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A Strategic Decision Model for the Justification of Technology Selection

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In this paper a new approach to the decision making on technology selection is proposed. In this approach a strategic decision-making model is used in which the tangible benefits of a technology are evaluated by addressing both cost and time dimensions, and the intangible benefits are evaluated using the analytical hierarchy process (AHP). In AHP, experts in the functional area give judgemental values required for the comparison matrices. However, the opinions of the experts may deviate, and also a single estimate is not realistic, hence, in this approach of evaluating alternative technology, a range of judgemental values are taken and three different levels are considered in the range. The change in the preference level of the alternatives with the change in objective factor weightage (α), and the range of α at which the transition in the choice of technology takes place, are analysed, which assists the decision maker.

Keywords: Extended Brown–Gibson model; Strategic decision making

1. Introduction

Strategic decision making, like technology selection, is very complex because the decision involves uncertain environment, lengthy time horizon, inadequate information and subjective factors, which cannot be easily quantified. Usually, in the selection of the best technology, objective factors such as cost, profit, revenue, saving in time, time of completion, etc. are considered but subjective factors such as flexibility, learning, capacity increment, etc. are overlooked. This results in advanced technology not winning the confidence of top management. In this paper, a new approach to decision making for technology selection, considering the objective and subjective factors, involved is proposed. This approach makes use of the extended Brown–Gibson model (EBG), a brief description of which is given in Section 2. An elaborate explanation of the new approach, as applied to an automobile parts manufacturing industry is given in Section 4.

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2. Extended Brown–Gibson Model (EBG)

This model is extended from the Brown–Gibson model [1] used for plant location selection. This extended Brown–Gibson model is used to assist in the strategic decision-making process considering both objective and subjective factors [2–7] influencing the decision and addresses both time and cost dimensions in its objective factor measure. In this model, both the subjective and objective factors are converted into consistent and dimensionless indices to measure the manufacturing system preference measure (MSPM), which is given in Eq. (1).

$$MSPM_i = \alpha \{(CTE_i)\ 1/\Sigma\ CTE_i\} + (1-\alpha)\ SFM_i \qquad (1)$$

$MSPM_i$ = manufacturing system preference measure for alternative i
CTE_i = cost and time effectiveness for alternative i
α = Objective factor weightage
SFM_i = subjective factor measure for alternative i
$CTE_i(1/\Sigma\ CTE_i)$ = objective factor measure for alternative i

Deriving objective and subjective factors is dealt with in Sections 2.1 and 2.2, respectively.

2.1 Objective Factor Measure

An organisation's performance is measured in terms of cost and time dimensions.

The costs can be classified into effective and ineffective costs. Effective costs would include those costs which the organisation would like to maximise, such as profits and revenues; ineffective costs would involve the costs which are to be minimised, such as production costs and the overall total costs of the organisation. Similarly, the time factor can also be classified into effective and ineffective time. All productive time would be effective and all non-productive time would be ineffective. Organisations would like to maximise the effectiveness of cost and time and to minimise the ineffective cost and time.

An EBG model takes into account the effective cost, ineffective cost, effective time, and ineffective time dimensions for the evaluation of the cost and time effectiveness of alternatives. The CTE of an alternative i is given in Eq. (2).

$$CTE_i = EC_i\ 1/\Sigma\ EC_i + (IEC_i\ \Sigma\ 1/IEC_i)^{-1} + ET_i\ 1/\Sigma\ ET_i + (IET_i\ \Sigma\ 1/IET_i)^{-1} \quad (2)$$

CTE of an alternative is converted into dimensionless indices to obtain the objective factor measure.

2.2 Subjective Factor Measure

The analytical hierarchy process method is made use of in evaluating the subjective factor measure (SFM_i) required in the EBG model. Steps involved in the analytical hierarchy process are given in Section 3. More explanation of the EBG model development is given in [8]

3. Steps Involved in AHP

1. Identify the subjective factors, which influence the decision.
2. The subjective factors are grouped, based on their interdependence, as criteria, subcriteria, and subsubcriteria.
3. Formulate a hierarchical structure, i.e. the objective function is arranged in the top level, criteria, subcriteria and subsubcriteria and alternatives are arranged in the intermediate and lower levels.
4. For each level construct a pairwise comparison matrix A.
5. Find the maximum eigen value (λ_{max}) and its corresponding eigen vector using Eq. (3)

   $$A\ W = \lambda_{max}\ W \quad (3)$$

   Here,

   A = observed matrix of pairwise comparison
   λ_{max} = largest eigen value of A
   W = its principal eigen vector (a measure of relative importance weightage of the criteria or subcriteria or the alternative)
6. Then find consistencies index (CI) using Eq. (4).

   $$(\lambda_{max} - N)/N - 1) \quad (4)$$

   N is the order of the matrix A. Then from Table 1, find the value for corresponding N. CR is the ratio between CI and this table value. If the CR value is 10% or less the matrix is consistent.
7. The subjective factor measure is arrived at from the principal eigen vector calculated for the comparison matrix comparing criteria and subcriteria.

