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SIMULATION BASED INVESTIGATION OF DIFFERENT FLEET MANAGEMENT PARADIGMS IN OPEN PIT MINES-A CASE STUDY OF SUNGUN COPPER MINE

SYMULACJE I BADANIA RÓŻNYCH PARADYGMATÓW WYKORZYSTANIA FLOTY POJAZDÓW I URZĄDZEŃ W KOPALNIACH ODKRYWKOWYCH. STUDIUM PRZYPADKU: KOPALNIA MIEDZI W SUNGUN

Using simulation modeling, different management systems of the open pit mining equipment including non-dispatching, dispatching and blending solutions have been studied for the Sungun copper mine. Developed model has the capability of considering detailed features of both loading and hauling equipment. Productivity assessment scenarios have been established on the constructed model and the outputs revealed the noteworthy impact of the match factor of the trucks to the loaders on the production rate by over 40%. A dispatching simulation model with the objective function of minimizing truck waiting times have been developed and 7.8% improvement obtained by applying a flexible assignment of the trucks for the loaders compared to the fixed assignment system. Finally ore grade blending control unit has been introduced into the model. Getting the advantages of the newly added module it became possible to monitor the portion of material excavated from different operating benches and control truck dispatching rules for keeping the overall ore grade exactly at desired value.

Keywords: Simulation modeling, match factor, dispatching, ore blending, open pit mining

Przy użyciu modeli symulacyjnych zbadano różnorodne systemy zarządzania flotą pojazdów i urządzeń w kopalni odkrywkowej (wydawanie dyspozycji przewozu, wstrzymywanie przewozu oraz rozwiązania kwestii mieszania o rud o różnej zawartości pierwiastka użytecznego) na przykładzie kopalni miedzi Sungun. Opracowany model uwzględnia szczegółowe cechy sprzętu przeładunkowego oraz transportowego. Na podstawie modelu opracowano następnie scenariusze oceny wydajności, a wyniki jednoznacznie wykazały wielką wagę odpowiedniego skojarzenia ilości pojazdów i ładowarek. Opracowano model symulacyjny kierowania urządzeń do pracy, jako funkcję celu przyjmujący minimalizacje czasu przestoju ciężarówek. Uzyskano wynik lepszy o 7.8% poprzez elastyczne przydzielania pojazdów do ładowarek w porównaniu do systemu trwałego ich do siebie przypisania. W ostatnim etapie dodano do modelu system kontroli procesu mieszania rud o rozmaitej zawartości pierwiastka użytecznego. Korzystając z nowo-dodanego modułu, możliwe stało się monitorowanie porcji materiału wybieranego z poszczególnych poziomów

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i kontrolowanie rozsyłanych ciężarówek tak, by w skali całej kopalni możliwe było ciągłe utrzymanie zawartości pierwiastka użytecznego na żądanym poziomie.

Słowa kluczowe: modele symulacyjne, współczynnik dopasowania, dyspozycje do przewozu, mieszanie rud o różnej zawartości pierwiastka użytecznego, górnictwo odkrywkowe

1. Introduction

Truck and loader systems are widely used in open pit mines due to their flexibility and productivity features in comparison with the other haulage systems. Although these systems require the least infrastructure to be settled in mining operations (Rodrigo et al., 2013), but still haulage costs in earthmoving projects constitutes the main portion of total expenditures (Oraee & Asi, 2004). Lizotte et al. believe that material handling represents more than 50% of whole operating costs and some others estimate this amount to reach 60% in some cases (Alarie & Gamache, 2002). Hence the mining operation is a highly expensive industry; even a small reduction in these costs would be noteworthy for both managers and mine planners. In other words, reducing haulage costs just for a few percent would cause remarkable savings in both operating and capital costs.

As the need for raw material by the industry increases, open pit mines go deeper and low grade deposits look economic for exploitation (Ahangaran et al., 2012). Though trying to design bigger equipment was considered as the first step to respond to this query, that's why today we encounter some gigantic trucks with about 350 tons capacity and some big shovels to serve these dump trucks. But it seems that the trend for capacity increase cannot keep up with the high demand for productivity, so the next step in coping with this highly increasing demand is to try to find the best solution for the management of the operating fleet in mine.

There are some indices indicating the efficiency of the operating haulage system (Krzyzanowska, 2007), among which the match factor of trucks and loaders is one of the important ones. The match factor of truck and loader deals with both truck and loader cycle times and it is defined as having the ideal number of trucks for loaders. On the other hand, transition of fleet management paradigm from fixed to flexible assignment of trucks for loaders has been discussed for more than 35 years. Application of first dispatching system in a limestone quarry mine in Germany showed a great improvement in equipment efficiency (Eduardo Bonates, 1988) and since then different dispatching packages with diversity of optimization criteria have been introduced to mining industry.

