An AHP Based Model for the Selection of Horizontal Formwork Systems in Indian Residential Construction

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***Abstract*—In Indian construction industry, decision regarding formwork selection is primarily based on the intuitive and subjective judgments of formwork experts. With an objective to rationalize the process of horizontal formwork selection, the research identifies from literature eighteen attributes affecting selection of horizontal formwork. These attributes were then statistically analyzed to yield six formwork selection factors, namely: building design and architectural features; job specifications and conditions; local conditions; quantity of formwork; available capital and site characteristics, and organizational support. Further, analysis of the extracted factors using Analytical Hierarchy Process (AHP) revealed that the most dominant factor that governs the choice of formwork system for any construction project is 'available capital and site characteristics'. However, to ensure an optimal selection, all the factors should be considered judicially. Furthermore, the research develops a quantitative Decision Support Model (DSM) for horizontal formwork systems. Performance analysis of the model through case studies revealed that the developed model offers more than 80% accuracy.**

***Index Terms*—horizontal formwork system, decision support model, analytical hierarchy process**

I. Introduction

A. Role of Formwork Selection in Effective Construction Project Management

According to Ministry of Housing and Urban Poverty Alleviation, in 2012, there was a shortage of 18.78 million housing units in urban India. Nearly 95% of this shortfall was in Economically Weaker Sections (EWS) and Low Income Group (LIG) housing etc. No wonder a large number of high-rise construction projects are being undertaken in residential sector in India. Selection of an appropriate formwork system is an extremely crucial factor for the successful completion of any residential construction project.

Manuscript received May 25, 2015; revised January 11, 2016.

Time and cost are the two major constraints of these project. For high-rise residential building projects the most effective way to speed up the construction process is to reduce the floor to floor cycle time. By adopting sophisticated systems of formwork, it is possible to reduce the typical floor cycle time by more than 70% in comparison to the cycle time obtained from conventional timber formwork system. But the cost incurred in the adoption of such sophisticated formwork systems might not be always justified especially for small scale low-budget (affordable) projects. As per Shin (2011), formwork represents about 40% to 60% of the cost of concrete skeleton and about 10% of the total construction cost. [1].

Selection of a proper formwork system is also crucial from the quality, safety and productivity aspects. The choice of formwork, requirement of specialized skills and degree of difficulty involved affect quality of concreting-process as well as quality of the finished concrete. From the safety perspective, construction failure due to formwork collapse is considered to be one of the major causes of death and injury to workers and loss in property and other input resources. In formwork operations workers are necessarily subjected and exposed to risk-oriented job conditions. According to Hanna (1992) "*Structural collapses and failures involving concrete structures account for 25 percent of all construction failure. More than 50 percent of concrete structure failure during construction is attributed to formwork failure*" [2].

B. Current Scenario

Many researchers, across the globe, have worked in this field over the last three decades. Many quantitative models have also been developed using various decision making tools like fuzzy logic [3], boosted decision tree [4], artificial and probabilistic neural network methods [5] [6], adaboost algorithm [1], [7] etc. However, still in India decision making regarding formwork selection is primarily executed by subjective judgment of formwork experts. It is quite obvious that such intuitive decisions

doi: 10.18178/ijscer.5.2.80-86

might not be always correct and attuned to objective work-conditions.

The situation becomes even more complicated in the residential construction sector as it includes a plethora of additional factors like involvement of a widely varying range of contractors; dynamism in the project types; huge gap between the demand and supply etc. Driven by the motive to rationalize the process of formwork selection in India, this research aims at developing a quantitative evaluation frame work which can also be used for selection of the most appropriate system for any particular residential building project. For residential buildings, one of the key performance indices is the floor cycle time which in turn depends upon the choice of horizontal (slab) formwork system. Hence in the scope of this research primarily horizontal (slab) formwork systems are being considered.

C. *Research Objective*

- The overall objective of this study is to rationalize and quantify the process of formwork selection in India so that more consistent decisions can be taken in formwork selection.
- In a multi-criteria decision making problems like formwork selection, all the decision-making factors have to be considered carefully and in tandem. However, there is no standardized set of formwork selection factors being followed by the practitioners. Different researchers used different sets of factors for their research works. Thus one of the objectives of this research is to determine the different factors of formwork selection and to develop a knowledge-base with the help of statistical analysis so that their influence on the process of decision making could be understood.
- One of the key objectives of the research is also to identify an appropriate decision making tool which could be used to evolve a dynamic model.
- To develop a dynamic and quantitative evaluation framework which will be affordable and workable for implementation in Indian residential projects.
- To evaluate the performance and efficiency of the model from comparative case studies.

