Код МРНТИ 52.13.17

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TROLLEY TRUCK SIMULATION ON KACHAR MINE HAUL ROAD

Abstract. Transportation costs in open pit mining may take 50 to 70% of overall open pit mining cost. Diesel fuel consumption takes more than 25% of owning and operating costs of large mining haul trucks and represents about 50% of carbon emissions at open pit sites. Modern software uses built-in characteristics of machine as rimpull and breaking performance, fuel, and electricity consumption rates. Computer simulation of CAT 794AC with trolley assist on conditions of Kachar mine 3068-meter haul road with 1100-meter trolley line section demonstrated 22% fuel consumption reduction and 10,9% higher production compare with conventional CAT 794AC. Study shown possible future efficiencies and practical recommendations for trolley assist application. During the study the real haul road condition's data taken from mine site and used for simulation of future operational performance indicators.

Key words: *mining hauling truck; mine haul road; trolley assist; carbon emission, fuel efficiency, computer simulation, hydraulic front shovel, cost analyses, operator efficiency, lithium battery.*

Качар кені жолында троллей тасымалдау жүйусінің қолдану модельдеуі

Аңдатпа. Тау-кен ашық әдіспен өндіруге арналған тасымалдау шығындары, әдетте, ашық әдіспен өндірудің жалпы шығындарының 50-ден 70%-ға дейін болады. Дизельді отынды тұтыну ірі тау-кен жүк көліктерін иелену және пайдалану шығындарының 25%-дан астамын құрайды және карьерлерден шығатын көміртегі шығарындыларының шамамен 50%-ын құрайды. Қазіргі заманғі компьтерлік шешімдер машинаның кіріктірілген сипаттамаларын пайдаланады, мысалы, тарту және тежеу өнімділігі, отын мен электр энергиясын тұтыну. Компьтерлік симуляция 1100 м троллейбус желісі бар 3068 метрлік көлік жолының Качар кенінің ортасында троллей жүйесі бар CAT 794AC үлгісінің симуляциясы кәдімгі CAT 794AC-пен салыстырғанда отын шығынының 22%-ға төмендеуін және өнімділіктің 10,9%-ға артқанын көрсетті. Зерттеу болашақта мүмкін болатын тиімділікті және троллей тарту жүйесін пайдалану бойынша практикалық ұсыныстарды көрсетті. Зеріттеуде карьердер тасымалдауға арналған нақты жол жағдайлары пайдаланылды.

Түйінді сөздер: *тау-кен автосамосвалы; технологиялық жол; троллей тартқыш жүйесі; көміртегі шығарындылары, отын үнемдеу, компьютерлік модельдеу, гидравликалық экскаватор, шығындарды талдау, оператордың тиімділігі, литий батареясы.*

Моделирование применения технологии троллейной тяги в условиях технологических дорог Качарского рудника

Аннотация. Транспортные расходы при добыче открытым способом могут составлять от 50% до 70% от общих затрат на добычу. Потребление дизельного топлива составляет более 25% расходов на владение и эксплуатацию карьерных самосвалов и составляет около 50% выбросов углерода на карьерах. Современные программные решения используют встроенные характеристики машины, такие как тяговое усилие и тормозные характеристики, расход топлива и электроэнергии. Программное моделирование эксплуатации самосвала CAT 794AC с системой троллейной тяги в условиях Качарского рудника 3068-метровой технологической дороги с 1100-метровым участком троллейной линией продемонстрировало снижение расхода топлива на 22% и повышение производительности на 10,9% по сравнению с CAT 794AC в обычном исполнении. Исследование показало возможную эффективность в будущем и практические рекомендации по применению системы троллейной тяги.

