

# EFFECTS OF DELAY AND COST OVERRUN AT MULTI-STOREY PROJECTS IN TAMILNADU

Vaishnavi Devi S<sup>[1]</sup>, R.Jegan<sup>[2]</sup>, G Preethi<sup>[3]</sup>

Assistant Professor, Department of Civil Engineering, Sri Krishna College of Engineering and Technology, Coimbatore<sup>1</sup>

Assistant Professor, Department of Civil Engineering, Thiagarajar College of Engineering, Madurai<sup>2</sup>

Assistant Professor, Department of Civil Engineering, Sri Krishna College of Engineering and Technology, Coimbatore<sup>3</sup>

**Abstract—** Construction cost overrun is due to late completion of work compared to the planned schedule in which the costs are time dependent other than ongoing inflation in wage and material prices. In India, due to urban sprawl and industrialization people prefer multi-storey buildings rather than individual houses. The objective of this study is to investigate the delay factors that brings cost overrun in multi-storey projects undertaken by construction companies in different location of Tamil Nadu. The delay and cost overrun factors in entire life cycle of projects are categorized under 8 main factors and 62 sub-factors. The mitigation measures and implementation strategy were also identified through questionnaire survey from experts in construction industry. The data received from a detailed case study analysis for eighteen multi-storey projects was carried out for questionnaire survey using Statistical Package of Social Science (SPSS) to carry out reliability test, hypothesis and correlation. The survey results indicated the contractor's site management factors, which is being most significant among the other main factors that leads to delay in completion and increases the cost of projects during execution and as well design related factor delays the project which leads to cost overrun at execution.

**Index Terms—** Overrun Factors, Relative Important Index (RII), Statistical Package of Social Science (SPSS)

## I. INTRODUCTION

The Construction industry is one of the key economic industries in India and the main motivating force in Indian national economy. But, it suffers from a number of problems that affect time, cost and quality performances. Cost overrun is a global phenomenon in the construction industry and very rarely projects are finished within the budgeted cost. The issue of Estate Sector (2013-2017, 2017- 2022) volume 5, the labour costs are also increasing and currently a shortage of high skilled labour in industry at key city locations.

## II. NEED FOR THE STUDY

Successful management of construction projects is based on three major factors i.e. time, cost and quality. The success or failure of any project depends largely on cost. Delay in a project causes number of changes such as late completion, lost productivity, increase in cost and termination of relationship between parties.

According to estimates of the taskforce on rental housing, the urban population in India expected to inflate from 377 million in 2011 to 590 million by 2030.

According to research by CRISIL, 76% of total housing shortages arise from Uttar Pradesh, Maharashtra, Rajasthan, Gujarat, Tamil Nadu. . Due to urbanization, industrial development and job opportunity people migrate to various parts of India, so due to shortage of land space they prefer multi-storey buildings for their dwelling.

## III. AIM & OBJECTIVE OF THE STUDY

The aim of this study is to investigate delay factors responsible for cost overrun in life cycle of multi storey buildings in different locations of Tamil Nadu.

cost overrun in construction projects is very dominant in both developed and developing countries but this trend is very severe in developing countries where these overruns sometimes exceed to 100% of the anticipated cost. Government data suggest that a majority of projects experience 60 per cent of cost overrun. If present trends continue over eleventh and twelfth period (2008-2017), McKinsey estimates that India suffer a GDP loss of. US\$200 billion around 10 per cent of its GDP in financial year 2017. Based on investigation report by KPMG in February 2011, out of a total of 559 ongoing infrastructure projects in India, 293 were delayed and contribute to cost overrun. As well the construction related commodities costs are expected to continue to increase in the future and will be directly resulting in higher construction cost. Based on the report by NSDC in Building Construction and Real

The objectives are,

- To identify the critical delay factors in stages of life cycle of multi storey projects.
- To prioritize and correlate the significant delay factors causing cost overrun among various other sub-factors by Relative Importance Index (RII) and Statistical Package of Social Science (SPSS) respectively.
- To suggest measures to mitigate delay in multi-storey buildings.

## IV. LITERATURE REVIEW

Venkatesh M.P et al., (2012) stated that the 45 causes of delay were identified Indian construction projects undertaken by private, government and non-governmental organizations and developed the questionnaire for the quantitative confirmation of the most causes of delay. The results suggest that delays are mainly due to shortage of labours, shortage of construction materials and extra works (rework and change orders). The resources like manpower and materials are having highest contribution of about 24% compared to other sources. However this paper presents recommendations for a better project

management techniques & procedures which can be adopted during conceptual & detailed planning phases of the project in order to minimize the construction delay. The resources like material related factors are having a higher contribution of about 24% in the causes of delay. This shows that the resources have higher importance in the causes of delay. By taking care of these potential factors during project scheduling time in the present and future projects, construction participants can reduce and control the extent of delays.

