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A Probabilistic Fuzzy Logic Approach to Identify Productivity Factors in Indian Construction Projects

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Abstract: Preeminent performance of construction industry are unattainable with poor productivity resulting in time and cost over runs. Enhancement in productivity cannot be achieved without identifying and analyzing factors that adversely affect productivity. The objective therefore is to propose a productivity analysis model to quantify the probability of effect of factors influencing productivity by using fuzzy logic incorporated with relative importance index method, for various types of construction projects. To achieve this objective, a questionnaire survey was carried out targeting respondents of Indian construction industry, from four distinct projects, namely, residential, commercial, infrastructure and industrial projects. Based on questionnaire administered, the relative importance and ranks of factors demonstrated using relative importance index method. Probability assessment model to analyze productivity was then developed by using Fuzzy Logic Toolbox of MATLAB. The applicability of the proposed model was tested in seven construction projects and the probability of impact of factors on productivity evaluated. The results of application of model in the construction firms infers that the most contributing factor groups for most of the projects were discerned to be manpower, motivation and time group.

Keywords: Productivity, Construction, Fuzzy logic, Relative importance index, Probability assessment model

I. INTRODUCTION

The value of the construction industry in terms of its contribution to society is astonishingly remarkable. Because of its inescapable presence, it is not surprising that the construction sector is also a major contributor to the economy, as it influences and is influenced by GDP. The construction industry is of critical importance to the nation’s economy. There is nothing as dangerous to an economy as a decrease in productivity because it creates inflationary pressure, social conflict, and mutual suspicion.

Productivity, more often defined as a ratio between an output value and an input value used to produce the output, remains an intriguing subject and a prevalent issue owing to the fact that, it is one of the most crucial factors that affect the physical progress and profitability of construction projects (Borcherding et al., 1986). However, in India, poor productivity has been identified as one of the most daunting challenges faced by the construction sector to its future growth. Poor productivity has also been identified as one of the major reasons for cost and time over runs in construction projects, and hence demands for improvement in construction productivity.

Productivity improvement in the construction industry has been a major challenge, given its high impact on project results, i.e. higher cost savings can be achieved with minimal investment. Perhaps, for any improvement in construction productivity, it becomes highly necessary and mandatory to identify and quantify the factors that adversely affect productivity, and work out the critical ones out of the available factor.

Measuring and quantifying the impact of the factors influencing productivity for construction projects is a complex problem. These measurable calculations about the impact of productivity factors on the overall productivity of the construction projects are required for several purposes such as planning, scheduling and estimation of the construction project. From the past studies, it has been inferred that it is difficult to calculate such an impact, and at present there are no universally accepted standards to determine the impact of the influencing factors on productivity. The lack of methods for measuring the impact on productivity emphasize the need to enhance measurable assessments for the factors affecting productivity in construction industries and is supposed to be the topic of this research. With this in mind, this paper aims to develop a conceptual fuzzy model, to provide contractors with information on factors which they need to focus. The outcomes can also help the construction practitioners and researchers in quantifying the impact on productivity by its attributes, thereby developing a deeper and wider perspective on the factors influencing productivity of construction projects and may also provide guidance to the building contractors to have an appropriate strategy to improve the productivity of employees on their construction site.

II. LITERATURE REVIEW

A. Identification of Factors Influencing Productivity

Productivity has been one of the main issues from the conception of the project. The factors influencing construction productivity have been the subject of inquiry by many researchers. In order to improve productivity, a

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study of factors affecting it, whether positively or negatively, is necessary. Making use of those factors that positively affect productivity and eliminating (or controlling) factors that have a negative effect, will ultimately improve productivity.

A review of literature reveals numerous productivity factors and different classification schemes. Identifying the factors that impact construction productivity is not a new effort. There have been numerous efforts on identifying and classifying the factors that impact construction productivity, with a few attempting to identify the relative importance of the individual factors. Despite such intensive investigation, researchers have not agreed on a universal set of factors with significant influence on productivity. However, a consensus among research on the classification schemes of such groups is yet to be reached.

Several approaches have been adopted in relation to the classification of factors affecting construction productivity.

Makulsawatudom & Emsley (2004) identified lack of materials, incomplete drawings, incompetent supervisors, lack of tools and equipment, absenteeism, poor communication, instruction time, poor site layout, inspection delay and rework as the 10 most significant factors influencing productivity in Thailand using relative index ranking technique.

Enshassi et al. (2007) identified 45 factors affecting labour productivity within building projects in Gaza Strip, and quantified their relative importance from contractor's point of view. The study concluded that material shortage, lack of labour experience, lack of labour surveillance, misunderstandings between labour and superintendent, and drawings and specification alteration during execution were the main factors negatively affecting labour productivity.

Alinaitwe et al. (2007) conducted a survey in Uganda amidst the project managers of building projects, to rate the 36 factors affecting productivity with respect to time, cost and quality. The results of survey carried out by a questionnaire was analysed using Mean Combined Importance Index method and it indicated that the ten most significant problems affecting labour productivity were; incompetent supervisor, lack of skills from the workers, rework, lack of tools/equipment, poor construction method, poor communication, inaccurate drawing, stoppage of work, political insecurity, tool/equipment breakdown and harsh weather conditions.

Dai et al. (2009) conducted a study in US and employed factor analysis to define a classification scheme of the productivity factors. A craft worker survey involving 1996 craftsmen was carried out by the researchers to assess the impact of 83 factors on productivity. Factor analysis extracted 10 latent factors, namely, tool and consumable, direction and coordination, engineering drawing management, construction equipment, material, project management, foreman competency, superintendent competency, training and craft worker qualification, amongst which construction equipment, project management and craft worker qualification were identified as the areas with greatest potential for productivity improvement.

Rivas et al. (2011) administered a craftsmen questionnaire in Chile to both direct workers and midlevel employees to analyse factors influencing construction productivity based on the relative importance index method. The study recognized that the critical areas affecting construction productivity were related to materials, tools, rework, equipment, and truck availability and workers motivational dynamics.

Thomas & Sudhakumar (2013) conducted a questionnaire survey in the state of Kerala amongst 90 supervisors and site engineers to identify the factors that have a significant impact on construction labour productivity. The factors were categorized into 10 groups, namely: Tools & Equipment issues, poor labour motivation, improper supervision, poor material planning, poor site management, improper drawing management, project management incompetency, craftsmen issues, lack of meetings, and lack of communication. Based on the response obtained regarding the effect of factors and frequency of factors, importance index (II) and frequency index (FI) was calculated and thereby the severity index of each factor was computed, which served as the basis of ranking.

El-Gohary & Aziz (2014) identified and ranked factors that perceived to affect construction labour productivity in Egyptian construction context. The questionnaire comprised thirty productivity factors where they classified them under the following three primary categories: (a) human/labour (b) industrial (c) management. Relative importance index technique was employed to analyse the data, where the index was computed for every factor for each specific year of the participants' experience. The study revealed that labour experience & skills, incentive program, availability of material & ease of handling, leadership & competency of construction management, competency of labour supervision serves as the most significant factors that affect construction labour productivity.

