International Journal of Business and Economic Development
Vol. 1, No. 6; September, 2020. pp 1-11
ISSN 2692-5591 (print), 2692-5583 (online)

Published by International Center for Promoting Knowledge
www.icpknet.org

Coal Production by Longwall mining- A Study and Analysis of Equipment Breakdown Cause Patterns

Krishna Reddy Bhimavarapu
Department of Business Management
ICBM School of Business Excellence
Attapur, Hyderabad, Telangana- 500048.
INDIA.

Abstract

Coal production is a very complex process. It involves several causes of equipment breakdowns leading to down times. These down times reduce the production drastically depending up on their nature and type of breakdown. Ultimate result of these breakdowns is low productivity and stress on the managerial personal for repairing and bringing back the equipment into working condition. The present paper attempts to identify the causes of down times of equipment and to find out the inter relationships between them. To check for the association between the occurrences of C_1 to C_{12} a bi-variate frequency table has been obtained from among the occurrences of the variables and a Chi-square test has been applied.

1. Introduction

Energy is the fundamental resource for a variety of needs of modern living. Broadly, the sources of energy can be classified into conventional (Exhaustible) and non-conventional (Inexhaustible) energy sources. Coal, an exhaustible source of energy, contributes to a major part of the energy needs (60% nearly) of the country today. As it is evident that the coal reserves are depleting at a faster rate and there is every need to conserve them for our future generations. Coal production is undertaken in two ways, namely, Underground (UG) mining and Open Cast (OC) mining. Of the two methods, UG mining involves more complex mining process, needs rigorous as well as careful planning for the effective control and conservation of coal in its production (i.e., the production must keep in mind the higher percentage of extraction). In order to meet the ever-increasing demand of coal, the coal mining industry must keep pace with the latest and sophisticated technology to satisfy the demand. One such type of a highly mechanized technique used for coal production is *long wall* mining method. This method involves coal cutting and conveying it from the underground to the surface of the mine at a faster rate to satisfy the customer demand in varying quantities across the country.

The coal production through long wall mining experiences several problems which include the problems due to Incoming Power, Shearer, Armored Face Conveyor, Supports, Signals & Communication and so on. The detailed list of the causes are given in Table 1.

Table 1: Breakdown causes

Cause	Name	Cause	Name
C_1	INCOMING POWER	C_2	GATE-END BOX, TRANSFORMER, CONTROLLER, CABLE FAULTS etc.,
C_3	SHEARER	C_4	ARMOURED FACE CONVEYOR (AFC)
C_5	STAGE LOADER, LAMP BREAKER AND GATE BELT	C_6	FACE SUPPORTS, POWER PACK, HYDRAULICS & WATER SUPPLY
C_7	FADE SIGNAL AND COMMUNICATIONS	C_8	OTHER BREAK DOWNS
C_9	SPARE PARTS	C_{10}	STRATA PROBLEMS
C_{11}	SHIFT CHANGE HOURS AND OTHER DELAYS	C_{12}	TRUNK CONVEYOR AND OUTBYE SYSTEM

If one controls these problems effectively, the production of coal can be in higher volumes with the same resource inputs so that the customer needs can be satisfied. Therefore, the purpose of this paper is to identify the causes for down times so as to effectively control them and to help maximize the production.

2. Objectives

The following are the objectives of the present paper:

i) To analyse the causes of breakdowns on the basis of panels and locations of the mine.
ii) To identify the difference between panels and locations with regard to the occurrences of causes of down times.
iii) To check for the dependency, if any, between the causes of down times.

3. Data for the Study

The data for the study is collected from two places called as Location-1 and Location-2. The actual names of the places are not mentioned to preserve confidentiality as required by the mining company. In each of these places the coal is produced (extracted) through longwall mining technique. In the mining terminology this extraction is called as a panel. There are *four panels in Location-1* and *five* panels in Location-2. It is observed from the records of the company that the respective panels in each of the two locations worked for the following number of days as given in Table 2.

