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The Modified Nominal Group Technique (NGT) and Analytical Hierarchy Process (AHP) for Criteria Prioritization

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Abstract: *Decision making made by an individual from a variety of alternatives takes a lot of time, wasteful, and challenging. This paper looks at two approaches, the modified nominal group technique and analytical hierarchy process for determining criteria preference that will help criteria optimization in decision making. The result shows that there is slight difference in the two approaches in terms of criteria prioritization and this can also affects the selection process if adopted. However, the modified NGT tends to portray the true picture of the armature core design that was considered as the case study, choosing electrical resistivity as the most important property/criteria, while the AHP takes hardness as the most preferred criteria.*

Keywords: *Criteria preference, Prioritization, Decision making, Selection process, Weight aggregation*

1. Introduction

The thought of making a logical choice from the numerous available options has been a challenge and brain tasking. When trying to make a good decision regarding these choices, one needs to weigh the positives and negatives aspect of each option, and consider all the alternatives carefully. Decision-making methods are like flipping a coin ranging from reliance on possibility to the use of more organized decision-making tools. Sound decision-making involves taking all the factors that are crucial and analyzing it. For effective decision making, one must be able to predict the result of each option with some decision tools and analysis, and based on all these factors, the best option that will be appropriate for that particular situation is determined. Therefore, this paper will present the modified nominal group technique and analytical hierarchy process as one of the methods used in the decision making to assist decision makers choose the right option among different alternatives within the multiple criteria.

Though, these two methods are decision tools for multi-criteria optimization but they however vary in their procedures. The NGT is an approach used for group decision-making which gives room for high quality source of original ideas, equal involvement of all team members, with an arranged sequence of ranks based on a mathematical voting technique (Norton, 1980). It also gives everyone in the group equal opportunity for participation. However, the AHP is the technique for analyzing ways of making choices in form of psychology and mathematical representation. This was developed by Thomas Saaty in the 1970s. AHP has been reported to be very efficient in making difficult and irrevocable decisions. From literature, it has been proven that the NGT which is non-interactive approach used to reduce the subjectivity in obtaining preference weights as a result of human factor and has been verified to be useful in generating large number of ideas in a wide variety of contexts (Odu, 2017). While the AHP model in assigning weights is influenced on the values and judgments of individuals opinion and groups requires a lot of subjective information from the decision maker and the weights obtained from the pair wise comparison are strongly criticized for not reflecting people's opinions. Due to these differences in subjectivity, this paper tends to look at and compare the nominal group technique and the analytical hierarchy process regarding the use of their criteria weights in a multi-criteria analysis for decision making. This will be illustrated with an example.

The nominal group technique was originally developed by Delbecq and Van de Ven (1971). Actually it is a decision-making process and method which is highly controlled in small or large group process for the generation of ideas (Cantrill et al., 1996; MacPhail, 2001). It is useful when decisions are rendered quickly; especially the opinions of individual member in a group are allowed to count. This technique of tallying can be used in reaching a common conclusion or consensus and tends to differentiate the nominal group technique from other methods. At the starting level of the technique the individual have an equal opportunity to register their idea on the right result.

Solutions having the same the result are the removed from the collection, while the primary solutions are left alone. Then, each team member grades the left over solution using numerical values in terms of their preference, and these set of preferences are ranked as the most appropriate solution.

In addition, the NGT is a straight forward approach of idea generation with unique voting system. Though, the technique has a couple of variations which revolve around ideas being identified to individuals or being anonymously contributed, but caters for different categories of people and allows people who are less concern in achieving compromise to pitch their ideas in equal weight and consideration to others. Here, each individual member works at different location and sends the results though email or by post. However, the modified nominal group technique is a structured and well developed process designed to extract ideas from a team at their respective locations.

