Root Cause Analysis of Variations in Construction Tasks and Developing Effective Strategies to Reduce Variations

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Abstract— This paper is aimed at knowing the variations and causes of variation occurrence. The main objective of this research is to develop suggestive method to reduce such variation. The delays in planned work and actual work done during construction stage are considered as variations for this research purpose. The variation in construction task can affect the cost of the project to avoid this, it is necessary to improve organizational practices about delay problem in construction industry. The risk assessment matrix is used to know the effect of such causes on performance.

This study helps in knowing the exact causes of delay occurrences with the help of preparing risk assessment matrix. The study is done on the residential sites for this research purpose. The method developed can be useful for minimize the delay occurrence. The implementation of this method results in increase of PPC (percentage planned completed) from 83.3% to 87.5%

As the delay in construction is an issue this research has its own importance.

Index Terms— construction delay, delay analysis, variation, delay causes, risk assessment matrix.

INTRODUCTION:

The construction industry is complicated in nature. And all tasks in construction are interdependent. This interdependency of tasks causes much complexity because if one task is delayed, then it may affect all succeeding tasks and results in reducing productivity of the construction, so proper planning is necessary for better performance. The time is always considered as money, saving time at the time of construction is nothing but saving money, which is involved within construction. The delays can be observed at the time of variation in planned work and actual work done. So finding root causes of variation and minimization of this variation is important for construction sector. Consider if any task required 100 labour hours and actually it takes 125 labour hours then the variation is of 25 labour hours.

Variation almost always exists in the construction work process. The term variation is taken for this research as the time difference between actual planned duration and actual executed duration at site. The data collection is carried out through the prepared questionnaire. It will find the main causes among the various individual causes of variation.

The complete removal of variation is not possible in construction industry due to its complex nature. So minimization of the variations in construction tasks is necessary. The variation minimizations will definitely result in saving time and money.

This is necessity of construction industry to complete the project on time or within time and the main challenge is to avoid the delays. If the project is delayed for long time the respective company's reputation will damage as well as the loss due to delay is also another problem. So an avoidance of occurrence of delay is the best way to save money, reputation, and relationship with clients.

In this research the study is done only for residential sites and method is developed. But the same method can be adoptable for all types of constructions like commercial and industrial type of construction. Variations from planned time are considered as delays, and these variations may be positive or negative. The positive variations means the actual task is completed after planned task and negative variation means the actual task done before the planned task. The positive variation is taken as dangerous for project performance because this will affect on successor activities and which can be harmful for the project performance. In this research the positive variations are taken into account as they have high influence on project. The delay cannot be completely avoidable with any suitable method, but it can be minimized by proper means. Various factors are affecting on delay occurrence are like human habits, different site conditions, type of work force, nature of work, client or contractors interference etc. The research on this kind of issue is helpful to know delays and their causes.

MOTIVATION OF THE STUDY:

The project delay is major problem in construction industry. Many projects experience extensive delays and thereby exceed initial time and cost estimates. Due to complex nature the delay can be occurred and the study is necessary to know the root causes of variations and to know how to overcome the delay problems. The construction industry is a major player in

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the economy, generating both, employment and wealth.

The following study gives knowledge about the causes of variation and remedial methods to overcome such variations. The causes of delay which leads to exceeding the time and cost of the project should be eliminated or minimized.

Data collection from sites:

The data collection was done through prepared questionnaires. The suitable questionnaires are designed to collect appropriate data. The data collection is done from three residential projects. The residential sites with well-prepared bar chart are taken for this purpose. The planned data is compared to actual occurred data to know the occurrences of variation or delay in project progress, the bar chart scheduling is used as base line and the delayed time duration. And analysis of various causes of variation is done; to know the effect of each cause on the productivity of the project.

For data collection purpose the quantitative method of data collection is adopted. The collected data is further used for analysis purpose. The collected data is used to know the variations in task, as well as for knowing the individual causes of variation. The individual causes are grouped in main cause groups depending on their characteristics and nature of occurrence on site. The onsite interviews are taken for this purpose. In which the care is taken that the all levels of authorities are involved in this process i.e. from labour to the higher authority of the project. The necessity of involving all levels of authorities is to consider the perspective of all levels of authorities towards the delay problem. And also it gives the exact causes of the variation in construction tasks.

