

# PRIORITIZATION METHODOLOGY FOR PLANNING NEW ROAD PROJECTS IN DEVELOPING COUNTRIES\*

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## **Abstract**

*The objective of this paper is to develop an alternate methodology to prioritize new road projects in developing countries for future detailed economic and preliminary engineering studies. To date, an effective and efficient methodology has not been employed and the selection and prioritization of new road projects has largely relied on assumptions rather than a systematic quantification of road project attributes. The **proposed methodology** is not as complex and sophisticated as those developed for industrialized countries. **It is rather** designed to efficiently and effectively handle data that are commonly available in developing countries.*

*A hypothetical data set of variables commonly available in studying developing countries for road projects was used to test the proposed methodology. The same data were also used to test five existing methodologies that were developed in industrialized countries for making decisions on projects, investments, strategic plans, etc and comparative analyses were conducted on the results. The proposed methodology produced identical project rankings as the **two existing** methodologies **and** closely correlated with the third methodology but was **weakly** correlated with the fourth methodology. The fifth methodology was found to be the workable given the data set. The alternate methodology was proved to be a valuable screening tool to assist developing countries.*

*Keyword(s): Multicriteria decision making; New road projects; Attributes; Weights.*

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## **1. INTRODUCTION**

Road transport is vital in developing countries where ***the majority of the people live in rural areas about 75 percent of the people are engaged in traditional agriculture although, value added from agriculture is low compared to other sectors.*** However, the road density (km of road per km<sup>2</sup> of area) is still very low and as a result, limited access to agricultural areas has become one of the major inhibiting factors to exploit rural resources.

Most road projects in developing countries are ***financed*** by regional banks like the African Development Bank, the Asian Development Bank and the Inter-American Development Bank; by multilateral development banks like the World Bank and the European Bank for Reconstruction and Development; and multilateral financing institutions like the Nordic Development Fund. Securing funds from lending and granting agencies require a thorough analysis of project prioritization as well as detailed appraisal studies. Beneficiaries are required to produce well-prepared studies with defensible results. Normally, road project studies begin at the planning stages of identification and prioritization, before intensive feasibility studies are carried out. This paper focused on the planning aspect of new road project studies.

There are different economic, social and political factors that are considered during the planning stage of new road projects in developing countries, and one factor could be more important than the other regarding the national interest. The economic factors could be important to a country as compared to social or political factors and there could even be different degrees of importance amongst the economic factors under consideration. In addition, the purpose of a road can differ from one locale to the other or from one country to the other depending on economic and social resources. In developing countries, new roads may be constructed for one or a combination of the following: transportation of agricultural surplus, distribution of food in deficit areas, provision of access to people in remote areas, exploitation of forest and livestock resources, regional integration, etc.

Based on the above, this ***paper*** deals with the prioritization of new road projects and marshaling them into queue for future rigorous economic and engineering feasibility studies. In this regard, sufficient effort has not been done to develop a plausible methodology in developing countries, although a significant amount of new road network is required. This ***paper*** is meant to contribute in this direction. It is to be

noted that different models, such as the Highway Development and Management Tool (HDM-4), have been established for use in developing countries at the planning and programming stages of existing road projects. ***But this model applies to new road projects, not to the existing ones, which has not been given attention in developing countries.***

## **2. EXISTING MULTI-CRITERIA DECISION MAKING APPROACHES IN DEVELOPED COUNTRIES**

There have been a number of research studies undertaken regarding multi-/multiple criterion decision making models (MCDM) based on data and arguments typically available for developed countries. Triantaphyllou (2000) considered different MCDM methods and found the following five to be the most widely used in developed countries:

- Weighted sum model (WSM),
- Weighted product model (WPM),
- Analytic hierarchy process (AHP),
- Elimination and choice translating reality (ELECTRE), and
- Techniques for Order Preference by Similarity to Ideal Solutions (TOPSIS).

The following sections provide an outline of these approaches.