2. METHODOLOGY

2.1. The Modified Nominal Group Technique

The detail procedure of the modified nominal group technique was developed and presented in Odu and Charles-Owaba (2017) as stated in equation (1).

$$w_j = \frac{\sum_{k=1}^{Z} (\mathrm{N} - \psi_{\mathrm{kj}} + 1)}{\mathrm{ZN}(\mathrm{N}+1)/2} \tag{1}$$

Where w_j is the criteria weight for material property j

N is the criteria size

ψ_{kj} is the relative rank assigned by team member k to attribute j

Z is the team size, and

K is the design team member

2.2. The Analytic Hierarchy Process, AHP

Analytic Hierarchy Process is multi-criteria decision-making method that was developed by Thomas Saaty in the last two decades to weigh decision choices and prioritize them (Saaty, 1977; Saaty, 1980). According to Thomas Saaty in 1970s, AHP method was used in solving weapon tradeoffs, asset allocation and decision making problems such as high cost production with numerous factors that were not identified conflicting with one another. AHP is an organized form of hierarchy formulation being saddle with complex problem with various conflicting and subjective criteria in judging the decisions of each team members into number of levels in attempt to assign the weight of the criteria (Ishiaka and Labib, 2011).

The AHP is used to sort out conflicting factors using mathematical methods in form of algebra matrix to obtain an optimal solution. It is a general measurement theory which is subject to the values and judgments of team members (Alexandrer, 2012). One of the advantage of the hierarchical structure lies on the fact that it permits for detailed and systematic breakdown of the entire problem into its original components with some level of suppleness.

There are several ways the decision makers tend to derive subjective preference regarding criteria weights in a multi-criteria analysis. One of the most and widely applied methods is Analytic Hierarchy Process (AHP). In AHP, decision makers are expected to evaluate the relative importance of two criteria, which makes it more cumbersome especially when it involves many criteria. Though, the analytical hierarchy process (AHP) has come into existence in varied applications in multi-criteria decision making such as planning and resource distribution and so many other fields (Sarkis and Talluri, 2004; Ngai, 2003).

Most times, the classification and interpretation of criteria weights are differ from one person to another due to the complexity in terms of quantifying the criteria weights. Generally, in a multi-criteria optimization problem, the relative importance of each criterion is measured by its weights. Moreover, alternatives are picked based on various criteria and the weights preference. This is more reason why majority of the multi-criteria decision methods use criteria weights to evaluate the overall scores of the alternatives. There are two main types of classification to ascertain the criteria weights, namely objectives approaches and subjective approaches. In the case of objective approach, criteria weights are determined through some mathematical model with information gathered from each criterion (Aldian and Taylor, 2005). While on the other hand, the subjective approaches, criteria weights are derived from individual opinion or judgment. Usually, subjective preferences of decision makers takes too much time in computing the criteria weights, especially when considering a specific problem without an agreement between decision makers. At this moment, the team members have to come together to reach a compromise before arriving on a final decision. In multi-criteria decision making analysis, the decision makers need to map out a set of relevant questions that will be required in analyzing subjective judgment. According to Saaty (1990), the AHP applies the rules of eigenvector of positive pairwise comparison matrix to derive criteria weights and the decision makers are required to make comparison of the relative importance of two criteria.

2.2.1. Pairwise Comparison of the AHP

Ishizaka and Labib (2011) argued that it is simple and more precise to express one's idea on only two options instead of all alternatives put together. This also allows uniformity cross examine between the various pair-wise comparisons. The pair wise comparisons between the criteria is expressed by numerical judgments based on ratio scale, which is made up of verbal judgments ranging from equal to extreme (equal importance, moderately importance, strong importance, very strong importance, extreme importance) corresponding to the numerical judgments (1, 3, 5, 7, 9), then compromises are made between these values (2, 4, 6, and 8) (Saaty, 1990) as shown in Table 1.

Table1. *Judgment scale/pair wise comparison*

Scale of relative importance (numerical judgment)	Verbal/Logical Judgment	Explanations
1	Equal importance	Two criteria participate equally
2	Equally to Moderately importance	A common judgment is required
3	Moderate importance	Experience and judgment considerably favour one criterion over the other.
4	Moderately to Strong importance	A common judgment is required
5	Strong importance	Experience and judgment strongly favour one activity over the other.
6	Strongly to very strong	A common judgment is required
7	Very strong importance	A criterion that favoured very strongly over the other.
8	Very strong to Extremely	A common judgment is required
9	Extreme importance	To favour one criterion over the other with the highest possibility

Source: Saaty, (1994); Aldian and Taylor, (2005)