**M. Haseeb et al., (2011)** described that the most common factor of delay are natural disaster in Pakistan like flood and earthquake and some others like financial and payment problems, improper planning, poor site management, insufficient experience, shortage of materials and equipment etc. This paper covers the delay factors and causes of delay and some suggestion for reducing these delays in large construction projects in Pakistan. From survey it is predicted that some delay occur in projects due to shortage of labours. Delay also occurs due to external factor like change in government, regulation and location etc. Client must be mentally \*and financially strong for starting a new project due to which we can reduce delay in projects. For reducing delay in project contractor must have knowledge about his resources strength and obtain up-to-date Machinery, and try to obtain new equipment for construction. In Pakistan mostly delay occur in large construction projects is change of government due to which construction is stopped and new government propose new design for construction as well as bill are not easily passed by new government.

**Muhammad Saqib et al., (2008)** reported about the chosen seventy seven (77) factors categorized in seven (7) groups that the questionnaire respondents were asked to rank and score. A criticality score and a criticality index were used to identify the CSFs which, in descending order of importance, were found to be: Decision making effectiveness, Project Manager's experience, Contractor's cash flow, Contractor experience, Timely decision by owner/ owner's representative, Site management, Supervision, Planning effort, Prior project management experience, Client's ability to make decision. Further study on the key performance indicators (KPIs) is needed to identify the causal relationships between CSFs and KPIs. The causal relationships, once identified, will be a useful piece of information to implement a project successfully. The causal relationships, once identified, will be a useful piece of information to implement a project successfully. It can help in

selecting project team members, identifying the development needs of the project team members, and most important for forecasting the performance level of a construction project before it commences.

**K. L. Ravisankar et al., (2014)** described the influencing factors on 31 high-rise project in Indonesia and found that cost overrun occur more frequently and are perceived as more severe problems than time overruns. A detailed questionnaire is prepared based on the various factors influencing construction delay such as Financing, Material, Scheduling and controlling techniques, Planning, Contractual, Equipment, Governmental action, Labour, Design, External, Contractor, Consultant, Owner, Project, Engineer, Client, Operation factors are considered in this project. The most important causes identified by the survey, and based on overall results, were: (1) Shortage of unskilled & skilled labour; (2) Design changes by owner or his agent during construction; (3) Fluctuation of prices; (4) High waiting time for availability of work teams; (5) Rework due to errors; (6) Delay in financial support by owner to the contractor (Stage by stage payment); (7) Geological problems on site; (8) Poor site management & Inaccurate site investigation; (9) Wrong selection of type /capacity of equipment; (10) Bad weather conditions /Natural disasters (flood, earthquake); these are all the top ten delay factors which affect construction project.

**Phaniraj K, K S Sreekumar et al., (2014)<sup>[14]</sup>** highlighted the study about various factors attributed to delay in high rise building construction and effects. The research methodology includes literature review and questionnaire survey. The data was analyzed using relativity index method and multiple regression analysis. Based on the analysis of the data obtained from the survey, it was concluded that the most agreeable practical factors affecting the delay of high rise constructions are Low technical and managerial skills of contractors, Improper follow of schedule, Improper work methodology, Lack of qualified personnel, Changes in design, Late payment of bills. Time over run and cost overrun were found to be most critical effects of delay followed by dispute and arbitration. Total abandonment of project can only found to be in rare cases. But top factors for delay from the findings indicated that delay of construction is due to contractor related factors.