### **Weighted Sum Model (WSM)**

In respect of WSM, Triantaphyllou (2000) stated that if there are  $m$  alternatives and  $n$  criteria, the best alternative is the one that satisfies the expression:

$$A_{\text{WSM-score}}^* = \max_i \sum_{j=1}^n a_{ij} w_j \quad \text{for } i=1,2,3,\dots, m$$

where:  $A_{\text{WSM-score}}^*$  is the WSM score of the best alternative,  $n$  is the number of decision criteria,  $a_{ij}$  is the actual value of the  $i$ -th alternative in terms of the  $j$ -th criterion, and  $w_j$  is the weighty of importance of  $j$ -th criterion.

*Triantaphyllou further stated that 'additive utility assumption' governs this model, i.e. the total value of each alternative is equal to the sum of the products. WSM can be used without any difficulty with single-dimensional cases where all the units are the*

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same (e.g. dollars, feet, seconds). However, the difficulty emerges when it is applied to multi-dimensional MCDM problems. In this regard, Triantaphyllou concluded that the additive utility assumption is violated when different units are combined.

### **Weighted Product Model (WPM)**

Regarding the weighted product model (WPM), the following equation was established by Triantaphyllou:

$$R(A_k/A_L) = \prod_{j=1}^n (a_{kj}/a_{Lj})^{w_j}$$

where:  $n$  is the number of criteria,  $a_{ij}$  is the actual value of the  $i$ -th alternative in terms of the  $j$ -th criterion, and  $w_j$  is the weight of importance of the  $j$ -th criterion.

As stated by Triantaphyllou, WPM is similar to WSM except that WSM uses addition while WPM deals with multiplication. In WPM, if the term  $R(A_k/A_L)$  is greater than or equal to one, then  $A_k$  is more desirable than  $A_L$ . The best alternative is the one that is greater than or at least equal to all other alternatives. *Triantaphyllou further stated that since the structure of WPM eliminates any units, it can be used in single- and multi-dimensional MCDM with the advantage of using relative values instead of actual ones.*

### **Analytic Hierarchy Process (AHP)**

According to Triantaphyllou the analytic hierarchy process (AHP) model decomposes a complex MCDM problem into a system of hierarchies with the final structure dealing with  $m \times n$  matrix where,  $m$  is the number of alternatives and  $n$  is the number of criteria. In this case, the matrix is constructed by using the relative importance of the alternatives in terms of each criterion. The best alternative is:

$$A^*_{AHP-score} = \max_i \sum_{j=1}^n a_{ij} w_j \text{ for } i = 1, 2, 3, \dots, m$$

As stated by Triantaphyllou, the difference between WSM and AHP is that the former uses actual values while the latter most rely on relative values. In addition, the vector

$(a_{i1}, a_{i2}, a_{i3}, \dots, a_{in})$  for each  $i$  is the principal eigenvector of an  $n \times n$  reciprocal matrix which is determined by pairwise comparisons of the impact of the  $m$  alternatives on the  $i$ -th criterion.

### **Elimination and Choice Translating Reality (ELECTRE)**

Triantaphyllou says that the ELECTRE method focuses on "outranking relations" with pair-wise comparisons using separate alternative criteria. For example, under two alternatives  $A_i$  and  $A_j$ , the outranking relationship between the two describes that even when the  $i_{th}$  alternative does not dominate the  $j_{th}$  alternative quantitatively, the decision-maker may still take the risk of regarding  $a_i$  as better than  $a_j$ . This means that one alternative is dominated by another which makes it excel in one or more criteria while remaining equivalent in other criteria. However, Triantaphyllou noted that since the method yields a system of binary outranking relations between alternatives where the system is not necessarily complete, the method is sometimes unable to identify the most preferred alternative, only producing a core of leading alternatives. Regardless of the above shortcomings, the method has a clear view of alternatives by eliminating less favorable ones which is convenient when there are decision problems that involve a few criteria with a large number of alternatives.

### **Techniques for Order Preference by Similarity to Ideal Solutions (TOPSIS)**

According to Triantaphyllou, TOPSIS was developed as an alternative to the ELECTRE method. The basic concept of TOPSIS is that the selected alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in a geometrical sense. The method assumes that each criterion has a tendency of monotonously increasing or decreasing utility with easy definitions of ideal and non-ideal solutions. Under this method, a normalized decision matrix is constructed first (the same as under ELECTRE method) followed by a weighted normalized decision matrix. Then, ideal and negative-ideal solutions are determined followed by separation measures. The best alternative is the one that has the shortest distance to the ideal solution.