II. Research Methodology

A. *Identification of the Attributes Affecting Selection of Horizontal Formwork Systems*

In the preliminary stage, an extensive literature review was conducted in order to identify the potential factors that can affect the choice of formwork system for residential building projects. In order to ensure the comprehensiveness of the identified attributes, the list was then addressed to a panel of 20 industry and academic professionals for their review and feedback.

B. *Factor Analysis*

From literature study and expert consultation total eighteen tertiary level attributes were identified to have impact on the process of horizontal formwork selection. In any multi-criteria decision-making problem complexities increase reciprocally with the increase in the number of the attributes. So it was a necessity to reduce the number of attributes in order to be able to keep the model simple and with a minimal number of inputs. One way of doing that was by simply choosing some arbitrary factors from the mix depending upon intuitive judgments of the researchers about their relative level of importance. But that would not have been rational when the objective of the project itself was to eliminate the inconsistency in formwork selection due to intuitive decisions. It was decided that instead of choosing some factors randomly, proper statistical analysis of the attributes would be carried out. This was one way to ensure that even after reducing number of factors significantly the maximum possible portion of the total variance explained by the original attributes is taken into account. A survey was conducted to estimate the level of importance of the identified attributes on a five point Likert scale. The results obtained from the survey were statistically analyzed using SPSS. The principal component analysis (PCA) was used and six formwork selection factors were extracted from the eighteen identified formwork selection attributes depending upon Kaiser’s criteria. The nomenclatures for extracted factors were done in consultation with Technical Advisory Group (TAG).

C. *Model Development*

A quantitative model based on the six secondary level formwork selection factors was developed using the Analytical Hierarchy Process (AHP) in MATLAB. In order to determine the relative importance of these six new extracted formwork selection factors, a questionnaire survey was conducted. Respondents were asked to compare the factors in a pair wise manner and to rate their relative importance in a scale of 1 to 9 (as suggested by Saaty) [8]. In the model practitioners were asked to input values comparing each pair of alternatives on each criterion, on a scale of 1 to 9. The model uses the input values of practitioners and the relative weights of formwork selection factors to compute priority values (described as scores in this project) and rankings of the alternatives. The one with highest priority value is considered as the most suitable formwork system for that particular project. The model facilitates the practitioner to compare any number of formwork alternatives of his/ her own choice. The comparison values depend upon the constraints of the project for which the practitioner is going to select the system.

D. *Validation of the Model through Case Study*

The developed model was validated by implementing the model in real life test projects. Interviews were undertaken with the experts to illustrate/ demonstrate the functioning of the model. After using the model, users were asked to fill in feed-back questionnaire. The questionnaire were meant to explore and evaluate the performance of the model on six predefined criteria, namely, ease of use, relevance of inputs, access to outputs, accuracy of results, usefulness and overall performance. A five point Likert scale was used to evaluate the performance characteristics with 1 for poor performance to 5 for satisfactory performance.

III. Literature Review

Over the last three decades many researchers had worked in the field of formwork selection. Though most typically all the researchers have worked with their own unique set of attributes, perhaps the most comprehensive and well-structured set of attributes was proposed by Awad S. Hanna. Hanna identified twelve tertiary level attributes which directly affect the choice of formwork system in any project [2]. These tertiary level attributes were further categorized by Hanna under four secondary level attributes, namely: building design; job specification; load condition and supporting organization. However during the course of this research few additional attributes were identified which had not been considered in the attribute-tree proposed by Hanna. The complete list of formwork selection attributes is give in Table I.

