“Analysis of Operational Efficiency of Continuous Miner”

A PROJECT REPORT

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

BACHELOR OF TECHNOLOGY (MINING ENGINEERING)

SUBMITTED BY

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09th MAY,2024

CERTIFICATE

This is to certify that **Mr. Himanshu Shekhar (Admission No. 20JE0423) & Mr. Vivek Kumar (Admission No. 20JE1096)**, students of Bachelor of Technology, Department of Mining Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad jointly worked under my guidance and partially completed their project entitled **"Analysis of Operational Efficiency of Continuous Miner"** in partial fulfilment of the requirement for award of degree of Bachelor of Technology in Department of Mining Engineering from Indian Institute of Technology (Indian School of Mines), Dhanbad.

This work has not been submitted for any other degree, award, or distinction elsewhere to the best of my knowledge and belief.

Prof. Siddhartha Agarwal

Assistant Professor and Guide

Department of Mining

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Indian Institute of Technology (ISM)
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Abstract

Operational efficiency is a measure of how well a company or organization functions. It looks at how resources are utilized and how processes are managed to produce the desired output. In the case of continuous miners, operational efficiency can be determined by looking at factors such as cycle time, production rate, and machine utilization.

When it comes to cycle time, shorter is better. This is because it means that the continuous miner can move from one place to another more quickly, which increases productivity. The production rate measures how much coal the machine can cut in a given amount of time. Higher production rates mean that more coal can be mined in a shorter period of time, which also increases productivity. Finally, machine utilization looks at how much of the continuous miner's capacity is being used. A higher utilization rate means that more of the machine's potential is being realized, which leads to increased efficiency.

This is because mining is a very resource-intensive activity, so any gains in efficiency can lead to significant cost savings. Continuous miners are an essential part of the mining process, so it is crucial to ensure that they operate as efficiently as possible. By analyzing cycle time, production rate, and machine utilization, we can get a good understanding of how well these machines are performing and identify areas where improvements can be made.

CONTENTS

01. INTRODUCTIONS AND OBJECTIVES

1.1. INTRODUCTIONS

Continuous miners represent a transformative innovation in underground mining technology, revolutionizing the way coal and other valuable minerals are extracted from beneath the earth's surface. Continuous miners emerged as a response to the challenges faced by traditional mining methods, such as manual labor and conventional drilling and blasting techniques. Their development marked a paradigm shift in underground coal mining during the mid-20th century, offering a more efficient and mechanized approach to extraction. From rudimentary prototypes to sophisticated machines equipped with advanced technology, continuous miners have evolved significantly over the decades, reflecting ongoing efforts to enhance their performance and capabilities. In contemporary mining operations, continuous miners play a central role in underground coal mining, particularly in room and pillar mining and longwall mining methods. These versatile machines are capable of simultaneously cutting, loading, and conveying coal or ore, streamlining the extraction process and maximizing productivity. Their ability to operate in confined spaces and navigate through challenging geological conditions makes them indispensable assets in underground mines worldwide.

Continuous miners are synonymous with increased productivity and efficiency in underground mining operations. By mechanizing key aspects of the extraction process, they enable miners to extract larger quantities of coal or ore in less time compared to manual methods. This enhanced productivity translates into higher output and profitability for mining companies, contributing to economic growth and sustainability in the mining sector. Moreover, continuous miners facilitate continuous mining operations, eliminating the need for costly and time-consuming cycle times associated with traditional drilling and blasting techniques. One of the most significant contributions of continuous miners to the mining industry is their role in improving safety and occupational health for mine workers. By automating hazardous tasks such as coal cutting and loading, continuous miners reduce miners' exposure to risks associated with manual labor and underground hazards. Furthermore, their ergonomic design and advanced safety features prioritize the well-being of operators, mitigating the likelihood of accidents and injuries in the workplace. As a result, continuous miners have been instrumental in driving down accident rates and improving overall safety performance in underground mines. Continuous miners exemplify the mining industry's commitment to innovation and adaptability in response to evolving challenges and opportunities. Through ongoing research, development, and collaboration between mining companies, equipment manufacturers, and technology providers, continuous miners continue to evolve to meet the changing needs of the industry. From advancements in machine design and automation to the integration of digital technologies and data analytics, continuous miners remain at the forefront of innovation, driving efficiency gains and sustainable practices in underground mining.

Here, we will be discussing the operational efficiency of continuous miners. Continuous miners are a type of mining equipment typically used in underground mining operations to extract coal from the seam. The purpose of this analysis is to determine if there are any areas where the operational efficiency of continuous miners can be improved. We will look at factors such as cycle time, productivity, and downtime. For production prediction, we have used four different computing models based on machine learning algorithms (i.e., Linear Regression, Support vector machine, Decision Tree, and Random Forest).

1.2.OBJECTIVES

- To understand and draw insights about the operational features of continuous miners. (Cutting time, Idle time, Maintenance time, Marching time and settling time).
- Understanding the correlation between parameters that affect productivity in terms of their importance, degree.