In 1988 Eduardo Bonates and Yves Lizotte worked on evaluation of applying a dispatching system by use of a computer simulation model. In this model, they categorized fleet management systems in 3 main groups including: Manual Dispatching, Semi-Automated Dispatching and Automated Dispatching (Eduardo Bonates, 1988). The resulted model which was written in FORTRAN, attempts to take into account the real features of the mine and optimize the utilization of the trucks and shovels as an LP objective function (Eduardo Bonates, 1988). Z. Li introduced a methodology for optimum control of shovel and truck operation in 1989 (Li, 1989). The mentioned methodology was developed by applying 3 indicating questions and trying to find the best answer to each:

- How much load in each route should be handled inside the pit and which route network is the optimum?
- How are the trucks assigned to the shovels?
- What is the best number of trucks to achieve the excavation target?

Later F. Soumis et al. developed a procedure for solving dispatching problem (Soumis et al., 1989). Their research was based on a nonlinear objective function with 3 parameters including: deviation of shovel's operational excavation from its objective excavation, deviation of trucks' real working hours from their scheduled operating hours, the third factor consists of some penalties assigned for deviation from desired ore blending (Soumis et al., 1989). In 1993 B. Forsman et al. designed a computer simulation model for Aitik open pit mine (Forsman et al., 1993). Using a discrete event modeling microcomputer called METAFORA, they could build a graphical model of the mine. Simulation results dictated the optimum haulage network and number of trucks in order to reach desired excavation target (Forsman et al., 1993). D. Gove and W. Morgan worked on truck-loader matching and the influential parameters using CAT's fleet production and cost (FPC) software (Gove & Morgan, 1994). B. Kolonja and J.M. Mutmansky developed a simulation model for analyzing dispatching strategies using SIMAN (Kolonja & Mutmansky, 1995). A dispatching strategy is the way a dispatching system encounters with optimization problem (Kolonja & Mutmansky, 1995). Heuristic strategies try to find local optimums while in combined strategies an LP model takes the production objectives into account and then a heuristic procedure assigns the truck to the shovels (Kolonja & Mutmansky, 1995). M. Ataeepour and E. Y. Baafi worked on a simulation model for truck-shovel operation using Arena (Ataeepour & Baafi, 1999). The first step is to monitor the effect of number of trucks in system utilization and then applying a dispatching rule with objective function of minimizing trucks waiting times. In other attempt in 1999 A.J. Basu proposed a simulation model for Kalgoorlie Consolidated Gold Mines (KCGM) using GPSS/H. applied strategy in this model is to assign a truck to a shovel with least queue length (Basu, 1999).

S. Alarie and M. Gamache conducted a research on solution strategies used in truck dispatching systems for open pit mines (Alarie & Gamache, 2002). Based on their research, dispatching problem can be solved using two major approaches: a single stage approach tries to dispatch the trucks without applying any excavation constraint or blending while in a multistage approach an excavation target using LP or heuristic methods is set to the operation as the upper stage. In lower stages the assignments are handled in a way that the deviation of operational excavation from the targets that are suggested by upper stage to be minimum. Qiang Wang et al. studied truck real-time dispatching from macroscopic perspective (Wang et al., 2006). By evaluating the flow rates of the trucks and introducing some base nodes, the proposed model showed better results in comparison with the conventional dynamic programming methods.

In 2007 C.N. Burt and L. Caccetta proposed some approaches for calculation of match factor for heterogeneous truck and loader fleets (Burt & Caccetta, 2007, 2008). Based on their methods, match factor of a fleet consisting different types of trucks and shovels is attainable considering their cycle times. The proposed method is also capable of considering different haul road features.

A. Jaoua et al in 2009 developed a framework for realistic microscopic modeling of surface mining transportation systems (Jaoua et al., 2009). They believed the conventional macroscopic models lacked considering microscopic features of the system under study. Therefore a simulator called SuMiTSim is developed by A. Jaoua et al using SIMAN. An important indicator in this simulator is the occupancy level of the road segments (Jaoua et al., 2009). Real time study of the mine traffic using the strategy of optimizing the occupancy level of road segments makes it easy to deal with unwanted traffic congestions and strengthens the flexibility of the system. Comparisons of SuMiTSim with other macroscopic simulators concluded that the microscopic approach has the ability of considering detailed features of mining operation like interaction between equipment and operators. thus, the dispatching model based on microscopic approach has higher reliability level in contrast with other macroscopic models (Jaoua et al., 2009). E.K. Chanda and S. Gardiner compared different methods for prediction of truck cycle times (Chanda & Gardiner, 2010). The results approved that by using multiple linear regression method and artificial neural networks (NN), one can estimate the truck cycle time with the least deviation from reality while using simulation software like TALPAC leads to more deviated outputs.