In the pairwise comparison matrix formed in step 4, values ranging from 1 to 9 and its reciprocal values are assigned. This results in refinement of the subjective factor measure [9, 4]. Senior managers from each functional area should be involved in evaluating the criteria and subcriteria and give pairwise comparison values.

Table 1. Random consistency.

Order of matrix	Random index
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

4. Technology Selection Using EBG Model

An automobile parts manufacturing industry (which currently has a traditional manufacturing system – conventional technology (CT)), is considering the proposal to adopt a flexible manufacturing system – advanced manufacturing technology (AMT). This section deals with how this proposal is justified using the new approach of evaluation and selection of the technologies.

The benefits of adopting a technology can be classified into:

1. The tangible benefit arising out of objective factors.
2. The intangible benefit arising out of subjective factors.

Hence, we must evaluate both the objective and subjective factors to derive preference measures of the alternative technologies. The EBG model given in Section 2 assists in strategic decision making, e.g. technology selection, considering objective and subjective factors, hence an EBG model is made use of in this approach for technology selection. The objective factor measure of the technologies considered is calculated in Section 4.1, subjective factor measure is calculated in Section 4.2, and the performance measure is arrived at in Section 4.3.

4.1 Objective Factor Measure

The objective factor measure of a technology is arrived at from the cost and time effectiveness of that technology, which is calculated using Eq. (2).

The manufacturing industry considered reports on the implementation cost of the flexible manufacturing system (AMT) and the additional investment required for the traditional manufacturing system (CT) which is in the replacement stage. It reports on the cost of the production of the automobile parts in both the manufacturing systems, the annual cost incurred in both the systems and the demand for their products. The profit it makes per unit is also reported. (Table 2). The details in the report are confidential and hence have been screened. These

Table 2. Data on cost and demand for the alternative technologies.

Project	AMT	CT
Initial cost (lakh)	6200	2900
Annual cost (lakh /year)	1400	560
Production cost (lakh /unit)	2.226	2.60
Product selling price (lakh /unit)	4	4
Demand (units)	1000	1000

Table 3. Effective and ineffective cost.

Ineffective cost (IEC)	Effective cost (EC)
Present value of annual cost	Present value of profit
Present value of production cost	
Present value of depreciation	

Table 4. Present value of the effective and ineffective cost for AMT.

Cost (Lakh)	Present value (Lakh)
Annual cost (IEC)	7026.28
Profit (EC)	8903.30
Depreciation (IEC)	3111.16

Table 5. Present value of the effective and ineffective costs for CT.

Cost (Lakh)	Present value (Lakh)
Annual cost (IEC)	2810.51
Profit (EC)	7026.27
Depreciation (IEC)	1455.44

costs are classified into effective and ineffective costs, as shown in Table 3.

The annual cost represents the annual overhead cost. The costs, namely purchase cost, installation cost, etc. are capitalised as initial cost, and the initial cost is depreciated over 10 years, which is the life of both the proposed manufacturing systems. Depreciation is considered as an ineffective cost in the model. No tax is assumed. The present value of all the effective and ineffective costs involved in a life of 10 years at a capital cost of 15% is given for both AMT and CT in Tables 4 and 5.

Cost and time effectiveness for alternative i is calculated using Eq. (2).

$$CTE_{AMT} =$$
$$[8903.30/(8903.30 + 7026.27)] + [10137.44 \{(1/10137.44) + (1/4265.95)\}]^{-1}$$
$$= 0.8550$$
$$CTE_{CT} = [7026.27/(8903.30 + 7026.27)] + [4265.95 \{(1/10137.44) + (1/4265.95)\}]^{-1}$$
$$= 1.1450$$

The values are substituted in $(CTE_i)\ 1/\Sigma\ CTE_i$ and the objective factor measures for the alternatives are calculated and shown in Table 6.

