



COAL PRODUCTION BY LONGWALL MINING - A STUDY AND ANALYSIS OF EQUIPMENT BREAKDOWN CAUSE - PATTERNS

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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.

Keywords: Armoured Face Conveyor, Trunk Conveyor, Outbye System, Strata Problems, Breakdown, and Cause patterns, Chi Square test.

I. 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 is given below.



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	Face 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

Table 1: List of Breakdown Causes

If one controls these problems effectively, the production of coal can be in higher volumes with the same input resources 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.

II. Objectives

The following are the objectives of the present paper:

- To analyze the causes of breakdowns on the basis of panels and locations of the mine.
- To identify the difference between panels and locations with regard to the occurrences of causes of down times.
- To check for the dependency, if any, between the causes of down times.

III. 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.

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

Table-2: Panel wise working days

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. The following table presents the sample data collected for four days.

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

Table-3: Details of Occurrences of Causes

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 minimization 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.

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

These numbers can be put into a vector V, as $V = (4 \ 256 \ 2 \ 8 \ 32 \ 16 \ 1024 \ 1 \ 512 \ 64 \ 2048 \ 128)$

A row in Table-2 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 $V \times I_4 = \{4 \times 1 + 256 \times 0 + 2 \times 0 + 8 \times 1 + 32 \times 1 + 16 \times 0 + 1024 \times 0 + 1 \times 1 + 512 \times 0 + 64 \times 1 + 2048 \times 0 + 128 \times 0\} = \{4 + 0 + 0 + 8 + 32 + 0 + 0 + 1 + 0 + 64 + 0 + 0\} = 109$

This helps in identifying the number of causes that are operating along with their names like $\{C_1, C_2, \dots, C_{12}\}$. 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.

IV. 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). The most frequently occurring combinations of breakdowns in each of the panels are given below.

Location-1: Panel 1 (Working days = 204)			Table 4: Location-1: Panel 2 (Working days = 93)		
Frequency	Code total	Combination	Frequency	Code total	Combination
12	65	C_8, C_{10}	9	161	C_5, C_8, C_{12}
11	13	C_1, C_4, C_8	6	131	C_3, C_8, C_{12}
10	1	C_8	5	129	C_8, C_{12}
10	2	C_3	5	179	$C_3, C_5, C_6, C_8, C_{12}$
8	5	C_1, C_8	4	11	C_3, C_4, C_8



8	19	C ₃ ,C ₆ ,C ₈	4	49	C ₅ ,C ₆ ,C ₈
7	8	C ₄	4	163	C ₃ ,C ₅ ,C ₈ ,C ₁₂
7	17	C ₆ ,C ₈	4	171	C ₃ ,C ₄ ,C ₅ ,C ₈ ,C ₁₂
Table -4: Frequent Combinations			Table -5: Frequent Combinations		

Location-1: Panel 3 (Working days = 128)			Location-1: Panel 4 (Working days = 377)		
Frequency	Code total	Combination	Frequency	Code total	Combination
38	64	C ₁₀	66	2	C ₃
19	8	C ₄	38	64	C ₁₀
7	16	C ₆	36	0	No breakdown
5	3	C ₃ ,C ₈	22	65	C ₈ ,C ₁₀
4	161	C ₅ ,C ₈ ,C ₁₂	21	8	C ₄
3	24	C ₄ ,C ₆	9	16	C ₆
3	131	C ₃ ,C ₈ ,C ₁₂	7	3	C ₃ ,C ₈
3	171	C ₅ ,C ₆ ,C ₈ ,C ₁₂	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
Table -6: Frequent Combinations			Table -7: Frequent Combinations		

V. Analysis of Cause – Patterns:

a) Location-1:

In Panel 1, C₈ is most frequent with individual occurrence of 10 times and 46 times in combination with C₁, C₄, C₃, C₆, C₁₀ singly or severally.

In Panel 2, C₈ is most frequent with one or more of C₁₂, C₅, C₃, C₄ and C₆ to follow in that order.

In Panel 3, C₁₀ has occurred for 38 days out of 128 days, while C₄ and C₆ individually have occurred for 19 and 7 days respectively. In occurrences of more than one cause C₈ and C₁₂ jointly are most frequent either with C₃ or C₅.

Panel 4 of Location-1 experienced 66 days of occurrence of C₃ alone while C₁₀ 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 C₈ and C₁₂ jointly occurred with some of the other causes predominantly. With this pair of C₈ and C₁₂ one can notice the occurrence of C₃, C₅, C₄ and C₆ very often.

In conclusion, it is observed that C₈ and C₁₂ are crucial and are found to occur in combinations with others at Location-1.

Location-2: Panel 1 (Working days = 139)			Location-2: Panel 2 (Working days = 286)		
Frequency	Code total	Combination	Frequency	Code total	Combination
48	128	C ₁₂	91	128	C ₁₂
16	132	C ₁ ,C ₁₂	38	136	C ₄ ,C ₁₂
14	2048	C ₁₁	30	64	C ₁₀



10	136	C ₄ ,C ₁₂	20	8	C ₄
7	160	C ₅ ,C ₁₂	19	129	C ₈ ,C ₁₂
6	384	C ₂ ,C ₁₂	13	2	C ₃
5	130	C ₃ ,C ₁₂	12	160	C ₅ ,C ₁₂
4	129	C ₈ ,C ₁₂	9	132	C ₁ ,C ₁₂
4	256	C ₂	5	137	C ₄ ,C ₈ ,C ₁₂
Table -8: Frequent Combinations			Table -9: Frequent Combinations		