Data collection process is carried out on three construction sites from the Kolhapur, Maharashtra, India region. The 15 weeks data is recorded for data collection. And this data is used for data analysis.

Questionnaire design:

Questionnaire is prepared with, the site information, interviewer position and his authority towards work, type of task and factors causing delay for that task. The questionnaire is divided into two main parts. First part is related to general information for both the company and respondent. Second Part includes the list of the identified causes of delay in construction project. These causes are classified into nine groups according to the main sources of delay i.e. pervious task, drawing details, Labour, Management, Material, equipment, Work condition, weathering condition, and finance.

For each cause group two questions were asked i.e. what is frequency of cause occurrence? And what is the degree of severity of this cause on project delay? Both the frequency of occurrence and severity were categorized on a five-point scale system. Frequency of occurrence is categorized as follows: certain, likely, possible, unlikely and rare (from 5 point to 1 point on scale respectively). Similarly, degree of severity was categorized as follows: catastrophic, major, moderate, minor and low (from 5 to l point scale respectively). From which the severity index and the frequency index of the cause occurrence on site has came to know and which can further used in preparation of the risk assessment matrix.

Site selection for data collection:

In this the variation survey will be done at three residential construction sites and then root causes of these variations will be found through questionnaires at different level of management. The site selection process is done with following criteria:

- The site should be residential type.
- Scheduled bar chart should be prepared for the work and the work is followed with scheduled bar chart.
- The site should cover maximum activities within data collection period.

The following three sites are selected based on the criteria for data collection purpose in Kolhapur, Maharashtra, India region. The sites are with well-prepared bar chart.

1. Residential project of Amar Patil engineers and contractors, Shivaji peth Kolhapur
2. Palm grove project of Bedekar constructions Devkar panand road, Kolhapur
3. Eden garden housing project of Shree construction, Bawda road, Kolhapur

The magnitudes of occurred causes are measured with help of following format on sites.

Sr. no.	Activity name	Planned start date	Actual start date occurred	Variation occurred

The duration of delay is found out through above format. As each task is started the planned start time is noted from planned bar chart and then the actual start time is noted in next column. Through this data the occurrences of the variation is known to us by whom we go for cause finding process with the help of prepared questionnaires. The difference between planned and actual gives the magnitude of variation or delay.

Grouping of causes:

The grouping of causes is done as per category of the cause and nature of occurrence. The five point ranking system is adopted for ranking the nine main causes. The ranking of causes gives us the effectiveness of particular cause on the performance of the project. The nine causes are ranked with the help of mean score method. With risk assessment matrix the causes impacting maximum risk on the project performance are worked out for suggestive method development.

The five point ranking system is adopted, in which the 25 respondents related to construction industry are selected. And their responses are taken through frequency index forms and analyzed for following methods for ranking i.e. mean score method. The score is given in between 1 to 5 depending on their frequency of occurrence. This is done to know their perspective about the causes and their effect on the project performance.

The individual causes and their grouping:

The individual causes are carried out through prepared questionnaire and interviewing people on the site. These are selected with different level of authorities; the purpose is to take consideration of perspectives of each level of authority. In this the interview are taken from foremen to management level. The following chart shows the grouping of the individual causes into their main groups.

TABLE NO: 1
INDIVIDUAL CAUSES AND THEIR GROUPING

Cause Group	Individual causes
1.Previous task	1. Delay in previous task 2. Fast work in previous task
2.Drawing details	3. Client interference in drawings 4. Delay in client decision for changes 5. Delay for revised drawings 6. Drawing mistakes 7. Unclear specifications
3. Labour	8. Less availability of labour 9. Less labour productivity 10. Lack of skills 11. Poor distribution of labour
4. Management	12. Less coordination between management and construction parties 13. Improper planning of work 14. Not providing revised drawings on time 15. Less communication between labour and management 16. Poor management / lack of proper scheduling 17. Slow in making decisions
5. Material	18. Less availability of material 19. Poor quality of materials 20. Poor material handling on site 21. Late delivery of material 22. Poor resource management
6. Equipment	23. Less availability of equipment 24. Poor performance of equipment 25. Break down of equipment during work
7.Work condition	26. Less working space
8.Weather condition	27. Hot weather condition 28. Rainy condition
9. Finance	29. Fund availability by client

These are the individual causes which are carried out from residential sites survey and literature review of related studies. The 29 individual causes are grouped in 9 main cause groups. The groups are taken for ranking purpose and then as per risk assessment matrix the individual causes of cause group are considered for minimizing the variations from the construction tasks.