**V. METHODOLOGY**

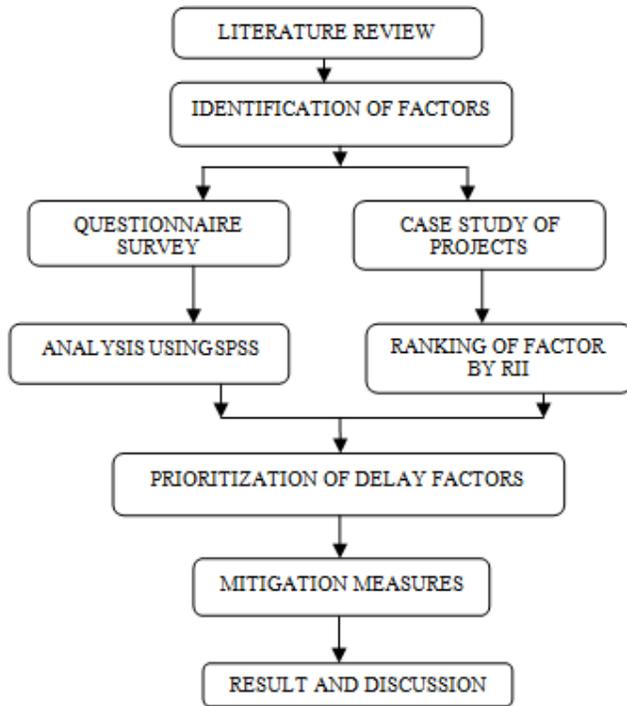


Figure 1: Methodology of the project



Figure 2: Debris collection and storage of materials

**A. Preparation of Questionnaire**

The issues listed were compiled to form a questionnaire in order to categorize the problem which is more crucial and to ranking them, through the information that can be gained from questionnaire survey, in order to find solutions for the issues site investigation with the project manager was carried out which was shown in Figure 2. Further the factors were transposed into a sixty two survey questions and circulated to the purposefully selected key industry player’s project engineers, project managers, quality surveyor, site engineer, planning and costing engineer from the construction industry. The questionnaire survey was distributed to the above professionals to assess the significant factors causing cost overrun.

**VI. DETERMINATION OF SIGNIFICANT FACTORS**

From the above mentioned journals, the factors causing cost overrun are deduced. These factors are categorized into main factor and sub factors. The frequencies of occurrence of different factors in various construction projects are identified. Predominantly, the ranking had been carried out by using Relative Importance Index (RII) and the reliability of the collected data from questionnaire survey is identified by using Statistical Package of Social Science (SPSS).

**A. ANALYSIS OF FACTORS USING LIKERT SCALE**

Likert scale is a psychometric response scale primarily used in questionnaires to obtain a participant’s preferences or degree of agreement with a statement or set of statements. Likert scales are a non-comparative scaling technique and are one-dimensional (only measure a single trait) in nature. Respondents are asked to indicate their level of agreement with a given statement by way of an ordinal scale. Each specific question can have its response analyzed separately, or have it summed with other related items to create a score for a group of statement. This is why likert scales are sometimes called summative scales.

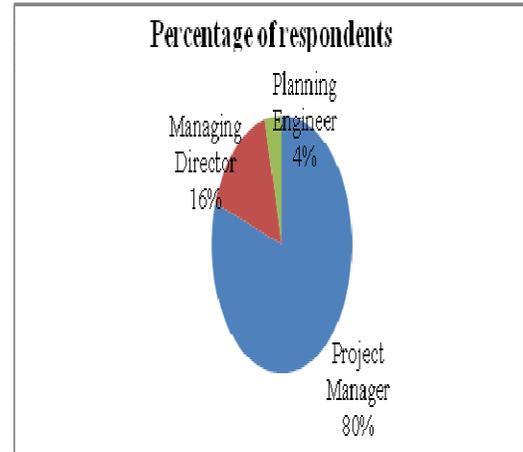
**B. STRENGTHS OF LIKERT SCALE ANALYSIS**

- Simple to construct

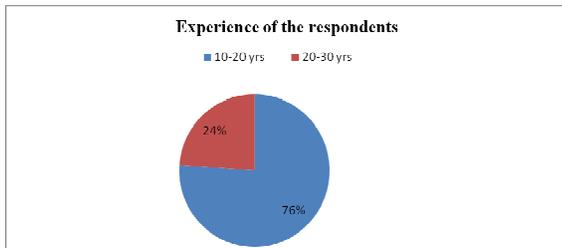
- Likely to produce a highly reliable scale
- Easy to read and complete for participants

**VII. DATA COLLECTION AND ANALYSIS**

Based on these above factors questionnaire was prepared and distributed through mail and direct interview to project managers in 70 construction companies which was shown in figure 3 and figure 4. Out of 70 only 44 responded. The data received from questionnaire survey was analyzed using Statistical Package of Social Science (SPSS) to carry out reliability test and Relative Importance Index (RII) for ranking.



**Figure 3: Responses of different profession holders in construction industry**



**Figure 4: Experience of respondents**

**VIII. A CASE STUDY OF COST OVERRUN FACTORS IN REAL PROJECTS**

A case study of eighteen projects from various location of Tamil Nadu was investigated for the delay factors that

**A. Relative Importance Index (RII)**

Relative Important index (RII) have been employed and calculated for ranking of causes of cost overrun in the construction project. The RII is used to rank the different causes. These rankings make it possible to cross-compare the relative importance of the factors as perceived by the groups of respondents. Each individual cause’s RII perceived by all respondents should be used to assess the general and overall rankings in order to give an overall picture of the causes of construction cost overrun in construction industry.