Table 6. Objective factor measure.

AMT	0.4275
CT	0.5724

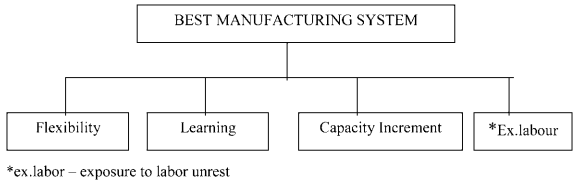

Fig. 1. Subjective factors in hierarchical form.

This objective factor measures of the alternatives shows that CT is a better option than AMT, but the decision should not be taken solely based on this measure because subjective factors are also involved in a technology, which give intangible benefits. This measure is arrived at in the Section 4.2.

4.2 Subjective Factor Measure

The analytical hierarchy process method is used in evaluating the subjective factor measure (SFM) used in the EBG model.

In this analytical hierarchy process, senior managers and experts are involved in identifying the subjective factors that influence the decision. In the industry considered, the subjective factors identified are flexibility, learning, capacity increment, and exposure to labour unrest. These factors are shown in hierarchal form in Fig. 1.

The alternative manufacturing technologies are analysed with respect to the factors in the lowest level (level 1) of the hierarchy, as shown in Fig. 2.

The next step to constructing the hierarchy is constructing the comparison matrices. Comparison matrices are formed at each level of the hierarchy for pairwise comparison of the factors in that level. The comparison matrix for comparing the factors in level 1 of the hierarchy is shown in Fig. 3.

A further comparison matrix is constructed comparing the alternatives with respect to each of the factors at the lowest level of the hierarchy. The matrices comparing AHP and CT

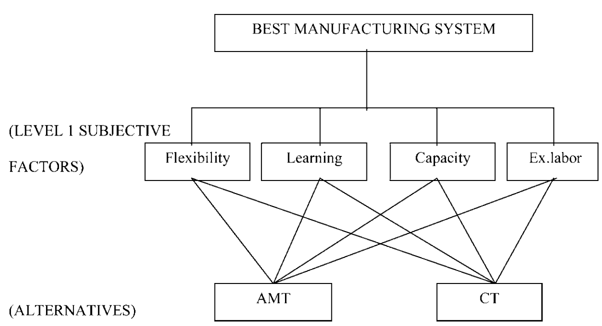

Fig. 2. Alternatives analysed with respect to the subjective factors at the lowest level of the hierarchy.

	Flexibility	Learning	Capacity	Exposure to labor unrest
Flexibility	1	FL (STRONG)	FC (STRONG)	FE (STRONG)
Learning	1/FL (WEAK)	1	LC (STRONG)	LE (STRONG)
Capacity increment	1/FC (WEAK)	1/LC (WEAK)	1	CE (STRONG)
Exposure to Labor unrest	1/FE (WEAK)	1/LE (WEAK)	1/CE (WEAK)	1

FL - importance of flexibility over learning
FC - importance of flexibility over capacity
FE - importance of flexibility over exposure to labor unrest
LC - importance of learning over capacity
LE - importance of learning over exposure to labor unrest
CE - importance of capacity over exposure to labor unrest

Fig. 3. Comparison matrix of level 1.

with respect to the factors in level 1 (lowest level) of the hierarchy are shown in Fig. 4.

In the comparison matrices, the factors in a row are compared with the factors in a column and the comparison value is given in the crossing cell. When the factor in a row is stronger (more significant) than the factor in a column, then the crossing cell is strong and its corresponding cell, which compares the latter with the former, takes a reciprocal value and is weak.

It is enough for the experts to give values for the strong cells. The weak cells take the value of the reciprocal of the corresponding strong cell and the diagonal cells take the value of 1. Thus, there are only six independent cells in the matrix shown in Fig. 3 and one independent cell in each of the four comparison matrices shown in Fig. 4.

The strong cell may take a value between 1 and 9 based on the relative importance. Table 7 assists in assigning values for each cell.

A group of experts are involved in determining the judgemental comparison value required by the independent cells in the comparison matrices. The relative importance perceived by the experts may differ. Hence, a single judgemental value will not arise.

Even though the perceptions of different experts are not same, and they do not converge to a single value, they will certainly narrow down to a range of values. In this paper, we suggest that this range of judgemental values should be taken and different levels of values be considered in that range for decision making.