Table 2: Panel wise working days

Panel number	Location-1	Location–2
1	204	139
2	93	286
3	128	235
4	377	286
5	Not applicable	303

The occurrences of breakdowns are classified into twelve causes. The occurrence of the cause on day to day basis is collected from these 9 panels for the entire duration of operation of each panel. The occurrence or non-occurrence of a cause on a day is recorded for the entire period of working of the panel using 1 and 0. Table 3 presents the sample data collected for four days.

Table 3: Details of occurrences of causes

Day	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
1	0	0	1	1	0	1	0	0	0	0	0	0
2	1	0	1	1	0	1	0	0	1	0	1	0
3	0	1	1	0	0	1	0	1	0	0	0	0
4	1	0	0	1	1	0	0	1	0	1	0	0

We can understand from the above that on 3rd day C_2 (the 2nd cause) has occurred and hence a '1' is assigned indicating its occurrence. Similarly, on the same day, we can notice the presence of '1' for C_3, C_6 and C_8. This indicates that these three causes have occurred on this particular day. The presence of number '0' for other causes indicates the non-occurrence of these causes on the said day. This table is also called as the *incidence matrix*.

Since many causes lead to down times of the equipment on any day, it will be of interest to examine the frequency of occurrence of the causes either individually or in combination with other causes, degree of association between the causes in terms of their occurrence on the same day. If a high degree of association exists among some of these causes, it is very likely that they all will have a common origin and hence improving the situation by controlling one will improve the overall situation. It is essential that the management understand the pattern of breakdowns for their minimisation and effective control. In order to facilitate this investigation, the following numbering scheme is adopted for naming the causes in operation on any given day. A power of '2' is assigned to each of these 12 variables in a specific way. The cause operating most frequently has been assigned with small number and so on as below.

$C_1 = 2^2$ $C_2 = 2^8$ $C_3 = 2^1$ $C_4 = 2^3$
$C_5 = 2^5$ $C_6 = 2^4$ $C_7 = 2^{10}$ $C_8 = 2^0$
$C_9 = 2^9$ $C_{10} = 2^6$ $C_{11} = 2^{11}$ $C_{12} = 2^7$

These numbers can be put into a vector V, where

$$V = (4\ \ 256\ \ 2\ \ 8\ \ 32\ \ 16\ \ 1024\ \ 1\ \ 512\ \ 64\ \ 2048\ \ 128\ )$$

A row in Table 3 is associated with a 12 component binary vector representing a day in terms of the occurrence of breakdowns. A typical occurrence of 4th day breakdown after converting to 0 and 1 is
$I_4 = (1\ 0\ 0\ 1\ 1\ 0\ 0\ 1\ 0\ 1\ 0\ 0\ )^T$

Multiplication of vector V with vector I_4 corresponding to 4th day results in a composite index whose binary expansion reveals the pattern of causes operating that day. The number obtained as a result of the inner product of V and I_4 is

$$\begin{aligned} V \times I_4 &= \{4 \times 1 + 256 \times 0 + 2 \times 0 + 8 \times 1 + 32 \times 1 + 16 \times 0 + 1024 \times 0 + \\ &\quad 1 \times 1 + 512 \times 0 + 64 \times 1 + 2048 \times 0 + 128 \times 0\} \\ &= \{4 + 0 + 0 + 8 + 32 + 0 + 0 + 1 + 0 + 64 + 0 + 0\} = 109 \end{aligned}$$

This helps in identifying the number of causes that are operating along with their names like C_1, C_2, … ,C_{12}. This total 109 can be decomposed to get back the details of occurrence of individual causes. Thus, we can determine the combination of causes operating on each day uniquely.

4. Frequency Distribution of Cause – Patterns

After finding the total as explained above a frequency distribution of the totals has been obtained. This distribution enables us in identifying the most frequent combinations of breakdowns in each of the 9 panels (4 panels at Location-1 and 5 panels at Location-2). In what follows, the most frequently occurring combinations in each of the panels.