02.LITERATURE REVIEW

A machine with a large rotating steel drum equipped with tungsten carbide teeth that scrape coal from the seam. Operating in a “room and pillar” system – where the mine is divided into a series of 20-to-30-foot “rooms” or work areas cut into the coalbed – it can mine as much as five tons of coal a minute – more than a miner of the 1920s would produce in an entire day. Continuous miners account for about 45% of underground coal production and also utilize conveyors to transport the removed coal from the seam. Remote-controlled continuous miners are used to work in various difficult seams and conditions, and robotic versions controlled by computers are becoming increasingly common.

Though there are many variations in design, continuous miners mostly consist of five main elements:

- A central body carries all other components mounted on some type of drive mechanism to provide mobility (most commonly caterpillar tracks).
- A "cutting head" usually rotating drum(s) and/or chains with cutting picks attached.
- A loading mechanism to pick up cut coal and deliver it to the central part of the machine.
- A conveying system, usually a chain conveyor running in a steel trough from front to the rear of the miner.
- A rear jib section capable of a degree of vertical and horizontal movement to enable the coal to be delivered into a transport or loaded at the desired point.

Some continuous miners (at one time, almost all) could not cut the full roadway width in one pass but had to be moved backward and forwards and from side to side to cut the full profile. This often results in a very rough rib line (bad for stability and ventilation flow) and delays the ability to install support into/under freshly exposed roof for a period. The advantages of the ability to cut the full profile in one pass was recognized early, but was not easy to achieve. Cutting forward in a straight line could be readily accommodated, but it is necessary to be able to turn corners, mostly at right angles, and to be able to retreat the cutting machine from one roadway to relocate at frequent intervals. These factors have proved major stumbling blocks to many developments. In machines which covered the full face, steering in the vertical plane could also be a major difficulty.

The term "continuous" as applied to development machines has been one of the biggest misnomers used for mining equipment because, on development, they are usually anything but continuously cutting. The main delays mostly occur while roof support is installed and often waiting for shuttle cars to return from their discharge point for reloading. When actually cutting, cutting rates are usually more than adequate, but when averaged over a shift cutting rates are often poor and this is one of the reasons many mines have difficulty developing at rates adequate to prevent long delays on longwall production. As a result, development is an area receiving major attention in recent times. Many of the difficulties have been overcome and most modern continuous miners are "full face" machines. They also have roof bolting equipment mounted on the miner in locations allowing roof bolts to be installed reasonably close to the face.

The "ideal" continuous miner would:

- Be able to cut the full face in one pass
- Be easily moveable between locations without dismantling parts
- Be able to excavate right-angle turns with a minimum radius
- Have roof and rib bolters fixed to the machine in a location where each row of the designed support pattern can be installed without moving the miner and be installed close to the cut face if necessary.

- Have adequate space alongside to allow good ventilation of the face area for efficient removal of gas and dust.
- Allow strata supports to be safely installed while coal cutting continues.

