# Chapter 4
# COMPARISON OF SIMULATION SOFTWARE

The survey for the study was conducted on 20 automobile manufacturers in North India. From among the 20 automobile manufacturers, completed questionnaires were received from 18 companies (list attached as ***Annexure-II***) and no reason was offered for non-compliance by the two firms namely Mahindra & Mahindra Ltd. and Ultra Motor India Pvt. Ltd., for not participating in the study. As shown in Table 4.1, a total of 40 usable questionnaires were obtained constituting an overall response rate of 90.00 percent. Thus the data has been analyzed for 18 automobile manufacturers using 40 questionnaires and the results have been computed accordingly.

**Table 4.1: Response Rate of Automobile Manufacturers**

| RESPONSE RATE | Frequency | Percentage |
|---|---|---|
| | | n = 20 automobile manufacturers |
| Total Response | 18 | 90.00 |
| Breakup of Response | | |
| Mail questionnaire | 06 | 33.33 |
| Personal visits | 12 | 66.67 |

**Table 4.2: Primary Product of Automobile Manufacturers**

| PRIMARY PRODUCT | Frequency |
|---|---|
| Heavy Commercial Vehicle | 01 |
| Medium Commercial Vehicle | 02 |
| Light Commercial Vehicle | 02 |
| Multi Utility Vehicle | 04 |
| Passenger Cars | 04 |
| Three Wheelers | 06 |
| Two Wheeler | 06 |
| Tractors | 07 |

*Note: Frequency total may vary for primary product of the company because one manufacturer may be manufacturing products in more than one category.*

There are 11 simulation software used by automobile manufacturers in North India. These are NX-IDEAS, ProcessModel, HyperMesh, Nastran, ProModel, AutoMod, Star-CD, Moldex 3D, Tecnomatix, CATIA V4, ExtendSim. These simulation software are compared against the developed framework.

## 4.1 KRUSKAL-WALLIS TEST

As one of the objectives of the study was to compare the average response of respondents across the eleven simulation software, for this purpose we resort to Kruskal–Wallis test, which is a non-parametric test. The Kruskal–Wallis test is most commonly used when there is one nominal variable and one measurement variable, and the measurement variable does not meet the normality assumption of an Analysis of Variance (ANOVA) (McDonald, 2009). It is the non-parametric analogue of a one-way ANOVA. A one-way ANOVA may yield inaccurate estimates of the p-value when the data are very far from normally distributed. The Kruskal–Wallis test does not make assumptions about normality. Like most non-parametric tests, it is performed on ranked data, so the measurement observations are converted to their ranks in the overall data set: the ranking is given in ascending order and the tied observations get average ranks (Kothari, 2007).

The sum of the ranks is calculated for each group (Table 4.3), then the test statistic, H, is calculated.

The test statistic H for this test is given by:

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{K} \frac{R_i^2}{n_i} - 3(n+1)$$

Where $n = n_1 + n_2 + \ldots\ldots + n_k$ and $R_i$ being the sum of the ranks assigned to $n_i$ observations in the ith sample.

We have used Kruskal-Wallis test to test the null hypothesis $H_0$ according to which all simulation software are drawn from the same population i.e. level of response of respondents across the simulation software are same.

**Table 4.3: Mean Rank for Various Simulation Software**

| Software | Mean Rank |
|---|---|
| NX-IDEAS | 80.58 |
| ProcessModel | 77.27 |
| HyperMesh | 70.54 |
| Nastran | 58.92 |
| ProModel | 75.69 |
| AutoMod | 67.42 |
| Star-CD | 78.85 |
| Moldex 3D | 82.08 |
| Tecnomatix | 70.04 |
| | 70.62 |
| ExtendSim | 60.00 |

| Test Statistics[a,b] | |
|---|---|
| | Mean |
| Chi-Square | 4.601 |
| Df | 10 |
| Asymp. Sig. | .916 |
| a. Kruskal Wallis Test | |
| b. Grouping Variable: Software | |

Since the significance value i.e. 0.916 is greater than p-value 0.05, so the null hypothesis i.e. there is no significant difference of means among software, is accepted. So, statistically there is no significant difference in the simulation software.

The significant difference is not visible in statistical application because of the small sample size. Therefore, in order to understand the subtle differences between software we shall resort to the methodology suggested by Hlupic (1997).

## 4.2 HLUPIC METHODOLOGY FOR COMPARATIVE EVALUATION

Hlupic (1997) methodology was based on comparative evaluation where evaluation of different packages was done on the basis of various case studies and to the overall impression and experience of the respondent gained through learning and using these software. Subsequently, a rating of the evaluated packages has been established for the purpose of their comparison, as a relative measure of their quality from the perspective of groups of criteria. Therefore, in Hlupic methodology rating does not represent an absolute value. In our study, in order to get relative importance of the package, we resort to questionnaire where respondent's responses were the sole criteria of relative importance. Therefore in our study responses of the respondents are evident and are not converted into ranking for comparison purpose. So, our comparison represents a relative value of respondent's responses.