B. Applications of Fuzzy Set Theory and Fuzzy Logic in Productivity Analysis

Though numerous researchers have utilized fuzzy set theory in their studies, a very few significant previous studies are pertinent to the topic of this research and hence explored.

Koehn (1984) studied the application of fuzzy sets to the complex problems of building or facility satisfaction and productivity on a construction site. The research aimed to provide a basic framework for the utilization of the theory in construction risk evaluation.

Fayek & Oduba (2005) conducted a research that aimed at illustrating the application of fuzzy expert systems to the modelling of a practical problem i.e., predicting the labour productivity of two common industrial construction activities: rigging pipe and welding pipe. This research illustrated on how to develop and test such a model, given the realistic constraints of subjective assessments, multiple contributing factors, and limitation of data sets.

C. Need for the Study

The review of past literatures reveals that, majority of the researches has been carried out in countries other than India, leaving back the applicability of the factors and the classification schemes in Indian construction industry unexplored, and hence making it essential to probe the issues impacting productivity in Indian context. However, Jarkas & Bitar (2012) maintain that the major productivity factors vary from country to country, place to place and project to project. Therefore, the author in this review proposed the following 10 primary categories for classifying the corresponding factors explored in this study: (1) Manpower (2) Motivation (3) Time (4) Material/Tools (5) Leadership (6) Supervision (7) Project (8) Safety (9) Quality and (10) External. Also, as most of the previous research studies identified the productivity factors from the perspective of any one type of construction project, there was a need for this research to capture the impact of factors influencing productivity for different types of construction projects, namely, residential, commercial, infrastructure and industrial projects. Moreover, since the efforts of previous research were limited to identification, classification and quantification of relative magnitude of factors that negatively influence construction productivity; therefore the present study aims at determining the probability of overall effect on productivity by the occurrence of all influencing factors on the project site, apart from merely determining the relative magnitude of each single factor separately. This is because, knowing the relative importance of factors would be probably enough to take appropriate actions, but it would nowhere give an idea or picture about to what extent the productivity of the project have been affected due to the subjective factors. This would give a better understanding about the loss of productivity in the project site. In other words, in construction industry contractors want to maximize their profit in order to grow in the market. To achieve this aim, it becomes crucial for contractors to carefully identify the factors that affect the success of project and estimate their impacts. Whilst, in a construction project where time truly equals money, the management of time is critical, thus predicting the likelihood of probability of effect on productivity may play a key role towards project success as poor productivity leads to non-completion of the project within the specified duration agreed on contract. The common results of loss of productivity are: Late completion of project, increased cost, work disruption, third party claims, disputes and abandonment or termination of contracts. Therefore loss of productivity in construction projects give rise to dissatisfaction to all the parties involved. It is hence clear that predicting the probability of effect on productivity plays a key role towards project success and the contractor should carefully quantify it to determine a reliable time contingency before the bidding stage in order to achieve project success. Thus, there exists a need to develop a probabilistic productivity analysis model as a decision support tool for contractors. Also, the lack of previous research into fuzzy techniques in productivity analysis problems encouraged the author to investigate employing fuzzy techniques to assist in estimating the probability of effect on productivity in construction projects. Moreover, in many decision making environments, it is often the case that several factors need to be taken into account simultaneously. Often, it is not known which factor(s) need to be emphasized more in order to generate a better decision. Somehow, a trade-off between the various (potentially conflicting) factors must be made. The general framework of fuzzy reasoning facilitates the handling of such uncertainty. Fuzzy systems are used for representing and employing knowledge that is imprecise, uncertain, or unreliable and thereby provoking the author to develop the productivity analysis model using Fuzzy Logic.

III. Research Methodology

This research is based on a questionnaire survey designed to gather all necessary information in an effective way. The survey presents 39 productivity factors that were extracted based on the related research works. The first phase of this survey includes pilot study, conducted among local field experts. The second phase includes administration of the modified questionnaire (based on pilot study) to the target respondents. The collected survey data were initially analysed using Relative Importance Index (RII) technique, thereby determining the weightage of each productivity factors. Based on the RII value obtained, productivity assessment models were then developed for residential, commercial, infrastructure and industrial projects, using fuzzy logic toolbox of MAT lab. Finally, the constructed models were tested in seven construction projects, to estimate the probability of effect on productivity at site, for different type of construction projects.

A. Questionnaire Design

The basic idea behind the questionnaire design was to design a simple questionnaire that could be easily understandable and accurately interpreted by the respondents. The questionnaire consisted of two sections, section 1 related to demographic information and section 2 where the respondents were asked to access the factors and to rate them in the way they affect productivity at construction site with respect to a specific type of project (residential, commercial, infrastructure or industrial) executed by them on a five point Likert scale, with "1" indicating very low effect; "2" indicating low effect; "3" indicating average effect; "4" indicating high effect; and "5" indicating very high effect, according to the degree of importance on construction productivity.

B. Pilot Study

A pilot study was conducted to validate and improve the questionnaire in terms of the wording of statements, the overall content, and the format and layout, thereby ensuring the clarity and relevance of the questionnaire to participants. The questionnaire was distributed to 4 experts, each involved in different types of construction projects (residential, commercial, infrastructure and industrial). Based on their feedback, changes were incorporated and the draft questionnaire revised to include the suggestions of these participants. The questionnaire was validated through this process, which provided the authors with improvement opportunities before launching the primary survey.

C. Data Collection

The data collection process used in this research had the choice of two basic methods: questionnaires and personal interviews. A structured questionnaire was preferred as the best effective and suitable data-collection technique for the study as it was a self-administered tool and also the questionnaire in a web-survey format comparatively requires less duration and saves cost for the researcher while permitting participants to respond to the questionnaire at their expediency. The questionnaires were distributed to about 150 respondents, out of which 133 complete questionnaires were received, representing approximately a response rate of 89%.

To consider the varying effect of factors influencing productivity on different construction projects, the target respondents (contractors, consultant and clients) were grouped into 4 groups: Group 1 representing respondents involved in residential projects, Group 2 representing respondents involved in commercial projects, Group 3 representing respondents involved in infrastructure projects and Group 4 representing respondents involved in industrial projects. The analysis of the questionnaire reveals that, out of 133 total respondents, 53 were involved in residential projects, 30 in commercial projects, 28 in infrastructure projects and 22 in industrial projects. Fig. 1 depicts the types of participating groups based on the nature of construction projects they are involved.

D. Data Analysis Approaches

D.1. Relative Importance Index Technique

RII is a statistical method which determines more precisely the relative weight of each variable among total variables. RII was computed for each sub factors of productivity, using the following equation:

$$RII = \frac{\sum W_i}{(A*N)} \tag{1}$$

where, RII = Relative Importance Index

W_i = weightage given to each factor by respondents (ranging from 1 to 5)

A = highest weight (i.e., 5 in this case)

N = total number of respondents

The RII value has a range from 0 to 1 (0 as not inclusive); and the higher the RII, the more important the factor influencing productivity.

