Comparative Analysis of Semi-Mobile In-Pit Crushing and Conveying System (SMIPCC) and Truck-Shovel System Using Python Programming: Case Study

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ABSTRACT

Semi-mobile in-pit crushers and conveying systems (SMIPCC) are a type of IPCC that attracted the miners due to their relocation nature as an alternative to conventional Truck-shovel (TS) haulage systems. Most of the cost of mining operations arises from purchasing and maintaining haulage trucks to transport material from the working face to the crushers located outside the mine. This study aims to understand the importance of SMIPCC and its comparison with the TS system and to use Python programming to develop a code for comparative analysis. This code is based on cost analysis and evaluating the environmental impacts of SMIPCC and TS. The code is run on real-time open-pit mine data to compare the feasibility of SMIPCC and TS in the early stages of a mining project.

1. Introduction

This article is intended to analyze the comparison between Truck-shovel (TS) and Semi-mobile In-pit crusher and conveying system (SMIPCC) based on capital expenditures (CAPEX) and operational expenditures (OPEX) for the life of an open-pit mine. Open-pit mining is a capital-intensive venture that involves huge capital expenses in the initial stages of the mine and operational expenses for the whole life of the mine. Therefore, deciding between alternatives for material handling and transport is critical. In this study, the alternatives are SMIPCC and TS operations for transporting and handling material from the mine to the processing plant. In large open pit mines, the in-pit crusher and conveying (IPCC) system gained momentum over conventional TS systems due to the increasing fuel cost and labor cost of the TS system and also less greenhouse gas emission in IPCC [1]. Most mining companies are still hesitant to adopt these systems (IPCC) despite their popularity [2].

About 50% of the OPEX in surface mining comes from truck-shovel operations to handle and haul the material as indicated in studies [3]-[6], etc. Also, the reason for the transformation from standard truck and shovel operations to IPCC is that as the mine becomes deeper and the haul roads get longer, conventional truck transportation expenses rise [7]. Therefore, it is the need of the hour to minimize this hauling cost with some other alternative. OPEX of TS comes from diesel, lubrication, tire, and labour costs. This study aims to compare this TS operation of surface mining to some other alternatives and decide between two alternatives. For this purpose, a Python code is developed that takes the inputs for both alternatives and calculates the cost associated with these two alternatives (TS and SMIPCC). Based on this cost analysis decision can be made to choose between alternatives.

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2. Methodology

The method is designed as a model that uses the data available from the early stages of the evaluation of mining projects, usually from the scoping studies, as an input parameter [8]. This study focuses on comparing two alternatives so the input parameters for both alternatives are discussed.

2.1. Input Parameters

Input parameters for both alternatives are discussed below:

2.1.1. Material

Input parameters for the material are:

a. Density
b. Swell Factor
c. Moisture Content

2.1.2. Trucks Operating parameters

a. Haulage distance
b. Rolling and grade resistance
c. Speed limits (Empty and Full trucks)
d. Fixed time (load time, spot time, dump time)
e. Travel and wait time
f. Mechanical efficiency
g. Hourly efficiency

2.1.3. SMIPCC operating parameters

a. Primary crushing
b. Motor power
c. Length and height of conveyor

2.1.4. Economic parameters

a. CAPEX of trucks and SMIPCC
b. OPEX of trucks and SMIPCC
c. Discount and Exchange rate

The above following inputs are being used to calculate the fleet size for both TS and SMIPCC.