Table2. *Scale Preferences on numerical Rating of 1–9 scale*

Verbal judgment for pair comparison (a_{ij})	Numerical Rating	Ratio scale of the pair comparison $(1/a_{ij})$
Equal importance	1	1 (1.000)
Equally to Moderately	2	1/2 (0.500)
Moderate importance	3	1/3 (0.333)

Moderately to Strong	4	1/4 (0.250)
Strong importance	5	1/5 (0.200)
Strongly to very strong	6	1/6 (0.167)
Very strong importance	7	1/7 (0.143)
Very strong to Extremely	8	1/8 (0.125)
Extreme importance	9	1/9 (0.111)

The pair-wise comparison scale (a_{ij}) between the two activities (item *i* and item *j*) is as follows:

1-2-3-4-5-6-7-8-9-8-7-6-5-4-3-2-1

$$A = \begin{bmatrix} 1 & a_{12} & & a_{1n} \\ a_{21} & \dots & a_{ij} & \dots \\ \dots & a_{ji} = 1/a_{ij} & \dots & \dots \\ a_{n1} & \dots & \dots & 1 \end{bmatrix} \quad (2)$$

Where a_{ij} is the comparison between element *i* and *j*

The preference ratio scale for pair-wise comparisons of two items or criteria ranges from the maximum value 9 to 1/9 (0.111 in decimal from). Assuming a_{ij} correspond to the comparison between item-*i* and item-*j*. And if criterion-*i* is 7 times (very strongly) more important than criterion-*j*, then the comparison $a_{ij} = 1/a_{ij}$ = 1/7 (0.143) which is the reciprocal value for the paired comparison between both criteria. Once the pair comparison is completed, an eigenvector is estimated. The eigenvector represents the priority vector where by the criteria weights are subject to the criteria being considered. Eigenvectors are derived from the eigen values of normalized measures (i.e., the proportion of the row/column). Normalization put the factors on a common or dimensionless scale ranging from 0 to 1. However, the highest eigen value gives a measure of consistency matrix, and if the matrix is perfectly consistent, then the transitivity rule in equation (3) holds for all comparisons.

$$a_{ij} = a_{ik}.a_{kj} \quad (3)$$

But when the largest eigen value from the comparison matrix far beyond the number of criteria being compared, then inconsistencies is bound to occur. The most creative task in making a decision is to choose the factors that are important for that decision. In the AHP, the factors that are carefully considered are arranged in a hierarchical structure ranging from the main goal to criteria, sub-criteria and alternatives in Sequential levels. Arranging the goals, attributes, issues, and stakeholders in a hierarchy serve two purposes. This helps the decision maker to assess if the issues or problem in each level is of the same order of magnitude so that decision maker can compare such homogeneous elements accurately. However, the AHP procedure is made up three primary functions of the following

However, the AHP procedure is made up three primary functions of the following steps.

- Structuring of the problem into a hierarchy: This shows an order of arrangement of property at the top level as the goal being compared with the alternatives to judge which one that is more influenced.
- Comparative Judgment: This involves question being asked in comparing two criteria on how important is one criterion with respect to the other. The purpose is to measure the relative importance of the criteria to the overall goal.
- Synthesis of the priorities: The calculated priorities of each criteria of the hierarchy are recorded by computing the overall score for each alternative.

2.3. Priorities Derivation and Weight Aggregation

The main objective is to find a set of priorities $P_1,\dots,P_n$ such that the ratio of P_i / P_j match the comparisons a_{ij} in a consistent matrix and whenever slight inconsistencies are introduced, priorities tend to vary only slightly. This method is based on three steps (Ishizaka and Labib 2011).

1. Sum the elements of each column *j*

$$\sum_{i=1}^{n} a_{ij} \tag{4}$$

Divide each value by its column sum

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{5}$$

Calculate the mean of row i

$$P_i = \frac{\sum_{j=1}^{n} a'_{ij}}{n} \tag{6}$$

Using equation (4), (5) and (6), the priority weight for criterion j by each team member is given by equation (7)

$$W_j = \frac{1}{n}\sum_{j=1}^{n}\left[\frac{a_{ij}}{\sum_{k=1}^{z} a_{ij}}\right] \qquad k = 1, 2, \ldots, z; \quad j = 1, 2, \ldots, n \tag{7}$$

The weight aggregation of group decision making is usually account for possibly different opinions of members of the group. There are two basic methods according to Forman and Peniwatti (1998) to aggregate the opinion of each team member and derive a set of priorities, P_i . These are:

- Aggregation of individual judgments (AIJ) and
- Aggregation of individual priorities (AIP).