TABLE 4: LOCATION-1: PANEL 1 (Working days = 204)

Frequency	Code total	Combination
12	65	C_8,C_{10}
11	13	C_1,C_4,C_8
10	1	C_8
10	2	C_3
8	5	C_1,C_8
8	19	C_3,C_6,C_8
7	8	C_4
7	17	C_6,C_8

TABLE 5: LOCATION-1: PANEL 2 (Working days = 93)

Frequency	Code total	Combination
9	161	C_5,C_8,C_{12}
6	131	C_3,C_8,C_{12}
5	129	C_8,C_{12}
5	179	C_3,C_5,C_6,C_8,C_{12}
4	11	C_3,C_4,C_8
4	49	C_5,C_6,C_8
4	163	C_3,C_5,C_8,C_{12}
4	171	C_3,C_4,C_5,C_8,C_{12}

TABLE 6: LOCATION-1: PANEL 3 (Working days = 128)		
Frequency	Code total	Combination
38	64	C_{10}
19	8	C_4
7	16	C_6
5	3	C_3,C_8
4	161	C_5, C_8,C_{12}
3	24	C_4,C_6
3	131	C_3,C_8,C_{12}
3	171	C_5,C_6,C_8,C_{12}

TABLE 7: LOCATION-1: PANEL 4 (Working days = 377)		
Frequency	Code total	Combination
66	2	C_3
38	64	C_{10}
36	0	No breakdown
22	65	C_8,C_{10}
21	8	C_4
9	16	C_6
7	3	C_3,C_8
7	81	C_6,C_8,C_{10}
6	1	C_8
6	163	C_3,C_5,C_8,C_{12}
6	171	C_3,C_4,C_5,C_8,C_{12}
6	187	$C_3,C_4,C_5,C_6,C_8,C_{12}$
5	26	C_3,C_4,C_6
5	178	C_3,C_5,C_6,C_{12}
5	185	C_4,C_5,C_6,C_8,C_{12}

5. Analysis of Cause – Patterns

5.1. Location-1:

In Panel 1, C_8 is most frequent with individual occurrence of 10 times and 46 times in combination with C_1, C_4, C_3, C_6, C_{10} singly or severally.

In Panel 2, C_8 is most frequent with one or more of C_{12}, C_5, C_3, C_4 and C_6 to follow in that order.

In Panel 3, C_{10} has occurred for 38 days out of 128 days, while C_4 and C_6 individually have occurred for 19 and 7 days respectively. In occurrences of more than one cause C_8 and C_{12} jointly are most frequent either with C_3 or C_5.

Panel 4 of Location-1 experienced 66 days of occurrence of C_3 alone while C_{10} occurred for 38 days in a total of 377 days. A very interesting feature of this panel is that there is no breakdown for 36 days. Among the combinations C_8 and C_{12} jointly occurred with some of the other causes predominantly. With this pair of C_8 and C_{12} one can notice the occurrence of C_3, C_5, C_4 and C_6 very often.

In conclusion, it is observed that C_8 and C_{12} are crucial and are found to occur in combinations with others at Location-1.

TABLE 8: LOCATION-2: PANEL 1 (Working days = 139)		
Frequency	Code total	Combination
48	128	C_{12}
16	132	C_1,C_{12}
14	2048	C_{11}
10	136	C_4,C_{12}
7	160	C_5, C_{12}
6	384	C_2,C_{12}
5	130	C_3,C_{12}
4	129	C_8,C_{12}
4	256	C_2

TABLE 9: LOCATION-2: PANEL 2 (Working days = 286)		
Frequency	Code total	Combination
91	128	C_{12}
38	136	C_4,C_{12}
30	64	C_{10}
20	8	C_4
19	129	C_8,C_{12}
13	2	C_3
12	160	C_5,C_{12}
9	132	C_1,C_{12}
5	137	C_4,C_8,C_{12}
5	392	C_2,C_4,C_{12}
4	1	C_8
4	168	C_4,C_5,C_{12}
4	384	C_2,C_{12}