2. Sungun mine features and model construction

Sungun copper deposit is the second largest copper mine in Iran. It is located in a mountainous area between Sungun and Pakhir rivers in Eastern Azerbaijan province of Iran, by the border of Azerbaijan and Armenia and 130 km from Tabriz, the capital of the province. The geological reserve of the deposit is estimated at 828 million tons with an average copper grade of 0.62 percent. Mining operations are handled using rigid frame rear dump trucks and hydraulic shovels and backhoes and front end loaders. Annual excavation target for the mine is 30M tons of ore and waste and the fleet is managed in non-dispatching mode. Operating fleet consists of Komatsu HD 785 and HD 325 dump trucks, Liebherr R9350 Hydraulic shovel, Komatsu PC 800 hydraulic backhoes, Komatsu WA 600 and CAT 988 front end loaders. There are 3 main dumping destinations for trucks: crusher, low grade stockpile and waste dump. Each working day consists of 3 shift rosters and the mine is operating 24 hours a day and 363 days in a year.

Required data for analyzing haulage system utilization is to record time periods for trucks' and loaders' cycle, queue time at loading point and loaders' idle time. These time sets are then used as input data for simulation software. For recording cycle times, a recording procedure was designed for each of the operating faces, so there was a chronograph instrument for each face recording mentioned time data. For recording each truck's cycle time, a reference time point was assigned for it which was the moment that the loader pours its first bucket load into the truck tray. This moment was recorded in the report paper in front of the truck's ID which was unique for each truck. When after a period of time the same truck appears in loading point, again the mentioned reference point was recorded to the truck, therefore, each truck cycle time would be attainable via deducting two following reference points. Similarly another reference point was assigned for recording of the loading times which was the moment that the empty truck at the loading point started to maneuver for positioning till it starts leaving the loading station. In this case the latter would be considered as loading with exchange time instead of just loading time. Truck waiting time was considered the time period from getting a truck to the loading point till starting to maneuver for loading. Gathered raw data were then inserted into a spreadsheet to conduct some statistical analysis. At first point some data were considered as outlier and omitted from following calculations (Forsman et al., 1993); the logic applied was considering a significance level of $\alpha = 0.05$ so that accepted data are as followed:

$$\bar{X} - 1.96S < x < \bar{X} + 1.96S$$

Where S is the standard deviation and $\bar{X}$ is the average of the sample data; then x would be accepted region for data. Once all data sets were approved through this procedure, each set was statistically analyzed to fit a distribution function. Using Kolmogorov-Smirnov and Chi Square tests, the best function with the least square error from the empirical data was selected.

TABLE 1

Specifications of the loading stations

No.	Loading Station	Dumping Station	Distance (m)	Loader	Hauler	No of Hauler
1	2037.5 S	Crusher	1000	CAT 988	Komatsu HD 325	3
2	2100	Crusher	2700	Komatsu WA 600	Komatsu HD 785	2
3	2087.5	Dump	1200	Hyundai 500	Komatsu HD 325	3
4	2025	Dump	1975	Komatsu PC 800	Komatsu HD 785	3
5	2087.5	Stockpile	2200	Hyundai 500	Komatsu HD 325	3

TABLE 2

Distribution Functions for Collected Data

Working Bench	Data Set	Best Fitted Model
1	Truck interarrivals	0.5+10*BETA(0.84,1.12)
	Waiting in queue	-0.5+7*BETA(1.08,1.43)
	Loading times	NORM(3.22,0.443)
	Hauling times to destination	2.19+3.29*BETA(1.32,1.82)
	Dumping times	0.4+ERLA(0.0579,4)
2	Truck interarrivals	7.5+ERLA(0.728,3)
	Waiting in queue	0
	Loading times	TRIA(4.39,4.68,6.26)
	Hauling times to destination	6+1.76*BETA(1.18,1.04)
	Dumping times	NORM(0.647,0.0973)
3	Truck interarrivals	2.5+GAMM(0.369,6.38)
	Waiting in queue	-0.5+ERLA(0.525,5)
	Loading times	TRIA(2.82,4.02,4.53)
	Hauling times to destination	3+1.66*BETA(2.48,2.5)
	Dumping times	0.4+WEIB(0.263,2.36)
4	Truck interarrivals	NORM(6.28,2.15)
	Waiting in queue	NORM(4.97,1.92)
	Loading times	NORM(5.29,0.67)
	Hauling times to destination	NORM(4.32,0.784)
	Dumping times	0.4+GAMM(0.0527,4.52)
5	Truck interarrivals	0.5+WEIB(6.4,2.01)
	Waiting in queue	-0.5+LOGN(0.912,0.733)
	Loading times	2.48+ERLA(0.233,5)
	Hauling times to destination	6.3+GAMM(0.246,4.56)
	Dumping times	0.4+GAMM(0.0527,4.52)

As it was screened inside the mine, there were 5 major loading faces, which were considered as 5 loading stations. Table 1 shows destinations for each station, distances from loading to dumping points, and specifications of fleet in each subsystem. (Contents in loading station column refer to elevation of the corresponding operating bench inside the pit). Table 2 shows the best fitted models for each data set. All times are in minutes in this table.