N = Total number of respondent

contributes cost overrun. From the eighteen projects the actual planned cost of each activity, delay of each activities and the cost contributing to each delay factors are enquired from the case study. The major factors are identified by using Relative Importance Index (RII), actual planned cost of each activity, delay of each activities and the cost contributing to each delay factors are enquired from the case study. The major factors are identified by using Relative Importance Index (RII)

$$RII = \frac{\sum W}{A \times N}$$

W = Weighting given to each factor by the respondents and ranges from 1 to 4

A = Highest weight (i.e. 4 in this case)

**Table 1: Ranking Criteria**

Very important for cost overrun	Important for cost overrun	Somewhat important for cost overrun	Not important for cost overrun
N4	N3	N2	N1
4	3	2	1

**TABLE 2: RESULT OF DELAY FACTORS AT PROJECT INITIATION AND PLANNING PHASE**

Sl. No	Sub Factors	Correlated value	Main group factors
1	Delay in decision making by owner	0.876	Owner
2	Changes in government rules and regulation	0.842	External
3	Land acquisition	0.799	External
4	Mistakes and discrepancies in design documents	0.784	Design
5	Delay in producing design documents	0.733	Design
6	Misunderstanding of owners requirements by design engineer	0.729	Design
7	Delay in obtaining approval from cooperation	0.684	External
8	Delay in revising and approving design by owners	0.656	Owner
9	Frequent changes in design by owners	0.622	Design
10	Effects of social and cultural factors	0.618	External

TABLE 3: RESULT OF DELAY FACTORS AT EXECUTION PHASE

Sl. No	Sub factors	Correlated value	Main group factors
1	Poor site management and supervision	0.986	Contractor
2	Poor financial control at site	0.922	Contractor
3	Poor site management	0.918	Contractor
4	Late procurement of materials by project team	0.876	Contractor
5	Fluctuation of material prices	0.852	External
6	Rework due to error at construction phase	0.843	Contractor
7	Delay in payment by owners	0.812	Owner
8	Mistakes and discrepancies in design documents	0.799	Design
9	Shortage of site workers	0.762	Labour
10	Traffic restriction and control at site	0.745	External

TABLE 4: RESULT OF DELAY FACTORS AT PROJECT CLOSURE PHASE

Sl. No	Sub Factors	Correlated value	Main group factor
1	Additional work by owners requirement	0.833	Owner
2	Rework due to error during construction phase	0.824	Contractor
3	Legal disputes between parties	0.803	Contractor
4	Mistakes and discrepancies in design documents	0.794	Design
5	Contractual claims such as extension of time and cost claims	0.778	Contractor
6	Delay in performing final inspection and certification	0.761	External
7	Changes in government rules and regulations	0.712	External
8	Payment issues between parties	0.685	Owner
9	Political situations	0.675	External
10	Effects of social and cultural factors	0.648	External

## IX. MITIGATION MEASURES

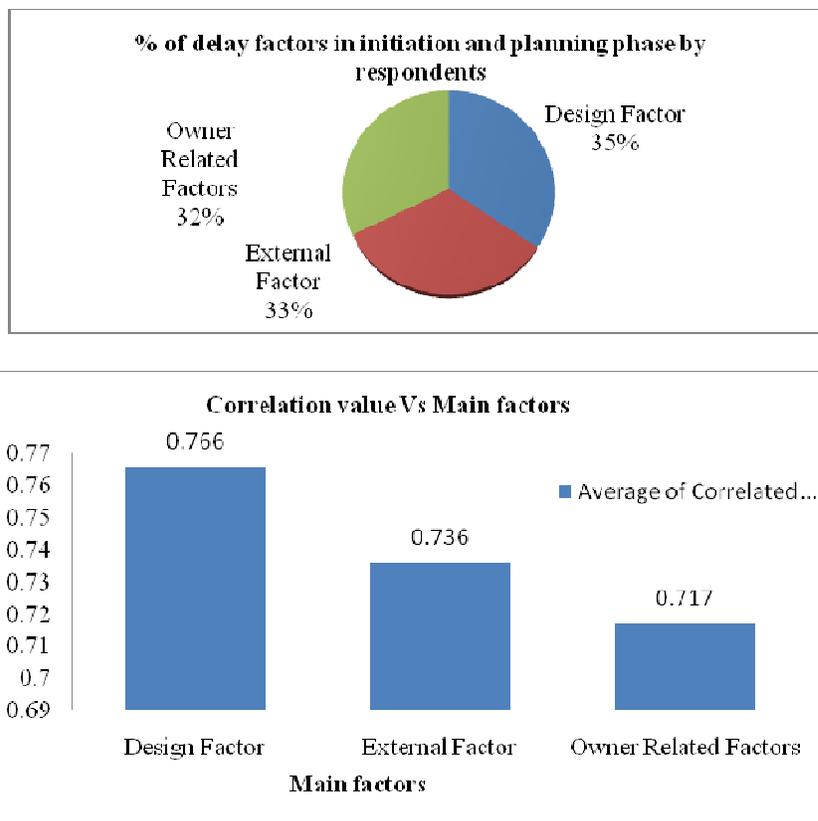
The mitigation of delays can be possible by also applying the knowledge gained through previous projects experience and these can be implemented where ever their application can be suited for any specific requirement in the process of project learning. Such knowledge management will help in mitigating delays and the awareness of such knowledge through lessons learnt feedback can in fact be helpful in preventing the delays itself. Managing construction cost is one of the important tasks in achieving successful project completion. Based on the factors of delay, the experts have suggested the mitigation measures on their experience and learning from each project. The generic suggestions were given from the forty four experts. The respondents classified each measure based on three approach of implementation strategy. Measures in pro-active (Pro) strategy are the measures that must be adopted in planning of project to predict and prevent cost overrun issues. Measures in re-active (Re) strategy are those which can be adopted to mitigate the effect of inhibiting factors in project control as a remedy while measures in organizational (Org) strategies are the measures which are normally in place of management style. Also, some of the measures are fluid which can be classified in more than one strategy. The majority respondent has felt that planning stage is crucial for the success of project to overcome delay factors in execution stage.