TABLE 10: LOCATION-2: PANEL 3 (Working days = 235)		
Frequency	Code total	Combination
29	136	C_4,C_{12}
27	128	C_{12}
25	0	No Breakdown
20	8	C_4
14	129	C_8, C_{12}
11	64	C_{10}
11	132	C_1,C_{12}
9	137	C_4,C_8,C_{12}
9	160	C_5,C_{12}
6	32	C_5
6	164	C_1,C_5,C_{12}
6	165	C_1,C_5,C_8,C_{12}
5	140	C_1,C_4,C_{12}
5	168	C_4,C_5,C_{12}

TABLE 11: LOCATION-2: PANEL 4 (Working days = 286)		
Frequency	Code total	Combination
32	64	C_{10}
32	128	C_{12}
18	129	C_8,C_{12}
13	2	C_3
13	130	C_3,C_{12}
11	131	C_3,C_8,C_{12}
8	136	C_4,C_{12}
8	192	C_{10},C_{12}
7	161	C_5,C_8,C_{12}
6	132	C_1,C_{12}
6	162	C_3,C_5,C_8,C_{12}
5	32	C_5
5	133	C_1,C_8,C_{12}
5	135	C_1,C_3,C_8,C_{12}
5	137	C_4,C_8,C_{12}
5	139	C_3,C_4,C_8,C_{12}

TABLE 12: LOCATION-2: PANEL 5 (Working days = 303)		
Frequency	Code total	Combination
18	64	C_{10}
17	137	C_4, C_8, C_{12}
13	1	C_8
13	9	C_4, C_8
12	73	C_4, C_8, C_{10}
10	8	C_4
10	72	C_4,C_{10}
8	65	C_8,C_{12}
8	89	C_4, C_6, C_8, C_{10}
8	129	C_8, C_{12}
8	203	$C_3, C_4, C_8, C_{10}, C_{12}$
7	192	C_{10}, C_{12}
7	201	C_4, C_8, C_{10}, C_{12}
7	217	$C_4, C_6, C_8, C_{10}, C_{12}$

5.2. LOCATION-2:

C_{12} alone occurred on 48 days out of 139 days in Panel 1, while C_{11} alone accounts for 14 days and C_2 for 4 days individually. Among the combinations, C_{12} has occurred with either of C_1,C_5, C_4, C_2, C_3 and C_8 singly or severally. In Panel 2, C_{12} alone accounts for 91 days in 286 days while C_{10} occurred for 30 days and C_4 for 20 days, C_3 for 13 days and C_8 for 4 days. In the combinations C_{12} is most frequent with C_4, C_8, C_5, C_1 and C_2 either pair wise or more than two at a time.

Out of 235 days, there is no breakdown for 25 days. Among the occurrences, the causes C12, C_4, C_{10}, C_5 individually have taken place for 27, 20, 11 and 6 days respectively in Panel 3. In combinations C_{12} is most frequent with one or more of C_4, C_5, C_1 and C_8.

Panel 4 of Location-2 experienced an equal number of occurrences of C_{10} and C_{12}, each for 32 days in 286 days. Individuals to follow are C_3 and C_5 with 13 and 5 days as the frequencies. C12 and C8 dominate pair wise

occurrences. C_{12} with C_3, C_4, C_{10} and C_1 are to follow in that order with respect to their frequencies. In the combination of three or more causes C_{12} and C_8 have occurred either with C_5, C_3, C_1 or C_4.

Out of 303 days, C_{10}, C_8 and C_4 have individually accounted for 18, 13 and 10 days respectively in Panel 5. Among the combinations of two or more occurrences C_{12}, C_{10} and C_8 are the ones, which are most frequent.
At Location-2, it is observed that C_{12} is the most predominantly occurring cause of down time and is a crucial variable. It is found to occur in combinations with C_8, C_{10}, C_4 and C_5.