**Table 4.4: Comparison of Evaluated Simulation Software in terms of groups of criteria**

| SIMULATION SOFTWARE<br>GROUPS OF CRITERIA | NX-IDEAS | ProcessModel | HyperMesh | Nastran | ProModel | AutoMod | Star-CD | Moldex 3D | Tecnomatix | CATIA V4 | ExtendSim |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C.A. | 2.35 | **3.00** | 2.15 | 2.1 | 2.62 | 2.06 | 2.83 | 2.46 | 2.46 | 2.5 | 1.83 |
| S.C. | 1.25 | **2.83** | 2.17 | 1.19 | 1.81 | 0.97 | 1.83 | 0.8 | 1.00 | 1.61 | 2.00 |
| U.S. | 3.2 | **3.69** | 3.37 | 2.27 | 2.67 | 2.79 | 2.69 | 3.5 | 2.85 | 2.69 | 2.46 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **F & T Features** | 2.5 | 1.64 | 2.26 | 2.2 | 2.53 | 2.67 | 2.68 | 2.27 | 2.5 | **2.71** | 2.3 |
| **G.F.** | 2.4 | 2.11 | 2.1 | 2.15 | 2.05 | 2.52 | **2.67** | 2.5 | 2.22 | 2.2 | 1.81 |
| **M.A.** | 3.09 | 3 | 2.81 | 1.97 | **3.6** | 2.28 | 2.93 | 3.39 | 2.33 | 2.33 | 1.78 |
| **V.A.** | **1.93** | 1.48 | 1.34 | 1.46 | 1.83 | 1.74 | 1.41 | 1.9 | 1.59 | 1.53 | 1.24 |
| **Efficiency** | 2.22 | 1.88 | 2.37 | 2.18 | 2.08 | 1.82 | 2.14 | **2.47** | 2.18 | 1.86 | 1.76 |
| **Testability** | 1.67 | 1.43 | 1.37 | 1.27 | 1.3 | 1.61 | 1.49 | **1.67** | 1.4 | 1.37 | 1.35 |
| **E.F.** | 1.22 | 0.92 | 0.94 | 1.21 | 0.84 | 0.85 | 1.1 | **1.31** | 1.27 | 1.05 | 1.08 |
| **S.F.** | 1.5 | 1.45 | 1.13 | 0.85 | 1.51 | 1.25 | 1.37 | **1.7** | 1.45 | 1.33 | 1.45 |
| **Input/Output** | 1.95 | 1.84 | 1.59 | 1.81 | 1.67 | 1.68 | 1.8 | **2.07** | 1.68 | 1.8 | 1.68 |
| **A.C.** | **1.00** | **1.00** | 0.67 | 0.67 | **1.00** | **1.00** | 0.67 | **1.00** | 0.67 | 0.33 | **1.00** |

This section deals with a comparative evaluation of eleven simulation software. A rating of the evaluated software has been established for the purpose of their comparison, as a relative measure of their quality from the perspective of groups of criteria. As such, this rating does not represent an absolute value. Table 4.4 shows a rating for the evaluated software, in terms of the general quality of features within particular groups of criteria. The highest rates achieved for a particular group of criteria are emphasized in bold letters. The general quality of software with respect to particular groups of criteria is rated on the scale of 1 to 5, where 1 represents very poor quality or absence of the features within particular groups of criteria, whilst grade 5 represents excellent quality. Appropriately, it is proposed that 2.5 should take to be a 'nominal acceptance level' or NAL in short. The grades for a certain group of criteria that are above the NAL indicate that software is performing adequately, whereas those below signify the opposite. Although the NAL is clearly subjective, it does provide a level against which the relative performance of software can be measured and reflected on. As the evaluation cannot be entirely objective, this qualitative measure of performance, the NAL, provides a relative measure. Nevertheless, clearly any particular grade is merely a 'qualitative' number, and the rules of arithmetic can only be applied with caution, if at all.

Table 4.4 shows that with respect to C.A., ProcessModel is rated as the best. ProModel, Star-CD and CATIA V4 have rated above NAL achieving second highest rates for C.A. because of the features like built-in logic builder, user defined functions, creations of macros and arrays and the facility of writing comments in model building activity. Moldex 3D, Tecnomatix and NX-IDEAS have rated slightly less than NAL because of the lower quality of features like efficiency of compilation, interface to user written programs and built in functions. Next in the sequence are HyperMesh, Nastran, AutoMod and ExtendSim which have rated far below than NAL for coding aspects because of the lower quality of almost all features specially interface to user written programs and built-in logic builder.

The quality of features with regard to S.C. is not very high and is above the NAL only for ProcessModel because of its compatibility with all types of packages i.e. spreadsheet, statistical and scheduling packages etc. Whilst majority of the software under consideration enable integration with spreadsheet packages, HyperMesh, ExtendSim, Star-CD, ProModel and CATIA V4 are slightly better ranked because they can be linked with multiple statistical packages and database management systems and also provide broad-level scheduling. NX-IDEAS is only compatible with spreadsheet and database management system. Nastran is neither compatible with database package nor with scheduling software.

With regard to U.S., ProcessModel is rated highest followed by Moldex 3D and HyperMesh. The suppliers of these software provide a high level of support in the form of good quality of manuals, run-time help, troubleshooting facility and user-community web page. NX-IDEAS, Tecnomatix, AutoMod, ProModel, Star-CD and CATIA V4 have also given the grades above than NAL, but slightly lower. They lack in features like frequency of training courses, software maintenance and quality of documentation. Nastran and ExtendSim are ranked below NAL.

