamic activities in a truck-shovel system and follow the logic and assumptions of a simulation model readily. The specific objectives are to:

1. study the impact of various heuristic dispatching policies;
2. test and compare several heuristic dispatching strategies for improving haulage productivity;
3. serve as a planning tool for estimating the expected production of a given truck haulage system;
4. reveal bottlenecks in a proposed truck haulage system;

5. use animation as a tool to convince decision-makers and to train dispatchers.

2.2 Truck dispatching systems

The significant improvements in computer technology have led the mining industry to develop several decision making models for deciding the best possible assignment of trucks in an open-pit mine. Computerized truck dispatching systems were developed in the late 1970`s and have become the common mode of operation at many large open pit mines. But, they were not economically justified for small and medium-sized haulage operations due to high costs of implementation. Fortunately, tremendous improvements in computer hardware and decreases in costs occurred since late 1980`s as well as the need for to increase productivity and equipment utilization. Truck dispatching systems can be classified into three major categories as: manual, semi-automated and full automated. Most of the dispatching systems in the literature are either semi-automated or full automated. The benefits and shortcomings of the dispatching systems are outlined in the following sections.

2.2.1 Manual Dispatching systems

The manual dispatching system is the standard practice of truck assignment. The trucks are assigned to a particular shovel and dump point at the beginning of the shift, changing the circuit according to the dispatcher's best judgment of the situation based on production requirements, shovel locations, fleet