Ключевые слова: *карьерный самосвал; технологическая дорога; система троллейной тяги; выброс углерода, топливная экономичность, компьютерное симулирование, гидравлический экскаватор, анализ затрат, эффективность оператора, литиевые батареи.*

Introduction

According to International Energy Agency mining companies should reduce their carbon emissions by 58% by 2050 compared with 2010. Meeting this target is going to be the big challenge considering that demand for minerals is growing as population is growing and mining is getting harder. Globe is running out high grade deposits and mining low grade ore means task to move more tonnage to longer distances[1].

Diesel-electric drive mining hauling trucks are widely used in mining industry and demonstrate efficient cost per ton parameters within a range 140-tonn payload up to 400-tonn. Already run electric motor drive components are opening opportunity to upgrade those trucks to hybrid or fully electric drive considering recent development of lithium battery technology become cost effective and safe energy storage. However, there is a treat regarding the shortage of lithium for battery production. The treat of lithium shortage shifted focus on recycling of batteries to ensure a continues supply of material and eliminating risk of lithium battery elements pollute the environment [1].

Nowadays there are solutions for significant reduction of diesel fuel consumption on large mining haul trucks from global original equipment manufacturers (OEM) are available.

Trolley assist solution

Caterpillar as a leading mining equipment manufacturer have available retrofit kit for CAT 794AC, 795AC, 796AC, 798AC trucks. With payload range from 291 to 372 metric tons. Trolley assist offers miners opportunity between 20 to 60% to reduce CO_2 emissions from diesel engine for more environmentally friendly sustainable mining operation. While trolley assist applied more than 90% fuel consumption and average wear of engine is reduced up to 25%. Trolley assist system[2] required wiring and pantograph equipment of trucks and significant mine site infrastructure investment such as AC substation, DC substations, support poles, catenary lines, and the load height check points (Figure 1, 2).

Boliden started trolley assist application project as trial to test potential of technology in weather conditions of the region where temperature can go down to minus 40 degree on Celsius. Trial 700 meters long trolley line was extended by 3000 meters to cover more mine haul road. As project was successful Boliden is planning to implement it Boliden's Kevitsa nickel mine in Finland. Target is overall diesel fuel saving by 5,5 million liters per year when implemented[3].

[1]Muralidharan R., Kirk T., Koch Blank T. Pulling the weight of heavy truck decarbonization. Exploring Pathways to Decarbonize Bulk Material Hauling in Mining. – Basalt (USA): Rocky Mountain Institute®, 2019. – 19 p.
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[3]Mining with principles at Boliden's Aitik mine in Sweden. – 2021 [electronic resource]. https://www.icmm.com/en-gb/case-studies/2021/icsv/boliden-electric-trolley

Figure 1. Trolley Assist truck run in Aitik iron ore mine of Boliden in Sweden.
Сурет 1. Болиден фирмасының Швециядағы Айтік темір кенішіндегі троллей жүйесі бар самосвал.
Рис. 1. Самосвал с троллейной системой на железорудном руднике Айтик компании Болиден в Швеции.

Figure 2. Mine site infrastructure in Aitik iron ore mine of Boliden in Sweden.
Сурет 2. Болиденнің Швециядағы Айтік темір кенішіндегі троллей желісінің инфрақұрылымы.
Рис. 1. Инфраструктура троллейной линии на железорудном руднике Айтик компании Болиден в Швеции.

Recommendations for haul roads

Trolley assist truck request significant improvement in mine road building and maintenance culture. Well-kept constant grade is mandatory for trolley assist section of the road. Reducing dust on trolley-assisted haul roads involves processes like evaluating haul road design, traffic flow management, inspection for structural failures such us rutting, analyses the upper layer and material selection and per site constrains[4]. Selection of appropriate water tank and water spaying equipment and dust suppression management are critical part of dust control in order to prevent dust build up on pantograph and trolley line. Mine haul road grade should be as per gradeability performance chart of mine haul truck manufacturers (Figure 3). Ambient temperature 30°C; *E* – Empty operating weight 217419 kg; *L* – Target GMW 521631 kg.

To determine gradeability performance: read from gross weight down to the percent of total resistance. Total resistance equals actual percent grade plus 1% for each 10 kg/t of rolling resistance[5].