6. Association of Down Time Causes

To check for the association between the occurrences of C_1 to C_{12} a bi-variate frequency table has been obtained from among the occurrences of the variables. The frequency of occurrence of C_8 with others and C_1 with others as a bivariate has been calculated as shown below.

Table 13: Frequency of occurrence of C_8 with others and C_1

Causes	C_8 and Others	Others but not C_8	Total
C_1 & others	65	3	68
Others but not C_1	60	76	136
Total	125	79	204

The expected frequency Table has been calculated as

(68 x 125) / 204 = 42	(68 – 42) = 26
(125 – 42) = 83	(79 – 26) = 53

Using $\chi^2 = \sum \{(O_i - E_i)^2 / E_i\}$, it is possible to check for the association between the selected pair (say C_1 and C_8).

This analysis has been carried out on some of selected most frequently occurring pairs. The results are tabulated with the pair, observed frequency (O_i), Total 1,Total 2, Expected Frequency (E_i) and Chi-square value. For the example shown, the pair is (C_1,C_8), observed frequency = 65, total 1 = 68, total 2 = 125, Grand Total = 204.
Expected frequency = (Total 1 x Total 2) / (Grand Total) = 42 and the value of $\chi^2 = 49.296$.

By comparing the calculated value of Chi-square with the tabulated value for 1 d.f., it may be concluded that the pair (C_1, C_8) in Panel 1 is associated. The details regarding various selected pairs are presented below. S in bracket indicates the significance of Chi-square value at $\alpha = 5\%$ Level of Significance.

TABLE 14: Association of Down time Causes at Location-1:

Pair	O_i	Total 1	Total 2	E_i	Chi- Square
Location-1: Panel 1(204):					
C_1,C_8	65	68	125	42	49.296 (S)
C_4,C_8	43	65	125	40	0.858
C_3,C_8	42	76	125	47	2.214
C_6,C_8	37	61	125	38	0.099
C_1,C_4	30	68	65	42	13.419 (S)
C_3,C_6	29	76	61	23	3.592
C_1,C_3	22	68	76	25	0.852
C_5,C_8	22	47	125	29	5.726 (S)
Location-1: Panel 2(93):					
C_5,C_{12}	37	54	67	39	0.856
C_3,C_{12}	33	47	67	34	0.517
Location-1: Panel 3(128):					
C_8,C_{12}	34	40	43	13	72.56 (S)
C_5,C_{12}	23	30	43	10	33.07 (S)
C_6,C_{12}	23	40	43	13	16.45 (S)
C_3,C_8	22	32	40	10	27.93 (S)
C_5,C_8	21	30	40	9	29.65 (S)

C_3,C_{12}	19	32	43	11	11.87 (S)
Location-1: Panel 4(377):					
C_8,C_{12}	69	136	89	32	87.402 (S)
C_5,C_{12}	63	76	89	18	184.739 (S)
C_3,C_8	56	168	136	61	1.163
C_6,C_8	54	98	136	36	19.276 (S)
C_5,C_8	53	76	136	28	44.368 (S)
C_3,C_6	52	168	98	44	3.569
C_3,C_{12}	48	168	89	40	3.806
C_4,C_8	48	101	136	37	7.067 (S)
C_6,C_{12}	46	98	89	23	40.552 (S)
C_3,C_4	45	168	101	45	0.000
C_8,C_{10}	45	136	96	35	6.042 (S)
All with 1 d.f.					