Once the required input data were prepared for all operating faces, a simulation model should be constructed to represent real characteristics of loading and hauling operations. To this end, *Arena* simulation software which is one of the most powerful discrete event simulation tools was applied for building a model of haulage system.

Since two of the five operating subsystem's destination is crusher, a distinct model should be considered for representation of these two subsystems in order to realistically take the effect of crushing process into account. Figure 1 shows the layout of the constructed model.

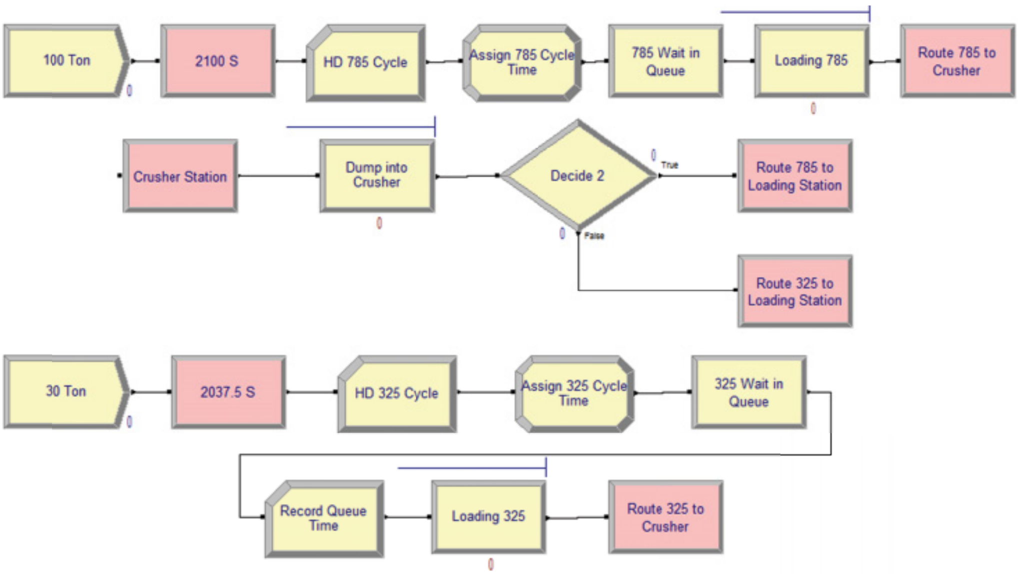

Fig. 1. Layout of Non-Dispatching Model in Arena

To have an acceptable reliability of the model and to ensure that the model truly represents the real system, there should be an indicating factor for comparing model outputs with the real system (Gove & Morgan, 1994). The most important output of the model is trucks cycle time, because it involves all time variables in it; therefore it was applied as an indicating factor for validation of the model. As it can be seen from Figure 2, constructed model represents the characteristics of the system under study with a high level of confidence.

A useful methodology for investigation of the utilization of the haulage system is based on the match factor of the trucks and loaders in a given system. The equation used is:

$$MF = \frac{(number\ of\ trucks)(loader\ cycle\ time)}{(number\ of\ loaders)(truck\ cycle\ time)}$$

This variable was calculated for each of 5 subsystems and the results are shown in Table 3. Results showed that all subsystems were totally under-trucked, in other words, there were not enough trucks for each subsystem to be served by the loader.

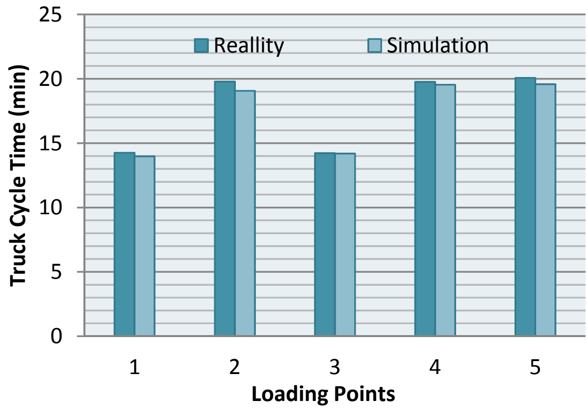

Fig. 2. Comparison of real data with simulation results

TABLE 3

Match Factor Analysis for the Operational System

Loading station	Avg. truck cycle (min)	Avg. loader cycle (min)	No. of trucks	MF
1	13.98	3.28	3	0.70
2	19.07	5.16	2	0.54
3	14.19	3.83	3	0.80
4	19.54	5.24	3	0.80
5	19.59	3.64	3	0.55

For each of the five loading points some scenarios were assigned based on changing of the number of trucks in each subsystem and screening the changes in model outputs to improve productivity parameters including: fleet match factor, productn rate and system utilizations. After analyzing of the simulation outputs for each of the scenarios, the best arrangement that leads to maximum system utilization and production rate was chosen. Table 4 compares productivity parameters of the operating fleet with the modified one.

