MINERAL POTENTIAL MAPPING OF COPPER MINERALS WITH GIS

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ABSTRACT:

Lack of a systematic idea for collecting, managing and integrating various geo-spatial data from different sources and in different scales make mineral deposit exploration to be encountered with difficulties. Since most of the information related to mineral deposit exploration activities are geo-spatial, GIS can describe and analyse interactions, to make predictions with models, and to provide support for decision-makers. Steps of mineral potential mapping includes identify mineralization recognition criteria, data preparation and structuring, producing factor maps and combining of factor maps in the appropriate inference networks.

In this research, conventional models for combining factor maps have been investigated and index overlay and fuzzy logic models were selected in mineral deposit exploration in detailed stage. Also an integration model using of appropriate models have been proposed. For experimental test, the mineral potential map of Rigan Bam copper deposit in the south east of Iran, with appropriate methods in different inference networks have been produced and 3 appropriate inference networks (one network by Fuzzy Logic model and two networks by integrated model) are selected. Results of three-selected network are in a good accordance with drilling results (%75). Proposed model in Rigan Bam deposit capability with required variation can be used for mineral potential mapping in other deposit.

1. INTRODUCTION

Mineral exploration is a multi-stage activity that begins at a small scale and progresses to large scale. In each stage, topographical, geological, geochemical, geophysical data collected, processed and integrated. After analysing each stage produced mineral potential map and the study area becomes smaller.

Mineral potential mappig with using of conventional methods are very difficult and sometimes impossible. Geographical Information System (GIS) has potential for storing, updating, retreiving, displaying, processing, analysing and integration of different geo-spatial data. In order to overcome difficulties such as: large mass of data, existence of data in the analogue form, non-existence of stanards and related directions for collecting, managing and processing the data, differnet environments for storing and processing, non-existence of an environment for integrating data into conventional models in mineral deposit exploration, using of GIS is essential.

In this paper, after an introduction, Steps of Mineral potential mapping is outlined in section 2. section 3 outlines the conventional models with can be used for Mineral potential mapping. Evaluation of appropriate models in Rigan Bam copper deposit are presented respectively in the section 4. And finally the paper is concluded in section 5.

2. MINERAL POTENTIAL MAPPING

In mineral deposit exploration the divers maps, each having particular specifications, are collected, processed and integrated. After analysing each stage, mineral potential map is produced. The most important aspect of mineral deposit exploration is the mineral potential mapping composing of following steps:

- Identifying mineralization recognition criteria
- Data preparation and structuring
- Producing factor maps
- Combining of factor maps in the appropriate inference networks.

Mineralization recognition criteria is identified based on mineral deposit model (conceptual model) and expert knowledge. In conceptual modeling of copper deposite exploration, total mineralization recognition criteria is appointment and relation between factors (criteria) are defined and presented in an ERD (Entity Relationship Diagram). Then all the appropriate data gatherd into a GIS environment. In GIS the input layers are processed, based on the following functionalities, and the factor map is extracted.

- Map reclassification
- Producing Proximity Map
- Operation on attribute tables
- Spatial, topological and geometrical modeling
- Producing Geochemical and geophysical anomaly map
- Assigning appropriate weight to each factor
- Converting factor maps format to raster
- Producing intermediate factor map

For example a geological map generalized into smaller number of map units or classes. Also contact from the geological map is selected and buffered, to produce aproximity map. Conceptual modeling and knowledge driven, helps in data modeling, selecting features to be enhanced and extracted as evidence (factor), and deciding how to weight the relative importance of evidence in estimating mineral potential. Interpretation of spatial inter-relationship between geospatial data in weighting of spatial phenomena is essential.

Factor maps can be combined by using of conventioal models in appropiate inference network. After section outlines the conventional models with can be used for Mineral potential mapping.

3. DESCRIPTION OF CONVENTIOAL MODELS

Different models exist for mapping mineral potential. These models are based on data-driven and knowledge-driven. In this section, conventional models for integrating data in mineral deposit exploration are investigated.

Bolean modelling involves the logical combination of binary maps resulting from the application of conditional AND and OR operators. In practice, it is usually unsuitable to give equal importance to each of the criteria being combined. Evidence needs to be weighted depending on its relative significance. Expert knowledge can not interfere in this model.