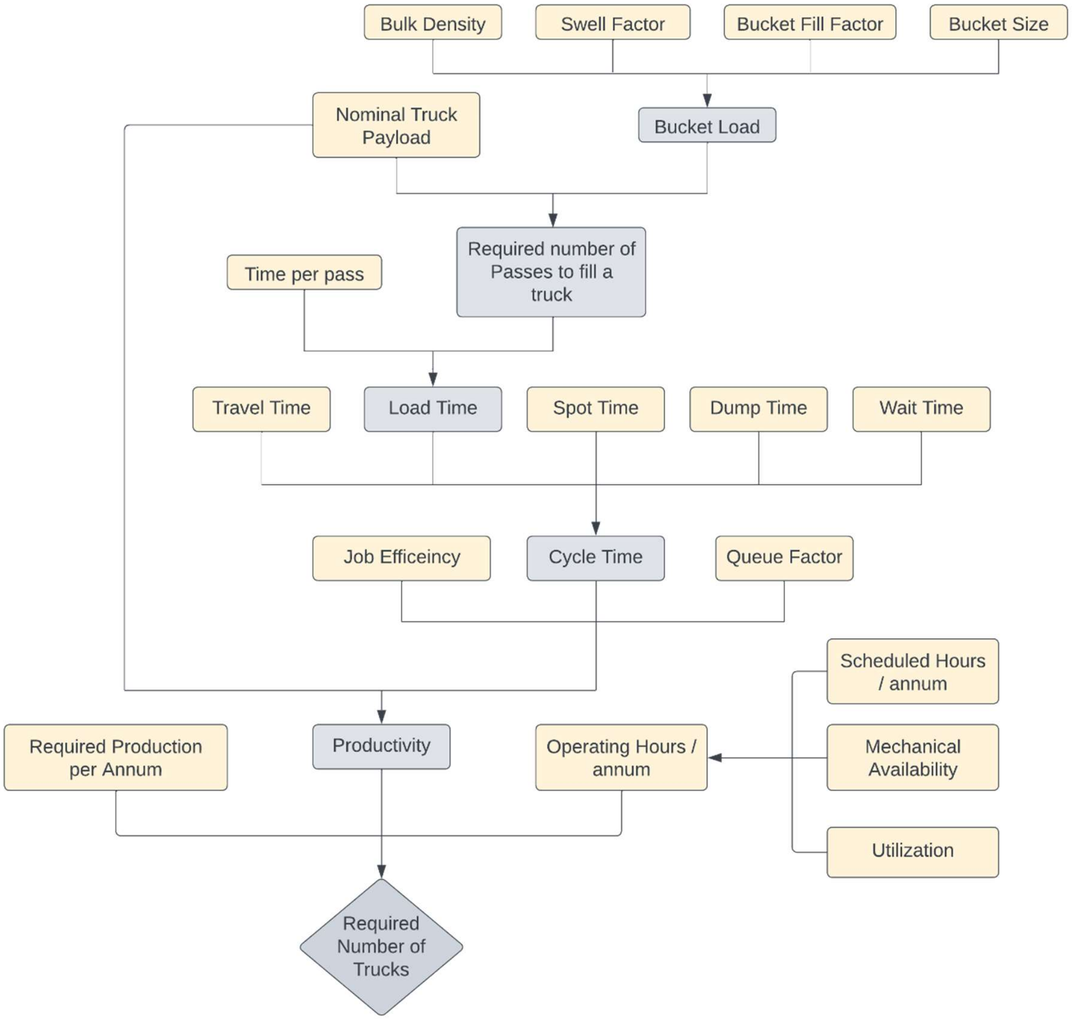
2.2. Fleet Sizing

Fleet sizing is calculated to find the number of trucks, excavators, and conveyors to handle and haulage the material being mined.

2.2.1. Truck Fleet Sizing

The following calculations are used to find the number of trucks required to handle and transport the material. Figure 1 illustrates the whole process for calculating the fleet sizing for trucks.

Figure 1. Fleet sizing for Trucks



a. Number of passes required to fill the trucks

The number of passes required to fill the trucks depends on the nominal payload of a truck and the bucket load. The nominal payload of a truck is the load that a truck can carry and is given by the manufacturer of the truck. Bucket load can be calculated using the density of the material being mined, bucket fill factor, and bucket size.

$$BL = \frac{BC \times BFF \times den}{SF} \tag{1}$$

Where BL is bucket load (*tonne*), BC is bucket capacity (m^3), BFF is bucket fill factor (*%*), den is density of the material ($tonne/m^3$), and SF is swell factor of the material being mined.

After calculating the bucket load, the number of passes required to fill the truck can be calculated using Eq. (2):

$$\text{Number of passes} = \frac{\text{Nominal payload of truck (tonne)}}{\text{Bucket load (tonne)}} \tag{2}$$

b. Calculated truck payload

This payload is the average payload that the truck will carry after considering all of the above factors. It is calculated using Eq. (3):

$$\text{Calculated truck payload} = \frac{\text{Bucket load (tonne)}}{\text{Number of passes to fill truck}} \tag{3}$$

c. Load time

It is the time required to load a truck. It is calculated using Eq. (4):

$$\text{Load time (min)} = \text{time per pass (min)} \times \text{Number of passes to fill truck} \tag{4}$$

d. Fixed time

The time is essentially invariable for a truck and loading unit combination. It is the sum of load, spot, and dump time. Spot time depends on the nature of the spotting nature being used at the mine site and dump time depend on a truck's rear and bottom dump configuration. Fixed time can be calculated using Eq. (5):

$$\text{Fixed time (min)} = \text{Load time (min)} + \text{Spot time (min)} + \text{Dump time (min)} \tag{5}$$

e. Cycle time

It is the total time required for a truck to load, travel, and return for another trip. Travel time depends on the section length, maximum attainable speed, and speed factor. The speed factor for any truck can be found using a rimpull curve. The rimpull curve is the curve between the gross weight of the vehicle (GVW), the road's effective grade, and the truck's speed. Using Eq. (6), the travel time for any truck either it is empty or loaded with material can be calculated.