CATIA V4 is ranked as the best regarding F&Tfeatures followed by Star-CD and AutoMod. This is because of their high frequency of update and upgrade, lower price, moderate installation cost, add-on facility and free technical support. ProModel, Tecnomatix and NX-IDEAS are also rated above NAL but slightly lower because of the features like types of contracts available, heavy price of training course and poor add-on facility. ExtendSim, Moldex-3D, HyperMesh, Nastran and ProcessModel have rated below NAL.

Star-CD is rated highest with regard to G.F. followed by AutoMod and Moldex 3D because of their user friendliness, less experience required for software use, ease of learning and efficient branch decision making capability. NX-IDEAS, Tecnomatix and CATIA V4 are rated slightly lower than NAL. NX-IDEAS have good conceptual model generator, easy to use templates but lacks in representativeness of models and ease of learning. Tecnomatix have good representativeness of model capability and user friendliness and run-time interface capability but lacks in capability to build near real-time simulation models and customizable window environment. CATIA V4 has easy to learn capability and good conceptual model generator but lacks in representativeness of models and distributed simulation capability. Nastran, ProcessModel, HyperMesh, ProModel and ExtendSim have rated far below NAL.

M.A. is rated highest for ProModel and also rated high for Moldex 3D, NX-IDEAS and ProcessModel mainly because of intelligent prompting, 3D models library and bubble help. Then comes Star-CD and HyperMesh which are ranked slightly lower but above NAL. Star-CD has good warning messages capability but lacks in 3D models library and context sensitive prompting. HyperMesh has good context sensitive prompting but lacks in insert comments facility and facility for designing reusable user defined elements. Tecnomatix, CATIA V4, AutoMod, Nastran and ExtendSim have rated below NAL.

With regard to V.A., none of the software have rated above NAL. NX-IDEAS have rated highest followed by Moldex-3D because of quality 3D animator, scenario viewer, virtual screen facility and dashboard facility. Then come ProModel and AutoMod that have rated slightly lower. ProModel have good logical animation and network animation facility but lacks in virtual screen facility and dynamic viewport scaling. AutoMod have good network animation and antialias display facility but lacks in playback mode and virtual screen facility. Tecnomatix, CATIA V4, ProcessModel, Nastran, Star-CD, HyperMesh and ExtendSim have rated very low and far below NAL.

None of the packages have rated above NAL as far as efficiency is concerned although Moldex-3D has rated very close to NAL followed by HyperMesh and NX-IDEAS. They have good features like adaptability to model changes, reliability, number of queuing policies and model execution time. Then comes Natran, Tecnomatix and Star-CD that have slightly lower ranked. Nastran is good in features like robustness but lacks in model reusability. Tecnomatix is good in features like reliability and model execution time but lacks in multitasking and interactive handling of parameters during experimentation. ProModel, ProcessModel, CATIA V4, AutoMod and ExtendSim have rated very low.

None of the packages have rated above NAL as far as testability is concerned. NX-IDEAS and Moldex 3D have rated highest followed by AutoMod because of runtime error viewer facility, audible alarms, good syntax checker and OLE compatibility. Next are Star-CD, ProcessModel and Tecnomatix because of interactive debugger and quality of debugging. HyperMesh, CATIA V4, ExtendSim, ProModel and Nastran have rated still lower.

Moldex 3D and Tecnomatix are best ranked regarding E.F. providing features such as automatic batch run, stepwise simulation run, scheduled execution of scripts and sensitivity analysis. NX-IDEAS, Nastran and Star-CD are slightly lower ranked because of lower quality of features like stepwise simulation run, accuracy check and sensitivity analysis. Then comes ExtendSim, CATIA V4, HyperMesh, ProcessModel, AutoMod and ProModel which have ranked very low.

It is judged that Moldex 3D has the best S.F. in comparison with the other evaluated simulators. It has large number of theoretical statistical distributions and random number streams and also provide time dependent distributions and goodness-of-fit tests. ProModel and NX-IDEAS have ranked slightly lower. They provide goodness-of-fit tests and have ability to specify random number seed. Then comes ProcessModel, Tecnomatix and ExtendSim which have ranked still lower which do not provide random number generation by probability distribution, distribution fitting and goodness-of-fit tests. Star-CD, CATIA V4, AutoMod, HyperMesh and Nastran have very lower ranked as far as statistical facilities are concerned.

Concerning the input/output capabilities, Moldex 3D has achieved the highest performance because of its dialogue boxes, database maintenance, quality of output reports and periodic output of simulation results. Next in the sequence are NX-IDEAS, ProcessModel, Nastran, Star-CD and CATIA V4 due to snapshot reports, task timeline report, automatic rescaling of histograms and formattable result summary. Finally AutoMod, Tecnomatix, ExtendSim, ProModel and HyperMesh come last in the sequence.

As far as A.C. are concerned, NX-IDEAS, ProcessModel, ProModel, AutoMod, Moldex 3D and ExtendSim have rated highest because of their good capability to do what-if analysis and conclusion-making report. Then comes in sequence HyperMesh, Nastran, Star-CD and Tecnomatix. CATIA V4 has rated the least in the sequence.