TABLE 4

Outputs of the Modified Non-Dispatching Fleet

	Current operating fleet				Proposed modified fleet			
	No. of trucks	MF	System Utilization	Production (m^3 per Shift)	No. of trucks	MF	System Utilization	Production (m^3 per Shift)
1	3	0.70	0.52	1414	4	0.94	0.64	1778
2	2	0.54	0.51	1700	4	1.06	0.91	3094
3	3	0.80	0.63	1372	4	0.98	0.73	1694
4	3	0.80	0.55	2380	4	1.05	0.63	2856
5	3	0.55	0.54	1036	5	0.93	0.82	1652

Figure 3 shows that by selecting correct number of trucks, overall production of the mine would improve by 40%.

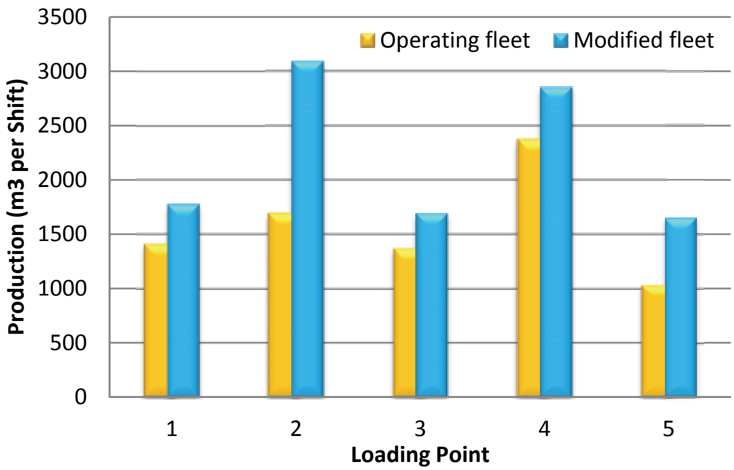

Fig. 3. Change in Match Factor and Production Rate by fleet modification

3. Modelling of Dispatching System

Once the system evaluated by match factor index, it seems all independent sub fleets should operate in a way that there should not be any waiting time for loaders and no queue of trucks at the loading faces, but due to the inherent variability in mining operations, in some cases queue lines of trucks or idle loaders have been observed. This variability which can occur because of unwanted traffic congestion or a special loading condition, leads to disarrangement of the fleet. Therefore, applying a flexible managing system for trucks which monitors the dynamic condition of in pit operation seems inevitable. Such a system dispatches every truck to a loader in a way that an optimization criteria be satisfied and leads to a condition that waiting times are set to minimum.

Unique geologic condition of Sungun copper mine forces the mine managers to apply front end loaders rather than shovels due to their high operational flexibility. Considering this condition and also by comparing operational costs of loaders with trucks, it is decided to set the dispatching objective function on minimizing truck wait times and applying of the strategy of dispatching one truck to *n* shovels.

Dispatching model was applied for the 5 working benches of the study, though for loading and hauling times, the data used from fixed assignment model and applied to have proper situation for future comparison of these two managing systems. It was approved that using dispatching systems in a condition that the system is over-trucked or under-trucked makes no efficient improvement in system utilization, though the important factor while setting the input data is the number of trucks. Therefore it is crucial to have the correct number of trucks while using dispatching system. Consequently the number of trucks in dispatching model was set to those applied in the modified fixed assignment model.

Dispatching decisions are made in two dumping sites, including crusher and waste dump based on specified objective function and related constraints, Figure 4. Applied variables in the model are shown in Table 5.