The cause group previous task involves the delay due to previous tasks which is completed before new task. The cause group drawing details involves causes related to incorrect drawings, change in drawings by client and by contractor etc. The method of execution of labour and other labour related problems are taken in group Labour. The causes related to miss-management are grouped in Management group. The material source and its demand and supply related causes are grouped in Material group. The cause group equipment involves causes related to faulty equipment; less availability etc. likewise work condition group involves the availability of work space, Site layout etc. Weather condition group involves causes related to bad weather condition. And finance group involves causes related to finance supply

Mean score method for ranking of the cause groups:

The cause groups are analyzed by using mean score method of ranking. For this purpose 25 respondents are selected concerning to civil industry. As they have enough knowledge about causes of variation. The respondent has experience of 2-10 year in construction industry.

The formula used for this method is as below

$$\text{Mean score} = \Sigma (f * s/N)$$

Where, f is frequency of the respondent, s is score given by the respondent (i.e. in between 1 for lowest possibility to 5 for highest possibility)

This five point scale is used to calculate the mean score for each factor, which is then used to determine the relative ranking of each factor. The low mean score assigned low ranks and high scores allocated as high ranks. The mean score for each factor is computed by using the above formula. For ranking purpose the frequency of occurrences of the cause are take out through prepared pointing form. The data can be used for mean score method of ranking and also for calculation of frequency index.

Results for mean score ranking method:

TABLE NO: 2
RESULTS FOR MEAN SCORE RANKING METHOD

Group	Response rate (No of respondents=25)					Mean	Rank
	5	4	3	2	1		
Previous task	8 32%	6 24%	9 36%	2 8%	0	**3.80**	3
Drawing details	9 36%	9 36%	5 20%	1 4%	1 4%	**3.96**	2
Labour	10 40%	8 32%	4 16%	3 12%	0	**4.00**	1
Management	8 32%	8 32%	5 20%	2 8%	2 8%	**3.72**	4
Material	3 12%	4 16%	5 20%	5 20%	8 32%	**2.56**	6
Equipment	8 32%	5 20%	3 12%	3 12%	6 24%	**3.24**	5
Work condition	3 12%	3 12%	2 8%	7 28%	10 40%	**2.28**	7
Weather condition	0	1 4%	5 20%	3 12%	16 64%	**1.64**	9
Finance	0	3 12%	4 16%	6 24%	12 48%	**1.92**	8

From above mean score method of ranking it can be conclude that the cause labour has first rank having mean score of 4.00 and in that the 40% respondent give 5 point, 32% respondent give 4 point, 16% respondent give 3 point and 12% respondent give 2 point, and no one give 1 point for this cause. Likewise the other ranking is done; the lowest rank is for cause weather condition. It has mean score of 1.64
The results of mean score method are as follows.

TABLE NO: 3 CAUSES AND THEIR RANKS

Cause group	Mean score	Rank
Labour	**4.00**	1
Drawing details	**3.96**	2
Previous task	**3.80**	3
Management	**3.72**	4
Equipment	**3.24**	5
Material	**2.56**	6
Work condition	**2.28**	7
Finance	**1.92**	8
Weather condition	**1.64**	9

The ranking gives us the idea about causes and general perspective of respondents about the causes.

Severity index:

Severity index shows the severity of the cause occurrences from which it is come to know that, which cause group is more severely occurred or which group is more responsible for delay. In this method the severity index for each cause is calculated with following formula:

$$\text{Severity index} = \Sigma\, a\,(n/N)*(100/5)$$

Where, a is constant expressing weighting given to each response, which ranges from 0 for no influence up to 5 for very high; n = frequency of the responses; and N = total number of responses.