D.2. Construction of Productivity Analysis Model

Productivity analysis model is developed for predicting the probability of effect on productivity in Mamdani type inference, using Fuzzy logic toolbox of MATLAB. The fuzzy model was constructed using the five primary graphical user interface tools, namely, FIS Editor, Membership Function Editor, Rule Editor, Rule Viewer and Surface Viewer. These tools facilitates building, editing and observing the fuzzy assessment model in the fuzzy inference systems toolbox**.**

To develop the proposed model, the following steps are performed on fuzzy logic tool box of MATLAB:

1. The input and output parameters of fuzzy inference system determined and defined in FIS Editor.
2. Linguistic variables, for both input and output parameter identified.
3. The shape, parameters and range associated with each linguistic variable (membership function) determined and defined in Membership Function Editor.
4. Fuzzy rule set identified and defined in Rule Editor.
5. Appropriate methods for fuzzification, fuzzy inference and defuzzification determined.
6. System evaluated through Rule Viewer and Surface Viewer.

IV. Data Analysis

A. Quantification of the Relative Importance of the Factors Influencing Productivity

In this part, the relative importance of sub factors (RII) influencing productivity for different types of projects, namely, residential, commercial, infrastructure and industrial was quantified using Eq. (1) and the category importance index (of main factors) was calculated using the average of the RII of the factors in each group. The results of this part demonstrated the ranking of the sub factors and main factors according to their level of importance perceived by the respondents in relation to their degree of effect on productivity. These results also served to determine the weights of fuzzy rules in constructing the fuzzy assessment model to estimate the probability of effect on productivity in the following part. The importance index calculated for the sub factors and main factors along with their rankings is shown in Table I and Table II.

B. Modelling in Fuzzy Inference System

Fuzzy logic is a powerful modelling technique that is specifically designed to handle natural language and approximate reasoning, similar to human reasoning process. The concept of fuzzy logic was first introduced by Zadeh (1965). A fuzzy set representing a linguistic concept is characterized by its membership function, which represents numerically the degree to which an element belongs to the set and fits the linguistic concept. Fuzzy logic unlike the crisp/conventional set theory (where elements are either in or out of a set), allows elements to have partial membership in a set, ranging from 0 (no membership) to 1.0 (full membership). In other words, fuzzy logic which is an extension of classical Boolean logic, allows for partial and multivalued truths. This facilitates fuzzy logic to deal with the imprecision inherent in linguistic concepts and subjective judgments used in human decision making. To develop the model, the following approaches prior to its construction in MATLAB is followed:

Step 1: Identification of input and output to construct the model

The identified thirty nine productivity factors were considered as the main input and the probability of effect on productivity was considered as the output for the assessment model. Acronyms were used in the model to define each input and output. The acronyms used in the model are listed in Table III.

Step 2: Determination of Linguistic variables and fuzzy membership functions for the defined input and output

The membership function gives numerical meaning for each label by representing the fuzziness degree of linguistic variables. There are different shapes of membership functions, viz. triangular, trapezoidal, gaussian, bell-shaped, piece wise- linear etc. Owing to the popularity, membership function as a combination of trapezoidal and triangular forms were used for the linguistic variables categorized as very low (VL), low (L), average (A), high (H) and very high (VH), out of a scale ranging from 0 to 100. Fig. 2 depicts the membership function associated with each linguistic variables, for the defined inputs and outputs.

Step 3: Construction of the fuzzy rules

To perform the fuzzy inference, the rules that connect the input variables to the output variables in *If…Then…*forms (Mamdani – style fuzzy rules) were used to describe the desired model in terms of linguistic variables (words) rather than mathematical formulas. 5 rules were constructed for each sub factors and main factors of productivity, thereby facilitating the construction of 195 rules for the development of fuzzy assessment model (for all major groups) and 50 rules for the development of productivity analysis model.

Step 4: Assigning weights to the fuzzy rules

The relative importance indices calculated for each sub factor and group factor in Table I were assigned as weights to the fuzzy rules framed in the MATLAB software. The weightage of each fuzzy rule differed as the RII of each factors influencing productivity had a distinct value. Thus, ensuring the relative importance of each if-then fuzzy rules constructed. A sample of the fuzzy rules along with their assigned weights constructed for the fuzzy assessment model is shown in Table IV.

Step 5: Method of Aggregation

Aggregation is an operation by which several fuzzy sets are combined in a desirable way to produce a single fuzzy set. Max method was selected as an aggregation method in this model development due to its popularity in the literature.

Step 6: Method of Defuzzification

Defuzzification is a mathematical process used to extract crisp output from fuzzy output set(s). This process is necessary as all fuzzy sets inferred by fuzzy inference in the fuzzy rules must be aggregated to produce one single number as the output of the fuzzy model. Various types of defuzzification have been suggested by Cox and Hagen (1998). In this research, centre of gravity method was selected as a defuzzification method, which is based on the notion of finding the centroid of a planar figure.

V. RESULTS

A. Fuzzy Assessment Model for each Major Group of Factors

In this study, ten fuzzy assessment model were constructed, one for each main group, to determine the probability of impact on each major group due to the occurrence of each sub factors within the group. Fig. 3 depicts the input and output parameters used for the development of fuzzy assessment models.

To test the proposed assessment models and to assess the effect on productivity by various influencing factors, case studies were undertaken in seven construction projects.

The project managers were asked to, fill in the probability evaluation form by assigning input values (i.e., the probability of effect on productivity by each factor) to the productivity factors ranging from 1 (very low probability) to 100 (very high probability), by the way they affect productivity at construction site.

To fulfil these tasks, the range associated with each linguistic variables determined by its membership function (Very Low: 0-20, Low: 20-40, Average: 40-60, High: 60-80, Very High: 80-100), was provided to the interviewees to serve as guideline. The input values assigned by the project managers (involved in various types of construction projects) for the productivity factors, obtained through probability evaluation form are shown in Table V.

The input values hence obtained from Table V serves as the basis for the calculation in MATLAB program software, hence determining the probability of effect on productivity by each major groups, at construction site due to various influencing factors. Table VI shows the probability outputs of the case studies, obtained using the fuzzy assessment model developed using Fuzzy logic toolbox of the MATLAB program software.

B. Productivity Analysis Model for Residential, Commercial, Infrastructure & Industrial Project

In this study, productivity analysis model was developed for each type of project, to determine the probability of effect on productivity at construction site. Fig. 4 depicts the input and output parameters used for the development of productivity analysis model.

Fig. 5 shows the phases involved in construction of productivity analysis model for residential projects. The same is thereby followed for the development of productivity analysis model for commercial, infrastructure and industrial projects, owing to difference in rule weightage amongst different projects.

Finally, with this approach the probability of impact on productivity at the construction site for different type of projects were obtained. Table VII shows the probability outputs obtained using the productivity analysis model so developed, for different types of construction projects, using Fuzzy logic toolbox of the MATLAB program software.