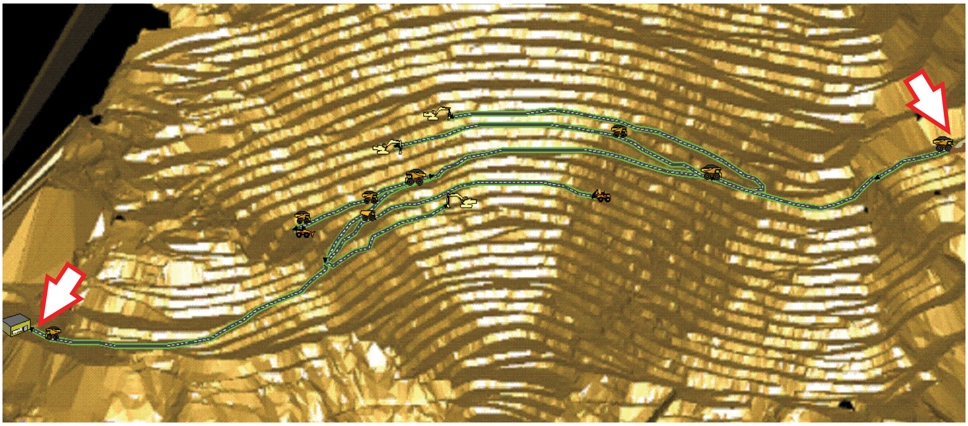

Fig. 4. Layout of Dispatching Points

TABLE 5

Applied Variables in Arena for dispatching model

Arena Variable	Definition
ECT(i,j)	Expected capture time of (i^{th}) loader by (j^{th}) truck
ACT(i,j)	Assigned capture time of (i^{th}) loader by (j^{th}) truck
ERT(i,j)	Expected release time of (i^{th}) loader by (j^{th}) truck
LOADING T(i,j)	Loading time of (j^{th}) truck by (i^{th}) loader
DEL(i,j)	Waiting time of (j^{th}) truck in (i^{th}) loader's queue
TRAVEL T(i,j)	Travel time of (j^{th}) truck from dump point to (i^{th}) loader
TARGET	Specified loader that satisfies dispatching criteria
TNOW	Current time

In this table index i refers to the number of loaders while j refers to the type of the truck, in other words there can be desired types of trucks based on their capacity and mechanical features.

Following calculations are carried out every time a truck dumps its load and asks for new assignment:

$$\mathrm{ECT}(i,j) = \mathrm{ACT}(i,j)$$

$$\mathrm{ERT}(i,j) = \mathrm{ECT}(i,j) + \mathrm{LOADING\ T}(i,j)$$

$$\mathrm{DEL}(i,j) = \mathrm{ERT}(i,j) - [\mathrm{TNOW} + \mathrm{TRAEL\ T}(i,j)]$$

$$\mathrm{TARGET} = \mathrm{Min}\{\mathrm{DEL}(1), \mathrm{DEL}(2), \ldots \mathrm{DEL}(5)\}$$

Once the truck assigned for a loader, the target loader's variables should be updated for the next calculations. Figure 5 shows the layout of the designed model for dispatching system.

The dispatching model after validation and assurance of the correctness of its framework is run for a period of one shift in order to be able to compare the outputs with fixed assignment model. Results of the simulations are shown in Table 6. It reveals that by applying dispatching system for trucks the production rate will improve by 7.8% in comparison with the modified fixed assignment system.