TABLE I. List of Formwork Selection Attributes Identified from Literature Review

S. No.	Attribute	Type
1	Building form & location [9]	Nominal
2	Building height [1] [4] [7]	Numeric
3	Typical floor area [1] [4] [7]	Numeric
4	Number of floors [7] [1] [4]	Numeric
5	Building Shape [1] [7] [4] [2]	Nominal
6	Slab type [2]	Nominal
7	Lateral load supporting system [2]	Nominal
8	Specification and quality of concrete [2]	Nominal
9	Concrete finish [2]	Nominal
10	Degree of repetition [9] [1] [4]	Nominal
11	Speed of construction [9] [2]	Nominal
12	Area of practice [2]	Nominal
13	Weather conditions [2]	Nominal
14	Site characteristics [2]	Nominal
15	Available capital [2]	Numeric
16	Hoisting equipment [2]	Nominal
17	Head office support [2]	Nominal
18	Supporting yard facility [2]	Nominal

IV. Factor Analysis

A. Data Collection

A questionnaire survey was conducted to collect the data required for factor analysis. In the questionnaire the respondents were asked to indicate the level of importance of each identified attribute on a five point Likert Scale. In order to eliminate the probabilities of inaccurate responses the survey was confined to practicing industry experts with an average 10 years of experience and a pilot survey was also conducted before conducting the main survey. The feedback and suggestions obtained from the pilot survey were incorporated in the main survey questionnaire.

B. Data Analysis

Factor analysis is a broad term used for a set of statistical techniques which enables the users to understand the unobserved structure underlying the observed variables and their inter-relationships [10].The responses obtained from survey were analyzed using the SPSS (Statistical Package for the Social Sciences).

1) Analysis of data obtained from pilot survey

The responses obtained from the pilot survey were analyzed for Reliability Statistics. The Cronbach's Alpha test was conducted in the SPSS. The Cronbach's Alpha value obtained was 0.716 which is more than the minimum acceptable value of 0.7.

2) Analysis of data obtained from main survey

As described earlier, through literature review and pilot survey, a total of eighteen attributes having had impact on horizontal formwork selection were identified. Multivariate analysis technique has been performed to identify the inter-relationship among these eighteen formwork selection attributes and to examine the possibility of summarizing these attributes into a smaller number of factors. However, before conducting the factor analysis, the suitability of the survey data for factor analysis is tested.

a) The Kasier-Mayer Olkin's (KMO) Measure of Sampling Adequacy (MSA)

The KMO's measure of sampling adequacy (MSA) is an index used to compare the magnitudes of the observed correlation coefficients to the magnitudes of the partial correlation coefficients. The value of KMO ranges from 0 to 1. If the variables share common factor(s), then the partial correlations should be small and the KMO should be close to 1. The minimum acceptable KMO value is 0.5. The KMO value obtained for this project is 0.528 which falls in the acceptable range or ambit.

b) Bartlett's test of sphericity

Bartlett's Test of Sphericity tests the null hypothesis. Lesser the level of significance in Bartlett's Test, better will be the suitability for factor analysis. In this study the significance obtained was of the order 10^{-3}, which is much lower than the threshold value of 0.05. In addition the high value of chi-square obtained also implies that the correlation among the variables is significant (high) and hence factor analysis will be appropriate.

c) Communality test

Communality is the amount of variance involving variable shares with all the other variables in consideration. It also indicates the proportion of variance explained by the common factors. The value of communality ranges from 0 to 1 with a threshold of 0.3 which qualifies the factor model to be reliable. In this study, the communalities obtained for all the variables is much higher than the threshold value of 0.3. The minimum communality value obtained after extraction was 0.453, which signifies that the factor model is reliable.

d) Factor extraction

In factor analysis a reduced number of components or factors are extracted from the original set of attributes/ variables using the principal component analysis which says that every observed value can be written as a linear combination of attributes. In other words in PCA it is assumed that each principal component or each extracted variable/ factor can be written as a linear combination of the original variables/ attributes. However the contribution of any particular attribute in the extracted factor is interpreted from the value of the multiplying factor (factor loading) to that particular attribute. Greater is the absolute value of the factor loading, higher will be the contribution of the attribute in the extracted factor.

The number of extracted factors to be considered is determined by Kaiser's Criteria or Scree Test. For this research work based on Scree Test and Kaiser's Criteria a total of six factors were extracted from the eighteen originally identified formwork selection attributes. Summary of the results obtained from factor analysis is given in Table II.

e) Nomenclature of extracted factors

The nomenclature of the extracted factors is done based on the attributes which emerge from it. Finalization of the nomenclature has been done in consultation with the technical advisory group.