## 4.3 FACTOR ANALYSIS

Factor Analysis has been applied to identify the features that are common and hence most important in each of 9-groups of criteria. A factor explains the correlations among a set of given variables. Factor analysis is a multivariate statistical technique in which the whole set of interdependent relationship is examined, generally used for data reduction and summarization (Malhotra, 2002, p. 586). In other words, it simplifies the diverse relationships that exist between a set of observed variables by explaining some common factors that link together the apparently unrelated variables (Dillon and Goldstein, 1984). The main purpose of this technique is to condense the information contained in a number of original variables into a smaller set of new composite dimensions with a minimum loss of information (Joseph, 1995). For conducting Factor Analysis, minimum sample size should be atleast four times of the variables taken under consideration (Sen and Pattanayak, 2005). As a total of 40 questionnaires are available, the present study qualifies the sample size requirement for applying the Factor Analysis on each group of criteria.

### 4.3.1 Adequacy of the Data for Factor Analysis:

For checking the adequacy of the data for Factory Analysis, the various recommended techniques are:

(a) Construction of Correlation Coefficient Matrix of Explanatory Variables

(b) Construction of Anti-Image Correlation Matrix

(c) Kaiser-Meyer-Oklin (KMO) Measure of Sampling Adequacy

(d) Bartlett's Test of Sphericity

**(a) Construction of Correlation Coefficient Matrix of Explanatory Variables:**

It is a lower triangle matrix showing simple correlations among all possible pairs of variables included in the analysis. For the application of factor analysis, it is obligatory that the data matrix should have good correlations. If visual inspection reveals no substantial number of correlations greater than 0.30, then Factor Analysis is probably inappropriate (Hair, 2003, p.99). The Correlation Coefficient Matrix has been computed for the data to check the inter-correlation between various variables. For the factor analysis to be appropriate, the variables must be correlated. Perusal of Table 4.6 clearly indicates that there are enough correlations indicating the suitability of data for application of Factor Analysis.

**(b) Anti-Image Correlation Matrix :**

It is the matrix of partial correlations among variables. The diagonal contains the measures of sampling adequacy for each variable and the off-diagonal elements are the partial correlations among variables. If true factors existed in the data, the partial correlations would be small (Hair, 2003, p. 99). Present study has also computed Anti-Image correlations and found that the partial correlations are very low indicating that true factor existed in the data. Table 4.7 contains the Matrix of Anti-Image correlations.

**(c) Kaiser-Meyer-Oklin (KMO) Measure of Sampling Adequacy :**

It is an index used to examine the appropriateness of factor analysis. High values (between 0.5 and 1.0) indicate adequacy of data for the use of Factor Analysis (Malhotra, 2002, p. 588). Here, the computed value of KMO statistic is 0.573 indicating the adequacy of data for Factor Analysis (Table 4.8).

**(d) Bartlett's Test of Sphericity:**

It is a test often used to examine the hypothesis that the variables are uncorrelated in the population i.e., population correlation matrix is an identity matrix (Malhotra 2002, p. 588). This test finds the overall significance of correlation matrix, and provides the statistical probability that the correlation matrix has significant correlations among at least some of the variables (Hair, 2003, p. 99). Here, Bartlett's Test's Chi-square value is 96.661 (approx), Df = 21, significant at 0.000 (Table 4.8). This significant value indicates that correlation coefficient matrix is not an identity matrix. All this ensures the adequacy of data for application of Factor Analysis.

**Table 4.6: Correlation Coefficient Matrix of Explanatory Variables**

**Correlation Matrix[a]**

| | | Q2.2.1 | Q2.2.2 | Q2.2.3 | Q2.2.4 | Q2.2.5 | Q2.2.6 | Q2.2.7 |
|---|---|---|---|---|---|---|---|---|
| Correlation | Q2.2.1 | 1.000 | .709 | .178 | .556 | .313 | .414 | -.169 |
| | Q2.2.2 | .709 | 1.000 | .130 | .603 | .131 | .243 | -.044 |
| | Q2.2.3 | .178 | .130 | 1.000 | .605 | .294 | -.127 | -.072 |
| | Q2.2.4 | .556 | .603 | .605 | 1.000 | .459 | .231 | -.141 |
| | Q2.2.5 | .313 | .131 | .294 | .459 | 1.000 | .431 | .136 |
| | Q2.2.6 | .414 | .243 | -.127 | .231 | .431 | 1.000 | -.101 |
| | Q2.2.7 | -.169 | -.044 | -.072 | -.141 | .136 | -.101 | 1.000 |
| Sig. (1-tailed) | Q2.2.1 | | .000 | .139 | .000 | .026 | .004 | .152 |
| | Q2.2.2 | .000 | | .215 | .000 | .214 | .068 | .395 |
| | Q2.2.3 | .139 | .215 | | .000 | .035 | .220 | .331 |
| | Q2.2.4 | .000 | .000 | .000 | | .002 | .079 | .196 |
| | Q2.2.5 | .026 | .214 | .035 | .002 | | .003 | .204 |
| | Q2.2.6 | .004 | .068 | .220 | .079 | .003 | | .271 |
| | Q2.2.7 | .152 | .395 | .331 | .196 | .204 | .271 | |