In **Weight of Evidence models** mineralization recognition creteria by using the known mineral occurance (control points) and statistical methods (Baysian theory), were wieghted and integrated. This method only application in regions where the response variable (e.g. distribution of known mineral occurrences in the case) is fairly well known. This method is not always applicable in mineral deposit exploration in detailed stage but this model in the small scale is approprite method.

In **Index overlay** method, each class of every map is given a different score, allowing for a more flexible weighting system and the table of scores and the map weights can be adsjusted to reflect the judgment of an expert in the domain of the application under consideration.At any location, the output score, S ,is defined as (equation 1)

$$S = \frac{\Sigma W_i A_i}{\Sigma W_i} \qquad (1)$$

Where wi is the weight of the i-th map, and Ai is i-th map. The greatest disadvantage of this method probably lies in its linear additive nature.

In the **Fuzzy Logic** method, total of sheet maps (fuzzy membership) based on the significance distance of features are weighted (for each pixel or spatial position particular weight between 0 to 1 is appionted). Five operators that were found to be useful for combining exploration datasets, are the fuzzy AND, fuzzy OR, fuzzy algebric product, fuzzy algebric sum and fuzzy gamma operator (Bonham earter, 1994). These operatore are briefly reviewed here.

The **fuzzy AND** operation is equivalent to a Boolean AND operation on classical set. It is defined as (equation 2)

$$W_{\text{Combination}} = MIN(W_A, W_B, W_C, ...) \qquad (2)$$

Where W_A , W_B ,… is the fuzzy membership values for maps A, B, … at a particular location. This operation is appropriate where two or more pieces of evidence for a hypothesis must be present together for the hypothesis to be accepted.

The **fuzzy OR** is like the Boolean OR operation.This operator is defined as (equation 3)

$$W_{\text{Combination}} = MAX(W_A, W_B, W_C, ...) \qquad (3)$$

This operatore where favorable evidences for the occurrence of mineralization are rare and the presence of any evidence may be sufficient to suggest favourability.

The **fuzzy algebric product** is defined as (equation 4)

$$W_{\text{Combination}} = \prod_{i=1}^{n} W_i \qquad (4)$$

Where Wi is the fuzzy membership values for the i-th (i= 1,2…,n) maps that are to be combined. The combination fuzzy membership values is alwayes smaller than ,or equal to, the smallest contibuting fuzzy membership value, and is thus , 'decreasive'.

The **fuzzy algebric sum** operator is complementary to the fuzzy algebric product, and is defined as (equation 5).

$$W_{\text{Combination}} = 1 - (\prod_{i=1}^{n} (1 - W_i)) \qquad (5)$$

The result of this operation is alwayes larger than , or equal to, the largest contributing fuzzy membership value. The effect is thus 'increasive'. Two or more pieces of evidence that both favour a hypothesis reinforce one another and the combined evidence is more supporitve than either piece of evidence taken individually

The **fuzzy gamma** operation is defined in term of the fuzzy algabric product and the fuzzy algabric sum by (equation 6)

$$\mu_{Combinaticn} = (Fuzzy\ Agabric\ Sum)^{\gamma} * (Fuzzy\ \text{Algabric Produet})^{1-\gamma} \qquad (6)$$

γ is a parameter chosen in the range (0,1), (Zimmermann and Zysno, 1980). Judicious choice of gamma produces output values that ensure a flexible compromise between the 'increasive' tendencies of the fuzzy algabric sum and the 'decreasive' effects of the fuzzy algabric product.

Evidence map can be combined together in a series of steps, by using an inference network. The inference network an important means of simulating the logical thought processes of an expert. Concerning the rule of conceptual modeling, the expert knowledge, existing data and characters of the models for combining factor maps, Index Overlay and Fuzzy Logic models were selected in mineral deposit exploration in the detialed stage. Also integrated of Boolean operation, Index Overlay and Fuzzy Logic models is checked and result of this model is investigated.

4. CASE STUDY

The area of Rigan Bam is located at the 80 km south of the Rigan and 175 km southwest of the Bam city in Iran. This area is a small part of a volcano-plutonic rocks operating in NW-ES direction. The locatin of the area as well as ils geological map is illustrated in figure 1. Based on study discaussed on section 3, the mineralization recognition creteria(factors) of porphyry copper mineral deposit of Rigan Bam is appointed.