**Table 5: % of responses for mitigation measures Vs implementation strategy**

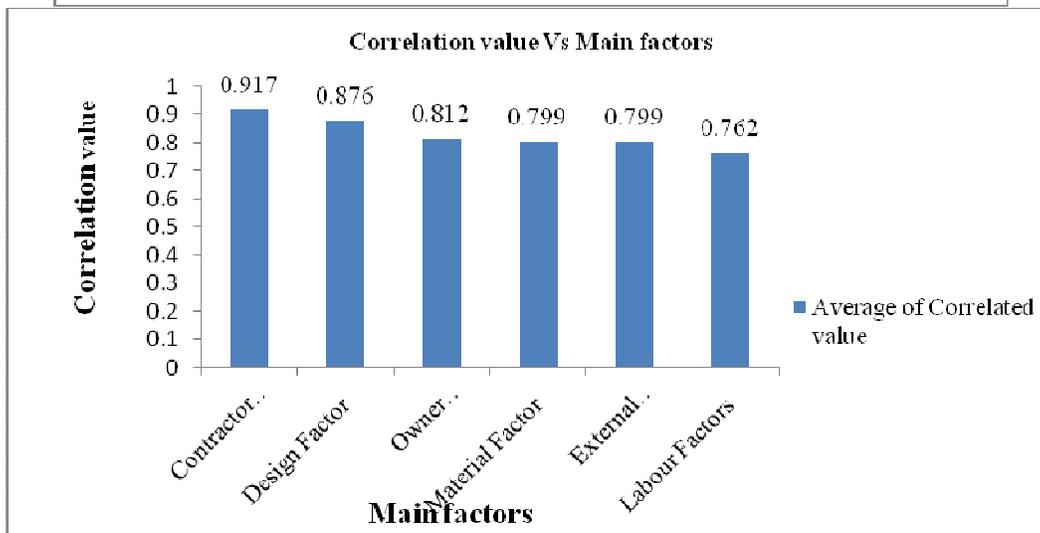
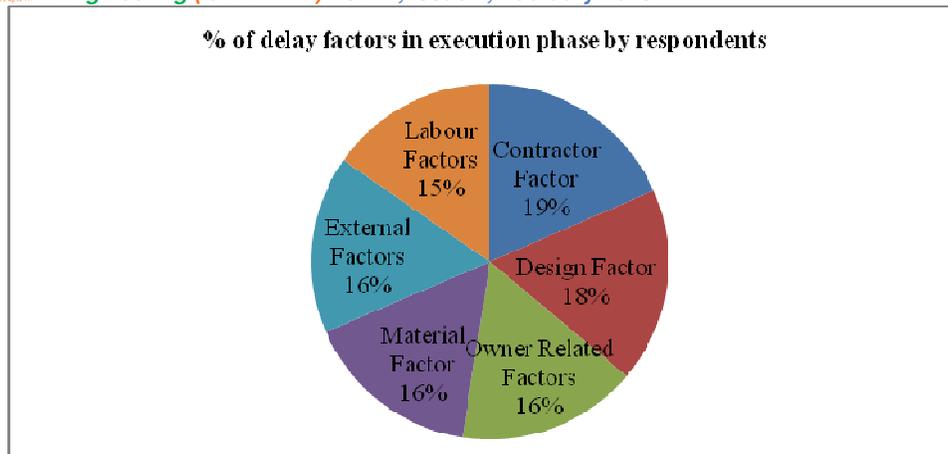
Sl. NO	MITIGATION MEASURES	Pro (%)	Re (%)	Org (%)	Pro-Re (%)	Pro-Org (%)	Re-Org (%)	P-R-O (%)
1	Effective strategic Planning	75	0	16.67	0	0	0	8.3333
2	Contractors experience and competence	0	0	66.67	0	20.83333	8.33333	16.667
3	Use appropriate construction method	70.833	8.333	4.167	8.3333	4.166667	0	4.1667
4	Use of experienced subcontractors and suppliers	8.3333	45.83	29.17	8.3333	4.166667	0	4.1667
5	Adequate funding	20.833	41.67	20.83	4.1667	4.166667	4.16667	4.1667
6	Effective planning of project activities	70.833	0	16.67	12.5	0	0	0
7	Effective communication channel	54.167	8.333	25	0	4.166667	8.33333	0
8	Effective cost control system	0	54.17	25	4.1667	4.166667	8.33333	4.1667
9	Effective Scheduling and time control system	66.667	0	16.67	16.667	0	0	0
10	Proper site management	0	41.67	16.67	16.667	8.333333	4.16667	12.5
11	Human skill availability	4.1667	8.333	75	0	12.5	0	0
12	Use up to date technology utilization	29.167	54.17	8.333	0	8.333333	0	0
13	Effective project monitoring	4.1667	50	25	4.1667	4.166667	0	0
14	Frequent progress meeting	0	54.17	33.33	0	0	0	12.5
15	Project management knowledge in site	16.667	45.83	16.67	4.1667	4.166667	8.33333	4.1667
16	Proper resource planning and site investigation	54.167	25	12.5	8.3333	0	0	0
17	Effective coordination between parties	16.667	20.83	50	4.1667	0	4.16667	4.1667