a. Determinant = .062

**Table 4.7: Anti-image Correlation Matrix of Explanatory Variables**

**Anti-image Matrices**

| | | Q2.2.1 | Q2.2.2 | Q2.2.3 | Q2.2.4 | Q2.2.5 | Q2.2.6 | Q2.2.7 |
|---|---|---|---|---|---|---|---|---|
| Anti-image Covariance | Q2.2.1 | .394 | -.210 | -.028 | -.006 | -.077 | -.119 | .114 |
| | Q2.2.2 | -.210 | .340 | .119 | -.165 | .134 | .016 | -.121 |
| | Q2.2.3 | -.028 | .119 | .485 | -.225 | -.038 | .180 | 3.17E-005 |
| | Q2.2.4 | -.006 | -.165 | -.225 | .278 | -.136 | -.029 | .096 |
| | Q2.2.5 | -.077 | .134 | -.038 | -.136 | .546 | -.229 | -.224 |
| | Q2.2.6 | -.119 | .016 | .180 | -.029 | -.229 | .621 | .102 |
| | Q2.2.7 | .114 | -.121 | 3.17E-005 | .096 | -.224 | .102 | .846 |
| Anti-image Correlation | Q2.2.1 | .713[a] | -.575 | -.065 | -.017 | -.167 | -.240 | .197 |
| | Q2.2.2 | -.575 | .531[a] | .292 | -.535 | .310 | .034 | -.225 |
| | Q2.2.3 | -.065 | .292 | .475[a] | -.613 | -.074 | .328 | 4.96E-005 |
| | Q2.2.4 | -.017 | -.535 | -.613 | .615[a] | -.350 | -.071 | .197 |
| | Q2.2.5 | -.167 | .310 | -.074 | -.350 | .545[a] | -.394 | -.329 |
| | Q2.2.6 | -.240 | .034 | .328 | -.071 | -.394 | .589[a] | .141 |
| | Q2.2.7 | .197 | -.225 | 4.96E-005 | .197 | -.329 | .141 | .247[a] |

a. Measures of Sampling Adequacy(MSA)

**Table 4.8: KMO and Bartlett's Test**

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .573 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 96.661 |
| | df | 21 |
| | Sig. | .000 |

From the above discussion, the following results are extracted:

(i) Correlation Coefficient Matrix contains enough high correlations.

(ii) Anti-Image Correlation Matrix contains low partial correlations.

(iii) Value of KMO statistic is large.

(iv) Value of Bartlett's Test of Sphericity is significant.

Now, after testing the adequacy of data, the set of 7 statements regarding the coding aspects of simulation software were subjected to factor analysis. **Principal Component Analysis (PCA)** was used for extraction of factors and the number of factors to be retained was on the basis of Latent Root Criterion (Eigen Value Criterion). An eigen value represents the amount of variance associated with the factor. Thus, only the factors having latent roots or eigen values greater than 1 are considered significant; all the factors with latent roots less than 1 are considered insignificant and are disregarded (Hair, 2003, p.103). Therefore, factors with eigen values more than one should be selected. Table 4.9 contains the initial eigen values for all the components. Perusal of Table 4.9 indicates that only three components have eigen values greater than unity and total variance accounted for by these three factors is 75.300 percent and remaining 24.700 percent was explained by other factors.

**Table 4.9: Total Variance Explained by Initial Eigen Values**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2.849 | 40.693 | 40.693 | 2.849 | 40.693 | 40.693 | 2.409 | 34.415 | 34.415 |
| 2 | 1.266 | 18.089 | 58.782 | 1.266 | 18.089 | 58.782 | 1.668 | 23.833 | 58.248 |
| 3 | 1.156 | 16.518 | 75.300 | 1.156 | 16.518 | 75.300 | 1.194 | 17.052 | 75.300 |
| 4 | .926 | 13.227 | 88.528 | | | | | | |
| 5 | .352 | 5.022 | 93.549 | | | | | | |
| 6 | .297 | 4.240 | 97.789 | | | | | | |
| 7 | .155 | 2.211 | 100.000 | | | | | | |

Extraction Method: Principal Component Analysis.

Further, the Component Matrix (without rotation) was constructed as exhibited in Table 4.10. Perusal of Table 4.10 indicates that there are many variables having loading on more than one factor. "Although the unrotated factor matrix indicates the relationship between the factors and individual variables, it seldom results in factors that can be interpreted, because factors are correlated with many variables" (Malhotra, 2002, p. 595). The solution to above problem lies in Varimax Rotation.

**Table 4.10: Component Matrix[a] (Without Rotation)**

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Q2.2.1 | .822 | -.265 | -.199 |
| Q2.2.2 | .745 | -.172 | -.291 |
| Q2.2.3 | .482 | .798 | .026 |
| Q2.2.4 | .870 | .324 | -.047 |
| Q2.2.5 | .590 | .029 | .656 |
| Q2.2.6 | .504 | -.648 | .274 |
| Q2.2.7 | -.162 | .069 | .723 |

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

In the next step, the principal factors were orthogonally rotated using Varimax Rotation. This method minimizes the number of variables that have high loading on a factor and thereby enhancing the interpretability of factors (Sen and Pattanayak, 2005 and Malhotra, 2002, p. 595). Rotation does not affect the communalities and the percentage total variance explained. However, the percentage of variance accounted for by each factor does change. The variance explained by the rotated factors is redistributed by rotation.

The factor loadings greater than 0.45 should be retained (ignoring signs) because loadings below it are poor (Bhaduri, 2002, Sidhu and Vasudeva, 2005). The Present study has also followed the same criterion for factor loadings. The Varimax Rotated Factor Loading Matrix has been presented in Table 4.11.