Results for severity index:

TABLE NO: 4 SEVERITY INDEX TABLE

Group	Severity index response rate (No of respondents=25)					Severity index (%)
	5	4	3	2	1	
Previous task	12 48%	6 24%	5 20%	2 8%	0	82.40
Drawing details	9 36%	8 32%	5 20%	2 8%	1 4%	77.60
Labour	10 40%	9 36%	6 24%	0	0	83.20
Management	11 44%	5 20%	5 20%	2 8%	2 8%	76.80
Material	0	0	7 28%	8 32%	10 40%	37.60
Equipment	1 4%	2 8%	5 20%	6 24%	11 44%	40.80
Work condition	0	0	2 8%	5 20%	18 72%	27.20
Weather condition	1 4%	0	2 8%	5 20%	17 68%	30.40
Finance	0	0	0	3 12%	22 88%	22.40

Causes and their severity indexes are as below:

TABLE NO: 5 CAUSES AND THEIR SEVERITY INDEXES

Cause group	Severity index
Labour	83.20%
Previous task	82.40%
Drawing details	77.60%
Management	76.80%
Equipment	40.80%
Material	37.60%
Weather condition	30.40%
Work condition	27.20%
Finance	22.40%

From above results it is clear that the severity index for cause-labour is highest (83.20%) so it is more affecting cause for delay occurrence. And the cause- finance has severity index lowest (22.40%) so this cause does not much affect for delay. The following relation is made for severity index and their impact level on the project performance.

Severity Index Scale and Corresponding Impact Level:

TABLE NO: 6 SEVERITY INDEX AND IMPACT LEVEL

Range (%)	Impact level
0–09	Low
10–19	Minor
20–49	Moderate
50–79	Major
80–100	Catastrophic

So from obtained results about severity the no one cause group in low and minor category, the causes like equipment, material, weather condition, work condition, finance are in moderate category. Drawing detail and management these causes are in major category. And the causes previous task and labour are in catastrophic category.

Frequency index:

The frequency index is calculated by using the following formula. The frequency of delay occurrence can be known by following formula:

$$\text{Frequency Index} = \Sigma\, a\,(n/N)*(100/5)$$

Where, a is the constant expressing weighting given to each response (ranges from 1 for rarely up to 5 for certain), n is the frequency of the responses, and N is total number of responses.

Results of Frequency index:

TABLE NO: 7 FREQUENCY INDEX TABLE

Group	Frequency index response rate (no of respondents N=25)					Frequency index (%)
	5	4	3	2	1	
Previous task	8 32%	6 24%	9 36%	2 8%	0	76.00
Drawing details	9 36%	9 36%	5 20%	1 4%	1 4%	79.20
Labour	10 40%	8 32%	4 16%	3 12%	0	80.00
Management	8 32%	8 32%	5 20%	2 8%	2 8%	74.40
Material	3 12%	4 16%	5 20%	5 20%	8 32%	51.20
Equipment	8 32%	5 20%	3 12%	3 12%	6 24%	64.80
Work condition	3 12%	3 12%	2 8%	7 28%	10 40%	45.60
Weather condition	0	1 4%	5 20%	3 12%	16 64%	32.80
Finance	0	3 12%	4 16%	6 24%	1248%	38.40

Causes and their frequency indexes are as below:

TABLE NO: 8 CAUSES AND THEIR FREQUENCY INDEX

Cause group	Frequency index
Labour	80.00
Drawing details	79.20
Previous task	76.00
Management	74.40
Equipment	64.80
Material	51.20
Work condition	45.60
Finance	38.40
Weather condition	32.80

From above results it is clear that the Frequency Index for cause labour is highest (80.00%) so it is frequent cause for delay occurrence. And the cause weather condition has Frequency Index lowest (32.80%) so this cause rarely occurred. The following relation is made for Frequency Index and their impact level on the project performance.

Frequency Index Scale and Corresponding Impact Level:

TABLE NO: 10 FREQUENCY INDEX AND IMPACT LEVEL

Range (%)	Impact level
0–09	Rare
10–19	Unlikely
20–49	Possible
50–74	Likely
75–100	Certain

From above chart and obtained results it can be conclude that the no one cause group is in rare and unlikely category. Weather condition, finance, and work condition are in possible category; and the causes like material, equipment, management are in likely category. And in certain category the causes like previous work, drawing details, and labour are obtained.