With processing of input data, which was discaussed on section 3, factor maps are prepared. Figure 2 and Tabel 1 shown the factor maps and the weighting for porphyry copper mineral deposite of Rigan Bam respectively

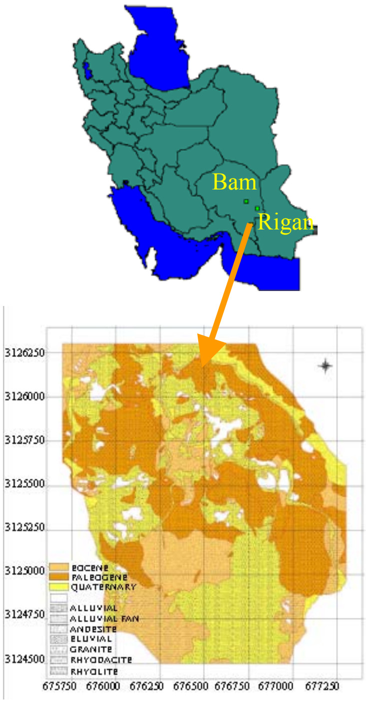

Figure 1 : Geology map of Selected study area
(Rigan Bam)

Table 1 : Factor Maps weighting table of porphyry copper mineral deposite of Rigan Bam

Host rock type factor map	Weight	Alteration factor map	Weight
Granite Granite-Granodiorite	0.9 0.7	Phylic silicification Prophylitic Iron oxide Argillic	0.9 0.8 0.4 0.8 0.4
mineralization factor map	Weight	fault factor map	Weight
mineralization occurrence polygons Buffer 50 meter Buffer 100 meter Buffer 600 meter	0.81 0.63 0.45 0.09	Buffer 50 meter Buffer 100 meter Buffer 150 meter Buffer 200 meter Buffer 800 meter	0.63 0.49 0.35 0.21 0.07
dyke factor map	Weight	Granite- diabase rock type factor map	Weight
dyke polygons Buffer 100 meter Buffer 200 meter Buffer 300 meter Buffer 600 meter	0.35 0.42 0.49 0.56 0.07	rock type polygons Buffer 100 meter Buffer 200 meter Buffer 300 meter Buffer 600 meter	0.35 0.42 0.49 0.56 0.07
andesite-toff-dasite rock type factor map	Weight	Additive index Cu-Zscore+Mo-Zscore factor map	Weight
rock type polygons Buffer 100 meter Buffer 200 meter Buffer 300 meter Buffer 600 meter	0.35 0.42 0.49 0.56 0.07	Anomaly area Medium area Background	0.81 0.54 0.09
metal factor zone	Weight	magnetic intensity zone	Weight
Anomaly area Medium area Background	0.81 0.54 0.09	Anomaly area Medium area Background	0.54 0.36 0.06