Saaty (1980) proposed the AHP method in decision making in order to determine strengths with which various elements in one level influence the elements on the next

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higher level so that the relative potency of the impacts of the elements of the lowest level on the overall objectives can be computed. He described the development of weights to be associated with individual activities, based on group quantified judgments and said that if there are  $n$  activities ( $C_1, C_2, \dots, C_n$ ), the quantified judgments on pairs of activities ( $C_i, C_j$ ) are represented by  $n$ -by- $n$  matrix. Saaty further stated that, there are two rules for entries of elements in the matrix: rule one says  $a_{ij}$  is the reciprocal of  $a_{ji}$ , and rule two says, if  $C_i$  is judged to be of equal importance to  $C_j$ , then, both  $a_{ij}$  and  $a_{ji}$  will be equal to 1. Finally, the weights and entries are treated to develop selection criteria. Saaty proposed crude estimates of vector calculation as follows:

- i) Add the elements in each row and normalize them by dividing each sum by the total of all the sums, so that the results add up to unity. The first entry of the resulting vector is the priority for the first activity; the second entry for the second activity, and so on.
- ii) Take the sum of the elements in each column and form the reciprocals of these sums. Divide each reciprocal by the sum of the reciprocals to normalize them so that thus add to unity.
- iii) Divide the elements of each column by the sum of that column and the elements in each resulting row and divide this sum by the number of elements in the row. This is a process of averaging out the normalized columns.
- iv) Multiply the  $n$  elements in each row and take the  $n$ th root normalize the resulting numbers.

Pomerol and Barba-Romero (2000) also dealt with a number of multi-criteria decision making models. They stressed the absence of a recognized rule for qualitative criteria and thus, proposed normalization procedures. They stated that if evaluation of  $m$  alternatives are given by  $a_{ij}$  for a given criterion  $j$ , a normalization procedure will transform the vector ( $a_{1j}, a_{2j}, \dots, a_{mj}$ ) into a normalized vector ( $v_{1j}, v_{2j}, \dots, v_{mj}$ ) using one of the following four procedures:

$$\text{Procedure 1: } v_i = \frac{a_i}{\max a_i} \qquad \text{procedure 2: } v_i = \frac{a_i - \min a_i}{\max a_i - \min a_i}$$

$$\text{where : } \qquad 0 < v_i \leq 1 \qquad \qquad \qquad 0 \leq v_i \leq 1$$

Procedure 3:  $\frac{a_i}{\sum a_i}$

Procedure 4:  $\frac{a_i}{(\sum a_i^2)^{1/2}}$

where :  $0 < v_i < 1$

$0 < v_i < 1$

Pomerol and Barba-Romero further suggested that the interpretation of Procedure 1 is made by considering the percentage of maximum  $a_i$ ; Procedure 2 as percentage of range ( $\max a_i - \min a_i$ ); Procedure 3 as percentage of the total sum, and procedure 4 as the  $i^{\text{th}}$  component of unit vector. After normalization, weights ( $w_i$ 's) are calculated with the sum of 1. Finally, by applying the weighted sum model, evaluations are made such that  $R(a_i) = \sum_j w_j a_{ij}$ , ( $i=1,2, \dots, m$ ) and the chosen alternative  $a_i$  will be the one which gets the highest value of  $R(a_i)$ . If there is a tie, either one can be taken.

### 3. MCDM APPLICATION IN THE PLANNING OF NEW ROAD PROJECTS IN DEVELOPING COUNTRIES

#### Application of MCDM in Developing Countries

MCDM models can incorporate both qualitative and quantitative data. As stated above, the three general factors that are employed in the selection of development projects are: Alternatives which focus on road project; criteria which are attributes of road projects such as resources potential; and factor weights. The first two are quantitative in nature while the third one is qualitative. Generally, the decision making process involves five stages: road project identification, establishment of attributes, development of weights, analyses and decision making.

