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Strategy in Dispatching Trucks and Shovels with Different Capacity to Increase the Operating Efficiency in Cao Son Surface Coal Mine, Vietnam

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Abstract. In surface mining operations, the operating costs of truck-shovel system constitutes 50-60% of the total. Only a little save in the operation costs in this system will bring large profit for the mines. Due to many investment periods, the capacity of both trucks and shovels in Cao Son surface coal mine is different. This leads to the low efficiency and the difficulty in dispatching strategy for the mine. This paper presents the current situation and selection of advanced dispatching strategy for increasing the efficiency trucks and shovels at this surface coal mine. The results show the detailed match factor reflects the state of each team of loader and trucks and should be use as the indicator for dispatching decision for the heterogeneous truck and shovel fleet at Cao Son surface coal mine.

Keywords: Truck dispatching, Truck-shovel system, Dispatching strategy, Detailed match factor

1. Introduction

Cao Son surface coal mine is one of the biggest coal mines in Vietnam. Currently, the total volume of waste rock that need to be loaded and hauled is from 26 to 32 million m^3/year. Trucks and shovels are used for loading and transporting of waste rock directly to the outside waste dumps or to the crusher of conveyor belt system. In 2017, there was about 50.58% of waste rocks transported by trucks to conveyor belt system (about 13 million m^3). It was increased to 78.34% (17.8 million m^3) in 2018. In 2020, the volume of waste rocks transported by the combination of trucks and conveyor belt in was increased to 20 million m^3. Due to long operating time, the mine has invested many types of mining equipment and they are still operating together. There are both rope shovels and hydraulic excavators with different bucket's capacity from 3.3 m^3 to 12 m^3 using at the mine. About 20 electric rope shovels were invested about 40 years ago and the interruptions during shifts such as breakdown or maintenance may occur quite often. The other 11 newer hydraulic excavators are used for loading coal and waste rock. Due to the reduction in productivity of shovels and excavators over time, they are classified by into type A, type B and type C. The standard productivity of equipments type A is 110% higher than type B, and equipments type C is about 85% productivity of equipments type B. For the mining trucks, the capacity of truck has the range from 27 – 96 tons, but only the trucks with capacity from 55-96 tons are selected to transport waste rock. The modern of trucks is quite diversity such as: CAT 777D (96 tons), HD 785-5 (91 tons), HD 465 (58 tons), CAT 773 E (58 tons), HD 465 (55 tons), Belaz-7555B. There is total 121 trucks with capacity from 55-96 tons using for hauling waste rock. The average haulage distance is about 3.9 km. By increasing the volume of waste rock transported by the combination of trucks and conveyor belt system, the average haulage distance was decreased to nearly 3 km (in 2020). As the general rule, when the mine is going deeper, difficult working conditions increase. In order to complete the delivery output, the older equipments have to increase working hours, overcome the longer haulage distance, and the productivity of mining trucks decline in rainy season due to slippery routes (Figs. 1, 2) [1].

According to the data, the percentage of machine utilization for electric rope shovels EKG – 4.6, 5A (with bucket's capacity of 4.6-5 m^3) is about 32%, meanwhile, nearly 70% of their time for repairing or maintenance or other reasons such as: power-off: 1%; stopped by damage: 4%; shift handover: 16%; repair time: 2%; stopped by other reasons: 45%. Other type of electric rope shovels, the rope shovel EKG 8i, also have low working time, about 38%. The situation is better for the hydraulic excavators with about 63% working time, and 37% waste time for other activities. There are also 8 types of loaders with the difference in bucket capacity. At this time, the dispatchers of the mine are usually based mostly on their experiences to allocate the trucks to these diversity types of excavators [2].

The operating costs for truck haulage usually takes about 50 to 60 percent [3]. Even a small improvement in this shovel-truck system will bring profit for the mine. For Cao Son surface coal mine, their heterogeneous truck and loader fleet needs to select a suitable dispatching strategy. In this paper, the dispatching strategy is based on our GPS tracking app on smartphone which is placed in trucks and shovels for tracking their real time positions and other timing parameters for dispatching work. The GPS data are collected and sent directly to the management software for optimization calculation. The ability to increase the dispatching strategy of the mine can not do without the support of real time GPS information and with the help of new modern developed managing trucks and shovels software. Dispatching strategies for truck – shovel fleet in an open pit mine has important roles that will bring a good approach for operating this job on site.