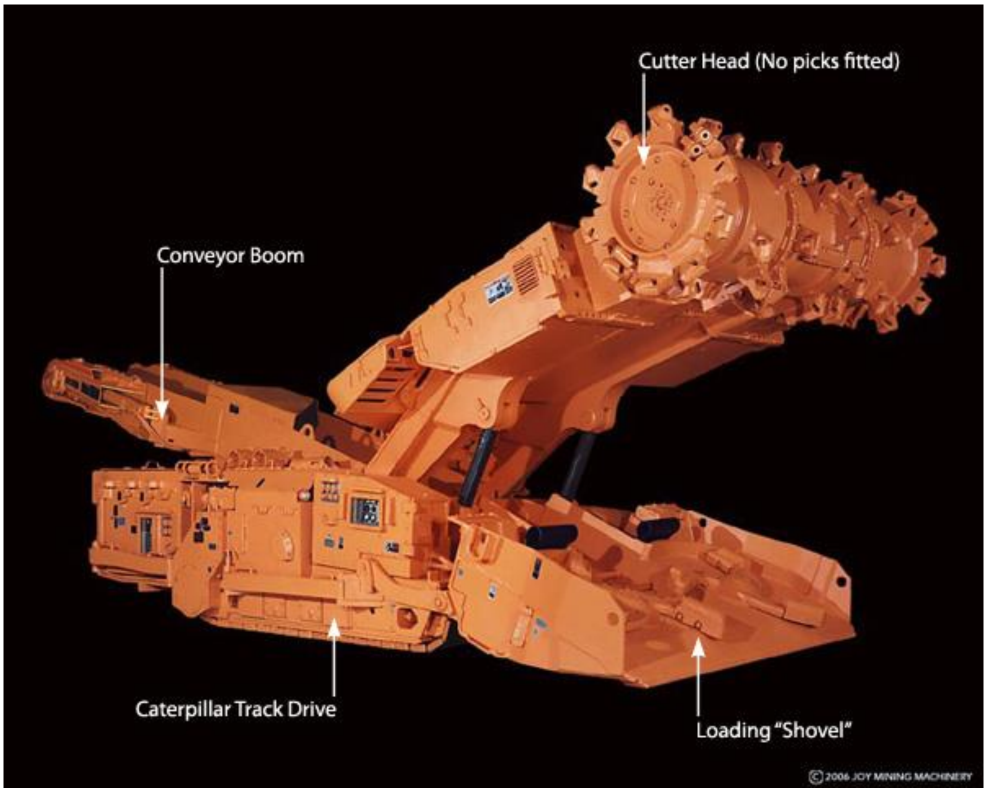
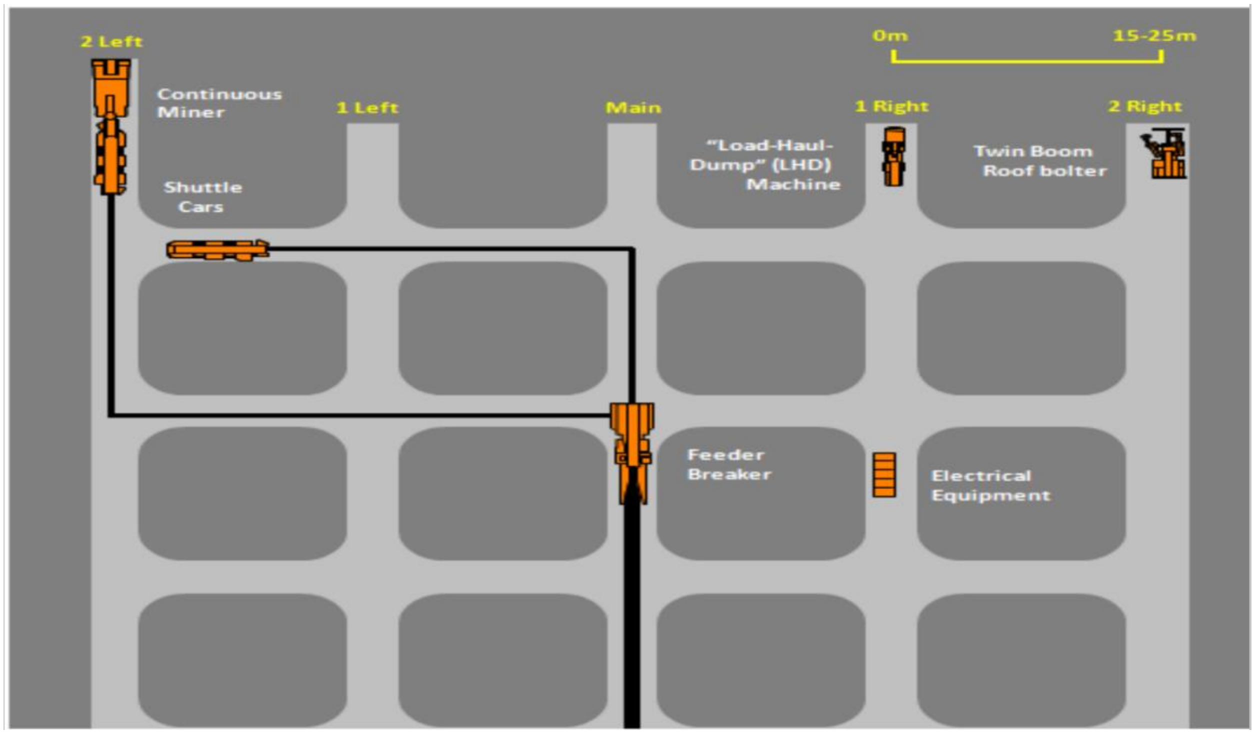


Fig: Continuous Miner

Many of these ideals have been achieved to varying degrees of satisfaction (the last being an area of minimal success), but matching development rates with longwall retreat rates is still a major problem for many mines. Increasing numbers of development units to attain longwall continuity is expensive and provides extra strain on all other service functions (personnel, ventilation, materials handling, power and water supplies, gas drainage, etc, etc) and is not usually a satisfactory solution.

BORD & PILLER DEVELOPMENT WITH CONTINUOUS MINER



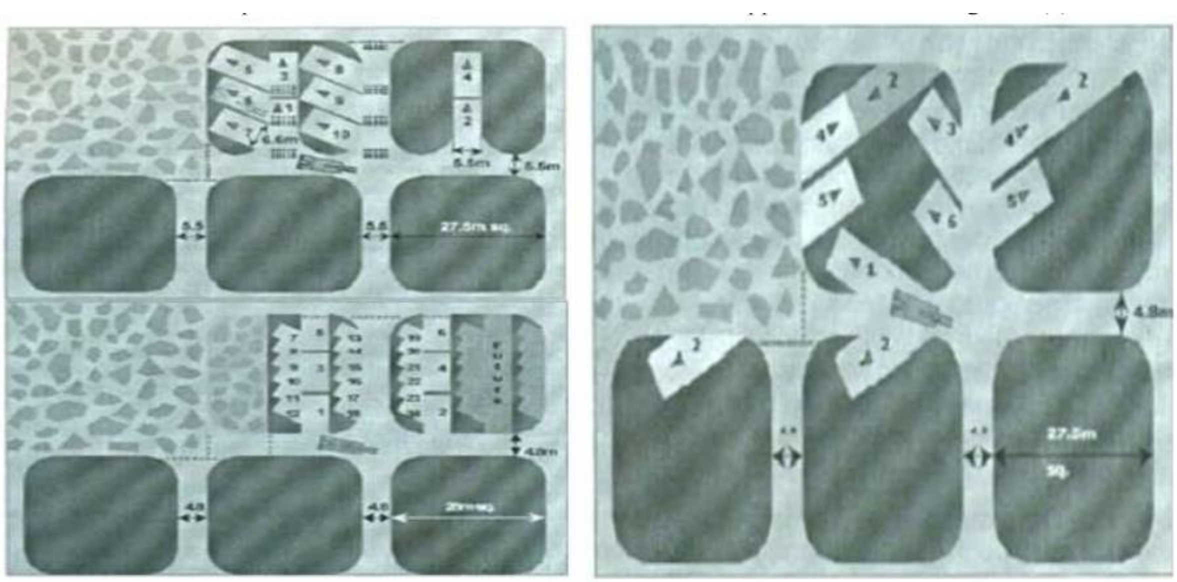
- The standard layout consists of a five road development, with the main conveyor and feeder breaker positioned in the central roadway.
- This provides working areas to carry out all the development functions.
- One heading for the CM deployed for cutting,
- One heading ready for cutting,
- One heading for Crushing, Belt Conveyor & ventilation,
- One heading for cleaning by LHD,
- One heading for supporting by Quadbolter/Twinbolter.