TABLE II. SUMMARY OF FACTOR ANALYSIS RESULTS

Details of Factors and Attributes	Variance explained	Cumulative Variance
Factor 1_ Building design and architectural features	14.27%	14.27%
Concrete finish		
Lateral load supporting system		
Specification and quality of concrete		
Slab type		
Factor 2_ Job specifications/ conditions	13.91%	28.18%
Weather conditions		
Speed of construction		
Degree of repetition		
Building shape		
Building height		
Factor 3_ Local conditions	11.79%	40%
Supporting yard facility		
Area of practice		
Building form and location		
Factor 4_ Quantity of form-work	10.43%	50.4%
Number of floors		
Typical floor area		
Factor 5_ Available capital and site characteristics	8.50%	58.89%
Available capital		
Site characteristics		
Factor 6_ Organizational support	7.74%	66.63%
Hoisting equipment		
Head office support		

V. Development of the Model

A. Selection of the Decision Making Tool

The Analytical Hierarchy Process (AHP) was used to develop a decision support model for formwork selection. The AHP is a "decision theory" developed by Saaty in late 1970's. It is used in multi-criteria decision making problems and has proved to be popular in recent years because of its mathematical properties and simple implementation. The AHP uses a logically structured multilevel hierarchy of objectives, criteria and alternatives, known as analytical hierarchy tree to decompose the overall goal. It provides an effective way for properly quantifying the pertinent data which are obtained by using a set of pair-wise comparisons. These comparisons are used to obtain the weights or importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. Thus after finalizing the factors governing formwork selection the next step of decision making was to determine the relative weights to be given to each of these factors. An AHP questionnaire survey was performed for this purpose and the data obtained from the survey responses were analyzed to ascertain the relative weights of formwork selection factors. Another benefit of using AHP is that it also provides a mechanism for improving consistency, if the comparisons are not perfectly consistent.

B. Prioritization of Attributes

1) Data collection

The data required for prioritizing the formwork selection factors were collected through questionnaire survey. The need for a second survey was felt because there is a lack of documented data from which one can ascertain the relative weights for the formwork selection factors during decision making.

2) Development of survey questionnaire

A preliminary questionnaire was developed to meet afore-said objectives. The preliminary questionnaire contained two parts: Part A was meant to gather information about the respondent's field experience while Part B consisted of the questions meant to explore the relative weights of each formwork selection factor. In Part B the respondents were asked to indicate the level of relative importance of the formwork selection factors through pair-wise comparison of the factors. The questions were drafted to seek answer on two aspects. The respondents were asked to indicate which one is more important factor in each pair of formwork selection factors and then they were to indicate the relative importance of the more important factors of the pair on a nine point scale [11].

a) Pilot survey

The main objective of a pilot survey was to refine the preliminary questionnaire so that the main questionnaire could be developed. Pilot survey was conducted through telephonic conversation with experts and by sending questionnaire through mail.

b) Development of main survey questionnaire

The main questionnaire was developed based on the inputs and knowledge gained from the pilot survey conducted on the preliminary questionnaire. In the main questionnaire there were three parts.

In Part A the respondents were asked the questions meant to explore respondents' field experience.

Part B consisted of a description about the purpose of the survey and the procedure for filing the questions in Part C. A hypothetical example was also included in Part B to illustrate the procedure for filing the questions in Part C. Part B was structured on the feedbacks obtained from pilot survey.

Part C of the main AHP questionnaire was same as the Part B of preliminary questionnaire. In Part C the respondents were asked to indicate the level of relative importance of the formwork selection factors through pair-wise comparison of the factors on a nine point scale.

c) Collection of data

The sample size considered for the main survey was 96 (Population: Unknown; Confidence Level: 95%; Confidence Interval 10%)

In order to ensure the accuracy of data collected, the survey was kept confined among practitioners with minimum 3years of experience in formwork planning.

A total of 197 questionnaires were sent, out of which 104 responses came back which was about 53% of the total questionnaires sent. On an average the respondents have seven to eight years of professional experience.

3) Data analysis

The data obtained from each respondent were fed into Micro Soft Excel spread sheet. Each respondent was assigned to a unique number e.g. R1, R2… for each respondent an inventory of 6 x 6 pair-wise comparison matrix was thus created based on their survey responses.

From literature review two methods were identified for determining the final pairwise comparison matrix from the inventory of survey responses.