In this case, the relative importance of one factor over the other, and the preference values of the alternatives with respect to the factors, are taken at three levels.

In the industry under consideration the product design changes frequently with changing requirements. Owing to the frequent change in design, flexibility is required in the manufacturing system to be installed. The industry is unique in many ways, and also looks for a competitive advantage to be gained through the early adaptation of new technology and the technical excellence gained through factor learning. The company has an industrial market and the demand is steady over the coming period. Hence, the capacity requirement of the system to be installed is almost constant. Past records shows that labour unrest in the industry is very low.

Based on these concerns the experts in the functional area concerned compared the factors involved. They gave a range of judgemental values for the pairwise comparison of different factors. In that range of values, three different levels are taken.

The three levels of the pairwise comparison value at level 1 as given by the experts in the industry are given in Table 8.

Similarly, the experts compared the alternative technologies with respect to each of the subjective factors at the lowest level (level 1), and based on their level of activity gave a

Flexibility

	AMT	CT
AMT	1	AC_F (STRONG)
CT	$1/AC_F$ (WEAK)	1

Learning

	AMT	CT
AMT	1	AC_L (STRONG)
CT	$1/AC_L$ (WEAK)	1

Capacity

	AMT	CT
AMT	1	AC_C (STRONG)
CT	$1/AC_C$ (WEAK)	1

Ex. labor

	AMT	CT
AMT	1	AC_E (STRONG)
CT	$1/AC_E$ (WEAK)	1

AC_F - Preference of AMT over CT with respect to flexibility
AC_L - Preference of AMT over CT with respect to learning
AC_C - Preference of AMT over CT with respect to capacity increment
AC_E - Preference of AMT over CT with respect to exposure to labor unrest

Fig. 4. Matrices comparing alternatives with respect to the factors at level 1.

Table 7. Ratio scale.

Numerical rating	Verbal judgement or preference
1	Equal importance
3	Weak importance of one over other
5	Essential or strong
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

Table 8. Three levels of the pairwise comparison value of the factors (level 1).

	(FL)	(FC)	(FE)	(LC)	(LE)	(CE)
Level 1	4	6	7	3	5	2
Level 2	5	7	8	4	6	3
Level 3	6	8	9	5	7	4

range of judgemental values. The three levels of the preference value of the alternatives with respect to the factors are given in Table 9.

When the comparison value of the factors at level 1 are considered in three levels, it is possible that 729 different comparison matrixes (3^6 different comparison matrices) can be formed using different combination of these values, but all the matrices formed may not be consistent. Each matrix is checked for consistency following steps 5 and 6 from Section 3. All the consistent matrices are considered in the decision making.

For each consistent matrix, a principal eigen vector is found. This eigen vector gives the relative weightage of the factors compared in that matrix.

As an example, consider one combination of the comparison value comparing the factors, in which the relative importance of flexibility over learning (FL) is taken at level 1 (level 1 value of FL), FC at level 2, FE at level 3, LC at level 2, LE at level 2, and CE at level 3. A comparison matrix is formed using these values.

To check the consistency of this combination of values an eigen vector and an eigen value is calculated using the eigen value method. λ_{max} is 4.2486. This value is substituted in Eq. (4) to obtain CI. CR is calculated as the ratio between CI and random consistency index. The random consistency index is taken from Table 1.

$$CI = (4.2486 - 4) / (4 - 1) = 0.0828$$
$$CR = 0.0828 / 0.9 = 0.092$$

Since CR is less than 0.1, the comparison matrix formed out of this combination of values is consistent. The comparison matrix and its eigen vector are shown in Fig. 5.

Similarly, when the preference value of the alternatives with respect to the factors in the lowest level of the hierarchy (level 1) are considered in three levels, 81 different sets of comparison matrixes (3^4 different set of comparison matrices) comparing the alternatives with respect to each of the factors can be formed.

For example, if we consider AC_F at level 2, AC_L at level 2, AC_C at level 1 and AC_E at level 1, then that set of comparison matrices and their respective eigen vectors, which give the relative preference of the alternatives with respect to that factors, are as shown in Fig. 6.

The subjective factor measure of an alternative is arrived at from the relative weightage of the subjective factors (given by the eigen vector of the comparison matrix comparing the factors), and the relative score of the alternatives with respect to each of the factors (given by the eigen vector of the comparison matrices set comparing the alternatives with respect to each of the factors). The relative score of the alternative with respect to the subjective factor is multiplied by the relative weightage of that subjective factor, and all the scores of that alternative are summed.