Recommendations of off-the-road (OTR) tire manufacturers also must be taken into consideration while designing mine haul road grade and profile. Most of OTR manufacturers recommend 8% grade as optimal to reach target life of OTR tires.

Methodology

Preliminary modeling and simulation of various equipment and technology is important part of decision making in mining industry. Fleet Production and Cost Analysis (FPC) software designed by Caterpillar Inc. for estimation of productivity and costs for different combinations of earth moving equipment models and site conditions.

FPC takes as inputs such as: speed limits, grades, rolling resistance, distance, waiting time, loading time, dumping time, machine availability, bucket fill factor, material density, operator efficiency and costs data. FPC use rimpull and retarding capabilities of mining dump trucks and cycle time of loading tool and provides accurate prediction of current and future productivity. Miners can identify bottle necks as truck spotting, operator efficiency or road conditions as well as safety aspects of operations.

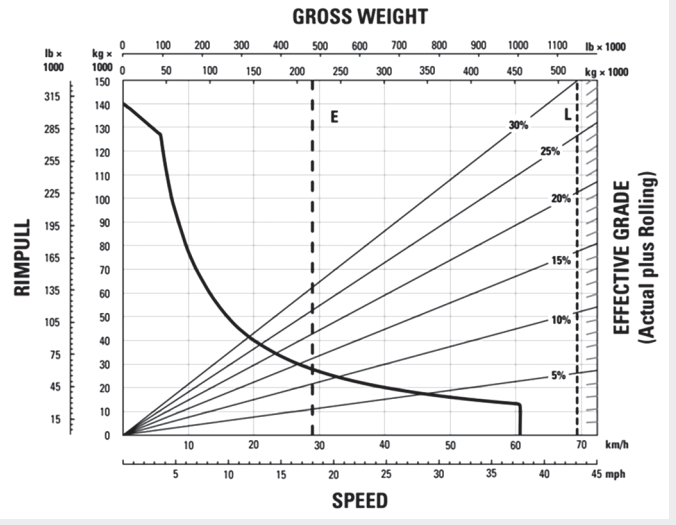

Figure 3. Gradeability performance chart of CAT 794AC at sea level.
Сурет 3. CAT 794AC самосвалының теңіз деңгейіндегі тарту сипаттамаларының графигі.
Рис. 3. График тяговых характеристик самосвала CAT 794AC на уровне моря.

[4]Adams T. Trolley-assisted haul roads construction and maintenance. / Industry articles. – 2022 [electronic resource]. https://globalroadtechnology.com/trolley-assisted-haul-roads-construction-and-maintenance/
[5]CAT 794AC Mining Truck Specifications. Caterpillar. AEHQ7160-03 (05-2016). – 2016 [electronic resource]. https://caterpillar.scene7.com/is/content/Caterpillar/CM20200930-dba70-c067f