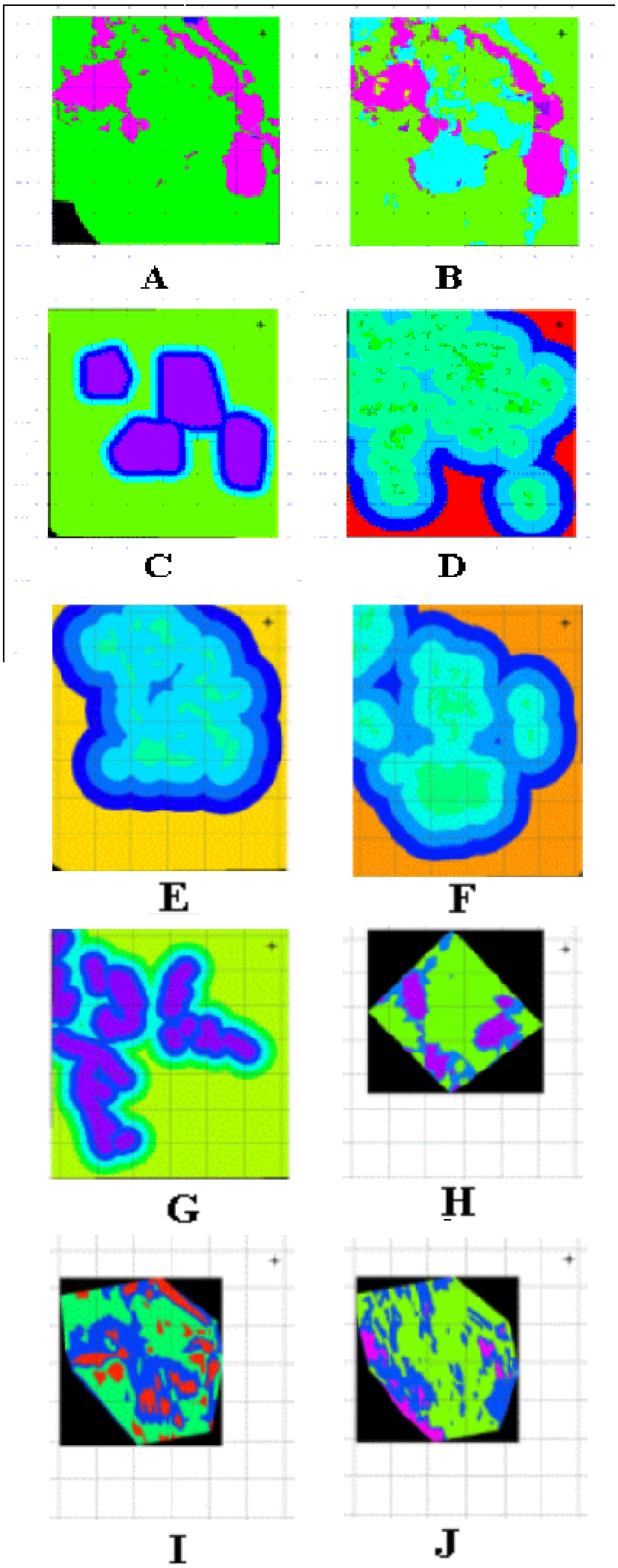

figure 2: Factor maps porphyry copper mineral deposite of Rigan Bam:

A) granite\ granite-granodiorite rock type B) Alteraton C) mineralization occurance D) dyke E) Granite- diabase rock type F) andesite-toff-dasite rock type G) fault in NW-SE and NE-SW azimuth H) additive index Cu-Zscore+Mo-Zscore I) magnetic intensity zone J) metal factor zone

The factor maps of this area is produced using fuzzy logic, index overlay and integrated methods in 16 different inference networks. Schematic inference network and approprite operators for generating mineral potential map of porphyry copper mineral deposite of Rigan Bam is shown in figure 3 and table 2.

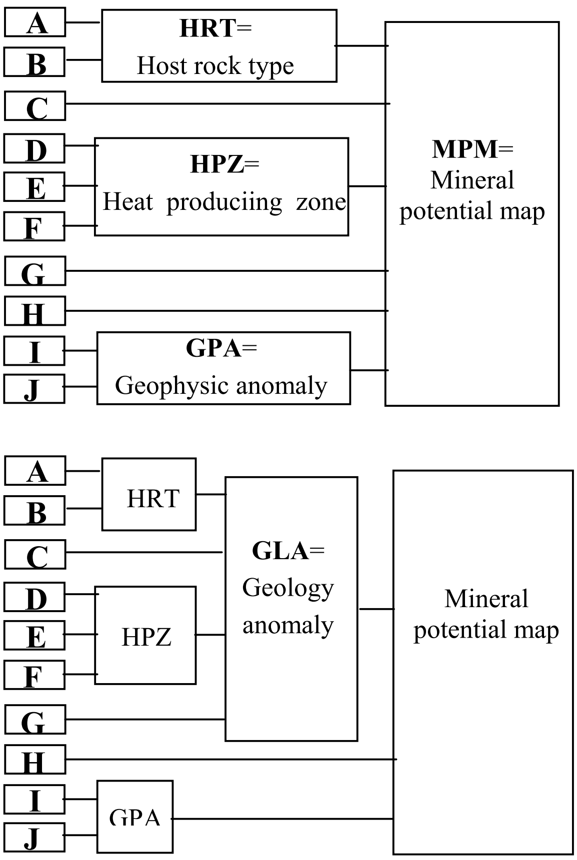

Figure 3: Schematic Inference Networks for generating mineral potential map of porphyry copper mineral deposit of Rigan Bam