VI. DISCUSSION AND PRACTICAL IMPLICATIONS

The results of the case studies, provides a macro view of the factor groups influencing productivity at different construction sites.

Project A

Project A is a small scale residential project with a budgeted cost of 16.5 lakhs, executed by a construction firm established 4 years ago. The firm specializes in construction of residential and commercial projects. The importance given to productivity by this firm is considerably high, which is achieved through recruiting experienced and skilled labourers. The probability of effect on productivity for this project was calculated to be 37.9%. The most contributing factor groups in this project were identified to be associated with supervision group (50.6%) and leadership group (46%). This result is justified as the optimum utilization of human resources and technical resources can be secured only through proper leadership and supervision of the management. Inefficient management often results in deteriorated performance of the employees, thereby resulting in lower productivity at the site.

Project B

Project B is a large scale residential project with a budgeted cost of 33 crores, executed by a construction firm established 61 years ago. The firm specializes in residential, commercial, industrial and infrastructure projects. The importance given to productivity by this firm is substantially very high and is achieved through recruitment of skilled labourers and proper planning and scheduling of work to be executed by them. The probability of effect on productivity for this project was calculated as 27.8%. External group (39.2%) and motivational group (33%) were found to be the most important factor groups influencing the productivity at this site. This result is acceptable as optimum weather conditions and motivated operatives who are usually more enthusiastic and initiative are necessary for timely completion of project.

Project C

Project C is a large scale residential project with a budgeted cost of 2.85 crores, executed by a construction firm established 6 years ago. The firm specializes in residential, commercial and industrial projects. The importance given to productivity by this firm is significantly high and is achieved by strictly adhering to time schedule. The probability of effect on productivity for this project was calculated as 31%. The major factor groups affecting construction productivity at this site were associated with human resource issues, i.e. motivational group (43.8%) and manpower group (38.5%). This result might be justified as lack of primary motivators related to pay and incentives, lack of recognition of good and efficient workers, and disregard of craftsmen suggestions can create negative motivational forces in the craftsmen, which get reflected in the productive capacity of workforce. Likewise, the experience and age of the labourers also have a detrimental role in determining the productive capacity of labourers at job site as inexperienced workmen can slow down the work; whilst with aging the labour speed, agility and strength decline over time, contributing to reduced productivity at site.

Project D

Project D is a commercial project with a budgeted cost of 27 crores, executed by a construction firm established 61 years ago. The firm specializes in residential, commercial, industrial and infrastructure projects. The importance given to productivity by this firm is considerably high owing to better labour and material management. The probability of effect on productivity for this project was calculated as 39.9%.The most contributing factor groups were identified to be associated with time group (58.3%) and manpower group (43.9%). This result is acceptable since most of the commercial projects are fast track projects, it demands working overtime and increasing number of labourers in site so as to accelerate the pace of work, to complete the work within the stipulated time frame, thereby declining productivity at site. Manpower group also serves to have a profound influence on productivity at site as poorly trained, unskilled and aged operatives are commonly characterized with low and faulty outputs coupled with unjustifiably high inputs, hence declining the productivity (Makulsawatudom et al., 2004).

Project E

Project E is a commercial project with a budgeted cost of 48 lakhs, executed by a construction firm established 15 years ago. The firm specializes in residential, commercial, industrial and infrastructure projects. The importance given to productivity by this firm is average. The probability of effect on productivity for this project was calculated as 44.9%. Motivation group (61.4%) and time group (56%) were found to be the most contributing factor groups affecting productivity at this site. This result might be justified as construction practitioners have always recognized factors relating to pay and incentives as significantly affecting the productivity of labourers at site. However, satisfying and fulfilling the motivational needs of craftsmen in a timely manner is essential to keep things going and maintain high productivity level. Whilst, among time related group, working overtime was determined to have an intense effect on labourers productivity. This effect is because overtime work causes physical fatigue to the labourers and decreases their stamina, agility and motor skills; thus leading not only to low productivity, but also for a high probability of poor workmanship, rework and worst accidents on site.

Project F

Project F is an infrastructure project with a budgeted cost of 1450 crores, executed by a construction firm established 79 years ago. The firm specializes in residential, commercial, industrial and infrastructure projects. The importance given to productivity by this firm is average. The probability of effect on productivity for this project was calculated as 61.9%. The most contributing factor groups were identified to be associated with external group (79.4%) and quality group (67.7%). This result is justified as the changes made in the government regulations during the last years and the adverse winter weather conditions such as rain and wind have an immense effect on productivity of infrastructure projects, as it involves external works. Decrease in productivity can also be attributed to the quality issues as high quality of work cannot be achieved with the usage of poor equipment and materials, as it causes breakdown and leads to prolonged completion time, thereby reducing the productivity at the project site.

Project G

Project G is an industrial project with a budgeted cost of 2500 crores, executed by a construction firm established 6 years ago. The firm specializes in industrial and infrastructure projects. The importance given to productivity by this firm is average and it is attributed to the employment of both skilled and unskilled labourers on site. The probability of effect on productivity for this project was calculated as 41.2%. The major factors affecting construction productivity at this site were associated with time group (59.4%) and motivation group (56.3%). Time affects productivity in various ways. Overtime working may increase productivity in initial stages but later it decreases due to fatigue. Misuse of time schedule may interrupt the continuous flow of work, resulting in maximization of confusion and misunderstanding, thereby demanding high volume of rework. Lack of total completion time for execution of work, proliferates the need of increasing number of labourers in the site so as to accelerate work, thus resulting in congested work environment leading to decreased productivity on site. On the other hand, provision of financial and non-financial benefits also plays an instrumental role in determining the productivity of labourers, as it gives site workers satisfaction such as achievement, sense of responsibility and pleasure of the work itself.

This research has high lightened factors impacting productivity in the Indian context. Based on the results obtained from the case studies, manpower group, motivational group and time group were profound to have a great influence on the construction projects in India. Very few companies in India has its own system for training labours. Therefore, Indian construction industry suffers from “lack of trained, experienced and skilled labour.” The investment made on people is very valuable in developing countries like India with an enormous population. The outcome of this research reveals the importance of developing construction labours skills and experience, which can thereby prove to enhance the construction industry and the overall economy. In this regard, the governmental policy must encourage and pay more attention to the apprentice programs and the formal secondary education. Also, the craftsmen should provide strong support and assistance regarding the continual training of their craftsmen. The field of construction in India also regards “payment delay and lack of incentive programs” as a major hurdle towards improving construction labour productivity. Delays in payment from owner to contractor has a bad effect on the labour mood. Progress payments should be hence made on time. Owners are encouraged to facilitate payments to contractors in order to avoid delays, disputes and claims. Also there should be effective funding of the project by project owners to avoid unnecessary payment delay. In India, majority of workers come from rural areas to cities and work for low wages on a daily basis without any kind of insurance. A monetary incentive scheme thus promotes the objective of those operatives and creates a high level of satisfaction and motivation amongst the workers, thereby as an outcome higher efficiency is achieved on the project site. Hence, in the light of these findings it is recommended that incentive programs should be a part of Indian contractor’s policies. Time factors such as, “working overtime and lack of total completion time” also serves as a contributing factor for decline in productivity as in India labours work more than 8hours/day. This makes the construction labours physically and mentally weak/ exhaust, thereby declining their productive effort. In India, where most of the projects are fast track projects, lack of total completion time for execution serves to be a great problem. This demands overstaffing of trades at the project site to complete the work at the earliest, thereby declining the productivity in return. Productivity can best be accomplished when these factors are addressed properly by the management. On the contrary, the safety conditions are rarely perceived to affect productivity, as India is not among those countries where safety rules are flouted. A safe environment has often been recognized as an important motivator of construction workforce as an unsafe working conditions can slow down the work progress as labourers have to be more cautious while working. A close scrutiny of the results from the case studies, reveals the incompetency of the management in managing construction projects and stress the importance of proper project management in construction industries of India. Opportunity for productivity improvement exists and lies in the hands of management.