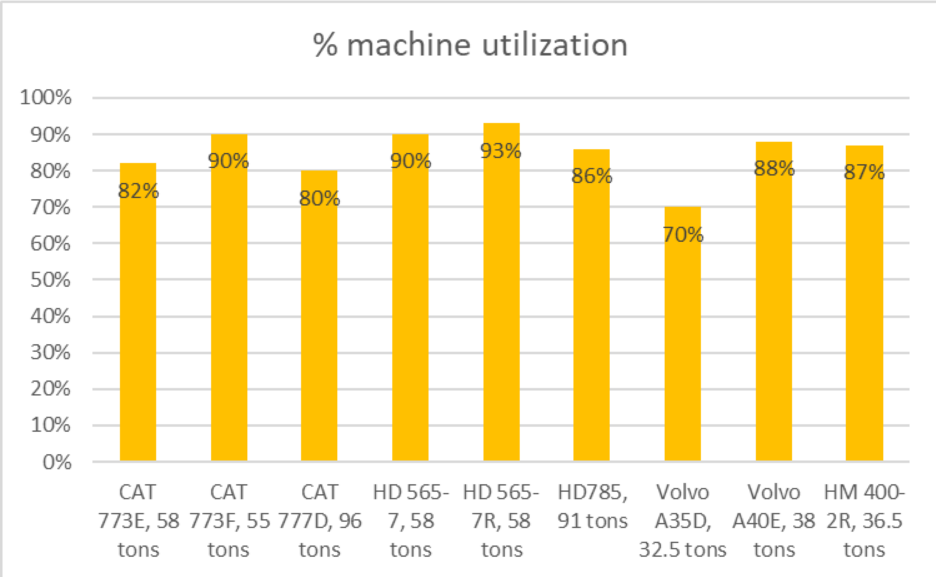

Fig. 1. The % machine utilization of some types of mining trucks at Cao Son surface coal mine [2].

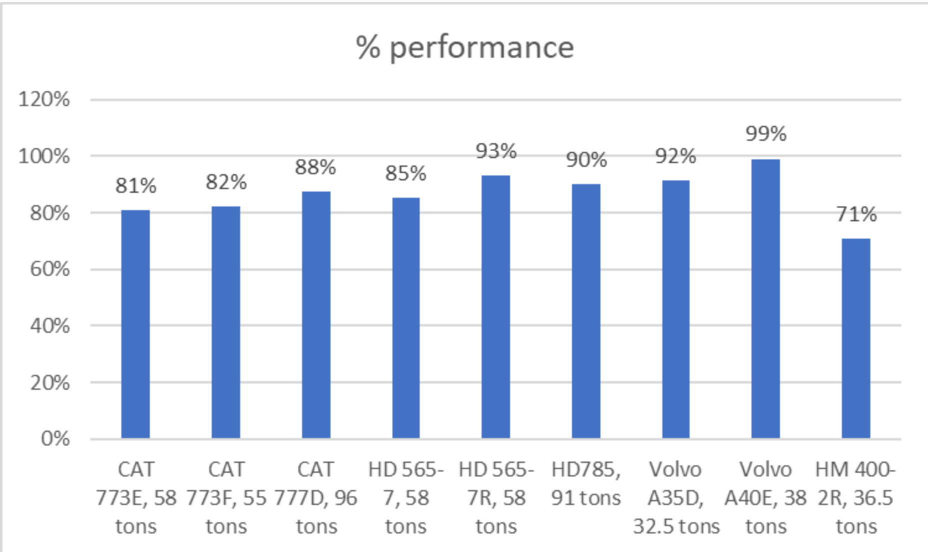

Fig. 2. The % performance of some mining trucks at Cao Son surface coal mine [2].

2. The hardware and software for managing and dispatching truck – shovel fleet

The management of a large truck -shovel fleet on a surface mine is always a priority for the improvements for many generations. These improvements on dispatching system are mostly based on the development of interdisciplinary fields such as: electronics, telecommunication, computer technology… From the computerized truck dispatching systems which were developed in late 1970's with higher price of hardware, to the cheaper systems due to the decrease in costs of computer hardware, the truck dispatching systems are classified into: manual, semi-automated and full automated. Today, lots of truck dispatching systems are based on current modern technologies. Based on current advantages, our project is to build a semi-automated truck – shovel dispatching system for Cao Son surface coal mine (Fig. 3).