The first method incorporates the geometric mean of the survey responses. That means the relative weight will be calculated as $(x1.x2...xk)^{1/k}$ where x1, x2 … are the survey responses for that particular pairwise comparison and k is the total number of survey responses. Though AHP offers a measure for checking the consistency of the overall survey result obtained using geometric mean still it does not prove the validity of responses even if the consistency ratio comes out to be lower than the threshold value of 0.1. *Consistent responses do not mean that they are valid in practice, because a crazy person can be perfectly consistent about a non-existent reality* [12].

The more appropriate way of calculating the relative weights of the factors is to use the priority weights to raise the judgments to that power and then multiplying them [12]. Priority weights for the judgments of an individual respondent may be assessed by calculating the respondent's consistency ratio and subtracting it from 1.

In this research project the second method was adopted for computing the relative importance of the factors in comparison matrix. The final relative weightages for the six formwork selection factors, as determined after normalizing the pair wise comparison matrix is given in Table III. The final pairwise comparison matrix and the normalization matrix are shown in Table III and Table IV respectively.

TABLE III. FINAL PAIR-WISE COMPARISON MATRIX

	F1	F2	F3	F4	F5	F6
F1	1.0	2.6	2.8	0.8	0.2	2.9
F2	0.4	1.0	1.5	0.7	0.2	3.1
F3	0.4	0.7	1.0	0.3	0.2	3.5
F4	1.3	1.4	3.0	1.0	0.3	5.6
F5	5.6	4.0	4.8	3.0	1.0	5.8
F6	0.3	0.3	0.3	0.2	0.2	1.0

TABLE IV. NORMALIZED RELATIVE WEIGHTAGE MATRIX

	F1	F2	F3	F4	F5	F6
F1	0.111	0.255	0.207	0.125	0.083	0.133
F2	0.043	0.1	0.11	0.117	0.116	0.142
F3	0.04	0.068	0.075	0.055	0.098	0.158
F4	0.146	0.141	0.226	0.166	0.153	0.256
F5	0.623	0.404	0.36	0.507	0.47	0.265
F6	0.038	0.032	0.022	0.03	0.08	0.046

In the AHP the comparison matrix is obtained by the pair-wise comparison of two factors, for which the consistency of the overall model is not guaranteed. The AHP admits and measures inconsistencies of the decision-maker that may reflect the quality of the decision-maker's knowledge, the content of judgments, and the stability of the solution [12]. In fact, one of the most practical issues in the AHP is that it allows for slightly non-consistent pairwise comparisons [13]. Consistency Ratio (CR) is used in the AHP as a measure of the consistency of comparison matrix obtained from the responses. Lesser is the value of consistency ratio, better will be the consistency of the survey.

According to Saaty a consistency ratio of less than 0.1 (10%) may be considered good enough to qualify the AHP model.

Consistency Ratio (CR), for a comparison matrix is determined as below:

$$CR= CI/RCI \qquad (1)$$

where, CI is the consistency index and RCI is the random consistency index.

The value of RCI mainly depends upon the total number of factors (n).

For this study RCI value is taken as 1.24 as total number of factors, n=6 [11].

Consistency index CI is calculated using the following formula:

$$CI= (\lambda_{max}-n)/(n-1) \qquad (2)$$

where n is the total number of factors and λ_{max} is the maximum eigen value.

Maximum eigen value (λ_{max}) is calculated by adding the columns in the comparison matrix and multiply the resulting vector by the vector of priorities (i.e., the approximated eigenvector) obtained from the row averages of normalized matrix.

For this research work the value of consistency ratio obtained is 0.071 which is less than the threshold value of 0.1. So the comparison matrix could be considered consistent.

TABLE V. RELATIVE WEIGHTS OF FORMWORK SELECTION FACTORS

Factor No.	Factor Name	Relative Weight
Factor_1	Building design and architectural features	15%
Factor_2	Job specifications/ conditions	11%
Factor_3	Local conditions	8%
Factor_4	Quantity of formwork	18%
Factor_5	Available capital and site	44%
Factor_6	Organizational support	4%

C. Development of Model

After determination of the relative weights of the formwork selection factors the next step was to evaluate the formwork alternatives in terms of the decision criteria. For this the alternatives are compared with one another in terms of each one of the decision criteria.