$$\text{Travel time (min)} = \frac{\text{Section length (m)} \times 0.06}{\text{Maximum attainable speed }(\frac{\text{km}}{\text{hr}}) \times \text{Speed factor}} \tag{6}$$

After calculating the travel time (for empty and full truck), total travel time can be calculated by adding empty and full truck travel time. The cycle time is calculated using Eq. (7).

$$\text{Cycle time (min)} = \text{Fixed time (min)} + \text{Travel time}_{\text{Full+Empty}}\text{(min)} + \text{Wait time (min)} \tag{7}$$

Wait time is the time a truck has to wait while the other truck is being loaded. This time depends on the excavator's configuration for loading the trucks.

f. Productivity

It is the amount of material being transported in a given time. It depends on efficiency, cycle time, calculated truck payload and queue factor. The queue factor is the time loss in queuing of trucks. It ranges from 0.7 to 1.0 depending on the amount of time lost in placing the truck on a given position for loading. Productivity can be calculated using Eq. (8):

$$\text{Productivity}\left(\frac{\text{tonne}}{\text{hr}}\right) = \frac{\text{Efficiency (\%)}}{\text{Cycle time (min)}} \times \text{Queue factor} \times \text{Truck payload (tonne)} \tag{8}$$

Efficiency is basically the proportion of an hour as productive. It deducts the time being used in other operations like clean-up, fuelling, inspection etc.

g. Utilization

It is the measure of how much a mechanical unit can be utilized. It depends on mechanical availability and use of availability. It can be calculated using Eq. (9):

$$\text{Utilization (\%)} = \text{Mechanical availability (\%)} \times \text{Use of availability (\%)} \tag{9}$$

h. Operating hours

Operating hours per annum depend on the scheduled and utilization hours. It can be calculated using Eq. (10):

$$\text{Operating hours per annum} = \text{Scheduled hours per annum} \times \text{Utilization (\%)} \tag{10}$$

i. Production

Production (tonne/annum) depends on productivity (tonne/hr) and operating hours per annum. Production can be easily maximized by maximizing productivity.

$$\text{Production per annum (tonne)} = \text{Productivity}\left(\frac{\text{tonne}}{\text{hour}}\right) \times \text{Operating hours per annum} \tag{11}$$

j. Required units of trucks

Total number of units of trucks depends on the annual required production and the estimated annual production.

$$\text{Number of trucks} = \frac{\text{Annual required production (tonne)}}{\text{Estimated production per annum (tonne)}} \tag{12}$$

2.2.2. Excavator Fleet sizing

An excavator is used to mine and load the material into the trucks. Calculating the fleet size for the excavator is an important aspect to consider in feasibility studies. The process of finding the number of excavators required for a certain amount of production depends on productivity. It can be calculated using Eq. (13).

$$\begin{aligned}\text{Productivity}\left(\frac{\text{tonne}}{\text{Hour}}\right) = {} & \frac{\text{Efficiency (\%)}}{\text{Load time + Sopt time}} \\ & \times \text{Calculated truck payload} \\ & \times \text{Propel factor} \times \text{Presentation factor}\end{aligned} \tag{13}$$

Propel factor accounts for the time lost due to the movement of loading units around the mine. It depends on the loading unit type, pit size and the amount of movement required. It generally ranges from 0.95 to 1.0 for rope shovel and front-end loader, respectively. The presentation factor accounts for the time lost during waiting for a truck. It also generally ranges between 0.95 to 1.0. Rest of the process for calculating the number of excavators required is the same as for the number of trucks required, as explained before. Figure 2 shows the process for calculating the number of excavators required for a required annual production.