TABLE 15: Association of Down time Causes at Location-2:

Pair	O_i	Total 1	Total 2	E_i	Chi-Square
Location-2: Panel 1(139):					
C_1,C_{12}	19	21	107	16	2.795
Location-2: Panel 2(286):					
C_4,C_{12}	63	90	208	65	0.325
C_8,C_{12}	35	42	208	31	2.300
C_5,C_{12}	26	31	208	23	1.690
C_1,C_{12}	22	24	208	18	3.862 (s)*
Location-2: Panel 3(235):					
C_4,C_{12}	61	94	148	59	0.304
C_8,C_{12}	39	48	148	30	9.060 (S)
C_1,C_{12}	35	38	148	24	16.318 (S)
C_5,C_{12}	34	49	148	31	0.998
Location-2: Panel 4(286):					
C_8,C_{12}	112	138	195	94	20.912 (S)
C_3,C_{12}	66	96	195	65	0.072
C_3,C_8	61	96	138	46	14.133 (S)
C_5,C_8	47	67	138	32	17.574 (S)
C_5,C_{12}	44	67	195	46	0.361
C_4,C_{12}	42	61	195	42	0.000
C_1,C_{12}	40	50	195	34	4.012 (S)
C_4,C_8	40	61	138	29	10.107 (S)
C_1,C_8	38	50	138	24	19.031 (S)
Location-2: Panel 5(303):					
C_4,C_8	133	178	210	123	6.412(S)
C_8,C_{12}	104	210	128	89	14.324 (S)
C_8,C_{10}	95	210	148	103	3.974(S)*
C_4,C_{12}	87	178	128	75	8.035 (S)
C_4,C_{10}	81	178	148	87	1.962
C_6,C_8	67	77	210	33	82.296 (S)
C_3,C_8	61	77	210	53	5.209 (S)
C_4,C_6	53	178	77	45	4.592 (S)
C_3,C_4	47	77	178	45	0.287
C_3,C_{12}	38	77	128	33	1.780
All with 1 d.f. (*BARELY SIGNIFICANT AT 5%)					

7. Analysis

The occurrence of significant pairs with C_8 from Tables 13 and 14 are:

LOCATION–1		Location–2	
(C_8, C_1) AND (C_8, C_5)	*PANEL 1*	*(C_8, C_{12})*	Panel 3
(C_8, C_{12}), (C_8, C_3) AND (C_8, C_5)	*PANEL 3*	*(C_8, C_{12}), (C_8, C_3), (C_8, C_5), (C_8, C_4) AND (C_8, C_1)*	*PANEL 4*
(C_8, C_{12}), (C_8, C_6), (C_8, C_5), (C_8, C_4) AND (C_8, C_{10})	*PANEL 4*	*(C_8, C_4), (C_8, C_{12}), (C_8, C_{10}), (C_8, C_6) AND (C_8, C_3)*	*PANEL 5*

C_8 is occurring quite significantly with other causes. It only means that various specified causes are associated with various other causes, which have not been specifically identified. This fact strengthens the feeling that it would be better if this could be looked into depth to identify, which other specific causes may be occurring under this heading.

With C_1 the following significant pairs are noticed.

Location–1		Location–2	
(C_1, C_4)	Panel 1	(C_1, C_{12})	Panel 2
		(C_1, C_{12})	Panel 3
		(C_1, C_{12})	Panel 4

The problem of *Incoming Power (C_1) has a tendency of preventing the occurrence of other causes* and hence one should except a negative association, if not any interference. We find that (C_1, C_4)is significant and as expected has a negative association (Expected under independency of hypothesis is 42 and the observed occurrences are only 30). While (C_1, C_{12}) is barely significant and hence no importance need be given for this cause.
From the remaining, the significant pairs of combinations are

Location–2	
(C_{12}, C_5), (C_{12}, C_6) and (C_{12}, C_3)	Panel 3
(C_{12}, C_5) and (C_{12}, C_6)	Panel 4
(C_{12}, C_4) and (C_6, C_4)	Panel 5

Whenever the combinations which are significant and are present in the panels of the same place, then it suggests the possibility of special reasons common to geological location, management, equipment and so on.

8. Cause – Pattern Analysis

Tables 14 and 15 present Panel-wise information of these 12 causes in each of the panels according to their occurrence either singly or in combination and if in combination, with what causes they are occurring.