COAL PILLAR EXTRACTION BY CONTINUOUS MINER:

Bord and Pillar mining is one of the widely preferred methods of coal extraction in India. Prior to the development of continuous mining technology, the mining cycle was composed of undercutting the coal, drilling, blasting and loading. This non cyclic method suffers from poor productivity. With the introduction of continuous miners in bord and pillar method, all the unit operations are performed continuously. The extent of improvement in productivity is governed by geomining conditions, sequence of extraction, cutout distance, support requirements and deployment of compatible transport system.

Continuous miners consist of large rotating steel drum equipped with tungsten carbide teeth that scrape coal from the seam. Continuous miners are generally used in combination with shuttle cars to transport the extracted coal from the face to a transfer point (feeder breaker). From there the coal is typically tipped onto the underground conveyor system and taken to the surface.

After development of pillars in the Bord and Pillar method consideration has to be given to the extraction of coal pillars; which is known as pillar extraction or depillaring. In the process of pillar extraction, the extraction line should be so arranged as to facilitate roof control. Diagonal line or step diagonal line of extraction is commonly followed. In special cases, a steep diagonal line of face or even straight line of face are also used. Diagonal or step diagonal line of face provides protection as the working places are supported by solid pillars and also when the roof caves, there is less risk of goaf flushing into the working faces.



(a) Split and fender method (b) Nevid method

Figure 1 Methods of depillaring by continuous miner

03.METHODOLOGY

- Importing the data.
- Cleaning of data (checking null values).
- Checking the correlation of each feature with respect to production for feature selection.
- Scaling the features.
- Applying linear regression, random forest, decision tree, AdaBoost, and support vector machine.
- Conclusion.

Collection of Data

Data was collected for 10 days in a cycle of three shifts. Each shift of eight hours, cutting time, idle time, maintenance time, marching time and settling time was recorded. Production in each shift was also recorded.

DATE	SHIFT	CUTTING TIME	IDLE TIME	MAINTENANCE TIME	MARCHING TIME	SETTLING TIME	TOTAL	PRODUCTION (in TON)
5/16/2023	1	190	25	220	30	15	480	266
	2	285	60	0	90	45	480	770
	3	265	30	125	30	30	480	336
	TOTAL	740	115	345	150	90	1440	1372
5/17/2023	1	126	54	240	45	15	480	490
	2	170	280	10	10	10	480	840
	3	315	50	0	95	20	480	504
	TOTAL	611	384	250	150	45	1440	1834
5/18/2023	1	145	110	195	20	10	480	84
	2	180	190	50	45	15	480	564
	3	315	15	70	70	10	480	588
	TOTAL	640	315	315	135	35	1440	1236
5/19/2023	1	145	40	255	30	10	480	588
	2	230	160	0	60	30	480	756
	3	375	45	0	40	20	480	1162
	TOTAL	750	245	255	130	60	1440	2506
5/20/2023	1	130	50	220	50	30	480	504
	2	225	130	60	40	25	480	560
	3	330	20	60	55	15	480	1050
	TOTAL	685	200	340	145	70	1440	2114

IDLE (REASON)	BREAKDOWN (REASON)
Shift change	General maintenance
Shift change, Roadway maintenance	
Shift change	Chain conveyor jam
Shift change, Bunker full	General maintenance
Shift change, Conveyor belt maintenance	Water pressure issue
Shift change, Goaf setting	
Shift change, Feeder maintenance	General maintenance, Picks change
Shift change, Feeder and road maintenance	Chain conveyor cleaning
Shift change	Chain conveyor jam, Water pressure
Shift change	General maintenance
Shift change, Load center connection	
Shift change, BH wheel issue	
Shift change, Cable hanging	General maintenance
Shift change, BH battery charging	Chain conveyor jam
Shift change	Chain conveyor cleaning