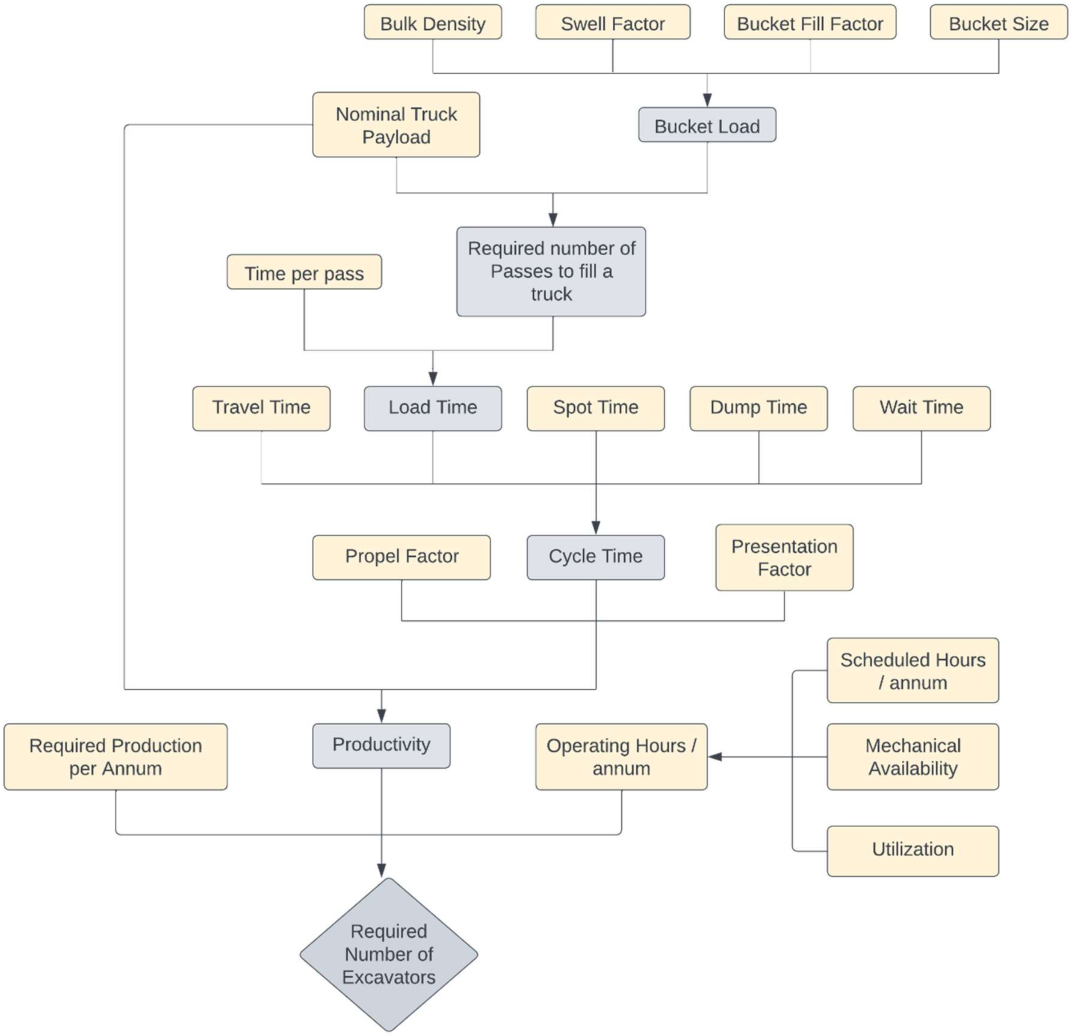


Figure 2. Fleet sizing for excavator

2.2.3. Conveyor Dimensions

As an alternative to truck shovel systems for material handling in mine, semi-mobile in-pit crushers and conveying (SMIPCC) systems are receiving more attention due to the rising cost of truck haulages, fuel price, and spare parts. SMIPCC is considered a low-operating-cost alternative due to its continuous operation, reduced labour, and lower energy consumption, but it requires high capital cost and has reduced flexibility (London et al. 2014).

In this study, SMIPCC aims to reduce the number of trucks and operation expenditures. In-pit crushers are being installed inside the pit at some location depending on the geotechnical properties and also to minimize the distance from the working face of the pit. Trucks haul the material from the face of the mine, and then IPCC crushes and conveys this material outside the pit using a conveyor. The cost of the following items is considered in the IPCC cost calculation.

- Conveyor belt
- Crusher
- Motors required to run the conveyor
- Head and tail assemblies
- Take up and Transfer towers
- Miscellaneous (20%)

The operational expenditures is related to the power required to run the motor. The power required to drive the conveyor belt is calculated using the following steps.

a. Power to drive empty belt

It is the power required to run the empty belt. It can be calculated using Eq. (14):

$$P_e = m_i\left(L+45\right)\times g\times \mu_e \times v \tag{14}$$

Where P_e is power to drive empty belt (Watt), m_i is the conveyor belt mass per unit length. It depends on the mass of the total conveyor belt length and the mass of the conveyor belt on idlers; taken from manufacturers' catalogues (kg/m). L is the conveyor length (m), g is acceleration, 9.81 m/s2, μ_e is the belt's friction coefficient on idlers, and v is velocity of the belt (m/s).

b. Power to convey the material

It is the power required to convey the material to the desired length. It is calculated using Eq. (15).

$$P_m = T\times L\times g\times \mu_e \tag{15}$$

Where T is carrying capacity of bulk solids in belt conveying system (kg/s).

c. Power to raise or lower the material

The power required to raise or lower the material to some height is calculated using Eq. (16).

$$P_r = T\times g\times h \tag{16}$$

Where h is the elevation change between the outlet and inlet (m).