TABLE 9: LOCATION-2: PANEL 3 (Working days = 235)			TABLE 10: LOCATION-2: PANEL 4 (Working days = 286)		
Frequency	Code total	Combination	Frequency	Code total	Combination
29	136	C ₄ ,C ₁₂	32	64	C ₁₀
27	128	C ₁₂	32	128	C ₁₂
25	0	No Breakdown	18	129	C ₈ ,C ₁₂
20	8	C ₄	13	2	C ₃
14	129	C ₈ ,C ₁₂	13	130	C ₃ ,C ₁₂
11	64	C ₁₀	11	131	C ₃ ,C ₈ ,C ₁₂
11	132	C ₁ ,C ₁₂	8	136	C ₄ ,C ₁₂
9	137	C ₄ ,C ₈ ,C ₁₂	8	192	C ₁₀ ,C ₁₂
9	160	C ₅ ,C ₁₂	7	161	C ₅ ,C ₈ ,C ₁₂
6	32	C ₅	6	132	C ₁ ,C ₁₂
6	164	C ₁ ,C ₅ ,C ₁₂	6	162	C ₃ ,C ₅ ,C ₈ ,C ₁₂
6	165	C ₁ ,C ₅ ,C ₈ ,C ₁₂	5	32	C ₅
5	140	C ₁ ,C ₄ ,C ₁₂	5	133	C ₁ ,C ₈ ,C ₁₂
5	168	C ₄ ,C ₅ ,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 -10: Frequent Combinations			Table -11: Frequent Combinations		

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

Table -12: Frequent Combinations

b) Location-2

C₁₂ alone occurred on 48 days out of 139 days in Panel 1, while C₁₁ alone accounts for 14 days and C₂ for 4 days individually. Among the combinations, C₁₂ has occurred with either of C₁, C₅, C₄, C₂, C₃ and C₈ singly or severally.

In Panel 2, C₁₂ alone accounts for 91 days in 286 days while C₁₀ occurred for 30 days and C₄ for 20 days, C₃ for 13 days and C₈ for 4 days. In the combinations C₁₂ is most frequent with C₄, C₈, C₅, C₁ and C₂ 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, C₄, C₁₀, C₅ individually have taken place for 27, 20, 11 and 6 days respectively in Panel 3. In combinations C₁₂ is most frequent with one or more of C₄, C₅, C₁ and C₈.

Panel 4 of Location-2 experienced an equal number of occurrences of C₁₀ and C₁₂, each for 32 days in 286 days. Individuals to follow are C₃ and C₅ with 13 and 5 days as the frequencies. C₁₂ and C₈ dominate pair wise occurrences. C₁₂ with C₃, C₄, C₁₀ and C₁ are to follow in that order with respect to their frequencies. In the combination of three or more causes C₁₂ and C₈ have occurred either with C₅, C₃, C₁ or C₄.

Out of 303 days, C₁₀, C₈ and C₄ have individually accounted for 18, 13 and 10 days respectively in Panel 5: Among the combinations of two or more occurrences C₁₂, C₁₀ and C₈ are the ones, which are most frequent.

At Location-2, it is observed that C₁₂ is the most predominantly occurring cause of down time and is a crucial variable. It is found to occur in combinations with C₈, C₁₀, C₄ and C₅.

VI. Association of Down Time Causes

To check for the association between the occurrences of C₁ to C₁₂ a bi-variate frequency table has been obtained from among the occurrences of the variables. The frequency of occurrence of C₈ with others and C₁ with others as a bivariate has been calculated as shown below.

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

$(68 \times 125) / 204 = 42$	$(68 - 42) = 26$
$(125 - 42) = 83$	$(79 - 26) = 53$

Using $\chi^2 = \sum \{(O_i - E_i)^2 / E_i\}$, it is possible to check for the association between the selected pair (say C₁ and C₈).

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 (C₁, C₈), observed frequency = 65, total 1 = 68, total 2 = 125, Grand Total = 204.

Expected frequency = (Total 1 x Total 2) / (Grand Total) = 42; Value of $\chi^2 = 49.296$.



By comparing the calculated value of Chi-square with the table value for 1 d.f., it may be concluded that the pair (C₁, C₈) 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.

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 13: Association of Down time Causes at Location-1					

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%)					
Table 14: Association of down time Causes at Location-2:					

VII. Analysis

The occurrence of significant pairs with C₈ 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

C₈ 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 C₁ 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 (C₁) 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 (C₁, C₄) is significant and as expected has a negative association (Expected under independency of hypothesis is 42 and the observed occurrences are only 30). While (C₁, C₁₂) 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.

VIII. Cause – Pattern Analysis

Panel Number		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-15: Cause Pattern Analysis of Location-1:

Panel Number		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,	1,2,3,5,6,	1,2,3,5,6,7,8,

	Others			6,8,10, 12	7,8,10,11,12	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
C ₆	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 BREAKDOWN has occurred		3	0	25	2	1

Table-16: Cause Pattern Analysis of Location-2:

In general, it is found that very few of the causes occur singly in any of the panels. The exceptions being C₁₀ occurring singly in panels 3 and 4 of Location-1 and Panels 2, 4 and 5 of Location-2 and C₁₂ 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.



IX. 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.

X. Applicability of The Study

- i) The manager working in the field can effectively plan for the operations, Spares and so on by understanding environment of the panel.
- ii) 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.

XI. References

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