5/21/2023	**1**	85	60	285	30	20	***480***	**504**
	2	210	85	125	40	20	***480***	**476**
	3	60	75	325	10	10	***480***	**238**
	TOTAL	***355***	***220***	***735***	***80***	***50***	***1440***	***1218***
5/22/2023	**1**	0	0	480	0	0	***480***	**0**
	2	320	50	90	10	10	***480***	**770**
	3	220	25	155	50	30	***480***	**476**
	TOTAL	***540***	***75***	***725***	***60***	***40***	***1440***	***1246***
5/23/2023	**1**	215	20	165	55	25	***480***	**462**
	2	70	30	360	10	10	***480***	**42**
	3	220	20	220	10	10	***480***	**546**
	TOTAL	***505***	***70***	***745***	***75***	***45***	***1440***	***1050***
5/24/2023	**1**	105	15	300	40	20	***480***	**462**
	2	230	30	160	40	20	***480***	**560**
	3	290	50	40	70	30	***480***	**672**
	TOTAL	***625***	***95***	***500***	***150***	***70***	***1440***	***1694***
5/25/2023	**1**	180	15	245	30	10	***480***	**266**
	2	360	15	70	20	15	***480***	**714**
	3	305	30	30	80	35	***480***	**756**
	TOTAL	***845***	***60***	***345***	***130***	***60***	***1440***	***1736***

Shift change, Bunker full	General maintenance
Shift change, Cable hanging	Chain conveyor jam, Rod stuck in drum
Shift change, Feeder maintenance	Chain conveyor jam, CM L-side piston burst
	CM L-side piston replacement, Conveyor cleaning
Shift change, Bunker full	CM L-side piston replacement
Shift change, BH battery charging	Chain conveyor cleaning, General maintenance
Shift change, CM route occupied	General maintenance, Water pressure
Shift change	Power grid off due to tree fall
Shift change	Conveyor cleaning, Remote signal issue, Power cut, CM overload
Shift change	General maintenance, Picks change
Shift change	Chain conveyor jam
Shift change, Cable hanging	Chain conveyor jam
Shift change	General maintenance, Chain conveyor jam
Shift change	Chain conveyor jam
Shift change	Chain conveyor jam

Parameters

- Cutting Time
- Idle Time
- Maintenance Time
- Marching Time
- Setting Time

Linear Regression

Linear regression analysis is used to predict the value of a variable based on the value of another variable. The variable you want to predict is called the dependent variable. The variable you are using to predict the other variable's value is called the independent variable.

This form of analysis estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable. Linear regression fits a straight line or surface that minimizes the discrepancies between predicted and actual output values. There are simple linear regression calculators that use a "least squares" method to discover the best-fit line for a set of paired data. Then estimate the value of X (dependent variable) from Y (independent variable).

Why Linear Regression is important?

Linear regression models are relatively simple and provide an easy-to-interpret mathematical formula that can generate predictions. Linear regression can be applied to various areas in business and academic study. It is a mathematical model that helps predict future events based on past events. This predictive capability makes linear regression a powerful tool for businesses seeking to improve their operational efficiency. In its simplest form, the linear regression equation states that the dependent variable (y) is a linear function of the independent variable (x). The equation takes the following form:

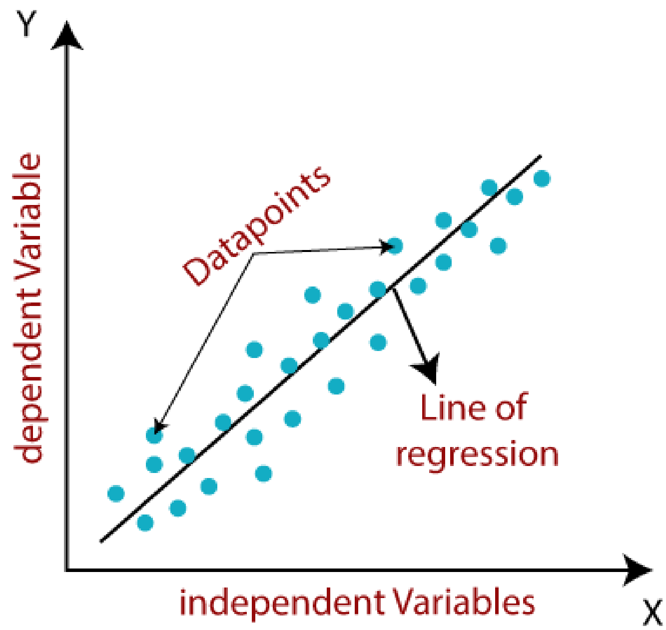
$$y = mx + b$$

where, m is the slope of the line and b is the intercept.

To determine the values of m and b, businesses must gather data on past events. This data can be historical sales data, production data, customer satisfaction data, etc. Once this data is gathered, businesses can use statistical software to calculate the values of m and b.

Once these values are calculated, businesses can plug in new values for x to predict future values of y. For example, if a business wants to predict next month's sales based on this month's sales, they would plug in the current month's sales figures as the independent variable (x) and use the calculated values of m and b to generate a predicted value for next month's sales (y).

This predicted value is not perfect, but it provides a good starting point for decision-making. Businesses can use linear regression to predict all sorts of future events, such as production levels, customer satisfaction scores, etc. By using linear regression to improve their decision-making process, businesses can improve their operational efficiency and better.