These two methods differs slightly in terms of how the aggregation is made, In aggregation of individual judgments, the aggregation occurs before the derivation of the priorities while for Aggregation of individual priorities, the aggregation is made after the derivation of the individual priority vectors. With respect to this study, aggregation of individual judgments (AIJ) was adopted for the weight aggregation of the respondent. The design team develops the paired comparison of each criteria and search for ways of computing the normalized eigenvector that identified the most important factor. Eigenvectors are derived from the eigen-values of normalized measures (i.e., the proportion of the row/column factors divided by the row/column sum).

3. NUMERICAL EXAMPLE

In this section, an armature direct current motor was use to prioritized the criteria preference using the two approaches. In the design of an armature direct current electric motor, the armature coil is a very important component that functions as a metallic housing where the field windings are wound. An armature is usually referred to one of the important electrical components of an electro-mechanical machine – usually in form of a motor or generator. The other component of the armature is the field winding, also referred to as field magnet. The specific function of the ‘field’ component is simply to create a magnetic field (magnetic flux) for the armature to act on, so this component can either be permanent magnets or electromagnets formed by a conducting coil. Table 3 shows a list of screened alternatives materials. The criteria responsible for the design and manufacture of an armature core are Density (D) - (g/cm^3); Yield strength (YS) – (MPa); Ductility (DU) – (%); Hardness (H) - (Rockwell B); Electrical resistivity (ER)-(microΩ-cm); and Cost of base material (C) - ($/kg). Also, the material property data for the armature core is shown in Table 4. The team used AHP and NGT to decide which material is most appropriate to produce the armature core of a d.c motor based on the criteria that was presented for consideration. The team then weighed and prioritized the alternatives accordingly. The first step in the analytic hierarchy process was to set up the problem. This is done by deciding the structure that best represented how the materials could be compared over the criteria used for the evaluation. Table 4 summarized the criteria and material choices the team considered.

Table3. *List of Alternative materials*

Alternative Materials	Code
AK Steel TRANS-COR H_O CARLITE, Grain oriented electrical steel	A1
AK Steel DI-MAX M-47 Non-oriented electrical steel	A2
AK Steel CARLITE M-4 Grain oriented electrical steel	A3
AK Steel DI-MAX HF-10 Non-oriented electrical steel	A4
AK Steel CARLITE M-5 Grain oriented electrical steel	A5
AK Steel DI-MAX M-36 Non-oriented electrical steel	A6

Table4. *Material Properties Data for an Armature Core*

Alt. Mat.	**Criteria/Attributes**					
	D	**YS**	**DU**	**H**	**ER**	**C**
A1	7.65	345	11	83	50	17.13
A2	7.75	269	34	61	37	10.06
A3	7.65	311	9	81	51	12.85
A4	7.65	350	20	78	56	17.25
A5	7.65	331	9	81	51	15.12
A6	7.70	290	30	64	43	5.30

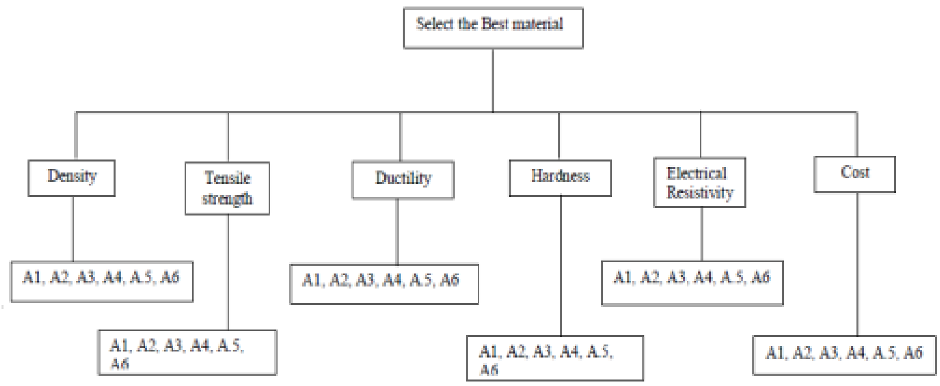

Fig1. *Hierarchy of attributes and alternative material decisions*

4. Result and Discussion

The top level in Fig.1 shows the overall goal of the hierarchy "Choose the Best material". The second level lists the criteria and the third level shows the alternative materials decisions. With respect to the objective (the best material for an armature core for a d.c machine), the resultant aggregation of the various individual respondent on applying Aggregation of Individual Judgment approach (AIJ) using Equation (7) is as presented in a 6x6 matrix as shown in Table 5.