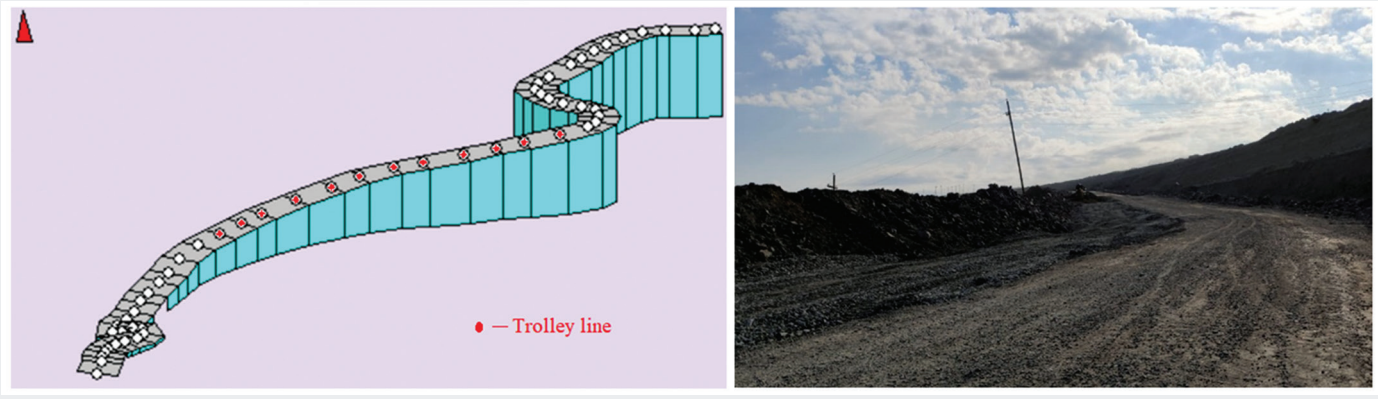

Figure 4. Kachar iron ore mine haul road for overburden removal.
Сурет 4. Қачар темір кеніші кенішінің үстіңгі қабатын тасымалдауға арналған технологиялық жол.
Рис. 4. Технологическая дорога по транспортировке вскрышной породы железорудного рудника Качар.

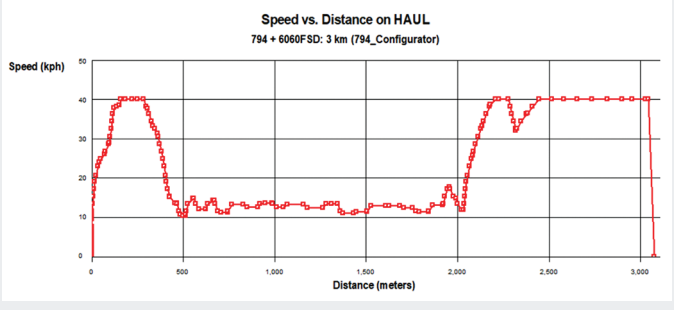

Figure 5. Speed vs Distance graph of conventional CAT 794AC truck. Average speed up-hill is 13 km/h.
Сурет 5. Кәдімгі дизайндағы CAT 794AC жолының қашықтығына жылдамдықтың өзгеру графигі. Орташа жылдамдықтың жоғарылауы 13 км/сағ.
Рис. 5. График зависимости скорости CAT 794AC обычного исполнения от протяженности дороги. Средняя скорость на подъем – 13 км/ч.

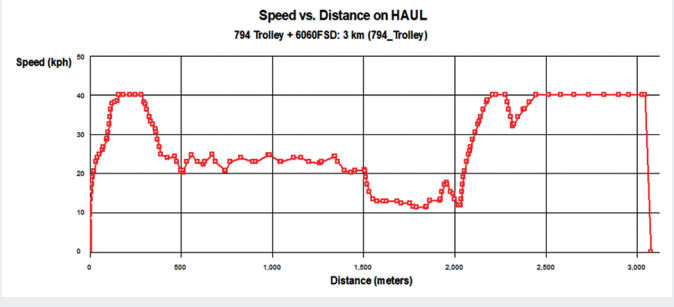

Figure 6. Speed vs distance graph of CAT 794AC with trolley assist. Average speed on route with 1100 meters trolley line is 23 km/h.
Сурет 6. Троллей жүйесі бар CAT 794AC жолының қашықтығына жылдамдықтың өзгеру графигі. 1100 метр торолей линиясы бар жолда орташа жылдамдықтың жоғарылауы 23 км/сағ.
Рис. 6. График зависимости скорости CAT 794AC с тролейной системой от протяженности дороги. На аналогичном участке с тролейной линией в 1100 м средняя скорость на подъем 23 км/ч.