Table-16: Cause pattern analysis of Location-1:

PANEL NO.		1	2	3	4
WORKING DAYS		204	93	128	377
C_1	Singly	0	0	0	0
	Combination	68	15	7	17
	With What Others	2,3,4,5,6, 8, 12	3,4,5,6, 8,12	2,3,4,5,6, 8,12	2,3,4,5,6,8, 10,11,12
C_2	Singly	0	0	0	0
	Combination	15	2	3	18
	With What Others	1,3,4,5,6,8, 10,12	3,4,5,6, 8,12	1,3,4,6, 8,12	1,3,4,5,6, 7,8,12
C_3	Singly	10	0	2	66

	Combination	66	47	30	102
	With What Others	1,2,4,5,6,8, 10,11,12	1,2,4,5,6,8,12	1,2,4,5,6,8, 12	1,2,4,5,6,7, 8,10,11,12
C_4	Singly	7	0	19	21
	Combination	58	32	22	80
	With What Others	1,2,3,5,6,8, 10,12	1,2,3,5, 6,8,12	1,2,3,5,6, 8,12	1,2,3,5,6,7, 8,10,11,12
C_5	Singly	1	0	2	2
	Combination	46	54	28	74
	With What Others	1,2,3,4,6,7, 8,10,12	1,2,3,4,6,8,12	1,3,4,6, 8,12	1,2,3,4,6,7, 8,10,11,12
C_6	Singly	0	0	7	9
	Combination	61	35	33	89
	With What Others	1,2,3,4,5, 8,10,12	1,2,3,4,5,8,12	1,2,3,4,5, 8, 12	1,2,3,4,5,7, 8,10,11,12
C_7	Singly	0	0	0	0
	Combination	1	0	0	18
	With What Others	5	---	---	2,3,4,5,6,8, 10,12
C_8	Singly	10	0	0	6
	Combination	115	87	40	130
	With What Others	1,2,3,4,5,6, 10,12	1,2,3,4,5,6,12	1,2,3,4,5, 6,12	1,2,3,4,5,6, 7,10,11,12
C_9	Singly	2	0	0	0
	Combination	0	0	0	0
	With What Others	---	---	---	---
C_{10}	Singly	4	0	38	38
	Combination	28	0	0	58
	With What Others	2,3,4,5,6, 8,11	---	---	1,3,4,5,6,7, 8,11,12
C_{11}	Singly	0	0	0	2
	Combination	1	0	0	6
	With What Others	3,10	---	---	1,3,4,5,6,8, 10,12
C_{12}	Singly	5	1	1	0
	Combination	18	66	42	89
	With What Others	1,2,3,4,5, 6,8	1,2,3,4,5,6,8	1,2,3,4,5, 6,8	1,2,3,4,5,6, 7,8,10,11
No. of days no cause occurred		5	1	0	36

Table-17: Cause pattern analysis of Location-2:

PANEL NO.		1	2	3	4	5
Working days		139	286	235	286	303
C_1	Singly	2	1	1	0	0
	Combination	19	23	37	50	8
	With What Others	2,4,5, 8, 12	2,4,5, 8, 12	2,4,5, 8, 12	2,3,4,5,6, 7, 8,10,12	2,3,4,6,8, 10, 12
C_2	Singly	4	0	2	0	0
	Combination	11	14	13	17	19