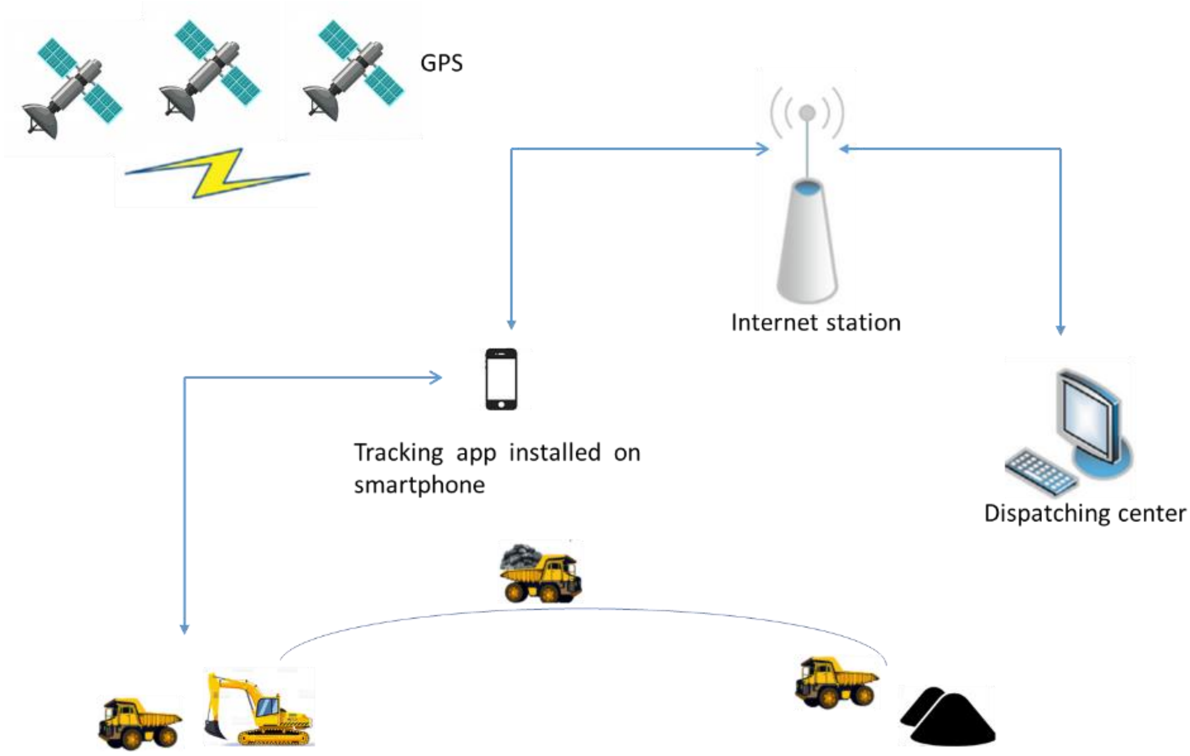

Fig. 3. Diagram of dispatching truck-shovel system for Cao Son surface coal mine [2].

The introduced system includes: software and hardware. The apps installed on smartphones and is placed on trucks or shovels for tracking the real time position, interacts between users and dispatching center and then send the data to dispatching center for analysis. The managing and dispatching software is installed on server and access by computer or other mobile devices such as ipad, tablet. The data from the trucks or shovels is transferred through communication network to the center dispatching software. Fig. 3 presents the diagram of dispatching truck-shovel system developed for Cao Son surface coal mine. When there are four or more satellites in the view, the GPS device integrated inside smartphones will calculate the information such as: velocity, position… The GPS device can work in any weather conditions, 24 hours per day and anywhere on earth [10, 11]. The realtime position of trucks and shovels and their timing data will be used for the next steps of analyzing and optimizing calculation. The dispatchers can monitor real time the loading and hauling activities of mine on the screens through the computer connected to internet.

The tracking apps installed smartphones with the function to monitor the timing parameters such as: loading time, truck cycle time, breakdown, unloading time, waiting time… These timing parameters is the basis for dispatchers and the system give a suitable dispatching decision for whole system.

3. Selection of dispatching strategy

Many dispatching strategies have been introduced such as: maximize truck, maximize shovel, match factor. In strategy of maximize truck, the available trucks are constantly reassigned to the shovel where they are most likely loaded first. When a truck is available for the calculation, many parameters such as: travel time of empty trucks end route, trucks waiting, and trucks being served of each shovel must be considered. The maximize truck strategy will increase the total productivity in comparison to fixed dispatching [4]. In this strategy, the utilization of shovel tends to disbalanced due to this dispatching procedure favors truck to shorter routes [5].