The total power required to transport the material from one place to another can be calculated by summing all the powers calculated by Eqs. (14), (15), and (16) .

$$P_t = P_e + P_m + P_r \tag{17}$$

This is the total power required to convey the material from the pit to the outside. Based on this power required, the number of motors can be found and the cost associated with them, as shown in Figure 3.

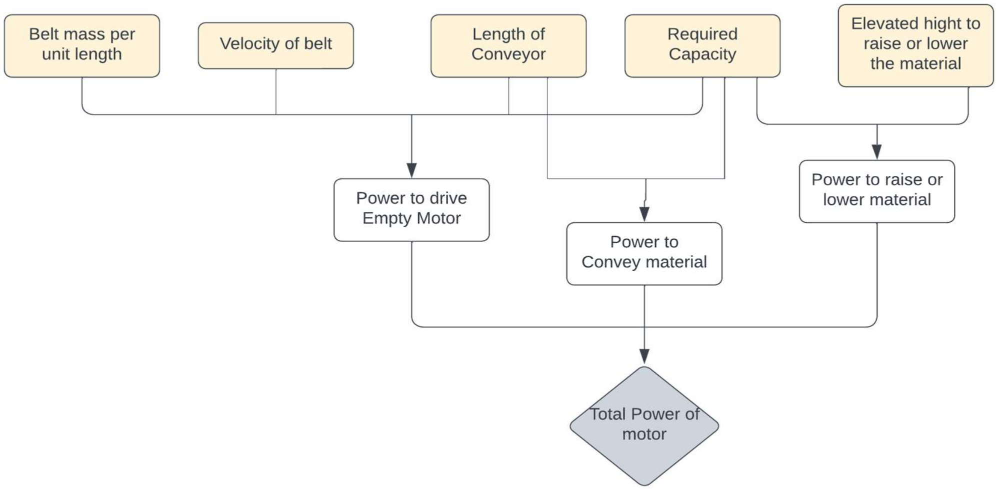


Figure 3. Fleet sizing for conveyor.

2.3. Economic evaluation

After calculating the fleet sizing for trucks, conveyors, and excavators, the next step is to evaluate the economics of these alternatives. The economic evaluation will take its CAPEX and OPEX, and based on these costs, the decision could be made.

2.3.1. Cost evaluation of trucks

In the TS haulage system, the CAPEX cost is purchasing the trucks, and its OPEX will be fuel, Lubrication, tires, and labour costs. Fuel cost for truck shovel alternative depends on the number of trucks required, fuel cost per litre, truck engine power, and fuel job factor (FJF). The FIF depends on machine and site-specific conditions. It usually ranges from 0.3 to 0.6. Fuel cost for trucks is calculated using Eq.(18).

$$\text{Fuel cost } \left(\frac{\$}{\text{hr}}\right) = \text{Engine power (kW)} \times 0.3 \left(\frac{\text{L}}{\text{h}} \text{per kW}\right) \times \text{FJF} \times \text{Unit cost } \left(\frac{\$}{\text{L}}\right) \tag{18}$$

After calculating the fuel cost for a required number of trucks lubrication cost can be calculated using the fuel cost. Generally, the lubrication cost is 15 – 40 % of the fuel cost. So, the total OPEX for trucks can be calculated by summing the cost of fuel, lubrication cost, labor cost, and tires cost as shown in Figure 4.

$$\text{OPEX}_{\text{TRUCK}} = \text{Fuel cost (\$)} + \text{Lubrication cost (\$)} + \text{Labor cost (\$)} + \text{Tire cost (\$)} \tag{19}$$

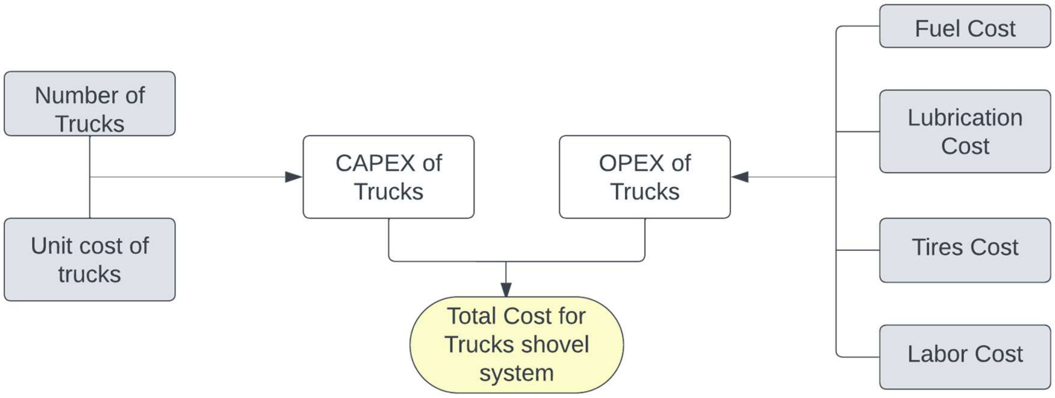


Figure 4. Cost evaluation for trucks.