16 Mineral potential maps for porphyry copper mineral deposite of Rigan Bam are produced. In this stage, these maps with drilling results of porphyry copper mineral deposite of Rigan Bam have been Compared. The field works are illustrated in figure 4 which describes the results of drilling in Rigan Bam. Evaluation of the results of drilling and its comparision with the results of mineral potential map of Rigan Bam is shown in table 3

Table 2: appropriate operators in 16 Inference Networks For Generating Map Mineral potential of porphyry copper mineral deposit of Rigan Bam

Model	**Host rock type**	**Heat produciing zone**	**Geophysic anomaly**
1:Index overlay	Index ov.	Index ov.	Index ov.
2:Index overlay	Index ov.	Index ov.	Index ov.
3:Fuzzy logic	F.A.S	F.O.G , γ = 0.6	F.O.G , γ = 0.8
4:Fuzzy logic	F.A.S	F.O.G , γ = 0.6	F.O.G , γ = 0.8
5: Integrated	Index ov.	OR	F.O.G , γ = 0.8
6: Integrated	F.A.S	OR	F.O.G , γ = 0.8
7: Integrated	Index ov.	OR	F.O.G , γ = 0.8
8: Integrated	F.A.S	OR	F.O.G , γ = 0.8
9: Integrated	Index ov.	OR	F.O.G , γ = 0.8
10: Integrated	F.A.S	OR	F.O.G , γ = 0.8
11: Integrated	Index ov.	OR	F.O.G , γ = 0.8
12: Integrated	F.A.S	OR	F.O.G , γ = 0.8
13: Integrated	Index ov.	OR	F.O.G , γ = 0.8
14: Integrated	F.A.S	OR	F.O.G , γ = 0.8
15: Integrated	Index ov.	OR	F.O.G , γ = 0.8
16: Integrated	F.A.S	OR	F.O.G , γ = 0.8

Model	Geology anomaly	Mineral potential map
1:Index overlay	-	Index overlay
2:Index overlay	Index overlay	Index overlay
3:Fuzzy logic	-	F.O.G , γ = 0.85
4:Fuzzy logic	F.O.G , γ = 0.9	F.O.G , γ = 0.85
5: Integrated	Index overlay	Index overlay
6: Integrated	Index overlay	Index overlay
7: Integrated	F.O.G , γ = 0.9	Index overlay
8: Integrated	F.O.G , γ = 0.9	Index overlay
9: Integrated	Index overlay	F.O.G , γ = 0.9
10: Integrated	Index overlay	F.O.G , γ = 0.9
11: Integrated	F.O.G , γ = 0.9	F.O.G , γ = 0.9
12: Integrated	F.O.G , γ = 0.9	F.O.G , γ = 0.9
13: Integrated	-	Index overlay
14: Integrated	-	Index overlay
15: Integrated	-	F.O.G , γ = 0.9
16: Integrated	-	F.O.G , γ = 0.9

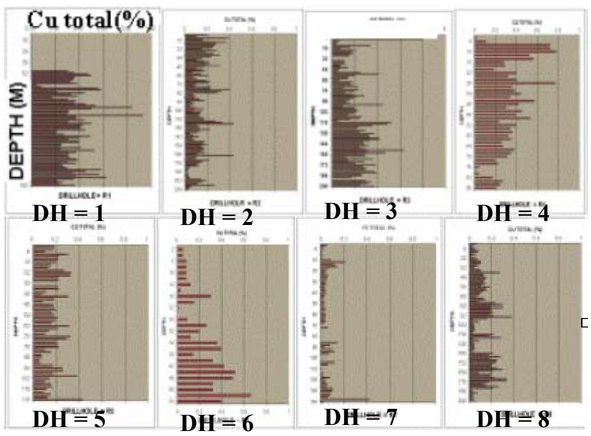

Figure 4: Profile of variation copper percent in depth porphyry copper mineral deposit of Rigan Bam drillholle

Table 3: Results of comparing and evaluation of the result of drilling and the results of mineral potential map of Rigan Bam by applying approprite inference networks