VII. Conclusion

Productivity problems can be avoided or minimized when their causes are clearly identified. This research investigated on determining the factors influencing productivity and took an integrated approach to link the relative importance index method into the fuzzy logic techniques, to propose a productivity analysis model to quantify the probability of effect on productivity in construction projects in India. The results of application of productivity analysis model in the construction firms infers that the most contributing factor groups for most of the projects, that have a major impact on productivity were discerned to be manpower group, motivation group and time group. Contractors should focus on these factors to improve productivity at site, which ultimately leads to higher projects from construction projects.

The study concludes that the power of fuzzy logic techniques can be very useful in the productivity problem environment, as its ability to represent the problem in natural language may provide the tool to investigate how human experts estimate the probability of effect on productivity in construction projects in the real world.

Since, the model is developed based on the perceptions of the individuals participated in the survey, so as to get a more accurate picture of the perceptions of the whole construction industry, the number of respondents can be increased. Also more number of factors affecting productivity to be discovered based on extensive site investigation at different project site.

Future studies could be performed for different specific types of construction projects, such as road and railway construction projects, utility projects, highways, viaducts and dam construction projects, etc. Future studies can also be carried by utilizing different model parameters such as: different number and group of factors influencing productivity, linguistic variables and membership functions, fuzzy rules, aggregation and defuzzification methods. This thesis hence opens up a realm of possibilities where future researchers can produce more powerful, user friendly software's that can analyse all the possible productivity factors thereby producing a fast and reliable results.

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TABLE I
RII & RANKING OF SUB FACTORS OF PRODUCTIVITY FOR RESIDENTIAL, COMMERCIAL, INFRASTRUCTURE AND INDUSTRIAL PROJECTS

Category	**Factors Influencing Productivity**	**Construction Projects**							
		Residential		**Commercial**		**Infrastructure**		**Industrial**	
		RII	**Rank**	**RII**	**Rank**	**RII**	**Rank**	**RII**	**Rank**
Manpower Group	Lack of labour experience	0.732	2	0.613	16	0.693	6	0.591	21
	Conflicts among labour	0.57	38	0.507	38	0.571	36	0.436	39
	Increase in labourers age	0.589	33	0.507	38	0.621	24	0.509	36
	Lack of labour attitude & morale (e.g. labour disloyalty, team spirit)	0.645	22	0.587	25	0.643	19	0.591	21
	Labour absenteeism (e.g. sickness, drug abuse, fatigue, strikes)	0.589	33	0.62	14	0.636	22	0.573	26
Motivational Group	Payment delay	0.717	7	0.607	20	0.679	9	0.7	1
	Lack of financial motivation system (e.g. bonus, pay hikes)	0.664	17	0.54	36	0.65	16	0.555	31
	Lack of labour recognition programs (e.g. rewards)	0.645	22	0.593	24	0.636	22	0.545	34
	Lack of non-financial benefits (e.g. transport, meals, uniform)	0.604	29	0.587	25	0.614	30	0.491	38
	Lack of training sessions	0.577	36	0.573	32	0.607	31	0.5	37
Time Group	Working overtime	0.691	10	0.667	3	0.621	24	0.573	26
	Lack of adherence to time schedule	0.634	24	0.66	5	0.65	16	0.618	14
	Lack of total completion time for the execution of work	0.694	9	0.613	16	0.671	10	0.573	26
	Increasing number of labors in the site, so as to accelerate work	0.691	10	0.647	8	0.714	3	0.7	1
Material/ Tools Group	Material shortage at site	0.725	3	0.647	8	0.721	2	0.6	18
	Shortage of tools & equipment necessary to do the job on site	0.721	4	0.653	6	0.714	3	0.682	3
	Unsuitability of material storage location (e.g. insufficient storage area)	0.687	13	0.647	8	0.657	11	0.655	9
Leadership Group	Misunderstanding between labour & superintendents	0.592	32	0.58	29	0.6	32	0.609	16
	Lack of periodic meeting with labour	0.585	35	0.573	32	0.564	37	0.555	31
	Lack of labour surveillance	0.608	28	0.607	20	0.586	34	0.573	26
	Poor recruitment & changing of foreman or crew	0.543	39	0.587	25	0.579	35	0.6	18

Supervision Group	Frequent revisions and alterations in design, drawings and specifications	0.721	4	0.7	1	0.75	1	0.682	3
	Inspection delay	0.672	15	0.607	20	0.707	5	0.555	31
	Supervisor absenteeism	0.649	21	0.58	29	0.643	19	0.582	24
	Rework due to field error commited by craftsmen	0.657	19	0.667	3	0.657	11	0.655	9
Project Group	Working within a confined space	0.698	8	0.52	37	0.557	38	0.582	24
	Interference from other trades or other crew members	0.66	18	0.547	35	0.493	39	0.527	35
	Inappropriate construction method / Obsolete technology	0.691	10	0.62	14	0.657	11	0.655	9
	Complex activities involved in the project	0.675	14	0.587	25	0.621	24	0.627	13
	Lack of availability of electricity, power & water at project site	0.762	1	0.7	1	0.693	6	0.673	6
Safety Group	Accidents involving a worker at site	0.596	31	0.633	11	0.621	24	0.564	30
	Violations of safety precautions by workers	0.615	26	0.613	16	0.621	24	0.6	18
	Non appointment of safety officer at the construction site	0.604	29	0.567	34	0.593	33	0.591	21
	Unsafe working conditions (e.g. poor lighting & housekeeping, noise)	0.615	26	0.58	29	0.657	11	0.664	7
Quality Group	Inefficiency of equipment used at site	0.668	16	0.627	12	0.657	11	0.618	14
	Low quality of raw materials used for construction operations	0.653	20	0.613	16	0.65	16	0.682	3
	High quality of required work	0.721	4	0.627	12	0.693	6	0.664	7
External Group	Harsh weather conditions	0.626	25	0.653	6	0.643	19	0.645	12
	Regulatory changes by government	0.577	36	0.607	20	0.621	24	0.609	16