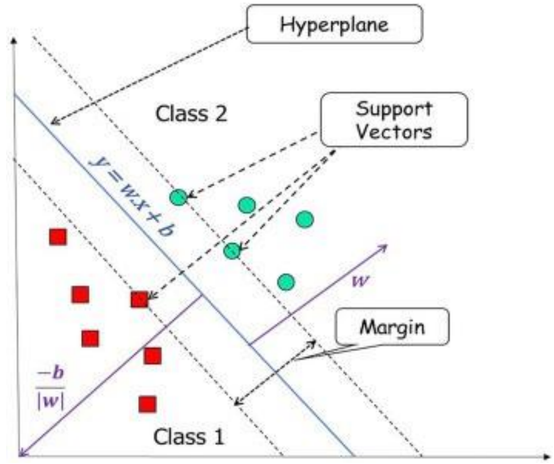


Support Vector Machine

Support Vector Machine or SVM is one of the most popular Supervised Learning algorithms, which is used for Classification as well as Regression problems. However, primarily, it is used for Classification problems in Machine Learning.

The goal of the SVM algorithm is to create the best line or decision boundary that can segregate n-dimensional space into classes so that we can easily put the new data point in the correct category in the future. This best decision boundary is called a hyperplane.

SVM chooses the extreme points/vectors that help in creating the hyperplane. These extreme cases are called support vectors, and hence the algorithm is termed as Support Vector Machine. Consider the below diagram in which there are two different categories that are classified using a decision boundary or hyperplane:



Example: SVM can be understood with the example that we have used in the KNN classifier. Suppose we see a strange cat that also has some features of dogs, so if we want a model that can accurately identify whether it is a cat or dog, such a model can be created by using the SVM algorithm. We will first train our model with lots of images of cats and dogs so that it can learn about different features of cats and dogs, and then we test it with this strange creature. So as the support vector creates a decision boundary between these two data (cat and dog) and chooses extreme cases (support vectors), it will see the extreme case of cat and dog. On the basis of the support vectors, it will classify it as a cat

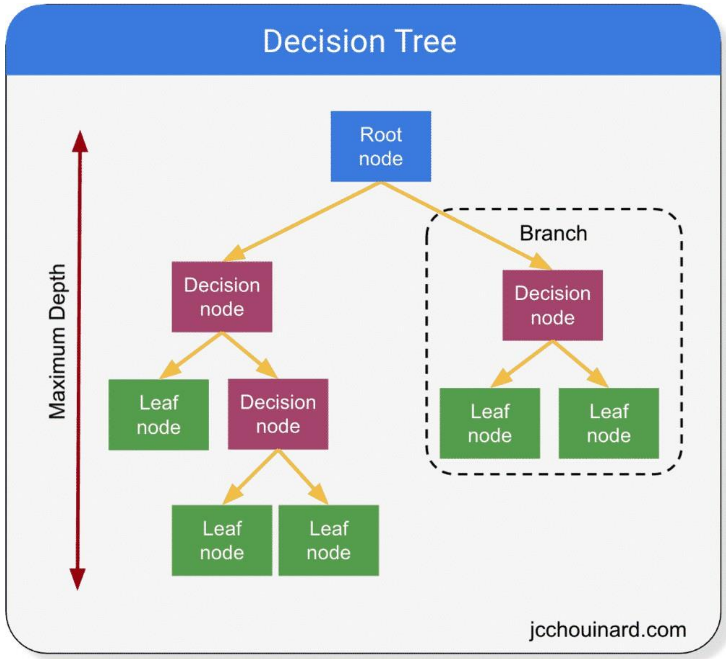
Decision Tree

A decision tree is a decision support tool that uses a tree-like model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. It is one way to display an algorithm that only contains conditional control statements.

Decision trees are commonly used in operations research, specifically in decision analysis, to help identify a strategy most likely to reach a goal, but are also a popular tool in machine learning.

A decision tree is a flowchart-like structure in which each internal node represents a "test" on an attribute (e.g. whether a coin flip comes up heads or tails), each branch represents the outcome of the test, and each leaf node represents a class label (decision taken after computing all attributes). The paths from root to leaf represent classification rules.

In decision analysis, a decision tree and the closely related influence diagram are used as a visual and analytical decision support tool, where the expected values (or expected utility) of competing alternatives are calculated.



A decision tree consists of three types of nodes:

Decision nodes – typically represented by squares

Chance nodes – typically represented by circles

End nodes – typically represented by triangles

Decision trees are commonly used in operations research and operations management. If in practice, decisions have to be taken online with no recall under incomplete knowledge, a decision tree should be paralleled by a probability model as the best choice model or online selection model algorithm. Another use of decision trees is as a descriptive means for calculating conditional probabilities.

Decision trees, influence diagrams, utility functions, and other decision analysis tools and methods are taught to undergraduate students in schools of business, health economics, and public health, and are examples of operations research or management science methods.