#### Road Project Identification

This activity is usually undertaken by government and public agencies. Agricultural offices, both public and private rely on road infrastructure to transport farm inputs to and outputs from development centers. Relief agencies require road infrastructure to

transport emergency food and other commodities to affected areas. Regional administrative offices require public transport to provide access to the people in remote areas and to foster regional integration. Potential road projects are identified by designated government offices taking into account all these activities.

### **Establishment of Attributes**

This section deals with the identification of relevant criteria which provide the basis for project evaluation and the quantification of attributes. Common national economic, social and other criteria can be established for designing all road projects. Although these criteria differ from country to country, they are more or less generic for most rural road projects. In developing countries, roads may be required to transport one or a combination of the following: subsistence/cash crop surplus to market centers, relief supplies to deprived areas, passengers to their destinations, and forest and livestock surplus to industries and consumption centers. Roads may also be needed for purposes of regional integration which could be entirely political.

Once appropriate criteria are identified, pertinent government agencies can undertake the quantification work. Agricultural institutions can estimate cash and subsistence crop as well as livestock and forest reserve potentials; relief agencies and non-government organizations can calculate the prevalent and long-term nutrient requirements in food deficient areas; statistical offices can estimate the number of people in project areas; and mapping institutions can estimate how far identified project areas are located from the nearest urban centers.

The next step is to establish weighing factors for each criterion. This is difficult due to the subjective nature of the task. Judgments could be inappropriate due to bias and misunderstanding of the facts. Ideally, the national interest must be the ultimate objective. Weights should be given for each attribute/criterion after a careful comparison with others. In general, all attributers are not considered to have equal values. For example, a country can be in need of foreign currency and thus exportable agricultural produce such as coffee and cocoa may be valued more than other agricultural produce such as wheat, maize, etc. On the other hand, the concern of a country may be the political strengthening of the nation; thus, regional integration may be given a higher priority. Thus, weights can be assigned to each attribute based on the particular need of a developing country or region.

However, reasonable estimates can be developed if knowledgeable and unbiased individuals are involved in the task. As stated by Souder (1980), a Delphi method can be employed since the opinions of several experts can sometimes be 'averaged' to cancel out the errors/biases of individual predictions. Similarly, Nutt (1984) noted that a Delphi survey systematically solicits and collates judgments to form a group consisting of different organizations. Accordingly, participants can be selected from government organizations, universities and private agencies. Experts from the offices of finance, central planning, statistics, transport, agriculture, industry, trade and relief agencies can represent governments; economists, statisticians and researchers can represent higher academic institutions; and traders, transport operators, consumers and farmers can represent private stakeholders.

According to Nutt, a series of questionnaires can be used. The initial questionnaire asks general questions with subsequent questionnaires built on the responses to the preceding questionnaire. Offices of central planning and road authority can be mandated to manage the study. Weights can be absolute or normalized values. The analyses can be done by road authorities/ministries of transport, systems analysts or consultants and the study can be monitored by a steering committee. Once the study is completed, decisions can be taken jointly by the offices of road agencies/ministries of transport, central planning agencies and higher level policy makers.

### **Proposed Alternate Methodology (AM)**

An alternate methodology (AM) is developed considering the requirements of developing countries with a focus on the resource types that are commonly utilized in those regions. The methodology focuses on attributes of new road project with the allocation of weights to prioritize and streamline the projects for future detailed economic and engineering studies. The approach developed through this paper is stated below:

Assumptions:

- (a) Let P denote a set of identified new road projects,
- (b) P is composed of a finite number of n alternatives, thus,  
$$P=(x_1, x_2, \dots, x_n)$$
- (c) Let A denote a set of attributes
- (d) A is composed of a finite number of m attributes. Thus, B represents the

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attributes of the subject roads with m number of attributes. Thus,

$$B=(B_1, B_2, \dots, B_m).$$

Next, weights are allocated. For example:  $w_1$  for attribute  $B_1$ ,  $w_2$  for attribute  $B_2$  and so on until  $w_m$  for  $B_m$ . Thus, normalized weights would be:

$$w_1 + w_2 + \dots + w_m = 1 \tag{1}$$

(Note: The values of  $w_j$ 's can be whole numbers and the sum can be greater than one provided that the ratios between them remain the same).