	With What Others	1,4,5,8, 10,12	1,4,5,8, 12	1,3,4,8, 10,12	1,3,4,5,6, 7, 8,10,12	1,3,4,6,7, 8, 10,12
C_3	Singly	2	13	2	13	5
	Combination	8	1	10	83	72
	With What Others	5,6,12	8	2,4,5, 8, 12	1,2,4,5,6, 8, 10,12	1,2,4,5,6,7, 8,9,10,11,12
C_4	Singly	0	20	20	2	10
	Combination	13	70	74	59	168
	With What Others	1,2,12	1,2,5,8, 12	1,2,3,5, 6,8,10, 12	1,2,3,5,6, 7,8,10,11,12	1,2,3,5,6,7, 8,9,10,11,12
C_5	Singly	1	1	6	5	1
	Combination	11	30	43	62	21
	With What Others	1,2,3,8, 12	1,2,4,8, 12	1,2,3,4, 8, 12	1,2,3,4,6, 7, 8,10, 11,12	3,4,6,7,8, 9, 10,12
C6	Singly	0	0	0	0	0
	Combination	1	2	3	23	77
	With What Others	3,12	10,12	4,12	1,2,3,4,5, 7, 8,10,12	1,2,3,4,5,7, 8,9,10,11,12
C_7	Singly	0	0	0	0	0
	Combination	0	0	0	4	13
	With What Others	---	---	---	1,2,4,5,6, 8, 10,12	2,3,4,5,6,8, 9,10,11,12
C_8	Singly	1	4	2	4	13
	Combination	9	38	46	134	197
	With What Others	1,2,5, 10,11,12	1,2,3,4, 5, 12	1,2,3,4, 5, 10,12	1,2,3,4,5, 6, 7,10,12	1,2,3,4,5,6, 7,9,10,11,12
C_9	Singly	0	0	0	0	0
	Combination	0	0	0	0	6
	With What Others	---	---	---	---	3,4,5,6,7,8, 10,12
C_{10}	Singly	2	30	11	32	18
	Combination	3	2	3	42	130
	With What Others	2,8,12	4,6	2,4,8,12	1,2,3,4,5, 6, 7,8,12	1,2,3,4,5,6, 7,8,9,11,12
C_{11}	Singly	14	0	0	0	1
	Combination	2	0	0	2	10
	With What Others	8	---	---	4,5,12	3,4,6,7,8,10
C_{12}	Singly	48	91	27	32	1
	Combination	59	117	121	163	127
	With What Others	1,2,3,4, 5,6, 8,10	1,2,4,5, 6,8	1,2,3,4, 5,6,8,10	1,2,3,4,5, 6,7,8,10, 11	1,2,3,4,5,6, 7,8,9,10
No. of days no cause occurred		3	0	25	2	1

In general it is found that very a few of the causes occur singly in any of the panels. The exceptions being C_{10} occurring singly in panels 3 and 4 of Location-1 and Panels 2, 4 and 5 of Location-2 and C_{12} in Panels 1, 2, 3 and 4 of Location-2. Thus, mostly the faults occur in combination with others, though their “degree of association" is mostly not significant.

9. Conclusions

1) It is observed that C_8 and C_{12} are crucial and are found to occur in combinations with others at Location-1. At Location-2, it is observed that C_{12} is the most predominantly occurring cause of down time and is a crucial variable. It is found to occur in combinations with C_8, C_{10}, C_4 and C_5.

2) C_8 is occurring quite significantly with other causes. It only means that various specified causes are associated with various other causes which have not been specifically identified. This fact strengthens the feeling that it would be better if this could be looked into depth to identify which other specific causes may be occurring under this heading.

10. Applicability of the Study:

- The manager working in the field can effectively plan for the operations, Spares and so on by understanding environment of the panel.
- The understanding on the previous panels always can be used as database and compared with the new panels under consideration. This comparison is of immense use in either eliminating or minimising the occurrence of down time causes leading to enhanced working hours and higher production. In addition, the managers can forecast the need for materials, components, spares in advance and get ready for any type of eventuality and control them.

References

Gnanadesikan, R., 1977. "Methods for Statistical data Analysis of Multivariate Observations", John Wiley & Sons, NY,.

Krishna Reddy, B., 1992. "Analysis and Modelling of Coal Mining Systems", Ph.D. Thesis, Osmania University, Hyderabad.

Lata Sujatha, T, 2008 . "Outsourcing Practices in Healthcare Industry – A study of Select Hospitals", Ph.D. Thesis, Osmania University, Hyderabad.

Peng., Syd S. and Chiang., H.S., 1984. " Longwall Mining", John Wiley & Sons, NY.

Seber, G.A.F., 1984. "Multivariate Observations", John Wiley & Sons, NY.