In strategy of maximize shovel, the truck is assigned to the shovel which has been waiting the longest or may be idle next [4]. The research from Sassos [6] showed this strategy brought a more uniform utilization of shovel.

Match factor is used as an indicator of productivity performance, and it is also a sign for the balance or unbalance of truck-shovel feet which strongly influenced on the performance of the system. The term match factor is defined as the ratio between truck arrival rate to loader service time. For the homogeneous truck and loader fleet (all the trucks are the same types and all the loader are the same type) [7]:

$$MF = \frac{No.of\ trucks\ \times loader\ cycle\ time}{No.of\ loader\ \times truck\ cycle\ time} \qquad (1)$$

Match factor of 1.0 is used as balance point. At this value, the trucks are arriving at the loader at the same rate as they are being served. A match factor is bigger than 1.0, that means trucks are arriving faster than they are being served (over-trucking). If a match factor is smaller than 1.0, this indicates that trucks are arriving slower, and the loader can serve faster (under-trucking).

For heterogeneous haulage and homogenous loading fleet, the match factor can be defined [8]:

$$MF_i = \frac{x_i}{t_i \sum_{i'} \frac{x_{i'}}{t_{i,i'}}} \quad (2)$$

Where: MF_i - the match factor for heterogeneous haulage and homogenous loading fleet;

x_i – number of trucks of type i;

t_i – cycle time for truck of type i;

$x_{i'}$ - number of loaders of type i';

$t_{i,i'}$ - time taken to load truck type i with loader type i';

The match factor with some advantages such as: it is simple and can be applied to both homogeneous and heterogeneous, it can be predicted the mean waiting time. However, the disadvantages when using match factor are the performance of each loader can not be determined, the trucks cannot be precisely allocated to the loaders, can not control the grade and tonnage of a mine. To solve this problem, a detailed match factor (DMF) is determined for each loader individually and then used as a dispatched indicator for the fleet. According to Dabbagh A. & Bagherpour R. [9], the trucks and loaders may operate at their maximum capacity with the match factor of approximately 1.0, at this value the number of loading anh haulage equipment is balanced. In a whole system with many loaders, the detailed match factor is determined for each loader separately. If the detailed match factor is bigger than 1, then the dispatcher will attempt to reduce the number of haulage equipments for this loader. In the opposite case, if the detailed match factor is smaller than 1.0, it means the loader needs to add haulage equipments to get the value of DMF as close to 1 as possible. It can be easy realized that if the detailed match factor of any loader is smaller than 1.0, the capacity of trucks and loaders is reduced without interrupting in the mining operation [9].

The Cao Son surface coal mine has the heterogenous trucks and loaders fleet, in this research we focus on the dispatching strategy for the heterogeneous fleet of the mine.

The detailed match factor for a team of a loader and trucks can be determined [9]:

$$DMF_{i'} = \frac{\sum t_{i,i'} x_i}{\overline{t_X}} \quad (3)$$

x_i - number of truck type i

$\overline{t_X}$ - average cycle time for the trucks

$$\overline{t_X} = \frac{\sum_i t_i x_i}{\sum_i x_i} \quad (4)$$

t_i - cycle time for truck of type i $\in$ X;

X - group of available trucks

The overall match factor of heterogeneous truck and loader fleets [8]:

$$MF = \left(\overline{t_X} \sum_{i'} \frac{x_{i'}}{t_{i'}}\right)^{-1} \quad (5)$$

With the hypothesis that the detailed match factor of each team of loader and trucks will be an indicator for the dispatcher in allocating the trucks in working shift. In this paper, the relationship between detailed match factor and overall match factor for heterogeneous truck and loader fleet will be examined.

4. Selection of the dispatching strategy for truck – shovel fleet at Cao Son coal mine

The loaders and trucks which are mostly used for waste rock haulage at Cao Son coal surface mine are presented in Tables 1 and 2.

Tab. 1. Some loaders used for waste rock haulage at Cao Son mine.

No.	Type	Bucket capacity, m^3	Number
1	Rope shovels ЕКГ – 4,6; ЕКГ – 5А	4.6 to 5.0	11
2	Rope shovels ЕКГ – 8И	8	8
3	Rope shovel ЕКГ – 10	10	1
4	Komatsu PC1800-6	12	1
5	Komatsu PC1250	6.7	4

Tab. 2. Some trucks used for waste rock haulage at Cao Son mine.