Then, weights are distributed among road projects based on the magnitude of attributes. The road projects and attributes are illustrated in the matrix below:

Attributes	Projects				→	Sum of Attributes
∴						
	$x_{11}$	$x_{12}$	...	...	$x_{1n}$	$\sum_{j=1}^n x_{1j}$
	$x_{21}$	$x_{22}$	...	...	$x_{2n}$	$\sum_{j=1}^n x_{2j}$
	...	...	...	...	...	...
	$x_{j1}$	$x_{j2}$	...	...	$x_{jn}$	$\sum_{i=1}^n x_{ij}$
	...	...	...	...	...	...
	$x_{m1}$	$x_{m2}$	...	...	$x_{mn}$	$\sum_{j=1}^n x_{mj}$

For each cell, a score is calculated based on the following formula:

$$V_{ij} = \frac{x_{ij}}{\sum_{j=1}^m x_{jn}} w_j \tag{2}$$

where:  $i = 1,2,3, \dots, n$   
 $j = 1,2,3, \dots, m$   
 $w = \text{weights}$

Subsequently, all scores for each road project are summed up as follows:

$$\begin{array}{rcl}
 P_1 & = & \sum_{j=1}^m v_{1j} = v_{11} + v_{21} + \dots + v_{m1} \\
 P_2 & = & \sum_{j=1}^m v_{2j} = v_{12} + v_{22} + \dots + v_{m2} \\
 \dots & \dots & \dots \\
 P_n & = & \sum_{j=1}^m v_{ij} = v_{1n} + v_{2n} + \dots + v_{mn}
 \end{array}$$

On the basis of this calculation, the project with the highest aggregated score will be selected to be the first for detailed feasibility study. This methodology is intuitive and can be utilized without difficulty by experts in developing countries. The methodologies formulated for use in industrialized countries are more complex and mathematically sophisticated, requiring trained experts, currently scarce in developing countries. In addition, most of the existing MCDM models cannot be applied in developing countries without modification.

### **Analyses and Comparison of Results**

Data which were postulated to describe the attributes of various road projects are presented in Table 1. The attributes are the major criteria that are normally considered during road project evaluations in developing countries.

MCDM analyses were carried out using the proposed alternate methodology (AM). The results generated by AM were compared with those calculated using the WSM, WPNM, AHP, Saaty and TOPSIS methods. The ELECTRE method was not used since TOPSIS is simply an improved version of it. In addition, as mentioned by Trantaphyllou, the ELECTRE, method yields a system of binary outranking relations between the alternatives where the system is not necessarily complete and sometimes it is unable to identify the most preferred alternative only producing a core

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of leading alternatives. Thus, the EL/ECTRE method has not been used for the purposes of comparison.

Five new road projects were considered with seven economic attributes. The weights are random values based on assumed importance of the attributes. The values in brackets (in Table 1) are randomized figures whose sum equals 1. Analyses were done using the AM method considering both randomized and non-randomized weights.

Analyses were carried out using the following six methods: Alternate Methodology (AM), Weighted Sum Model (WSM), Weighted Product Model (WPM), Analytic Hierarchy Process (AHP), Saaty and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The proposals by Saaty described above as (a), (b) and (d) do not work using this data. This is because (a) and (b) involve addition of attributes which is impossible in this case, since for example, crop surplus and population cannot be added together. Similarly, (d) is not workable since it involves the multiplication of attributes which result in values of zeros because of the "0" values provided in the data. The results incorporating values and rankings are shown in Table 2.

As shown in Table 2, AM (non-normalized) and AHP produce identical results, WSM and TOPSIS produce different results from the former two. It was not possible to conduct analyses using WPM because WPM utilizes ratios of attributes. Ratios cannot be produced with "0" values of denominators. WSM produced different values from AM and AHP because the degree of magnitudes of attributes were not considered. Instead, multiplications of weights and attributes are considered while AM and AHP apply weights after respective attributes have been divided by the corresponding sums. The relative weights of the attributes within each project alternative need to be calculated and should be used as a mechanism of prioritization. This is so because the relative magnitudes of attributes within projects can be measure and incorporated.