2.3.2. Cost Evaluation for Conveyors

SMIPCC uses conveyors to transport the material from the pit to the outside. The cost associated with the conveyor design can be calculated after calculating the sizing for the conveyor design. The CAPEX associated with the conveyor is the installation of in-pit crusher, belt price, motor price, head and tail assemblies, take-up and transfer towers, and miscellaneous costs (20%). The OPEX related to the conveyor can be found as the total power consumption by the main motor and the additional motors, and power taken by the crusher to crush the material as shown in Figure 5.

2.4. Python GUI for Calculation

The main objective of this study is to develop the GUI for the calculation of fleet sizing and then cost evaluation of both the alternatives (Truck-shovel and SMIPCC). All of the coding is done by using Python 3.11.3. GUI has been developed to take the inputs from the user, and then based on these inputs system calculates the fleet sizing for trucks, conveyors, and excavators. All of the inputs and the calculation formulas have been discussed above. Users can choose between SMIPCC and Truck-shovel system as shown in Figure 6.

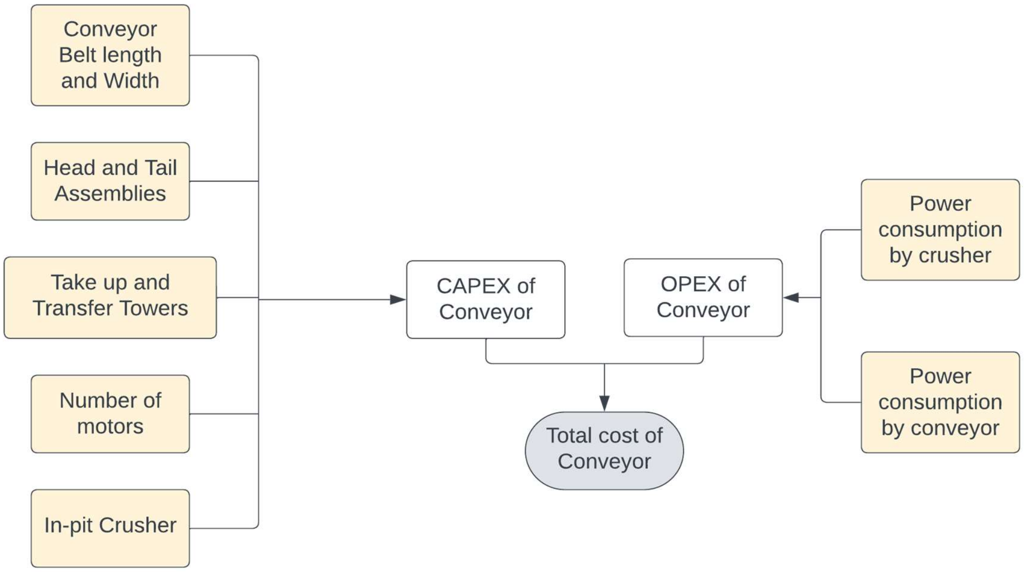


Figure 5. Cost Evaluation of IPCC.

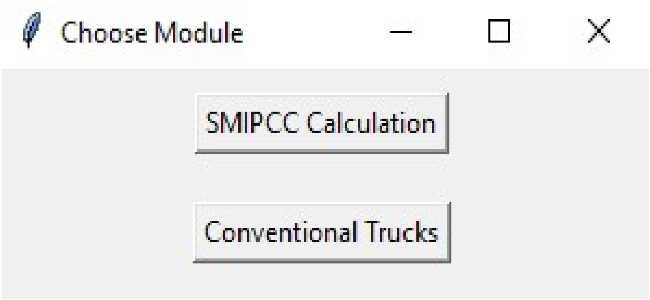
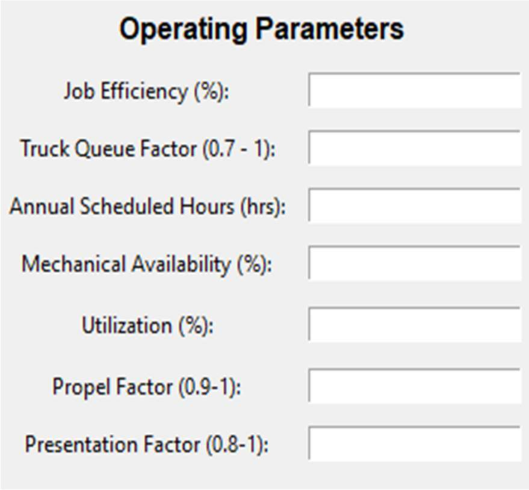


Figure 6. Starting GUI.