No.	Type	Capacity, tons
1	CAT 777D	96
2	HD 785	91
3	HD 465 - 7	58
4	CAT 773 E, F	58
5	HD 465 -5	55

To analyze the influence of dispatching strategy on the truck-shovel, some combinations between loaders and trucks were examined. The examined teams of loader and trucks service for routes at Cao Son surface coal mine are presented in Table 3. The density of blasted waste rock is of 1.6 tons/m^3. The bucket filling factor is 0.87, the bucket capacity of loader is exchanged unit into tons.

Tab. 3. Dispatching plan 1 for 3 teams of truck and shovel at Cao Son surface coal mine.

Team 1(route distance L_1 = 3.5 km)	Parameters		Truck (loader) cycle time, s	Time required for full load of one truck, s	Detailed match factor DMF	Overall match factor MFΣ
	Number of machines	Capacity, tons				
Loader EKG 8u	1	18	35		0.69	0.94
Truck CAT 777	4	96	1764	210		
Truck CAT 773	2	91	1680	175		
Team 2 (route distance L_1 = 3.7 km)					0.96	
Loader EKG 5A	1	11	35			
Truck CAT 777	3	96	1900	315		
Truck CAT 773	3	61	1800	280		
Team 3 (route distance L_1 = 3.85 km)					1.1	
Loader PC-1250-8	1	15	35			
Truck CAT 773	7	58	1670	140		
Truck HD 465-5	6	55	1620	140		

In dispatching plan 1, team 1 has the DMF_1 of 0.69 (smaller 1.0), so this team is lack of truck and needs to add trucks. In team 2, the detailed match factor DMF_2 is of 0.96 (it's close to 1.0). In team 2, the number of trucks is nearly balanced with the service rate of the loader (a little undertruck). If the dispatcher adds 1 more truck to the team 2, then the value of DMF_2 is bigger than 1.0 that means this team will be overtrucked. In this case, the dispatcher should not change the number of trucks for team 2. For team 3, the detailed match factor DMF_3 is of 1.1, this means it is overtrucked. If the dispatcher withdraws 1 truck from this team, then the detailed match factor DMF_3 will be equal to 1.0. This case it is a good dispatching decision, and the dispatcher should allocate 1 truck from team 3 to team 1.

Tab. 4. Dispatching plan 2 for 3 teams of truck and shovel at Cao Son surface coal mine.

Team 1 (route distance L_1 = 3.5 km)	Parameters		Truck (loader) cycle time, s	Time required for full load of one truck, s	Detailed match factor DMF	Overall match factor MF_Σ
	Number of machines	Capacity, tons				
Loader EKG 8u	1	18	35		1.34	**0.96**
Truck CAT 777	6	96	1764	210		
Truck CAT 773	6	91	1680	175		
Team 2 (route distance L_1 = 3.7 km)					1.12	
Loader EKG 5A	1	11	35			
Truck CAT 777	3	96	1900	315		
Truck CAT 773	4	61	1800	280		
Team 3 (route distance L_1 = 3.85 km)					0.6	
Loader PC-1250-8	1	15	35			
Truck CAT 773	3	58	1670	140		
Truck HD 465-5	4	55	1620	140		

In the dispatching plan 2, the detailed match factors of team 1 and team 2 are bigger than 1.0, they are of 1.34 and 1.12, respectively. That means, both team 1 and team 2 are overtrucked. However, in team 2, the detailed match factor is of 0.6 and it's largely undertrucked. It may need to add trucks from team 1 and/or team 2 to make the balance between truck service rate and loader service rate for each team of trucks and loader.

The overall match factor for dispatching plan 1 is of 0.94, and the overall match factor for dispatching plan 2 is of 0.96. If the dispatcher only looks at the values of the overall match factors in both dispatching plan 1 and 2, these overall indicators show the nearly balance between truck service rate and loader service rate for the fleet. In both plans, there is team of undertrucked loader with the detailed match factor much less than 1.0, and this team need to add more trucks to meet the requirement. There is also a team of overtrucked loader with the detailed match factor bigger than 1.0, and this team should reduce the number of trucks or dispatch the trucks to the teams with detailed match factor smaller than 1.0 (if is suitable).