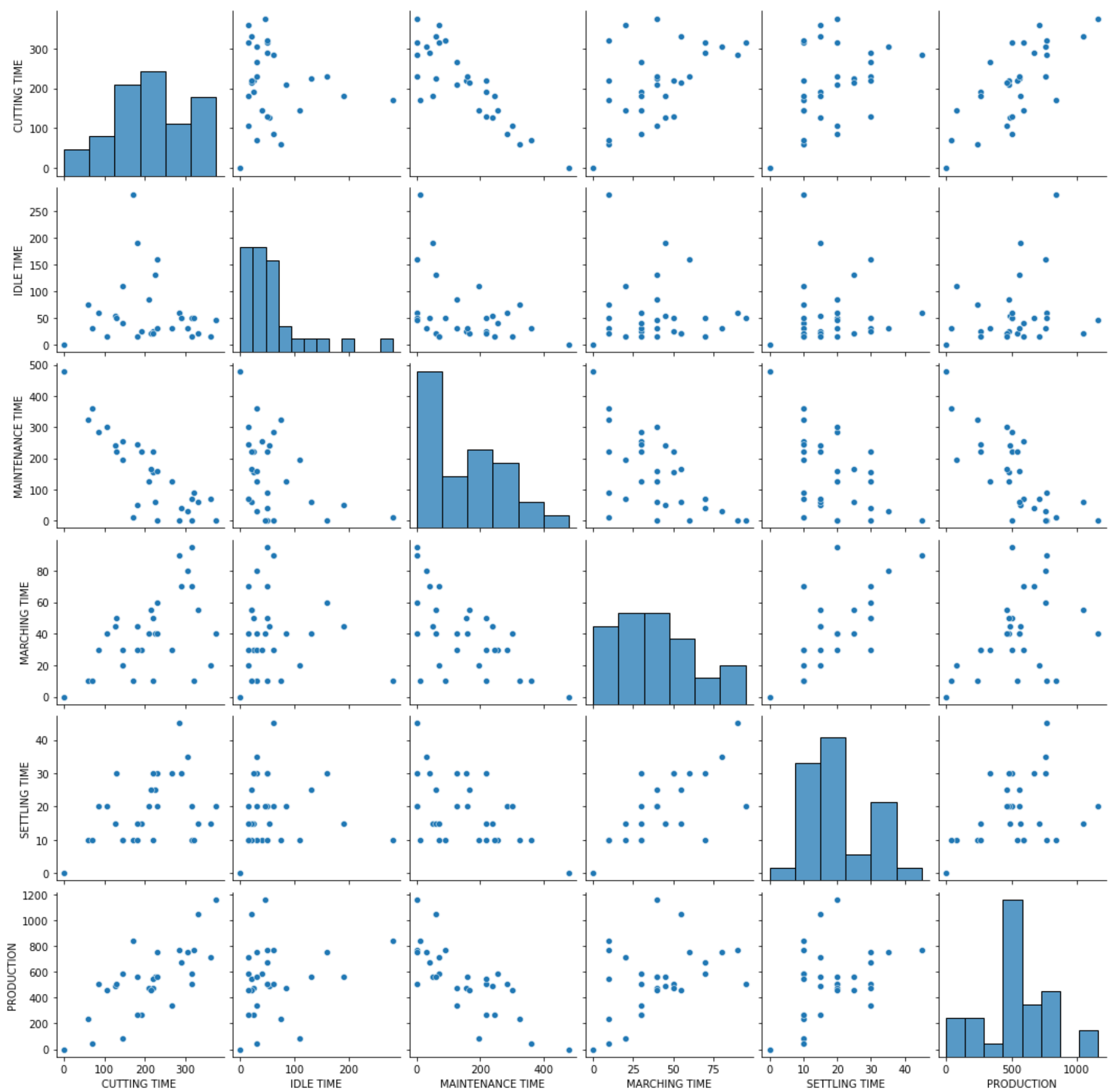
Handling a small dataset

Here, the given dataset is small. To apply machine learning models to perform better and more efficiently for prediction purposes, we started with simpler linear regression to avoid the chances of overfitting and progressively tried support vector machines, decision trees and random forest algorithms for better prediction.

To avoid unnecessarily increasing the complexity of the model, only important features are taken for training purposes

Shift 1 Data Interpretation

With the heatmap Plot, Cutting time and maintenance time are best found to have a relationship with production, with their correlation coefficients of 0.773032 and -0.680452, respectively. With an increase in cutting time, production increases. However, maintenance time has a negative correlation with production.



Shift 1 – Linear Regression

Using Sklearn, out of 5 features, 4 best features are chosen.

The measured and predicted values of production for data points are as shown below. These points have similar values.

Prediction on data point: -

```
predictions = result.predict(X_test)
predictions
```

```
array([592.43875628])
```

```
y_test
```

```
4    504
Name: PRODUCTION (in TON), dtype: int64
```

Error metrics: -

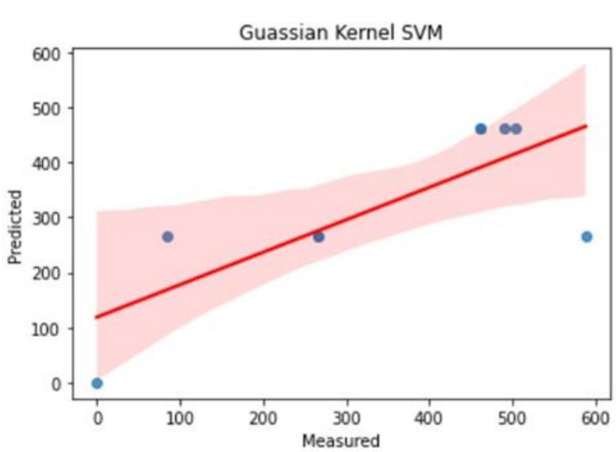
```
from sklearn import metrics
print('MAE:', metrics.mean_absolute_error(y_train, result.predict(X_train)))
print('MSE:', metrics.mean_squared_error(y_train, result.predict(X_train)))
print('RMSE:', np.sqrt(metrics.mean_squared_error(y_train, result.predict(X_train))))
```