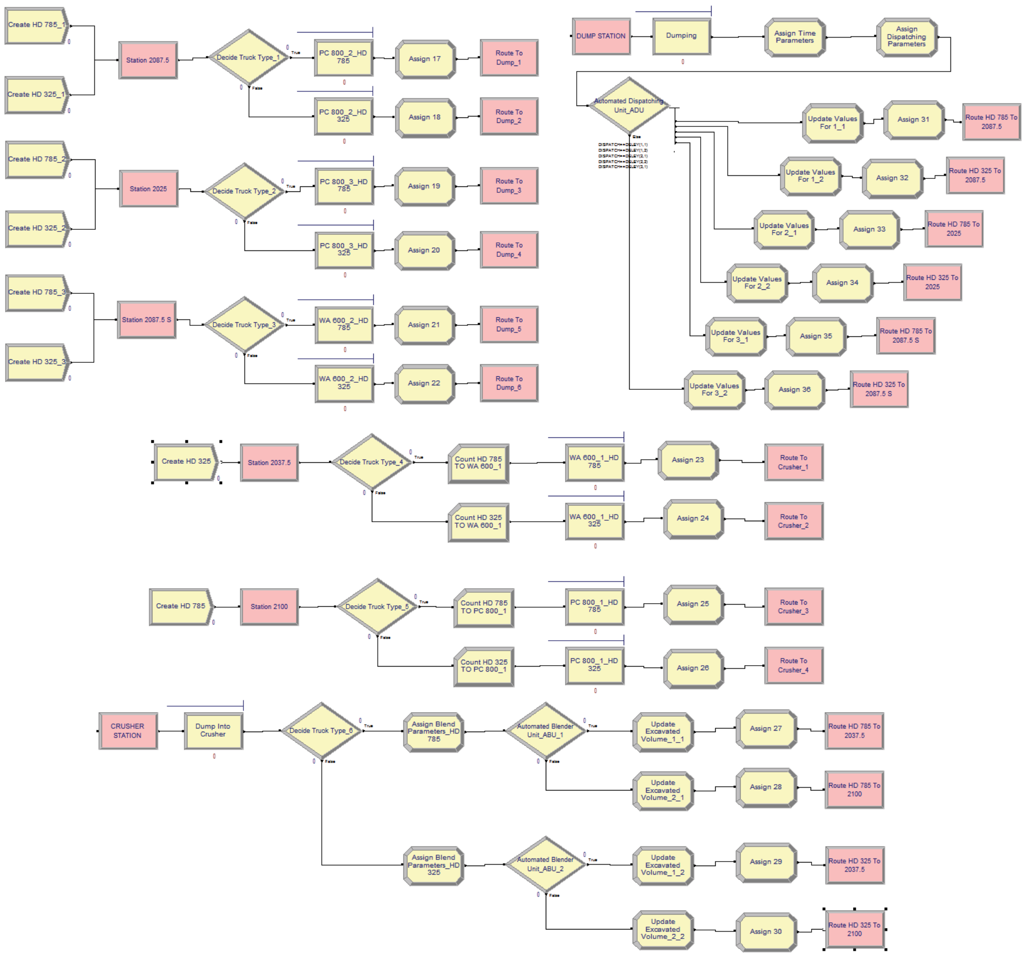

Fig. 5. Layout of Dispatching Model in Arena

TABLE 6

Simulation Results of Dispatching Model

Working Bench	No. of Trucks	Production of Dispatching model (m^3 per Shift)	Production of Modified fixed-Assignment model (m^3 per Shift)
1	4	1974	1778
2	4	3128	3094
3	4	1722	1694
4	4	3502	2856
5	5	1610	1652

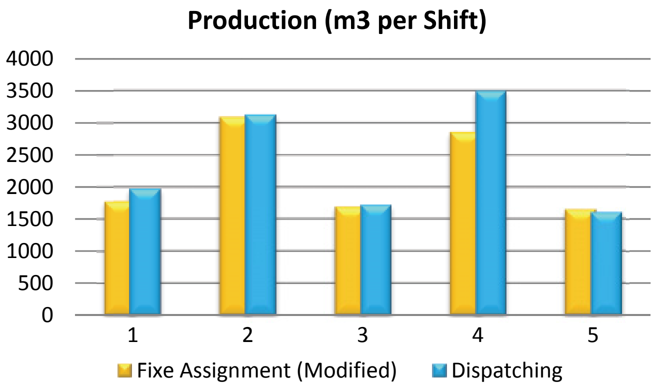

Fig. 6. Effect of Dispatching in Production Rate

4. Simultaneous modeling of Dispatching and Blending

An important factor in open pit mining operation is the concept of blending. Ore blending is the approach of managing ore grade and quality (Qinghua et al., 2010), is the process in which the material from different working benches are excavated in a way that the overall grade of mine output is a previously specified amount. In this case productivity and the recovery of the mineral processing plant can reach its maximum capacity.

Today, ore blending control in mines can be handled using computerized dispatching systems using a database of mine block model and the grade distribution inside the pit. Every time a loader settles in a working bench, blend controlling system monitors the quality and grade of the rock masses on its working area and dispatches the trucks in a way that excavation of different working benches with different ore grade will result in having a uniform output ore grade.

In this regards a blend controlling process was added to the previously mentioned variables of the dispatching model of the mine, in a way that if any truck is going to be assigned to a loader that is excavating ore material, the blending module will assess the average grade of the output ore and allows the truck to move toward that loader only if the constraint is satisfied. Table 7 defines the variables created for the process of blending model.

TABLE 7

Applied Variables for Blend controlling

Arena Variable	Definition
VOL(*i*)	Excavated volume by the (i^{th}) loader in working bench
C(*j*)	Capacity of (j^{th}) truck type
VOL_T(*j*)	Total excavated ore considering current (j^{th}) truck capacity
ASEXPOR(*i*)	Assigned excavation portion for (i^{th}) loader in working bench
EXPOR(*i*,*j*)	Excavate Portion of (i^{th}) loader in working bench considering current (j^{th}) truck capacity
BLDV(*i*,*j*)	Deviation from target blending by loadin current (j^{th}) truck by (i^{th}) loader

Following calculations are carried out every time a truck dumps its load and asks for new assignment:

$$VOL\_T(j) = \sum_{I=1}^{N} VOL(i) + C(j)$$

$$EXPOR(i,j) = [VOL(i) + C(j)]/VOL_{T(j)}$$

$$BLDV(i,j) = EXPOR(i,j) - ASEXPOR(i)$$

$$TARGET\_2 = Min\{BLDV(i,j)\}$$

Considering above mentioned constraints for dispatching module, a simulation scenario is designed to evaluate the effect of newly added codes to dispatching model of Sungun mine. As it was stated before, material in 1st and 2nd working benches were considered as ore and their destination was set to the crusher. Copper grades in these working benches were 0.57% and 0.97% respectively and desired ore grade of the mine output was set to 0.70%.

Running the model for a period of one shift and getting the resulted statistics approved that the overall ore grade of the mine is 0.75%. In other words, the ore grade of the material pouring into the crusher shows a deviation of 7% which is not acceptable and lowers the recovery of ore dressing plant. Bringing the ore grade controlling module into the simulation codes and running the model for the period of one shift resulted that while the production rate remains constant, overall ore grade of the mine is kept at 0.703%.

5. Conclusion

Simulation modeling is a widely accepted procedure for evaluation of the complex systems. In some conditions it is not possible to make the desired changes in real system and monitor the resulted effects; it's where simulation modeling comes in handy and lets the researcher exert any possible modifications and get the feedbacks with the lowest costs.