## X. RESULTS AND DISCUSSION

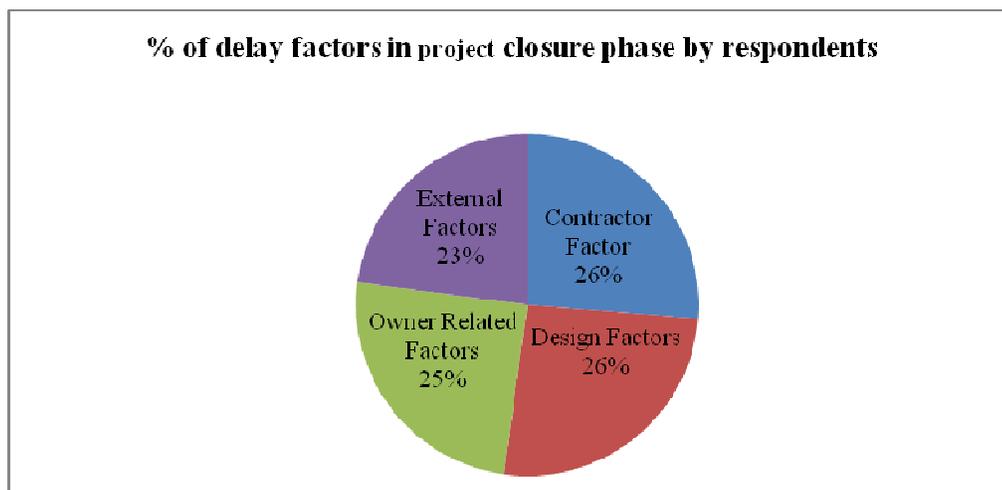
The questionnaire survey was prepared and distributed to 70 project managers and out of 70 only 44 responded. The result of this study indicates majority of causes for delay which contributes to cost overrun comes under contractor related factors in execution phase. Delay factor at each phase of project was analyzed using SPSS tool and it shows that contractor related factors were significant in project execution and closure compared to other major group factors. As well as the influence of main delay factors contributes to cost overrun at planning, execution, closure phase were listed below in pie chart at figure 5 which describes that due to design related issues the project will be delayed at the initiation stage of the project and figure 6 and figure 7 states that contractor related factors plays a major role in the project execution.