PREPARATION OF RISK ASSESSMENT MATRIX:

The risk assessment matrix is nothing but the matrix showing the graph of severity and frequency. For this research purpose the 5x5 matrix is used. The severity is grouped in five categorized as low (0-09%), minor (10-19%), Moderate (20-49%), Major (50-79%), Catastrophic (80-100%) etc. And the frequency is categorized as rare (0-09%), unlikely (10-19%), possible (20-49%), likely (50-74%), certain (75-100%) etc.

DIA: 1 RISK ASSESSMENT MATRIX

SEVERITY %	Frequency %					
		Rare	Unlikely	Possible	Likely	Certain
	Catastrophic	H	H	E	E	E
	Major	M	H	H	E	E
	Moderate	M	M	H	H	E
	Minor	L	M	M	H	H
	Low	L	L	M	M	H

L= low risk, M= Moderate risk, H= High risk, E= Extreme risk

Developed risk assessment matrix:

The matrix of frequency and severity is formed from obtained results. And the causes are placed in their respective fields. The final output of the result is as follows;

TABLE NO 11: RESULTS OF RISK ASSESSMENT MATRIX

SEVERITY %	Frequency %					
		Rare	Unlikely	Possible	Likely	Certain
	Catastrophic	------	------	------	P.T.	Labour
	Major	------	------	------	D.D., Mgmnt.	------
	Moderate	------	Weather Condⁿ Finance	Material Work condⁿ	Equip.	------
	Minor	------	------	------	------	------
	Low	------	------	------	------	------

TABLE NO: 12 CAUSES AND THEIR RISK ON PROJECT

Cause group	Risk on project
Labour, Previous task, Drawing details, Management	Extreme
Equipment, Material, Work condition	High
Weather condition, Finance	Moderate

The risk assessment matrix gives idea about the risk produced by the cause group on the project. The causes Labour, Previous task, Drawing details, Management produce extreme risk on project. The causes Equipment, Material, Work condition produces high risk. And the causes Weather condition, Finance produce moderate risk on project performance.

STRATERGIC METHOD DEVELOPMENT

The following process can be adoptable for delay analysis and as preventive measure for delay occurrence. Few steps of this are as mentioned below.

Analysis of project progress:

The weekly or monthly survey of scheduled progress and actual progress should be done, through which the variation from base line can be come to know. This will help us to know where the delay in construction tasks are occurred or not, and then we can also find out in which activity delay occurred with its magnitude. The project bar chart can be taken as base line for this survey purpose. And the mapping of project progress can be done.

Feedback system for delay analysis to know causes of delay:

The feedback system should be adopted to know the cause of delay occurrence. The feedback system should include different levels of authorities to know their perspectives about the delay, and to know the exact causes of delay. Also the severity and the frequency of such causes occurrence should be taken out from feedback system; from which we can come to know the impact of that cause.

Forming risk assessment matrix:

The risk assessment matrix should be formed to know the how much risk is having by that causes of variation. For that purpose the severity data and frequency data can be used and the severity index and frequency index for that causes can be computed with formulae.

And then the causes causing maximum risk can be taken out for the elimination with proper solution. The risk assessment matrix gives the idea about which causes producing low or high risk on project performance. The another advantage of this is we can concentrate on high degree risk causes than the low degree risk causes which will definitely saves the time of process improvement.

Making appropriate solutions:

The appropriate solution for the obtained cause of delay should be carried out and the preventive measure should be taken for that cause. The solution should have some technical bases. Some of the suggestive methods are given below.

1. **Grouping and redistribution of work force:**

The proper grouping of work force throughout the organization is necessary; if any task needs 25 labours and there is provision of 20 or 22 labours then there is probability of delay occurrence. And for that the proper distribution of work force of relative tasks should be adopted. The exact allocation of suitable work force on different types of work is needed.

2. **Training and improvement programs:**

The training program should be provided as per the requirement of improvement required. The training should include the solutions about current problems facing by the project progress, i.e. if in any case delay occurred due to lack of communication then there should be training program for improving the communication and coordination.