From Table 5, by dividing each column-entry by its respective column sum and applying equation (6) yields the eigenvector (prioritized judgment) as presented in Table 6.

Table5. *Pairwise comparison matrix for the criteria*

	Criteria					
	D	YS	DU	H	ER	Cost
D	1	0.698	1.073	0.52	0.73	0.506
YS	4.531	1	2.938	0.851	1.47	3.213
DU	1.688	0.53	1	1.147	0.705	1.364
H	5.416	2.854	3.816	1	3.208	4.25
ER	4.031	2.925	4.656	1.021	1	4.281
Cost	3.563	1.081	1.885	0.278	0.696	1
Column Sum	**20.23**	**9.087**	**15.37**	**4.817**	**7.808**	**14.61**

Table6. *Prioritized judgment of the criteria (Relative importance)*

	D	YS	DU	H	ER	Cost	Prioritized judgment
D	0.049	0.077	0.07	0.108	0.093	0.035	**0.072**
YS	0.224	0.11	0.191	0.177	0.188	0.22	**0.185**
DU	0.083	0.058	0.065	0.238	0.09	0.093	**0.105**
H	0.268	0.314	0.248	0.208	0.411	0.291	**0.290**
ER	0.199	0.322	0.303	0.212	0.128	0.293	**0.243**
Cost	0.176	0.119	0.123	0.058	0.089	0.068	**0.105**

The computed value of 0.072 represents criteria weight for row-1 taken as Density (D), thus row-2 through row-6 can be shown in equation 8.

$$W_j = \begin{matrix} D \\ YS \\ DU \\ H \\ ER \\ Cost \end{matrix} \begin{bmatrix} 0.072 \\ 0.185 \\ 0.105 \\ 0.290 \\ 0.243 \\ 0.105 \end{bmatrix} \tag{8}$$

Where D = Density; YS = yield strength; DU = Ductility; H = Hardness; ER = Electrical resistivity; C = Cost

The analysis from the expert opinion shows that hardness is most important for the design of an armature core of a direct current machine follow by electrical resistivity and cost with 29.0, 24.3, and 10.5 percent respectively.

However, the relative importance or criteria preference for an armature core of a d.c machine using the Modified nominal group technique in equation (1) is shown in equation (9). The criteria relative ranks were independently assigned by individuals from a team of twenty-eight (28) professional design engineers comprising of 11– Mechanical Engineers (ME), 7- Production/Industrial Engineers, 6- Electrical Engineers, and 4- Agricultural Engineers participated in the modified nominal group technique (see Appendix A).

$$W_j = \begin{matrix} D \\ YS \\ DU \\ H \\ ER \\ Cost \end{matrix} \begin{bmatrix} 0.172 \\ 0.179 \\ 0.165 \\ 0.212 \\ 0.308 \\ 0.209 \end{bmatrix} \tag{9}$$

The criteria priority rating shows that Electrical resistivity is the most important for the design of armature core follow by hardness and cost with 30.8, 21.2 and 20.9 percent respectively.

The armature core is usually made of laminated iron or steel to reduce the induced eddy current to the barest minimum ad subsequent heating. This is more reason why the modified NGT has distinguished the electrical resistivity as the most important criteria when selecting material for the armature core. Moreover, resistivity is a fundamental property in the design of an armature core because it signifies how strongly a given material opposes the flow of electric current; this applies that a low resistivity material is required which indicates a material that readily allows the movement of electric charge. In view of this, the modified NGT has identified the electrical resistivity as the most important criteria among other criteria selected for consideration as compared to the AHP approach having hardness as the most preferred as indicated in Table 7 and Figure 2.