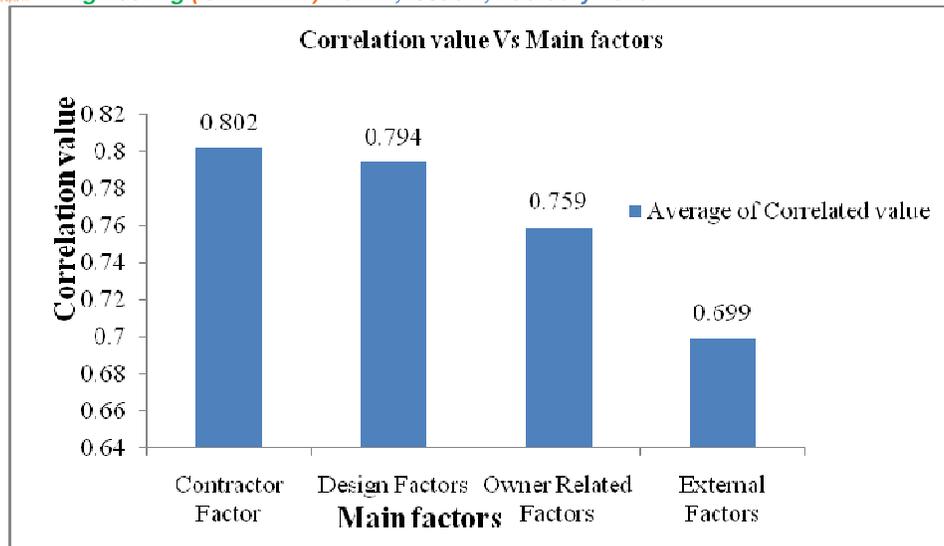


**Figure 5: Main group of delay factors at project initiation and planning phase**



**Figure 6: Main group of delay factors at project execution phase**





**Figure 7: Main group of delay factors at project closure phase**

Further, the study includes seventeen mitigation measures to overcome these delay factors through questionnaire survey from the experts. The outcome includes pro-active strategy (to be adopted at planning stage), re-active strategy (to be adopted to mitigate the effect of inhibiting factors), Organizational strategy (management style) as mitigation measures. Among these three strategies project planning is very important and crucial to control and reduce the impact of cost overrun throughout the execution of project. It was found from the survey that proper project management knowledge among the contractor increases the positive impact on project completion without any major delay in projects.

**Table 6: Mitigation measures Vs strategy**

SL. NO	MITIGATION MEASURE	STRATEGY
1.	EFFECTIVE STRATEGIC PLANNING	PRO-ACTIVE
2.	CONTRACTORS EXPERIENCE AND COMPETENCE	ORGANIZATIONAL
3.	USE APPROPRIATE CONSTRUCTION METHOD	PRO-ACTIVE
4.	USE OF EXPERIENCED SUBCONTRACTORS AND SUPPLIERS	RE-ACTIVE & ORGANIZATIONAL
5.	ADEQUATE FUNDING	PRO-ACTIVE, RE-ACTIVE & ORG
6.	EFFECTIVE PLANNING OF PROJECT ACTIVITIES	PRO-ACTIVE
7.	EFFECTIVE COMMUNICATION CHANNEL	PRO-ACTIVE & ORGANIZATIONAL
8.	EFFECTIVE COST CONTROL SYSTEM	PRO-ACTIVE
9.	EFFECTIVE SCHEDULING AND TIME CONTROL SYSTEM	PRO-ACTIVE
10.	PROPER SITE MANAGEMENT	RE-ACTIVE
11.	HUMAN SKILL AVAILABILITY	ORGANIZATIONAL
12.	USE UP TO DATE TECHNOLOGY UTILIZATION	PRO-ACTIVE AND RE-ACTIVE
13.	EFFECTIVE PROJECT MONITORING	RE-ACTIVE & ORGANIZATIONAL
14.	FREQUENT PROGRESS MEETING	RE-ACTIVE & ORGANIZATIONAL
15.	PROJECT MANAGEMENT KNOWLEDGE IN SITE	RE-ACTIVE
16.	PROPER RESOURCE PLANNING AND SITE INVESTIGATION	PRO-ACTIVE, RE-ACTIVE, ORGANIZATIONAL
17.	EFFECTIVE COORDINATION BETWEEN PARTIES	ORGANIZATIONAL

## XI. CONCLUSION

The result of this study indicates that the causes of delay which contributes to cost overrun is mainly due to contractor related factors at execution and closure phase of project. The result shows that poor project management knowledge among the team and improper forecasting method in overall completion of project leads to delay. Further, the study includes seventeen measures for mitigation of delay in all phases of project. Among them effective strategic planning, use of appropriate construction method, effective planning of project activities, effective cost control system, effective scheduling and time control system are considered as pro-active strategy whereas contractors experience and competence, human skill availability are considered under organizational related strategy and finally the proper site management, project management knowledge in site are considered as re-active strategy. These three approaches of strategy implementation in project reduce the impact of cost overrun and avoid the hindrance during project execution phase.