For the comparison matrix given in Fig. 5, comparing the factors in level 1 and the comparison matrix set given in

Table 9. Three levels of the preference value of the alternatives.

	AC_F	AC_L	AC_C	AC_E
Level 1	6	2	4	3
Level 2	7	3	5	4
Level 3	8	4	6	5

	Flexibility	**Learning**	**Capacity**	**Exposure to labor unrest**	**EIGEN VECTOR**
Flexibility	1	4	7	9	0.620
Learning	0.250	1	4	6	0.242
Capacity increment	0.142	0.250	1	4	0.096
Labor unrest	0.111	0.166	0.250	1	0.041

Fig. 5. Comparison matrix and eigen vector for the example values (level 1).

Flexibility

	AMT	CT	Eigen vector
AMT	1	7	0.875
CT	0.14	1	0.125

Learning

	AMT	CT	Eigen vector
AMT	1	3	0.75
CT	0.33	1	0.25

Capacity

	AMT	CT	Eigen vector
AMT	1	4	0.80
CT	0.25	1	0.20

Ex.labor

	AMT	CT	Eigen vector
AMT	1	3	0.75
CT	0.33	1	0.25

Fig. 6. Comparison matrices and eigen vectors for the example values.

Table 10. Subjective factor measure.

AMT	0.831
CT	0.169

Fig. 6, comparing the alternatives with respect to the factors in level 1, the subjective factor measures of both AMT and CT are calculated as follows and the subjective factor measures are given in Table 10.

$$SFM_{AMT} = 0.875 \times 0.620 + 0.75 \times 0.242 + 0.8 \times 0.096 + 0.75 \times 0.041 = 0.831$$
$$SFM_{CT} = 0.125 \times 0.620 + 0.25 \times 0.242 + 0.2 \times 0.096 + 0.25 \times 0.041 = 0.169$$

Since 729 comparison matrices can be obtained in levels 1 and 81, comparison matrices can be obtained by comparing AMT and CT with respect to the factors in level 1. It is possible to generate 59 049 combination (729 × 81) of the matrix at level 1 and comparison matrices comparing AMT and CT with respect to the factors in level 1. Hence, it is possible to obtain 59 049 different subjective factor measures for both AMT and CT, but some matrices out of the 729 comparison matrices formed are inconsistent, and are not considered in the decision-making process. Hence, the number of effective subjective factor measures we obtain from the consistent matrices, for evaluating AMT and CT will be less than 59 049.

4.3 Performance Measure

The manufacturing system performance measures (MSPM) for both AMT and CT are arrived at from the objective and subjective factor measures using Eq. (1).

For the objective factor measure given in Table 6, the subjective factor measure of the above-considered example given in Table 10 and the objective factor weightage taken to be 0.3 the MSPM of AMT and CT is calculated and is given in Table 11.

$$MSPM_{AMT} = (0.3 \times 0.4275) + [(1-0.3) \times 0.832] = 0.710$$
$$MSPM_{CT} = (0.3 \times 0.5724) + [(1-0.3) \times 0.168] = 0.289$$

Since it is possible to generate 59 049 subjective factor measures for both AMT and CT, we obtain 59 049 values of MSPM for both AMT and CT. It should be noted that, as stated above, owing to inconsistency in some matrices formed, the number of SFM and hence MSPM may be less than 59 049.

A computer program is written in the C language to consider all the possible consistent combinations of the comparison matrices and to calculate all the MSPM values for AMT and CT for the given value of α.

Table 11. Performance measure.

AMT	0.710
CT	0.289

Table 12. Objective factor weightage, number of times AMT scores over CT and number of times CT scores over AMT.

α	AMT	CT
0.10	27 783	0
0.20	27 783	0
0.30	27 783	0
0.40	27 783	0
0.50	27 783	0
0.60	27 783	0
0.70	27 783	0
0.80	27 783	0
0.90	0	27 783
1.00	0	27 783

5. Sensitivity Analysis

The analysis can be carried out with the help of a computer program. The change in preference level of the alternatives with the change in objective factor weightage (α) is analysed. The objective factor weightage varies between 0 and 1. The value of objective factor weightage is incremented from 0 to 1 in steps of 0.1. For each value of α, performance measures are calculated for the alternatives for all the consistent combinations of comparison values and the number of times that one alternative scores over the other is determined. This is shown in Table 12.