TABLE II
RII & RANKING OF MAIN FACTORS OF PRODUCTIVITY FOR RESIDENTIAL, COMMERCIAL, INFRASTRUCTURE AND INDUSTRIAL PROJECTS

Category of Factors	Construction Projects							
	Residential		Commercial		Infrastructure		Industrial	
	RII	Rank	RII	Rank	RII	Rank	RII	Rank
Manpower Group	0.625	7	0.567	10	0.633	6	0.540	10
Motivational Group	0.642	6	0.580	9	0.637	5	0.558	9
Time Group	0.677	4	0.647	2	0.664	4	0.616	5
Material Group	0.711	1	0.649	1	0.698	1	0.645	2
Leadership Group	0.582	10	0.587	8	0.582	10	0.584	8
Supervision Group	0.675	5	0.638	3	0.689	2	0.618	4
Project Group	0.697	2	0.595	7	0.604	9	0.613	6
Safety Group	0.608	8	0.598	6	0.623	8	0.605	7
Quality Group	0.681	3	0.622	5	0.667	3	0.655	1
External Group	0.602	9	0.630	4	0.632	7	0.627	3

TABLE III
LIST OF ACRONYMS

Sl. No.	Input / Output Factors	Acronyms
1	Lack of labour experience	LLE
2	Conflicts among labour	CAL
3	Increase in labourers age	ILA
4	Lack of labour attitude & morale	LLA&M
5	Labour absenteeism	LA
6	Payment delay	PD
7	Lack of financial motivation system	LFMS
8	Lack of labour recognition programs	LLRP
9	Lack of non-financial benefits	LNFB
10	Lack of training sessions	LTS
11	Working overtime	WO
12	Lack of adherence to time schedule	LATS
13	Lack of total completion time for the execution of work	LTCTEW
14	Increasing number of labours in the site	INLS
15	Material shortage at site	MSS
16	Shortage of tools & equipment necessary to do the job on site	ST&E
17	Unsuitability of material storage location	UMSL
18	Misunderstanding between labour & superintendents	ML&S
19	Lack of periodic meeting with labour	LPML
20	Lack of labour surveillance	LLS
21	Poor recruitment & changing of foreman or crew	PR&CF
22	Frequent alterations in design, drawings and specifications	FADDS
23	Inspection delay	ID
24	Supervisor absenteeism	SA
25	Rework due to field error committed by craftsmen	RFECC
26	Working within a confined space	WCS
27	Interference from other trades or other crew members	IOTCM
28	Inappropriate construction method / Obsolete technology	ICM&OT
29	Complex activities involved in the project	CAIP
30	Lack of availability of electricity, power & water at project site	LAEPWP
31	Accidents involving a worker at site	AIWS
32	Violations of safety precautions by workers	VSPW
33	Non appointment of safety officer at the construction site	NSOCS
34	Unsafe working conditions	UWC
35	Inefficiency of equipment used at site	IEUS
36	Low quality of raw materials used for construction operations	LQRM
37	High quality of required work	HQRW
38	Harsh weather conditions	HWC
39	Regulatory changes by government	RCG
40	Effect on productivity by manpower group	EOPBMnG
41	Effect on productivity by motivation group	EOPBMoG

42	Effect on productivity by time group	EOPBTG
43	Effect on productivity by material group	EOPBMaG
44	Effect on productivity by leadership group	EOPBLG
45	Effect on productivity by supervision group	EOPBSuG
46	Effect on productivity by project group	EOPBPG
47	Effect on productivity by safety group	EOPBSaG
48	Effect on productivity by quality group	EOPBQG
49	Effect on productivity by external group	EOPBEG
50	Probability of effect on productivity	POEOP

TABLE IV
SAMPLE OF FUZZY RULE WITH ASSIGNED WEIGHTAGE

Residential Projects									
Rule	**Probability Of Productivity Rule**			**Consequence**			**Rule Weight**		
1	If	LLE	is	VL	Then	EOPBMnG	is	VL	0.732
27	If	PD	is	L	Then	EOPBMoG	is	L	0.717
53	If	WO	is	A	Then	EOPBTG	is	A	0.691
74	If	MSS	is	H	Then	EOPBMaG	is	H	0.725
90	If	ML&S	is	VH	Then	EOPBLG	is	VH	0.592
106	If	FADDS	is	VL	Then	EOPBSuG	is	VL	0.721
127	If	WCS	is	L	Then	EOPBPG	is	L	0.698
153	If	AIWS	is	A	Then	EOPBSaG	is	A	0.596
174	If	IEUS	is	H	Then	EOPBQG	is	H	0.668
190	If	HWC	is	VH	Then	EOPBEG	is	VH	0.626
196	If	EOPBMnG	is	VL	Then	POEOP	is	VL	0.625
Commercial Projects									
Rule	**Probability Of Productivity Rule**			**Consequence**			**Rule Weight**		
1	If	LLE	is	VL	Then	EOPBMnG	is	VL	0.613
27	If	PD	is	L	Then	EOPBMoG	is	L	0.607
53	If	WO	is	A	Then	EOPBTG	is	A	0.667
74	If	MSS	is	H	Then	EOPBMaG	is	H	0.647
90	If	ML&S	is	VH	Then	EOPBLG	is	VH	0.58
106	If	FADDS	is	VL	Then	EOPBSuG	is	VL	0.7
127	If	WCS	is	L	Then	EOPBPG	is	L	0.52
153	If	AIWS	is	A	Then	EOPBSaG	is	A	0.633
174	If	IEUS	is	H	Then	EOPBQG	is	H	0.627
190	If	HWC	is	VH	Then	EOPBEG	is	VH	0.653
196	If	EOPBMnG	is	VL	Then	POEOP	is	VL	0.567
Infrastructure Projects									
Rule	**Probability Of Productivity Rule**			**Consequence**			**Rule Weight**		
1	If	LLE	is	VL	Then	EOPBMnG	is	VL	0.693
27	If	PD	is	L	Then	EOPBMoG	is	L	0.679
53	If	WO	is	A	Then	EOPBTG	is	A	0.621
74	If	MSS	is	H	Then	EOPBMaG	is	H	0.721
90	If	ML&S	is	VH	Then	EOPBLG	is	VH	0.6
106	If	FADDS	is	VL	Then	EOPBSuG	is	VL	0.75
127	If	WCS	is	L	Then	EOPBPG	is	L	0.557
153	If	AIWS	is	A	Then	EOPBSaG	is	A	0.621
174	If	IEUS	is	H	Then	EOPBQG	is	H	0.657
190	If	HWC	is	VH	Then	EOPBEG	is	VH	0.643
196	If	EOPBMnG	is	VL	Then	POEOP	is	VL	0.633
Industrial Projects									
Rule	**Probability Of Productivity Rule**			**Consequence**			**Rule Weight**		
1	If	LLE	is	VL	Then	EOPBMnG	is	VL	0.591
27	If	PD	is	L	Then	EOPBMoG	is	L	0.7
53	If	WO	is	A	Then	EOPBTG	is	A	0.573
74	If	MSS	is	H	Then	EOPBMaG	is	H	0.6
90	If	ML&S	is	VH	Then	EOPBLG	is	VH	0.609
106	If	FADDS	is	VL	Then	EOPBSuG	is	VL	0.682
127	If	WCS	is	L	Then	EOPBPG	is	L	0.582
153	If	AIWS	is	A	Then	EOPBSaG	is	A	0.564
174	If	IEUS	is	H	Then	EOPBQG	is	H	0.618
190	If	HWC	is	VH	Then	EOPBEG	is	VH	0.645
196	If	EOPBMnG	is	VL	Then	POEOP	is	VL	0.54