From analyzing these above dispatching plans 1 and dispatching plan 2, it can be easy realized that the overall match factor does not show the effect inside of the truck-loader fleet. However, the detailed match factor for each team reflects the balance or unbalance of each team of loader and trucks. For the Cao Son surface coal mine with a heterogeneous truck and loader fleet, the dispatching strategy using detailed match factor of teams of loader and trucks as the indicator for dispatching procedure should be selected. The software bases on the detailed match factor to filter out the teams of loader and trucks that need to add or withdraw trucks. The dispatcher can choose the auto or semi-automated dispatching procedures for allocating trucks to loader with the purpose to balance the truck service rate and loader service rate (the detailed match factor for each team of loader and trucks should be as close as 1.0). Fig. 4 shows a diagram which presents an example that the trucks in team 2 can be dispatched to team 1 to make the balanced for the fleet. This can be done if the detailed match factor of team 1 is smaller than 1 and of team 2 is bigger than 1. In case the detailed match factors of team 1 and team 2 are smaller than 1, then the fleet have to add trucks.

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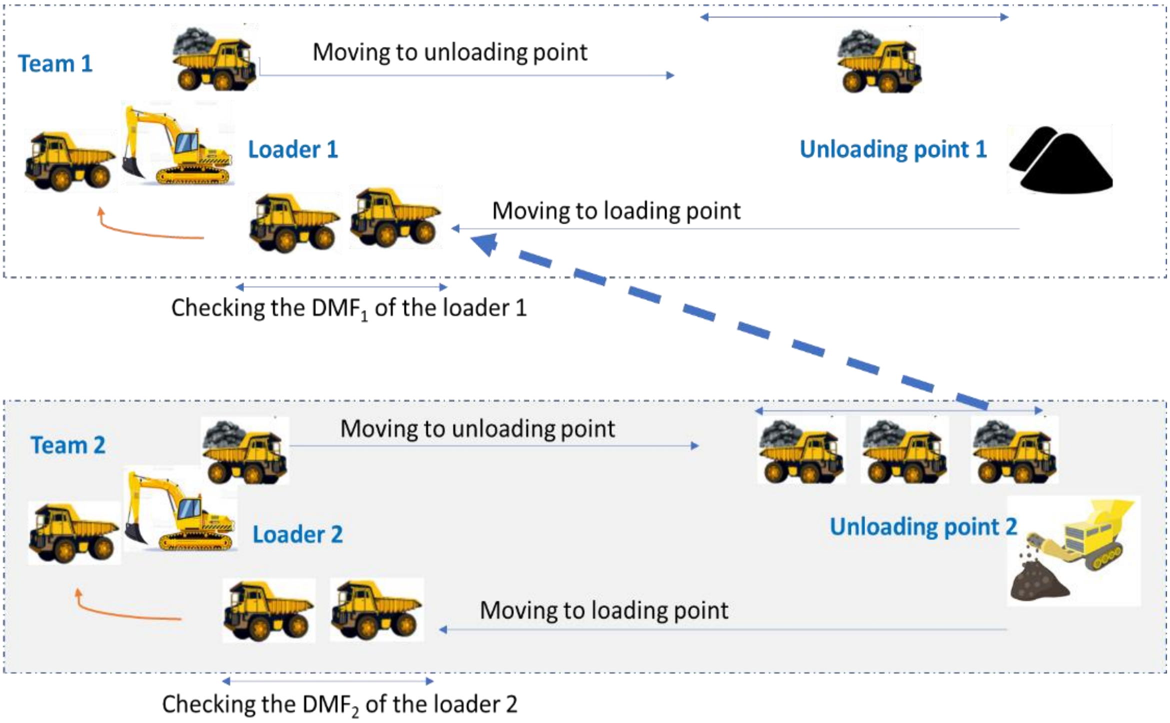

Fig. 4. Diagram presents the dispatching strategy for truck-shovel fleet for Cao Son surface coal mine.

5. Results and discussions

From the above analysis, it can be seen that the dispatching strategy using the detailed match factor reflects the state of each team of loader and trucks. With the realtime information of the trucks and loaders in the mines, any changes in truck cycle time, loader cycle time, waiting time, breakdown of the machines… that lead to the change in the detailed match factor of each team of loader and trucks. Therefore, the detailed match factor will be very helpful indicator for the dispatchers in effectively doing their work.

The balance point between loader service rate and trucks service rate or the detailed match factor is equal to 1.0 is the criterion for controlling the dispatching trucks in the system. In case of the heterogenous trucks and loaders fleet of Cao Son surface coal mine, the value of detailed match factor for each team of loader and trucks should be kept as close to 1.0 as possible. Mostly, the little undertrucked allocation can be accepted to keep the loaders time for auxiliary works at loading points.

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