The individual priority vectors are then calculated for each one of the six judgment matrices. The priority vectors constitute the columns of the final decision matrix.

The AHP decision matrix for the developed model is furnished in Table VI. The performance of a particular formwork system (Formwork Performance Index) can be calculated for any formwork system from the decision Matrix given in Table VI. (Ref-Equation (3))

TABLE VI. AHP DECISION MATRIX FOR FORMWORK SELECTION

	Criteria					
	F1	F2	F3	F4	F5	F6
Alt.	0.15	0.11	0.08	0.18	0.44	0.04
A1	a11	a12	a13	a14	a15	a16
A2	a21	a22	a23	a24	a25	a26
A3	a31	a32	a33	a34	a35	a36
…	…	…	…	…	…	…
…	…	…	…	…	…	…
…	…	…	…	…	…	…
Am	am1	am2	am3	am4	am5	am6

$$\mathrm{FPI_i} = \sum_{j=1}^{6} \mathrm{a_{ij} W_j} \quad \text{(for i= 1to m)} \qquad (3)$$

where FPI_i = Formwork Performance Index of ith formwork system

aij = Priority vector (Score of i^{th} formwork system w.r.t j^{th} factor/ criteria.

Wj= Relative weight of j^{th} factor/ criterion.

D. Model Coding

The coding for this model has been done using MATLAB. The model has a simplistic input and output feature. In the model the practitioners are asked to rate the relative preferences of formwork alternatives on each criteria. This is done by the pair wise comparison of formwork systems on each formwork selection factor in Saaty's nine point scale. In order to make the model flexible, the number of formwork alternatives is left to the practitioner. The practitioner can compare any number of formwork systems of his/her own choice using this model. So the practitioner also has to enter the number of formwork systems he/she wants to compare, as an input value. The decision matrix, FPI values of the formwork alternatives and the most appropriate formwork system for the concerned project will be displayed as output data of the project

VI. VALIDATION OF THE MODEL

A. A Comparative Case-Study Approach

This was done by implementing the model in 11 random test construction projects and tallying the results obtained from the model with the decisions taken by the experts. The test projects are real-life construction projects chosen arbitrarily. Small and medium projects were also taken into account as one of the objectives of this research work was to develop a formwork selection model which will be suitable for different construction practitioners. Before implementation, interviews were undertaken with the formwork experts of the sites to illustrate the model's description, function and main features. Furthermore, the use of the model was also demonstrated to the experts with the help of a sample case. It was found that in 9 out of 11 cases the results obtained from the model matched with the expert's decision. Apparently the results showed that the proposed model has a satisfactory accuracy.

B. Performance Analysis

Information about the performance and ease of use of the developed model was gathered from the implementation results. This was accomplished by distributing questionnaires to the experts who had used the model. The questionnaire was divided into two parts. In Part A, the respondents were asked to furnish information about their personal experience. In Part B, respondents were asked to evaluate the performance of the model on six criteria, namely:

- Ease of use,
- Relevance of inputs,
- Accuracy of results,
- Access to outputs,
- Usefulness and viability
- Overall performance.

The questionnaire was structured in such a manner that it can gather unbiased and objective information from the user. A five point Likert scale was used as a scale of evaluation, in which a rating of 1 was used for poor performance; 2 for fair performance; 3 for good performance; 4 very good performance and 5 for excellent performance. The average ratings obtained by the model on the aforesaid performance criteria are summarized in the Table VII. After a careful study of the survey results, it can be concluded from the table below that the overall performance of the model is “very good” on the set performance criteria.

TABLE VII. PERFORMANCE ANALYSIS RESULTS

Sl No.	Performance Criteria	Average Rating (Out of 5)
1	Ease of use,	4.2
2	Relevancy of inputs,	4.3
3	Accuracy of results,	3.9
4	Access to outputs,	4.1
5	Usefulness	3.8
6	Overall performance.	3.9

VII. CONCLUSION

The developed model was quite fast, efficient and flexible. But the model has been developed in MATLAB. To use this model the practitioner must have the MATLAB Software installed in his/ her system. Though using the software is itself easy and user- friendly but MATLAB is not a commonly used software in industry. Practitioner might not have a default access to MATLAB in their working system or they might not be familiar with MATLAB as much as they do for Microsoft Office based software etc. This may be considered as the limitation of the developed model.

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