		Fuzzy logic method	
NO. Drillhole	Class of Drillhole	Weight DHM=4	Evaluate
1	Best	0.86	-
2	Weak	0.41	+
3	Medium	0.82	+
4	Medium	0.70	+
5	Weak	0.74	-
6	Medium	0.86	+
7	Weak	0.0	+
8	Weak	0.64	+
Sum		6	

	Integrated method		Integrated method	
NO. DH	Weight DHM=6	evaluate	Weight DHM=10	evaluate
1	0.78	-	0.90	+
2	0.38	+	0.51	+
3	0.72	+	0.84	+
4	0.58	-	0.73	+
5	0.68	+	0.81	-
6	0.87	+	0.96	-
7	0.0	+	0.0	+
8	0.59	+	0.67	+
	6		6	

As can be seen in table 3, three appropriate inference networks (I.N) were selected (one of the Fuzzy Logic network and two of the integrated networks). Results of three selected networks are in a good accordance with drilling results (%75). Mineral potential maps of this area produced by the appropriate inference networks are shown in figures 5.

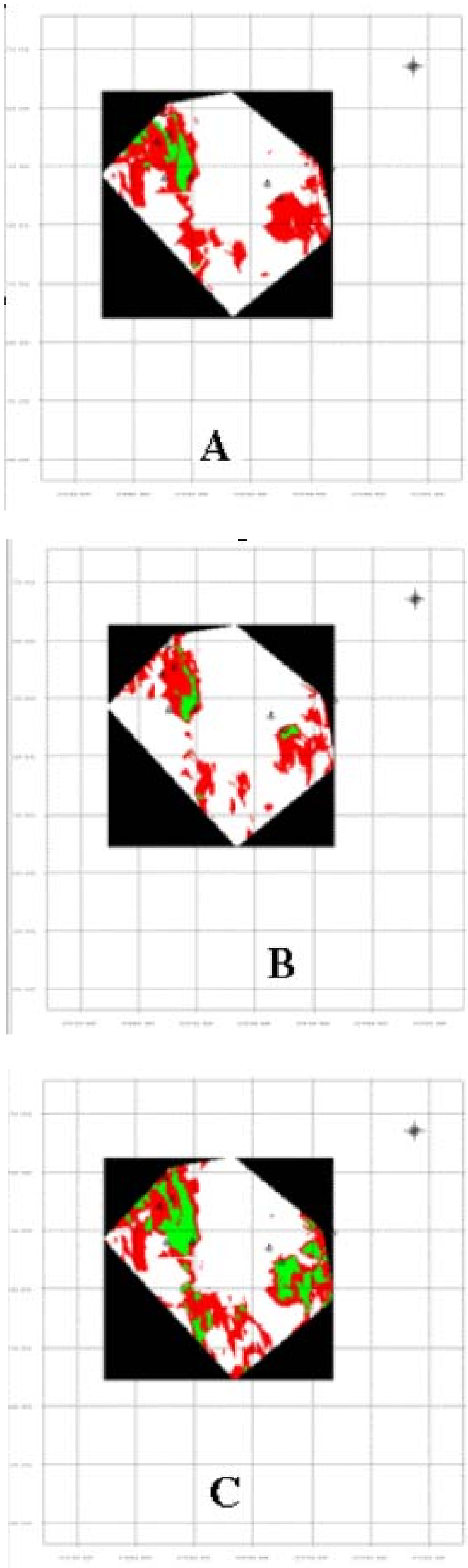

figure 5: Map Mineral Potential of porphyry copper mineral deposite of Rigan Bam
A: Fuzzy Logic method (I.N= 4)
B: Integrated method (I.N=6)
C: Integrated method (I.N=10)

5- CONCLUSION

Since most of the information related to mineral deposit exploration activities are geo-spatial, GIS has potential for storing, updating, retreiving, displaying, processing, analysing and integration of different geo-spatial data. Based on this study, for mineral potential mapping in the porphyry copper mineral deposite of Rigan Bam, 3 approp
rite inference networks were selected (one of the Fuzzy Logic network and two of the integrated networks). Results of three selected networks are in a good accordance with drilling results(%75). The proposed model for porphyry copper mineral deposite of Rigan Bam can be applied for mineral potential mapping in other regions by applying small variation in the model.

6- ACKNOWLEDGEMENT

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