It can be seen that CT is better than AMT for the objective factor weightage (α) between 0.8 and 0.9. Magnifying the transition region by incrementing the objective factor weightage by 0.005 in the region of $\alpha = 0.78$ and 0.85 and studying the number of times the alternatives score over each other, we obtain a further refined picture in the transition region, as shown in Table 13. Figure 7 shows the preference level of the alternatives in this region.

It can be seen that the transition in the choice of technology takes place in the region where objective factor measure ranges from 0.80 to 0.84. CT takes over from AMT at $\alpha = 0.82$.

The objective factor weightage value (α) depends on the company which makes the decision. When the objective factor

Table 13. Objective factor weightage, number of times AMT scores over CT and number of times CT scores over AMT.

α	AMT	CT
0.78	27 783	0
0.785	27 783	0
0.790	27 783	0
0.795	27 783	0
0.800	27 783	0
0.805	27 719	64
0.810	26 027	1756
0.815	23 108	4675
0.820	17 280	10 503
0.825	10 301	17 482
0.830	3458	24 325
0.835	8	27 775
0.840	0	27 783
0.845	0	27 783
0.850	0	27 783

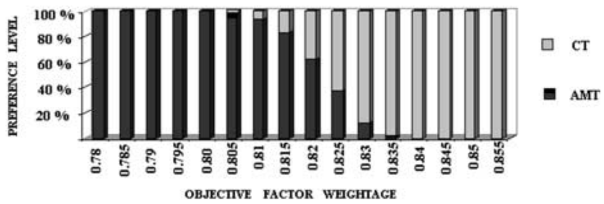

Fig. 7. Preference level of the alternatives vs. the objective factor rating.

weightage preferred by the industry deviates from the range of α at which the transition take place, the confidence level of the decision makers is increased and a firm decision can be taken.

In the industry under consideration, when the objective factors are compared with the subjective factors, the objective factors gain importance, but the subjective factors such as flexibility are also of great concern and hence they insist on the objective factor weightage lying between 0.60 to 0.75. This range within which the objective factor measure lies does not overlap with the transition region and is also in the AMT preference region. Further, the limits deviate from the transition region, which gives confidence to the decision maker.

6. Conclusion

In this paper an attempt is made to use strategic decision making for technology selection. Instead of point estimates which are not realistic, a range of judgemental values were taken into consideration and all the consistent combinations of the judgemental values were considered in decision-making process. The manufacturing system performance measure value (MSPM) for both the alternatives (CT and AMT), for all the consistent combinations were calculated using a computer program written in the C language. Sensitivity analysis was carried out in order to find the change in the preference level of the alternatives, with the change in objective factor weightage value (α). This analysis gave the value of α at which the crossover takes place between CT and AMT in the decision process and also gave the confidence level of the decision.

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Nomenclature

α	objective factor weightage
EBG	extended Brown–Gibson model
AHP	analytical hierarchy process
AMT	advanced manufacturing technology
CT	conventional technology
$MSPM_i$	manufacturing system preference measure for alternative i
$MSPM_{AMT}$	manufacturing system preference measure for AMT
$MSPM_{CT}$	manufacturing system preference measure for CT
CTE_i	cost and time effectiveness for alternative $_i$
CTE_{CT}	cost and time effectiveness for CT
ATE_{AMT}	cost and time effectiveness for AMT
SFM_i	subjective factor measure for alternative i
SFM_{AMT}	subjective factor measure for alternative AMT
SFM_{CT}	subjective factor measure for alternative CT
$CTE_i(1/\Sigma\ CTE_i)$	objective factor measure for alternative i
IEC	ineffective cost
EC	effective cost
A	observed matrix of pairwise comparison
λ_{max}	largest eigen value of A
W	principal eigen vector
CI	consistencies index
N	order of the matrix A
CR	consistency ratio
FL	importance of flexibility over learning
FC	importance of flexibility over capacity
FE	importance of flexibility over exposure to labor unrest
LC	importance of learning over capacity
LE	importance of learning over exposure to labor unrest
CE	importance of capacity over exposure to labor unrest
AC_F	Preference of AMT over CT with respect to flexibility
AC_L	Preference of AMT over CT with respect to learning
AC_C	Preference of AMT over CT with respect to capacity increment
AC_e	Preference of AMT over CT with respect to exposure to labor unrest
ex.labor	exposure to labor unrest