TABLE V
PROBABILITY EVALUATION FORM FILLED BY INTERVIEWEES INVOLVED IN RESIDENTIAL (SMALL SCALE & LARGE SCALE), COMMERCIAL, INFRASTRUCTURE AND INDUSTRIAL PROJECTS

Category	**Factors Influencing Productivity**	**Evaluation of Factors (1-100)**						
		Project A	**Project B**	**Project C**	**Project D**	**Project E**	**Project F**	**Project G**
Manpower Group	Lack of labour experience	45	25	60	80	55	65	35
	Conflicts among labour	10	30	10	40	60	25	30
	Increase in labourers age	25	20	45	20	40	35	40
	Lack of labour attitude & morale (e.g. labour disloyalty, team spirit)	20	35	30	10	75	30	40
	Labour absenteeism (e.g. sickness, drug abuse, fatigue, strikes)	60	25	25	10	60	50	25
Motivational Group	Payment delay	05	40	70	40	75	85	45
	Lack of financial motivation system (e.g. bonus, pay hikes)	20	35	20	70	50	60	50
	Lack of labour recognition programs (e.g. rewards)	35	20	50	50	55	50	75
	Lack of non-financial benefits (e.g. transport, meals, uniform)	15	30	25	10	50	45	60
	Lack of training sessions	50	20	10	10	55	70	50
Time Group	Working overtime	35	15	10	100	65	55	80
	Lack of adherence to time schedule	40	30	20	20	45	40	40
	Lack of total completion time for the execution of work	30	40	20	70	55	70	65
	Increasing number of labours in the site, so as to accelerate work	30	25	20	40	60	85	70
Material/ Tools Group	Material shortage at site	15	35	30	10	35	70	50
	Shortage of tools & equipment necessary to do the job on site	30	20	20	10	25	60	35
	Unsuitability of material storage location (e.g. insufficient storage area)	35	20	25	20	25	45	25
Leadership Group	Misunderstanding between labour & superintendents	40	15	10	40	20	20	20
	Lack of periodic meeting with labour	70	20	15	30	25	45	25
	Lack of labour surveillance	45	20	10	10	20	65	30
	Poor recruitment & changing of foreman or crew	15	25	10	00	25	60	35

Supervision Group	Frequent alterations in design, drawings and specifications	75	10	15	10	27	70	50
	Inspection delay	25	15	05	20	20	45	25
	Supervisor absenteeism	35	20	05	20	25	50	25
	Rework due to field error committed by craftsmen	75	20	10	40	20	65	35
Project Group	Working within a confined space	40	30	15	40	25	20	40
	Interference from other trades or other crew members	05	30	15	10	30	20	30
	Inappropriate construction method / Obsolete technology	15	25	00	30	28	20	15
	Complex activities involved in the project	25	15	00	20	20	40	75
	Lack of availability of electricity, power & water at project site	30	05	03	10	25	90	20
Safety Group	Accidents involving a worker at site	10	05	00	20	40	80	25
	Violations of safety precautions by workers	05	15	02	00	30	60	15
	Non appointment of safety officer at the construction site	50	20	00	20	25	60	10
	Unsafe working conditions (e.g. poor lighting & housekeeping, noise)	35	15	05	20	25	65	05
Quality Group	Inefficiency of equipment used at site	45	05	05	20	25	80	15
	Low quality of raw materials used for construction operations	20	05	05	40	28	60	10
	High quality of required work	15	05	25	20	80	70	50
External Group	Harsh weather condition	20	45	05	50	65	85	50
	Regulatory changes by government	20	30	00	00	25	80	30

TABLE VI
PROBABILITY OUTPUTS OBTAINED FROM THE FUZZY ASSESSMENT MODEL FOR CASE STUDIES

Category	**Probability Output (1-100%)**						
	Project A	**Project B**	**Project C**	**Project D**	**Project E**	**Project F**	**Project G**
Effect on productivity by Manpower group	38.6	29.9	38.5	43.1	55.5	47.2	35.5
Effect on productivity by Motivational group	30.5	33	43.8	42.7	61.4	57.1	56.3
Effect on productivity by Time group	36.9	30.1	19.1	58.3	55.6	61.7	59.4
Effect on productivity by Material/Tools group	26.9	29.3	25	19.1	32.2	57.1	38.2
Effect on productivity by Leadership group	46	22.3	16.3	28.1	24.6	46.5	29.5
Effect on productivity by Supervision group	50.6	18.6	16.6	27.3	24.9	56.5	39
Effect on productivity by Project group	28.6	21	15.8	26.7	25.3	56.6	43.6
Effect on productivity by Safety group	31.8	19.3	11.9	19.3	35.1	67.3	20.1
Effect on productivity by Quality group	31.9	11.5	21	33.1	49.8	67.7	31.7
Effect on productivity by External group	23.2	39.2	11.9	32.6	47.9	79.4	40.2

TABLE VII
PROBABILITY OUTPUTS OBTAINED FROM THE PRODUCTIVITY ANALYSIS MODEL FOR CASE STUDIES

Project	A	B	C	D	E	F	G
Probability of Overall Effect on Productivity	37.9%	27.8%	31%	39.9%	44.9%	61.9%	41.2%