**Table 4.11: Varimax Rotated Factor Loading Matrix**

**Rotated Component Matrix[a]**

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Q2.2.1 | .862 | .194 | -.064 |
| Q2.2.2 | .763 | .239 | -.170 |
| Q2.2.3 | .004 | .930 | .067 |
| Q2.2.4 | .584 | .720 | .070 |
| Q2.2.5 | .391 | .295 | .735 |
| Q2.2.6 | .715 | -.316 | .371 |
| Q2.2.7 | -.280 | -.052 | .688 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Further perusal of Table 4.11 indicates that variable 2.2.4 had been loaded on two factors namely 1 and 2, but on the basis of higher loading it was considered in Factor 2 only because we know "the process of underlining only the single highest loading as significant for each variable is an ideal" (Hair, 2003, p.113). Ultimately, it was found that the variables 2.2.1, 2.2.2 and 2.2.6 loaded on Factor 1, the variables 2.2.3 and 2.2.4 on Factor 2, 2.2.5 and 2.2.7 on Factor 3.

### 4.3.2 Interpretation of Factors:-

A factor loading represents the correlation between variable and its factor. Their signs are just like any other correlation coefficient. Like signs mean the variables are positively related and opposite signs mean the variables are negatively related. In fact the variables carried out in this research study do not reveal any negative related factor loading.

Now, question arises that how to label these factors? Factors can be labelled symbolically as well as descriptively. Symbolic tags are precise and help avoiding confusion (Rummel, 1970). Present study has also given symbolic labels to the factors. The factors along with their codes and factor loadings are given in Table 4.12.

**Table 4.12: Interpretation of Factors (For Coding Aspects)**

| Factors | Code | Factor loading | Statement |
|---|---|---|---|
| F1(Programming support) | 2.2.1 | 0.862 | Quality of the support for programming |
| | 2.2.2 | 0.763 | Efficiency of Compilation |
| | 2.2.6 | 0.715 | Built-in functions |
| F2 (Built-in Logic Support) | 2.2.3 | 0.930 | Built-in logic builder |
| | 2.2.4 | 0.720 | Program Generator |
| F3 (Help facility) | 2.2.5 | 0.735 | Snippet code help |
| | 2.2.7 | 0.688 | Ease of entering text/code |

Similarly, the PCA have been applied on other groups of criteria and factors identified are as shown below:

**4.3.3 Factors for User Support:** As far as factors of user support are concerned KMO value turns out to be 0.622 which is significant and value for Bartlett's test of sphericity is 1692.775 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.13: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 2.4.1 | | | | 0.895 |
| 2.4.2 | | | | 0.734 |
| 2.4.3 | | 0.831 | | |
| 2.4.4 | | 0.868 | | |
| 2.4.5 | | 0.629 | | |
| 2.4.6 | 0.847 | | | |
| 2.4.7 | 0.829 | | | |
| 2.4.8 | 0.733 | | | |
| 2.4.9 | | | 0.622 | |
| 2.4.10 | | | 0.771 | |
| 2.4.11 | | | 0.840 | |
| Eigen Values | 4.010 | 2.152 | 1.225 | 1.021 |
| % of variance explained | 21.517 | 21.011 | 19.632 | 14.275 |

**Table 4.14: Interpretation of Factors (For User Support)**

| **Factors** | **Code** | **Factor loading** | **Statement** |
|---|---|---|---|
| F1(Backend support) | 2.4.6 | 0.847 | Web based support |
| | 2.4.7 | 0.829 | Troubleshooting facility |
| | 2.4.8 | 0.733 | Quality of documentation |
| F2 (Software Assurance) | 2.4.3 | 0.831 | Run-time help |
| | 2.4.4 | 0.868 | Software maintenance facility |
| | 2.4.5 | 0.629 | Training course |
| F3 (Customer connectivity) | 2.4.9 | 0.622 | Demo models |
| | 2.4.10 | 0.771 | User group meetings |
| | 2.4.11 | 0.840 | Frequency of training courses |
| F4(User friendly manuals) | 2.4.1 | 0.895 | Quality of manuals |
| | 2.4.2 | 0.734 | Tutorial |

**4.3.4 Factors for Financial & Technical Features:** As far as factors of financial and technical features are concerned KMO value turns out to be 0.537 which is significant and value for Bartlett's test of sphericity is 2419.347 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.15: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **4** |
| 2.5.1 | | 0.422 | | |
| 2.5.2 | 0.907 | | | |
| 2.5.3 | 0.889 | | | |
| 2.5.4 | 0.719 | | | |
| 2.5.5 | | | 0.897 | |
| 2.5.6 | | | 0.541 | |
| 2.5.7 | | | 0.790 | |
| 2.5.8 | | 0.930 | | |
| 2.5.9 | | 0.678 | | |
| 2.5.10 | | 0.587 | | |
| 2.5.11 | | | | 0.738 |
| 2.5.12 | 0.580 | | | |
| 2.5.13 | | | | 0.878 |
| 2.5.14 | | | | 0.492 |
| Eigen Values | 3.927 | 2.293 | 2.108 | 1.423 |
| % of variance explained | 22.527 | 39.664 | 56.203 | 69.648 |