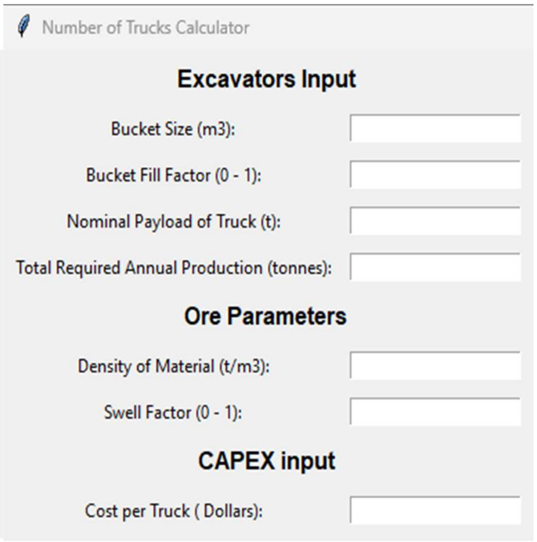
After selecting the choice by the user, the next window is to get input values from the user as shown in Figure 7. depicts the operational expenditures associated with the trucks. Similarly, the GUI for conveyor calculation and associated cost is developed as some part is shown in Figure 9.



Operating Parameters

Job Efficiency (%):
Truck Queue Factor (0.7 - 1):
Annual Scheduled Hours (hrs):
Mechanical Availability (%):
Utilization (%):
Propel Factor (0.9-1):
Presentation Factor (0.8-1):

Figure 7. GUI for inputs of Trucks calculator.



Excavators Input

Bucket Size (m3):
Bucket Fill Factor (0 - 1):
Nominal Payload of Truck (t):
Total Required Annual Production (tonnes):

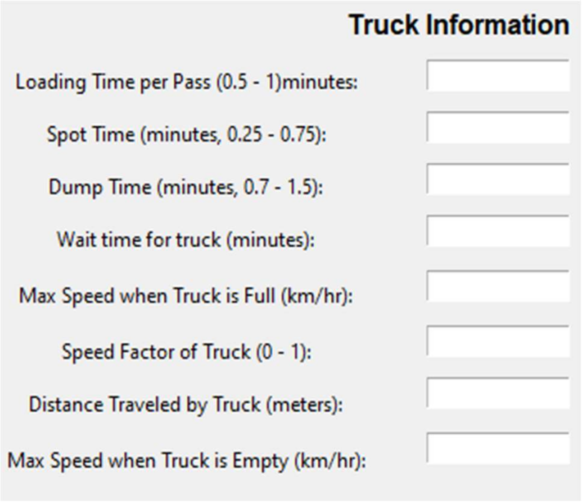
Ore Parameters

Density of Material (t/m3):
Swell Factor (0 - 1):

CAPEX input

Cost per Truck (Dollars):

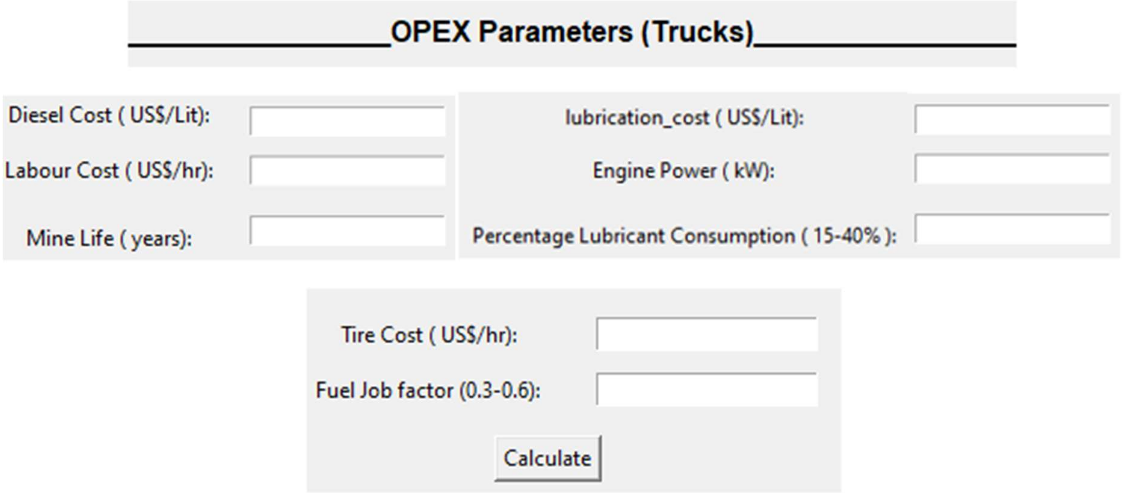
Figure 8. GUI for OPEX input for trucks.