3. **Improving the communication:**

For drawing details and drawing changes the proper communication system should be adopted in case if communication of drawing details is the cause of the delay. The computerized system can be adopted for fast communication of drawing, drawing details and changes. So misguidance about drawing cannot be adopted. Now days mailing the document are very common, cheap and fastest source of communication. If in any case there is less communication with clients then there should be one authority for handling the client side communications. So it will reduce time for decision by client.

4. **Timely updating the schedule:**

The schedule of the project should be revised at some time interval with neglecting previous delays. So the new goal can be formed within the organization.

Checking the impact on project by (parts project completed) PPC method:

Percentage planned complete (PPC) to indicate work plan variability. The PPC is the ratio of the number of tasks 100% completed to the number of tasks planned.

The project progress can be analyzed with checking the ratio of completed tasks to the planned task in some time interval say x i.e. the formula can be as follows:

PPC= no. of tasks completed in x duration / planned task for x duration

If there were 10 tasks planned on a monthly work plan, and at the end of the month, six of those tasks had been completed as per planned; then the PPC would be 60%.The value of PPC should be near to one; then only it can be said that the project is as per scheduled time. Lower PPC is understood to indicate greater work flow variation.

Repeating the process for continuous improvement:

The main thing is to repeat the process for continuous improvement after definite time interval i.e. after one or three month for better results and fast improvement in delay reduction. The repeating the process gives the exact causes of delay and can be minimized at the time of occurrence.

ANALYSIS OF ADOPTED METHOD:

The above method is implemented on residential site to check the feasibility of this method. The following results are observed. For feasibility analysis PPC ratio before implementation of method and PPC ratio after implementation is worked out.

Comparison of previous PPC and current PPC:

Previous PPC rate: No. of tasks to be perform in one month are 6, and No. of tasks fully completed are 5 The PPC ratio for that month is calculated as follows:

PPC = no. of tasks completed in one month / planned task for one month

=5/6

= 0.833

Current PPC rate: No. of tasks to be perform in one month are 8, and No. of tasks fully completed are 7 The PPC ratio for that month is calculated as follows:

PPC = no. of tasks completed in one month / planned task for one month

=6/7

=0.875

So we can conclude that the previous PPC ratio is 0.833 and the current PPC ratio is 0.875.

The previous PPC ratio is less than the current PPC ratio, hence the project performance is improved and which is beneficial.

CONCLUSIONS:

Conclusions from mean score method of ranking:

In this the nine cause groups are taken for ranking purpose. The cause labour has 1st rank; it has mean score of 4.00 out of 5. The cause drawing details has mean score of 3.96 with 2nd rank. Simultaneously the causes like previous tasks, management, equipment, material, work condition, finance, and weather condition are ranked form 3rd rank to 9th rank. The ranking of causes concludes that the impact of the respective causes from the perspective of respondent.

Conclusions from The results the severity index and frequency index:

The causes like Equipment, Material, Weather condition, Work condition, Finance has moderate severity on project progress as they have severity index ranges from 20-49%. And the Drawing detail and management these causes has major severity with severity index in between 50-79%. And the causes previous task and labour has catastrophic severity between 80-100%.

The causes Weather condition, finance, and work condition has possible frequencies as they have frequency index in between 20-49%; and the causes like material, equipment, management are likely occurred with frequency index ranges in 50-74%. And in certainly occurring causes are previous work, drawing details, and labour with frequency index in between 75-100%.

Conclusions from risk assessment matrix:

Risk assessment matrix concluded that the causes like labour, previous tasks, drawing details and management produces the maximum risk on the project progress. And these are the main causes of variations in construction tasks.

The causes like material, work condition, equipment produce high risk on project progress. And the causes like weather condition and finance produce moderate risk on project progress.

Conclusions from developed method:

The implemented method result shows the PPC ratio before implementing is 0.833 and PPC ratio after implementing developed method is 0.875. It means the PPC ratio is increased by adopting this method. The implementation of this method results in increased PPC from 83.3% to 87.5% and from this it can be concluded that the project performance is increased.

Future scope:

The study is done on the residential type of project. But the same study can be adoptable on the other type of projects like commercial and industrial sites. The complications of this study such as interviewing and calculations can be minimized with making appropriate software for delay analysis. This will give the fast results about the delay. The risk assessment matrix can be used for other constraints in civil engineering like waste minimization, labour productivity and its effect on performance etc.

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