Arena simulation software as one of the most comprehensive tools of discrete event simulation modeling has been used in this research for evaluation of the transportation system of the Sungun copper mine. A model was designed based on the site observations and collected empirical data representing the operational features of the loading and hauling units which currently function on a fixed assignments mode. Then the model is validated by comparing the model outputs with the real empirical data for truck cycle times, it was approved that the model in 95% level of confidence is valid and can be relied on for future assessments of the system under study.

Simulation results of operating haulage and match factor analysis approved that the current system is severely under-trucked. Therefore, optimization scenarios based on modification of the number of the trucks simulated on the model. Resulted outputs from these scenarios approved that by modifying the match factor of the haulage system, the production rate in the working benches of the research will increase by 40%.

Searching for productivity improvement, a dispatching model based on the strategy of dispatching one truck to many loaders and objective function of minimizing truck waiting times have been developed for the transportation equipment of Sungun copper mine. Simulation results showed a 7.8% improvement in the total production rate in comparison with the previously modified fixed assignment system.

Ore blend controlling model was then developed. Real time monitoring of the excavated volume of every ore bench using this module helps to keep the overall grade of the mine in a desired amount. Simulation results showed that while the desired ore grade is set to 0.700%, mine output grade is 0.750% without blend controlling module. By bringing this newly added constraint into the simulation codes, mine output grade reached to 0.703%.

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References

Ahangaran D.K., Yasrebi A.B., Wetherlet A., Foster P., 2012. *Real –Time Dispatching Modelling For Trucks With Different Capacities In Open Pit Mines*. Arch. Min. Sci., Vol. 57, No 1, p. 14.

Alarie S., Gamache M., 2002. *Overview of Solution Strategies Used in Truck Dispatching Systems for Open Pit Mines*. International Journal of Surface Mining, Reclamation and Environment, 16: 59-76.

Ataeepour M., Baafi E.Y., 1999. *ARENA simulation model for truck-shovel operation in dispatching and non-dispatching modes*. International journal of mining, reclamation and environment, 13, 125-129.

Basu A.J., 1999. *Simulation of a large open pit mine operation in Australia*. Mineral resources engineering, 8, 157-164.

Burt C.N., Caccetta L., 2007. *Match Factor for Heterogeous Truck and Loader Fleets*. International Journal of Surface Mining, Reclamation and Environment, 21, 262-270.

Burt C.N., Caccetta L., 2008. *Match Factor for Heterogeous Truck and Loader Fleets*. International Journal of Surface Mining, Reclamation and Environment, 22, 84-85.

Chanda E.K., Gardiner S., 2010. *A comparative study of truck cycle time prediction methods in open-pit mining*. Engineering, construction and architectural management, 17, 446-460.

Eduardo Bonates Y.L., 1988. *A computer simulation model to evaluate the effect of dispatching*. International Journal of Surface Mining, Reclamation and Environment, 2, 99-104.

Forsman B., Ronnkvist E., Vagenas N., 1993. *Truck dispatching computer simulation in Aitik open pit mine*. International journal of mining, reclamation and environment, 7, 117-120.

Gove D., Morgan W., 1994. *Optimizing Truck-Loader Matching*. SME Annual Meeting.

Jaoua A., Riopel D., Gamache M., 2009. *A framework for realistic microscopic modelling of surface mining transportation systems*. International journal of mining, reclamation and environment, 23, 51-75.

Kolonja B., Mutmansky J.M., 1995. *Analysis of truck dispatching strategies for surface mining operations using SIMAN*. SME annual meeting.

Krzyzanowska J., 2007. *The impact of mixed fleet hauling on mining operations at Venetia mine*. Journal of The Southern African Institute of Mining and Metallurgy, 107.

Li Z., 1989. *A methodology for the optimum control of shovel and truck operations in open pit mining*. Mining Science and Technology, 10, 337-340.

Oraee K., Asi B., 2004. *Fuzzy model for truck allocation in surface mines*. Taylor & Francis group, 585-591.

Qinghua G., Caiwu L., Jinping G., Shigun J., 2010. *Dynamic management system of ore blending in an open pit mine based on GIS/GPS/GPRS*. Journal of Mining Science and Technology, 20, 132-137.

Rodrigo M., Enrico Z., Fredy K. Adolfo A., 2013. *Availability-based simulation and optimization modeling framework for open-pit mine truck allocation under dynamic constraints*. International Journal of Mining Science and Technology, 23, 113-119.

Soumis F., Ethier J., Elbrond J., 1989. *Truck dispatching in an open pit mine*. International journal of mining, reclamation and environment, 3, 115-119.

Wang Q., Zhang Y., Chen C., Xu W., 2006. *Open pit mine truck real-time dispatching principle under macroscopic control*. First international confernce on innovative computing, information and control.

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