**Table 4.16: Interpretation of Factors (For Financial & Technical Features)**

| Factors | Code | Factor loading | Statement |
|---|---|---|---|
| F1(Upgradation Facility) | 2.5.2 | 0.907 | Frequency of update |
| | 2.5.3 | 0.889 | Frequency of upgrade |
| | 2.5.4 | 0.719 | Life cycle maintenance costs |
| | 2.5.12 | 0.580 | Hierarchical modelling capability (Model/Submodel Merge feature) |
| F2 (Costs) | 2.5.1 | 0.422 | Types of contracts available |
| | 2.5.8 | 0.930 | Installation costs |
| | 2.5.9 | 0.678 | Cost of Hardware required |
| | 2.5.10 | 0.587 | Free technical support |
| F3 (Price) | 2.5.5 | 0.897 | Price of training course |
| | 2.5.6 | 0.541 | Comprehensiveness of update |
| | 2.5.7 | 0.790 | Price of Software |
| F4(Ease) | 2.5.11 | 0.738 | Availability of free evaluation S/W |
| | 2.5.13 | 0.878 | Ease of installation |
| | 2.5.14 | 0.492 | Ease of modelling |

**4.3.5 Factors for General Features:** As far as factors of general features are concerned KMO value turns out to be 0.599 which is significant and value for

Bartlett's test of sphericity is 1308.555 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.17: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| 3.1.3 | 0.549 | | |
| 3.1.4 | | 0.882 | |
| 3.1.5 | | 0.798 | |
| 3.1.6 | | 0.596 | |
| 3.1.7 | | | 0.707 |
| 3.1.8 | | | 0.871 |
| 3.1.9 | 0.616 | | |
| 3.1.10 | 0.774 | | |
| 3.1.11 | 0.907 | | |
| 3.1.12 | 0.808 | | |
| Eigen Values | 3.407 | 2.090 | 1.266 |
| % of variance explained | 29.194 | 21.788 | 16.644 |

**Table 4.18: Interpretation of Factors (For General Features)**

| **Factors** | **Code** | **Factor loading** | **Statement** |
|---|---|---|---|
| F1(Decision making Capabilities) | 3.1.3 | 0.549 | Representativeness of models |
| | 3.1.9 | 0.616 | Run-time interface capability for scenario creation |
| | 3.1.10 | 0.774 | Conceptual model generator |
| | 3.1.11 | 0.907 | Multiple branch decision making |
| | 3.1.12 | 0.808 | Probabilistic branch decision making |
| F2 (Experience) | 3.1.4 | 0.882 | User friendliness |
| | 3.1.5 | 0.798 | Experience required for software use |
| | 3.1.6 | 0.596 | Formal education in simulation required for software use |
| F3 (Ease) | 3.1.7 | 0.707 | Ease of learning |
| | 3.1.8 | 0.871 | Ease of using |

**4.3.6 Factors for Modelling Assistance:** As far as factors of modelling assistance are concerned KMO value turns out to be 0.701 which is significant and value for Bartlett's test of sphericity is 1308.466 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.19: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | |
|---|---|---|
| | 1 | 2 |
| 3.2.1 | | 0.607 |
| 3.2.2 | | 0.929 |
| 3.2.3 | | 0.837 |
| 3.2.4 | 0.725 | |
| 3.2.5 | 0.884 | |
| 3.2.6 | 0.907 | |
| 3.2.7 | 0.779 | |
| Eigen Values | 3.660 | 1.406 |
| % of variance explained | 42.575 | 29.789 |

**Table 4.20: Interpretation of Factors (For Modelling Assistance)**

| **Factors** | **Code** | **Factor loading** | **Statement** |
|---|---|---|---|
| F1(Help) | 3.2.4 | 0.725 | Facility for designing reusable user defined elements |
| | 3.2.5 | 0.884 | 3D models library |
| | 3.2.6 | 0.907 | Bubble help |
| | 3.2.7 | 0.779 | Context sensitive prompt to facilitate model development |
| F2 (Warning Alerts) | 3.2.1 | 0.607 | Libraries and templates of simulation objects |
| | 3.2.2 | 0.929 | Warning messages |
| | 3.2.3 | 0.837 | Intelligent Prompting |

**4.3.7 Factors for Visual Aspects:** As far as factors of visual aspects are concerned KMO value turns out to be 0.626 which is significant and value for Bartlett's test of sphericity is 2023.269 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.21: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| 4.1.1 | | | 0.585 |
| 4.1.2 | 0.677 | | |
| 4.1.3 | 0.769 | | |
| 4.1.4 | 0.877 | | |
| 4.1.5 | 0.748 | | |
| 4.1.6 | 0.762 | | |
| 4.1.7 | | 0.683 | |
| 4.1.8 | | 0.899 | |
| 4.1.9 | | 0.922 | |
| 4.1.10 | | | 0.681 |
| 4.1.11 | | | 0.887 |
| Eigen Values | 4.435 | 2.262 | 1.444 |
| % of variance explained | 30.952 | 25.307 | 17.756 |