Truck Information

Loading Time per Pass (0.5 - 1)minutes:
Spot Time (minutes, 0.25 - 0.75):
Dump Time (minutes, 0.7 - 1.5):
Wait time for truck (minutes):
Max Speed when Truck is Full (km/hr):
Speed Factor of Truck (0 - 1):
Distance Traveled by Truck (meters):
Max Speed when Truck is Empty (km/hr):

Figure 9. GUI for OPEX of Conveyor.



OPEX Parameters (Trucks)

Diesel Cost (US$/Lit):

Labour Cost (US$/hr):

Mine Life (years):

lubrication_cost (US$/Lit):

Engine Power (kW):

Percentage Lubricant Consumption (15-40%):

Tire Cost (US$/hr):

Fuel Job factor (0.3-0.6):

Calculate

3. Case study and conclusion

Hypothetical data was input to this system to calculate the fleet sizing and was being cross verified with real-time data. The total distance from mine face to outside the crusher is 1600 meters. In the case of the truck shovel system, the material is mined and then transported to the outside crusher using only trucks. But using SMIPCC, the crusher is being installed at a distance of 500 meters from the face of the mine. So, the trucks deliver the material from the face of the pit to the crusher, which will then be crushed and transported to the outside of the pit by conveyor (1100 meters). Table 1 summarizes the rest of the data used in the evaluation.

Table 1. Hypothetical input data.

Equipment (Cat 789)			**OPEX truck data**		
Nominal payload	tonne	172	Electricity cost	US$/MWh	73.6
Material		Granite	Diesel cost	US$/l	0.7
Bulk density	tonne/m^3	2.65	Lubrication cost	US$/l	0.1
Swell factor		1.5	Tire cost	US$/h	68
Bucket load	tonne	38.87	Labour cost	US$/h	63.5
Time per pass	min	0.5	Engine power	kW	1082
Spot time	min	0.8	FJF	0.3-0.6	0.6
Dump time	min	1	Lubrication consumption	15%-40%	33.3
Travel time	min	12	**Time values**		
Waite time	min	0	Hours per year	hours	8760
Efficiency	min/hour	50	Effective hrs per year	hours	5887
Queue factor		1	LOM	yrs	20
Scheduled hrs/annum	hour	7580			
Availability	%	82			
Use of availability	%	85			

Required production	tonnes	1,000,0000
Propel factor	%	0.9
Presentation factor	%	0.8

This input data comprises values required for both TS and SMIPCC.

Based on the data, the model calculated the fleet sizing for both the TS system and SMIPCC.

Table 2 shows the fleet sizing for both conventional Truck shovel and SMIPCC. In conventional truck shovel the number of trucks is higher as compared to SMIPCC as in SMIPCC the section length is less than that of TS. Excavators, graders and bulldozer are same for both the alternatives. In SMIPCC there is conveyor to transfer the material from the mine to outside the pit.

After inputting the cost data, the TS system's CAPEX was low compared to the SMIPCC because a crusher and conveyor was installed in the pit as shown in Table 3. The prices are in thousands of dollars. But the OPEX of TS system is high as compared to the SMIPCC system because of the continuously fuel and maintenance cost involved in the trucks.

Table 2. Fleet sizing for TS and SMIPCC.

Fleet Sizing		
Equipment	Conventional	SMIPCC
Trucks	5	2
Excavator	1	1
Graders	1	1
Bulldozer	1	1
Conveyor	0	1

CAPEX of SMIPCC is almost 24% higher than that of the TS system as most of the capital is involved in installation of conveyor and crusher. This higher CAPEX of SMIPCC can be overcome if the life of the mine is more.

Table 3. Economic Results.

Thousands		**Conventional**	**SMIPCC**
Initial CAPEX	US $	$ 18,000	$ 22,350
OPEX	US $	$ 126,119	$ 76,694

But OPEX of trucks is about 37% more than that of the SMIPCC due to a smaller number of trucks involved in SMIPCC. Therefore, SMIPCC is getting more attention than the conventional truck shovel system, and the environmental concerns related to SMIPCC are less as in SMIPCC, few trucks are used compared to the truck shovel system. So, less fuel is burnt and less environmental hazard. The only problem that exists with the SMIPCC alternative is life of mine. Short mine life is not a feasible option because in SMIPCC, the CAPEX is high compared to the TS system and has a longer payback period.

4. References

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