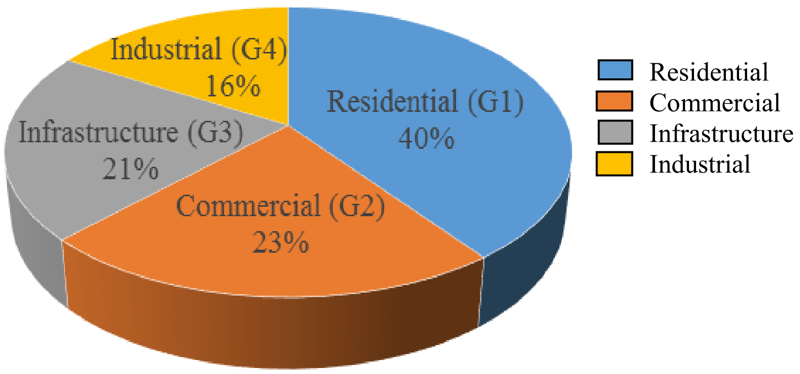

FIGURE I
Demographic information of the respondents

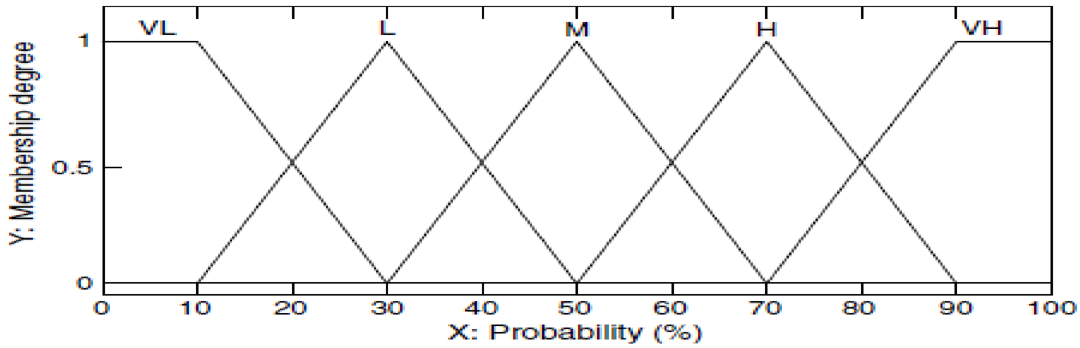

FIGURE II
Membership functions (for all inputs and outputs)

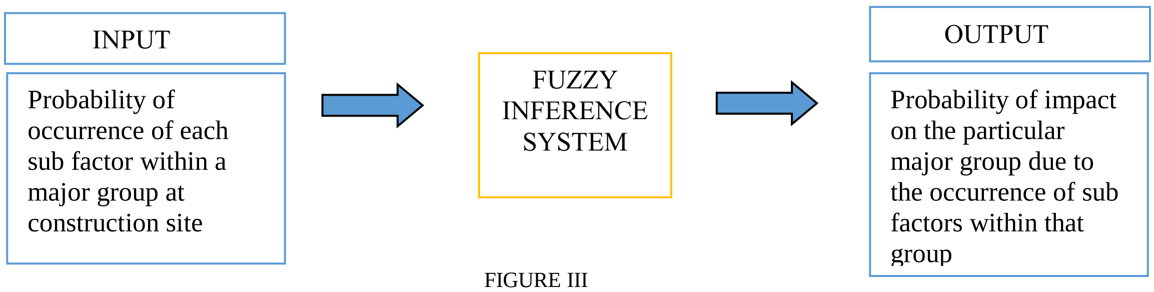

FIGURE III
Input and output parameters of fuzzy assessment model

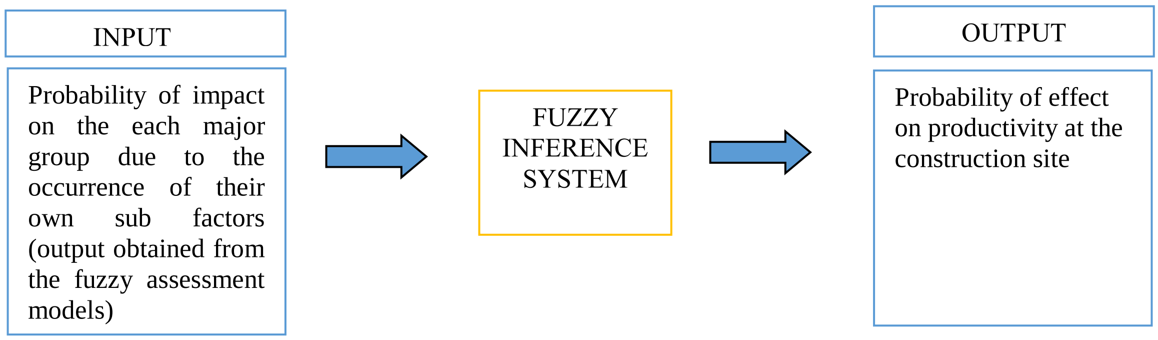

FIGURE IV
Input and output parameters of productivity analysis model

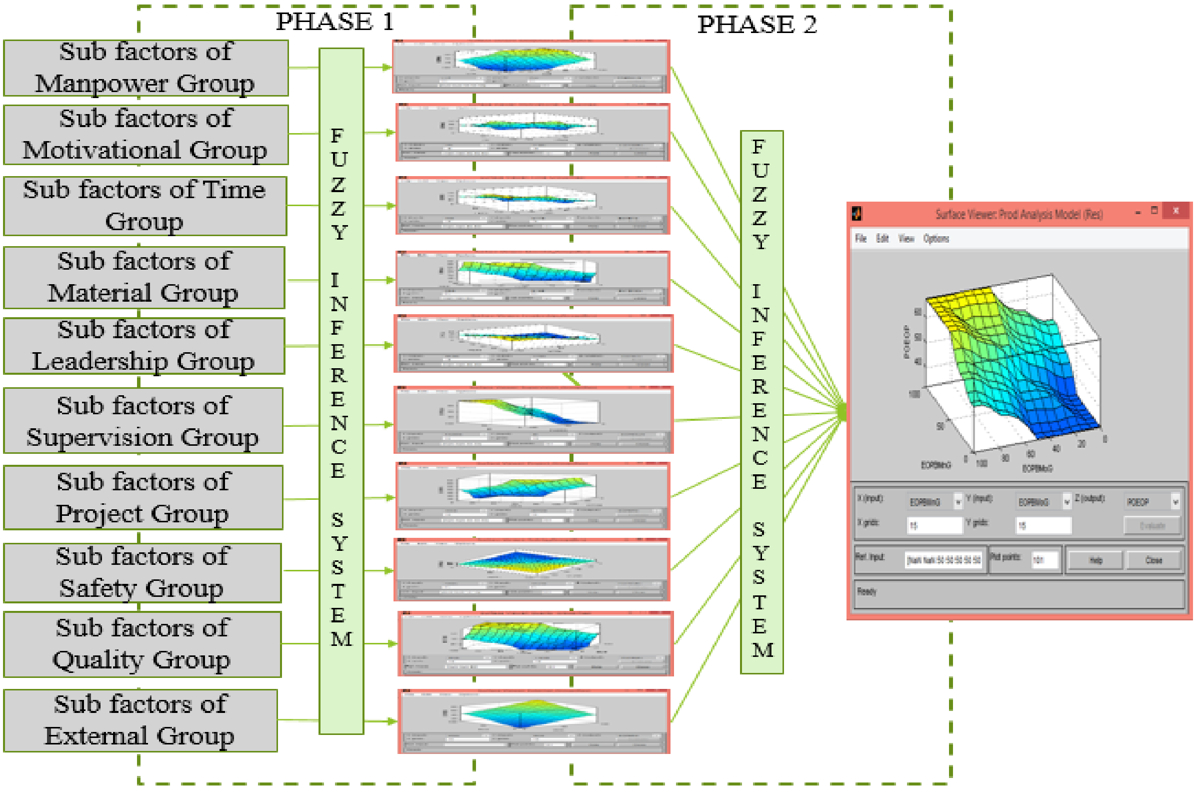

FIGURE V
Phases involved in fuzzy inference system