**Table 4.22: Interpretation of Factors (For Visual Aspects)**

| Factors | Code | Factor loading | Statement |
|---|---|---|---|
| F1(Animation) | 4.1.2 | 0.677 | 3D-animator |
| | 4.1.3 | 0.769 | Logical animation |
| | 4.1.4 | 0.877 | Network animation |
| | 4.1.5 | 0.748 | Scenario viewer |
| | 4.1.6 | 0.762 | Antialias display |
| F2 (Customization facility) | 4.1.7 | 0.683 | Dashboard facility |
| | 4.1.8 | 0.899 | Customizable entity appearance |
| | 4.1.9 | 0.922 | Customizable path appearance |
| F3 (Real-time animation) | 4.1.1 | 0.585 | Shape libraries |
| | 4.1.10 | 0.681 | Library for real-time simulations |
| | 4.1.11 | 0.887 | Virtual reality animation |

**4.3.8 Factors for Efficiency:** As far as factors of efficiency are concerned KMO value turns out to be 0.706 which is significant and value for Bartlett's test of sphericity is 876.067 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.23: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | |
|---|---|---|
| | 1 | 2 |
| 4.2.1 | 0.572 | |
| 4.2.2 | 0.877 | |
| 4.2.3 | 0.639 | |
| 4.2.4 | | 0.456 |
| 4.2.5 | 0.716 | |
| 4.2.6 | | 0.681 |
| 4.2.7 | | 0.881 |
| 4.2.8 | | 0.808 |
| 4.2.9 | 0.717 | |
| Eigen Values | 3.509 | 1.617 |
| % of variance explained | 31.270 | 25.683 |

**Table 4.24: Interpretation of Factors (For Efficiency)**

| **Factors** | **Code** | **Factor loading** | **Statement** |
|---|---|---|---|
| F1(Adaptability) | 4.2.1 | 0.572 | Robustness |
| | 4.2.2 | 0.877 | Level of detail |
| | 4.2.3 | 0.639 | Adaptability to model changes |
| | 4.2.5 | 0.716 | Number of elements in the model |
| | 4.2.9 | 0.717 | Model Protection |
| F2 (Executional reliability) | 4.2.4 | 0.456 | Reliability |
| | 4.2.6 | 0.681 | Number of queuing policies |
| | 4.2.7 | 0.881 | Time scale for model building |
| | 4.2.8 | 0.808 | Model execution time |

**4.3.9 Factors for Testability:** As far as factors of testability are concerned KMO value turns out to be 0.507 which is significant and value for Bartlett's test of sphericity is 922.514 which is significant at 0.000, suggesting the validity of results as significant ***(Refer Annexure-V)***.

**Table 4.25: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **4** |
| 4.3.23 | | 0.942 | | |
| 4.3.24 | | 0.898 | | |
| 4.3.25 | | | 0.752 | |
| 4.3.26 | | | 0.886 | |
| 4.3.27 | | | | 0.912 |
| 4.3.28 | 0.786 | | | |
| 4.3.29 | 0.918 | | | |
| 4.3.30 | 0.814 | | | |
| Eigen Values | 2.442 | 2.018 | 1.314 | 1.008 |
| % of variance explained | 27.518 | 23.189 | 17.782 | 16.289 |

**Table 4.26: Interpretation of Factors (For Testability)**

| **Factors** | **Code** | **Factor loading** | **Statement** |
|---|---|---|---|
| F1(Debugging) | 4.3.28 | 0.786 | Interaction with model while running |
| | 4.3.29 | 0.918 | Quality of error messages |
| | 4.3.30 | 0.814 | Quality of Debugging |
| F2 (Display) | 4.3.23 | 0.942 | Display of events on the screen |
| | 4.3.24 | 0.898 | Display of the workflow path |
| F3 (Flow analysis) | 4.3.25 | 0.752 | Flow analysis |
| | 4.3.26 | 0.886 | Interactive debugger |
| F4(Line by line debugging) | 4.3.27 | 0.912 | Line by line debugging |

**4.3.10 Factors for I/O Capabilities:** As far as factors of I/O capabilities are concerned KMO value turns out to be 0.704 which is significant and value for Bartlett's test of sphericity is 1357.297 which is significant at 0.000, suggesting the validity of results as significant *(Refer Annexure-V)*.

**Table 4.27: Varimax Rotated Factor Loading Matrix**

| Statements ↓ | Component | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| 5.1.1 | 0.860 | | |
| 5.1.2 | 0.922 | | |
| 5.1.3 | 0.718 | | |
| 5.1.4 | | | 0.929 |
| 5.1.5 | | | 0.659 |
| 5.1.6 | | 0.722 | |
| 5.1.7 | | 0.686 | |
| 5.1.8 | | 0.683 | |
| 5.1.9 | 0.732 | | |
| Eigen Values | 3.740 | 1.952 | 1.068 |
| % of variance explained | 32.206 | 21.504 | 21.403 |

**Table 4.28: Interpretation of Factors (For Input/Output Capabilities)**

| Factors | Code | Factor loading | Statement |
|---|---|---|---|
| F1(Quality of output ) | 5.1.1 | 0.860 | Static graphical output |
| | 5.1.2 | 0.922 | Dynamic graphical output |
| | 5.1.3 | 0.718 | Snapshot reports |
| | 5.1.9 | 0.732 | Understandability of output reports |
| F2 (Report generation) | 5.1.6 | 0.722 | Data Charting |
| | 5.1.7 | 0.686 | Custom report generation |
| | 5.1.8 | 0.683 | Quality of output reports |
| F3 (Database maintenance) | 5.1.4 | 0.929 | Database maintenance for input/output |
| | 5.1.5 | 0.659 | Dialogue boxes |

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