## XII. FUTURE SCOPE OF RESEARCH

The result of this research will help to construction project companies in Tamil Nadu to understand the cost overrun factors and mitigation to improve the poor quality of management skill in delay at completion of a project can be achievable only if the project managers were aware about the prediction of cost overrun. It can be done by adopting fuzzy model for cost overrun prediction.

## REFERENCE

- 1) Aditi Dinakar., "Delay Analysis in Construction Project", *International Journal of Emerging Technology and Advanced Engineering*, (ISSN 2250-2459, ISO 9001:2008, Volume 4, Issue 5, May 2014)
- 2) Afshari, H., Khosravi, S., Ghorbanali, A., Borzabadi, M., and Valipour, M., "Identification of Causes of Non-excusable Delays of Construction Projects", *International Conference on E-business, Management and Economics IPEDR*, vol.3 IACSIT Press, Hong Kong, 2014.
- 3) Aswini Arun Salunkhe, Rahul S Patil., "Effect of construction delays on project time overrun-Indian scenario", *IJRET*, Vol.03, pp.57-69, 2014.
- 4) Doloi H., Sawhney A., Iyer K.C. and Rentala S., "Analysing factors affecting delays in Indian construction projects", *International Journal of Project Management*, Volume 30, Issue 4, Pages 479-489, 2012.
- 5) Greeshma B Suresh, Dr. S. Kanchana., "A study on quantification of delay factors in construction industry (Kerala region)", *International Journal On Engineering Technology and Science (IJETS)*, ISSN(P): 2349-3968, Volume 2 - Issue 5, May 2015.
- 6) K. L. Ravisankar, Dr. S. AnandaKumar, V. Krishnamoorthy., "Study on the quantification of delay factors in construction industry", *International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, ISO 9001:2008, (Volume 4, Issue 1, January 2014).*
- 7) Mahamid, I., and Bruland, A., "Cost Overrun Causes in Road Construction Projects Consultants Perspective", *2nd International Conference on Construction and Project Management IPEDR*, vol.15 (2011) IACSIT Press, Singapore.
- 8) M. Haseeb, Xinhai-Lu, Anees Bibi, Maloof-ud-Dyian, Wahab Rabbani., "Problems of projects and effects of delays in the construction industry of Pakistan", *Australian Journal of Business and Management Research*, Vol.1 No.5, pp. 41-50, September-2011.
- 9) Muhammad Saqib, Rizwan U. Farooqui, Sarosh. H. Lodi., "Assessment of Critical Success Factors for Construction Projects in Pakistan", *International Conference on Construction in Developing Countries (ICCIDC-I) "Advancing and Integrating Construction Education, Research & Practice" August 4-5, 2008, Karachi, Pakistan.*
- 10) Oliveros, A.V.O and Fayek, A.R., "Fuzzy logic approach for activity delay analysis and schedule updating", *Journal of Construction Engineering and Management*, 131(1), pp.42-51, 2005.
- 11) Ogunlana S.O. Prokuntong, K. and Jearkijrm, V., "Construction Delays in Fast Growing Economy Comparing Thailand with Other Economies", *International Journal of Project Management* 14 (1),37-45, 1996.
- 12) Phaniraj K, K S Sreekumar., "Practical Factors Affecting Delay in High Rise Construction – A Case Study in a Construction Organization", *International Journal of Engineering Research & Technology (IJERT)*, ISSN: 2278-0181, Vol. 3 Issue 5, May – 2014.
- 13) Purvit Kumar Bhawsar, Dr. Nitin Joshi and Dr.Archna Keerti Choudhary., "Analysis of Cost Overrun For Flyover Bridges Construction Project Using Fuzzy Logic", *International Journal of Research*, p-ISSN: 2348-6848 e-ISSN: 2348-795X, Volume 03 Issue 17 November 2016.
- 14) Sharma, S., and Goyal, P. K., "Cost Overrun Assessment Model in Fuzzy Environment", *American Journal of Engineering Research (AJER)*, e-ISSN: 23200847 p-ISSN: 2320-0936, Volume-03, Issue-07, pp-44-53, 2015. 22



- 15) Shreenaath, A., Arunmozhi, S., and Sivagamasundari, R., "Prediction of Construction Cost Overrun in Tamil Nadu- A Statistical Fuzzy Approach", *International Journal of Engineering and Technical Research (IJETR)*, ISSN: 2321-0869, Volume-3, Issue-3, 2015.
16. Venkatesh, M.P., Renuka, S.M. and Umarani, C., "Causes of delay in Indian construction industry", *Applied Mechanics and Materials*, (Vol. 174, pp. 2768-2773), 2012.