In the case of TOPSIS, the distances for ideal and negative-ideal solutions were measured from the maximum and minimum values, respectively, based on a normalized decision matrix. The model, however, considers benefit and cost/loss criteria as fictitious alternative to measure solutions which do not usually appear in attributes of road projects. Ranking under AM, AHP and Saaty (iv) are similar.

Spearman rank correlations were calculated using Anderson et al. (1981) to measure the degree of closeness between the rankings. The correlation between AM/AHP/Saaty (iv) and WSM was 0.2 which is weak, the correlation between AM/AHP/Saaty (iv) and TOPSIS was 0.65 which is reasonably strong while the correlation between WSM and TOPSIS was -0.55 which is negatively correlated indicating that the ranking are opposite to the ranking of AM/AHP/Saaty (iv), under the given data.

**Table 1: Hypothetical Projects and Corresponding Attributes**

Attributes	Projects					Weight (w)
	A1	A2	A3	A4	A5	
Subsistence Crop Surplus (ton)	100000	75000	30000	0	0	4 (0.16)
Subsistence Crop Deficit (qts.)	0	0	0	60000	30000	3 (0.12)
Population	150000	200000	100000	75000	45000	4.5 (0.17)
Cash Crop Surplus (qts)	25000	35000	50000	30000	100000	5.0 (0.19)
Forest Reserve (m <sup>3</sup> )	65000	80000	45000	15000	10000	3.5 (0.13)
Livestock (no. of cattle)	250000	300000	150000	500000	450000	3.5 (0.13)
Regional Integration (distance from nearest urban centre in km)	350	500	750	1000	1200	2.5 (0.10)

**Table 2: Score and Ranks of Hypothetical Road Projects**

Project	Models												
	AM		WSM		WPM		AHP		Saaty (c)		TOPSIS		
	Value	R	Value ('000)	R	Value	R	Value	R	Value	R	Value	R	
<b>A1</b>	0.211*	5.47	2	325	4	NW	NW	5.47	2	0.775	2	0.11	1
<b>A2</b>	0.235	6.04	1	392	3	NW	NW	6.04	1	0.852	1	0.11	1
<b>A3</b>	0.152	3.96	5	228	5	NW	NW	3.96	5	0.551	5	0.51	4
<b>A4</b>	0.199	5.19	4	552	2	NW	NW	5.19	4	0.731	4	0.50	3
<b>A5</b>	0.205	5.34	3	563	1	NW	NW	5.34	3	0.734	3	0.52	5

\* Based on Normalized weights + Based on Non-Normalized weights, NW= Not Workable, R=Rank  
(Note: The results under Saaty (c) are the same with results under AHP/Non-Normalized weights under AM divided by the number of attributes which is 7 in this case.)]

#### **4. CONCLUSIONS**

In developing countries, appropriate prioritization methodologies for new road projects are not yet developed. The methodology proposed in this paper helps to streamline potential road projects for future detailed economic and preliminary engineering feasibility studies in developing countries. Using typical variables important to road projects in developing countries, a series of analyses were conducted utilizing the proposed alternate methodology (AM) and contrasted with the existing models developed specifically for developed countries. The existing models utilized in the analyses are: Weighted Sum Method (WSM), Weighted Product Method (WPM), Analytic Hierarchy Process (AHP), Saaty (iii) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

The WPM model was found to be the workable since it includes "0"s as denominators in its calculations. The results under WSM were different from AM since comparisons amongst the attributes within each road alternative were not conducted as the model proposes. The results under TOPSIS were also different because this method requires data describing benefit and cost/loss criteria which are not common in road project attributes in developing countries. The results under AM (non-normalized) and AHP were identical.

Regarding rankings, AM, AHP and Saaty (iii) produced similar results. AM, AHP and Saaty (iii) are plausible for use in developing countries although the last two are more sophisticated requiring greater effort. Saaty (iii) is the same as AM (non-normalized) and AHP except that it proposes values to be divided by the number of attributes. AM produced normalized as well as non-normalized values. It is simple to use and does not require sophisticated computer utilization as proposed by Saaty and Triantaphyllou. AM can easily handle data normally used in developing countries with no complication.

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