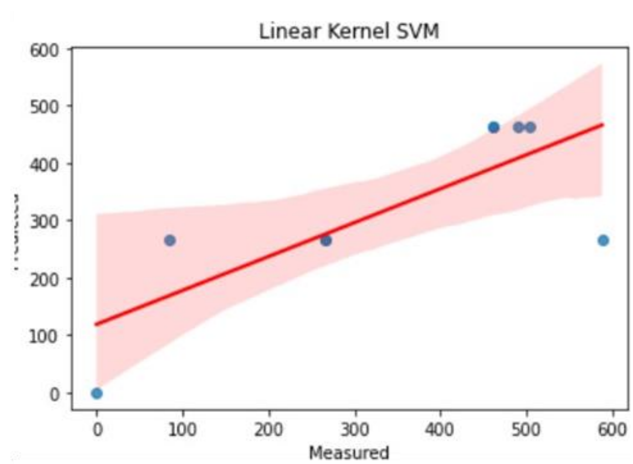
```
MAE: 87.10513222184348
MSE: 13250.471360335001
RMSE: 115.11069177246308
```

Shift 1 – Support Vector Machine

Using Linear Kernel – Using

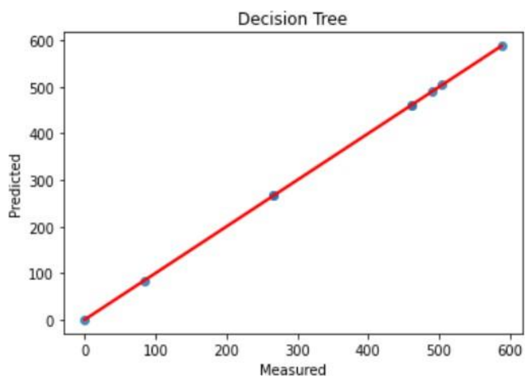
Gaussian Kernal





Shift 1 – Decision Tree

- With the decision tree, all the measured and predicted values fit accurately on the training dataset.
- Here, prediction on new data points varies by some amount as depicted in figure.




```
pred
```

```
array([462])
```

```
y_test
```

```
4    504
Name: PRODUCTION (in TON), dtype: int64
```

Errors Metrics: -

```python
from sklearn import metrics
print('MAE:', metrics.mean_absolute_error(y_train, dtree.predict(X_train)))
print('MSE:', metrics.mean_squared_error(y_train, dtree.predict(X_train)))
print('RMSE:', np.sqrt(metrics.mean_squared_error(y_train, dtree.predict(X_train))))
```

```
MAE: 0.0
MSE: 0.0
RMSE: 0.0
```

Prediction value taking all model into consideration:

For Cutting time- 130 minutes, Idle time- 50 minutes, Maintenance time- 220 minutes, Marching time- 50 minutes and Settling time- 30 minutes,

Production (in tons) = (592.43+462+462+462)/4 = 494.60 tons

Actual Value = 504 tons

Prediction error = (504-494.60) = 9.4 tons Percentage error = (504-494.60)*100/504 = 1.865%

Shift 2: -

For Cutting time- 225 minutes, Idle time- 130 minutes, Maintenance time- 60 minutes, Marching time- 40 minutes and Settling time- 25 minutes,

Production (in tons) = (665.38+756+476+564)/4 = 615.35 tons

Actual Value = 560 tons

Prediction error = (615.35-560) = 55.35 tons Percentage

error = (615.35-560) *100/560 = 9.8%

During training, a separate dataset is used for shift 2.

Shift 3: –

For Cutting time- 220 minutes, Idle time- 20 minutes, Maintenance time- 220 minutes, Marching time- 10 minutes and Settling time- 10 minutes,

Production (in tons) = (620.34+476+712+476)/4 = 571.08 tons Actual Value = 546 tons

Prediction error = (571.08-546) = 25.08 tons Percentage error = (571.08-546)*100/546 = 4.54%

During training, a separate dataset is used for shift 3.

4.0 CONCLUSION

- With the help of operational parameters, we were able to predict production. If we were given different parameters of continuous miner working in the same condition, we can estimate the production in advance.
- Marching time and settling time have their significant impact on production value during shift 1 Cutting time during each day does not fluctuate much.
- Maintenance time and Cutting time have more influence on production during shift 2 and shift3. cutting is more efficient during shift 2 and shift 3 than shift 1. Reason being, during shift 1, picks change and conveyor cleaning is more frequent.
- Other key parameters that also affect the productivity of continuous miners, including:
  * Pillar dimensions in the mine
  * Mine ventilation schemes
  * Haulage system design
  * Seam thickness and hardness of the rock/coal
- The above-mentioned parameters also affect the productivity of continuous miners but not included in this analysis.

5.0 REFERENCE

01.https://www.sciencedirect.com/science/article/pii/016790319191631Q

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