Table7. *AHP versus NGT Criteria preference*

Criteria	AHP Criteria Preference	Value in (%)	Modified NGT Criteria Preference	Value in (%)
D	0.072	(7.2)	0.172	(17.2)
YS	0.185	(18.5)	0.179	(17.9)
DU	0.105	(10.5)	0.165	(16.5)
H	0.29	(29.0)	0.209	(20.9)
ER	0.243	(24.3)	0.308	(30.8)
Cost	0.105	(10.5)	0.209	(20.9)

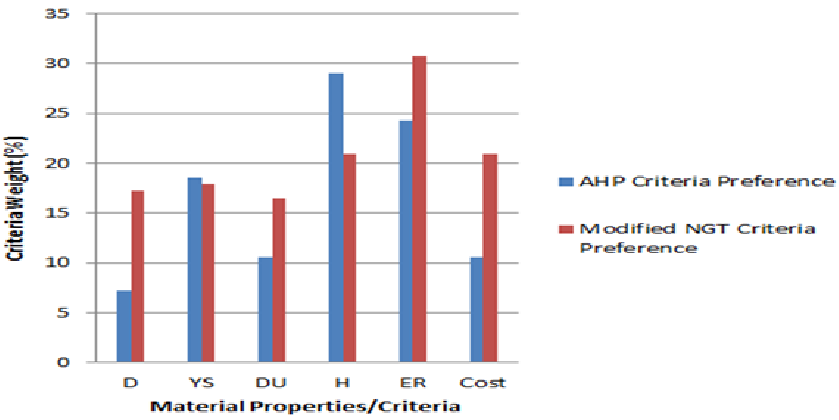

Fig2. *Graph of criteria preference of AHP and modified NGT*

4.1. Limitations of the AHP

Some of the drawbacks in AHP could be attributed to the following:

- The arrangement of the hierarchy structure strongly depends on the practical problem in question;
- Compromise may need to be reached in summative individual judgments to form the pair-wise comparison matrices;
- The final outcome depends not only on the quality of the data given but also on knowledge, experience and judgments of decision makers.

In addition, using AHP model in assigning weights depends on the values and judgments of individuals and team requires much more subjective information from the decision maker and the weights obtained from the pairwise comparison are strongly criticized for not reflecting people's view as expected. Also, data collection and the entering the data using pair comparison matrix are sometimes difficult and tedious, and as the levels of hierarchy increases, the difficulty and time it takes to synthesize weights also increases.

5. Conclusion

The modified nominal group technique and analytical hierarchy process are two weighting approaches being suggested which helps in optimization process of any engineering related decision making from among a large number of available alternatives for a given engineering product.

Criteria prioritization was considered with the two weighting approaches and the results shows that the modified nominal group technique considers electrical resistivity as the most preferred property, while in the case of analytical hierarchy process, hardness is chosen as more appropriate.

Appendix A

Relative Score of Design Specification-related Material Attributes for the Armature Core

S/N	Individual team members, (k)						
		D	YS	DU	H	ER	C
1	K1	5	3	4	2	7	6
2	K2	6	7	5	4	3	1
3	K3	2	7	1	6	8	5
4	K4	5	3	2	1	8	6
5	K5	1	5	2	3	7	4
6	K6	2	4	1	5	7	3
7	K7	1	3	2	4	7	5
8	K8	5	4	1	6	8	3
9	K9	1	4	2	6	7	5
10	K10	1	4	5	3	8	6
11	K11	4	3	6	2	8	1
12	K12	1	4	3	5	8	2
13	K13	7	6	2	3	4	8

14	K14	3	2	7	6	8	4
15	K15	1	3	6	4	8	5
16	K16	8	5	4	6	2	3
17	K17	3	6	5	7	4	1
18	K18	6	5	4	3	2	8
19	K19	1	2	3	7	5	8
20	K20	5	3	1	4	6	8
21	K21	4	1	2	6	5	7
22	K22	4	3	5	6	7	1
23	K23	6	7	8	1	2	5
24	K24	6	7	2	3	1	5
25	K25	7	4	2	1	8	6
26	K26	5	4	1	2	8	6
27	K27	3	4	8	1	5	2
28	K28	4	2	5	6	8	1
		101	**105**	**97**	**123**	**181**	**123**

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