Table 1
Estimated cost inputs used for FPC study
Кесте 1
FPC бағдарламасындағы есептеулер үшін пайдаланған кіріс деректер
Таблица 1
Вводные данные, использованные для расчетов в программе FPC

Parameter	Value		
	6060FSD	794AC	794AC Trolley
Ownership period, year	10	10	10
Operator cost, $/h	6	6	6
Fuel cost, $/h	217	173.13	141.12
Tires, $/h	–	50	50
Cost of trolley line, $/h	–	–	13

Notes: Owning costs of 794AC Trolley is higher than 794AC because of higher capital cost of machine equipped with pantograph. Cost of trolley line includes costs per 20 trucks and 20 years depreciation. All costs information is given for study purpose only as per life cycle cost calculation methodology of OEM based on recommended preventive maintenance and repair periods.

Table 2
Operational, fuel and electricity cost information inputs for FPC study
Кесте 2
Операциялық деректер, отын және электр энергиясы шығындары FPC бағдарламасына енгізіледі
Таблица 2
Эксплуатационные данные, затраты на топливо и электричество, введенные в FPC

Parameter	Value
Operator efficiency, %	90
Annual effective operational time, hours/year	5500
Diesel fuel price, $/liter	0.56
Electricity tariff, $/kWt-h	0.06

Note: Diesel fuel price and Electricity tariffs are taken as average on open market in Republic of Kazakhstan valid in June 2022.

Table 3

Key outcomes of FPC simulation study

Кесте 3

FPC бойынша негізгі модельдеу нәтижелері

Таблица 3

Ключевые результаты симуляции на FPC

Parameter	Value	
	794AC	*794AC Trolley*
Quantity required to reach annual production target of 100 mln. tonnes, Pcs	20	20
Total trip cycle time, min	21.11	19.77
Cycles per hour, c/h	2.84	3.08
Hourly productivity of fleet, t/h	14988	15 791
Hourly fuel consumption, liter/h	343.52	215.49
Hourly electricity consumption, kWt-h	–	198.34
Fuel consumption per total cycle, leters	120.88	70.99
Diesel fuel consumption for course, leters	41254632	24563278
Electricity consumption per course, kWt-h	–	68630552
Total diesel fuel equivalent consumption per course, leters	41254632	31916552
Tonnes per liter, t/l	2.42	3.13

Simulation of Trolley assisted CAT 794AC operation was done on FBC with bellow inputs. Figure 4 shows the real mine haul road of Kachar iron ore in the North Kazakhstan was used.

GPS data is taken 10th of May 2022 with the permission of mine management. Length of road 3068 meters. For FPC simulation purposes trolley line for 1100 meters are modeled for acceptable straight parts of the haul road. Average grade of trolley line in is 11% which is on acceptable recommended level. Rolling resistance is 2% for dry compacted gravel haul road. Speed limit of 40 km/h is applied as per Safety regulations for mining operation in Republic of Kazakhstan.

Simulation was done for production target of 100 million metric tonnes for year. Material bank density is 2320 kg per bank cubic meter (BCM) and material loosen density 1750 kg per loosen cubic meter (LCM).

CAT 6060FSD – hydraulic front shovel with 34 cubic meter bucket as per SAE 2:1 and CAT 794AC – mining haul truck with nominal payload 291 metric tonnes with trolley assist and without it. This combination is considered as the most optimal with 4-5 bucket pass match.

Table 1 and 2 shows number of inputs entered to FPC software to study performance of trolley assist.

Results

FPC taking to algorithm all inputs generated two scenarios of reaching target production and costs for each. Figure 4 and 5 shows how up-hill direction speed over the haul road on conventional 794AC and 794AC with Trolley assist higher for 13 km/h on 1100-meter trolley line.

Advantage of higher speed on trolley line let 794AC with Trolley assist make 3,08 trips per hour vs 2.84 trips for conventional 794AC truck.

Discussion

Fuel efficiency of CAT 794AC with trolley is 40% lower, FPC considers 60 630 552 kWt-h electricity consumption and convert it to equivalent fuel. Thus, total fuel equivalent consumption over the 10 year course is 31 916 552 liters for fleet of 20 trucks.

Figure 7a shows equivalent fuel consumption per course (fleet of CAT 794AC with trolley consumes 22% less fuel that fleet of conventional CAT 794AC); 7b – cost per tonnes of CAT 794AC with trolley 6,6% lower

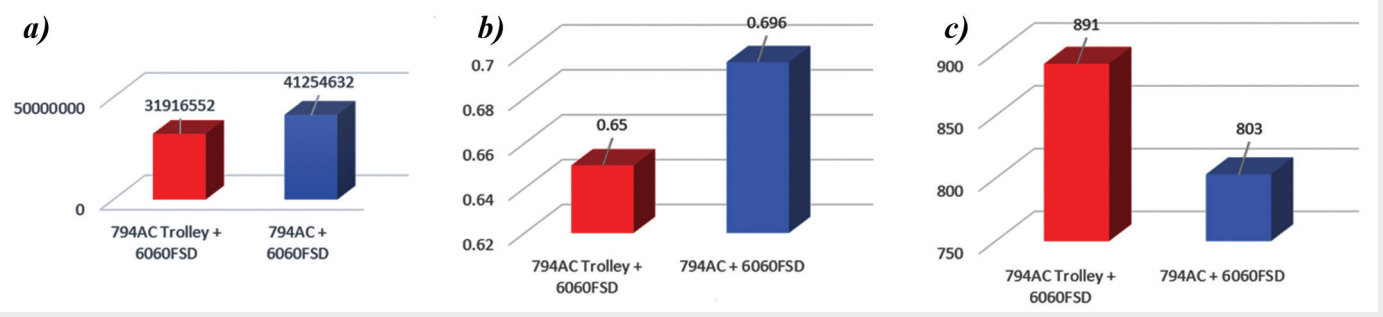

Figure 7. Graphical comparison of *a* – fuel consumption; *b* – cost per tonnes and *c* – production data.
Сурет 7. Графикалық салыстыру: *a* – отын шығыны; *b* – тоннаға кететін шығын; *c* – өнімділік.
Рис. 7. Графическое сравнение: *a* – расход топлива; *b* – себестоимость за тонну; *c* – производительность.

than conventional CAT 794AC; 7c shows that production of each CAT 797AC with trolley can be higher 10.9% than conventional CAT 794AC.

Difference in CO_2 emission between CAT 794AC with Trolley assist and conventional CAT 794AC can be calculated[6] by below formula:

$$CO_2(t) = \Sigma_i VK.$$

$$CO_2(t) = (41254632 - 31916552) \times 2{,}65 = 24745912 \text{ liters},$$

Where:
K – Diesel fuel burn CO_2 emission coefficient CO_2 EF kg CO_2/l – 2.65;
V – difference in fuel consumption.

Conclusion

Regulations to reduce carbon footprint for mining companies will grow year by year and designing of expansion and existing and mine mines should be done considering effective technologies on reducing CO_2 emissions by most economical effective way. Individual mine conditions should be considered during feasibility study of technology applications. Analyses of trolley assist use at mine sites are proven way to reduce diesel fuel consumption and dust, improve air quality at minesite and extend diesel engine overhaul intervals [2]. Road construction materials of higher strength and less cohesion improves the general properties of the road in terms of its carrying capacity and durability and can reduce the need for maintenance [3]. A dump truck operators can have a significant effect on the energy efficiency of material handling operations [4].

Using 1100 meter trolley line on CAT 794AC with trolley assist on conditions of 3068 meters haul of Kachar iron ore mine showed 22% fuel efficiency and 6,6% cost per tonnes efficiency.

[6]*Breisinger M. Greenhouse gas assessment emissions methodology. / Inter-American development bank. – 2012. – VPS8/ESG Technical note №IDB-TN-455. – 10 p. [electronic resource]. https://www.iadb.org/en*

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Authors are gratitude management of Kachar mine for provided haul road data and cooperation during the study.