Expert system to select tunnel boring machine (TBM)

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Abstract. This paper highlights the requirements for development of an Expert System for selection of Tunnel Boring Machine (TBM). TBM selection is a very intricate process requiring a great deal of expertise in the field of machine, geographical conditions, cost and many other factors. This paper briefly explains the need and methodology to select a TBM. This selection is done here on various geographical parameters. This preliminary stage developed software completely understands the various rules used and generates a promising result.

Keywords: Expert System, CLIPS, TBM, Knowledge-based system, Artificial Intelligence

1. Introduction:
As the growing demand in the current era of Industrial revolution 4.0, the requirement for the development of the AI infused machines have increased. Expert System is one such field of Artificial Intelligence which was developed in mid-1960’s era and has been the key for fault diagnosis and analysis, thereafter development and research boomed every successive year. An Expert system (ES) can be stated as “A computer based system that imitates the decision taking ability of a human expert under given domain of parameters” [1]. This could be summarised in a lay man terms as, a computer that understands all the needs and based upon the logics and rules takes the right decision just like expert human would have taken under given circumstances. Humans were always enthralled by intelligent machines and by the advent of technology this led to development of machine that just not followed or mimic human subject but could decide its own best action depending upon thousands of circumstances and chances. AI has touched almost all part of life be it health sector, defence sector, education or anything else. Military has started to develop most intelligent war machines that could save lives of soldiers and neutralise all threats ahead. Medical field has also seen its most advanced machines for x-ray, ultrasound or even surgery. Expert system to detect human eye disease has also been developed, which clearly shows how AI has covered almost every sector of our life [2].

ES is one such powerful tool that solves the most intricate problems by unheretical methods [3]. The term Expert system and KBS i.e. Knowledge based system is sometimes used analogously. Knowledge Based System (KBS) or ES can be divided into three main components, it illustrates in ‘Figure1’.
a) **Knowledge Base**: This contains the problem statement and solution in the form of different cases and coded as different set of facts & rules to satisfy various cases depending upon the incoming parameters.

b) **Interface Engine**: This contains the mechanism that deduces the new knowledge or insights from the knowledge base

c) **Interface**: This contains the query part that a user does with the system to interact with the KBS.
‘Figure 2’ is an interface template that encounters the user for the first time while running the software. The user has to select one out of the three options which leads him/her to next query. Input to next query is given by user which leads to next and there on to final result.

Most widely used technique for Expert System development is Rule based programming. Rule comprises of two part “IF” part and “THEN” part. “IF” is the part that has a series of patterns that are to be matched to get the fact/data activated. When the “if” portion is matched, compiler moves to “Then” portion to execute the action. It’s like cause and action [4]-[6]. This software consists of 81 main rules that help to decide the type of TBM to be selected.

TBM selection is completely dependent on the various parameters such as UCS, RQD, Type of soil etc.. These parameters serve as different layers or cases to identify the correct TBM type.

This expert system was developed using CLIPS language platform. CLIPS (C Language Integrated Production System) is a public domain software tool dating back to 1985 developed by NASA [7].

AI use has not only made the problems very easy for a common person but also reduced the expert dependency which saves a lot of money and there by optimising the cost of the project.

2. Problem Statement

Main use of this expert system is to remove any dependency on experts that are hired at high costs to decide the type of TBM that will be used for any given project. TBM selection is dependent on various parameters. Arrangement of all such parameters under a common scale of measurement was the problem statement for this project. After successful arrangement of the parameters in a definite hierarchical order, it was later used to develop the algorithm which was later converted to the Expert System.

Algorithm does not include factors like cost, time duration of project and budget of the project which could be added in second phase of the coding to make it more versatile. This basic version tried to cover one factor at a time. In this software all the geographical parameters have been included.

3. Tunnel Boring Machine

Tunnel Boring Machine (TBM) is also referred as the “mole”. This is a kind of machine that is used to dig into the earth’s crust and make a tunnel for various projects like making an underground metro line or train line, digging a passage under mountains etc. Tunnel cross-section diameter ranges from 1 m to 17.6 m and selection of TBM depends on various factors mainly soil type, rock strata and water content in it. Soil being hard or soft further classifies the TBM into hard rock TBM and soft ground TBM.

These are further classified into shielded and open type for hard rock. Shielded pressure balance machines (SPBM) and Slurry shield are used in case of soft ground condition [8]. This could be summarised by the following ‘Figure 3’.
4. Selection Parameters

This software uses total of 5 parameters to select the TBM type based on these parameters.

a) UCS (Unconfined Compressive Stress)

It is the Strength of a rock or soil sample under unidirectional crushing in tri-axial test without any lateral restraint. Rock categorisation based on the UCS value can be given by the table below [9].

Table 1. UCS Based Rock Classification

| Rock Type               | UCS Value  |
|------------------------|------------|
| Extremely hard rock    | >250 MPa   |
| Very strong rock       | 100-200 MPa|
| Strong rock            | 100-50 MPa |
| Medium strong rock     | 25-50 MPa  |
| Weak rock              | 5-25 MPa   |
| Very weak rock         | 1-5 MPa    |
| Extremely weak rock    | <1 MPa     |

b) Rock Quality Designation (RQD)

RQD is quality of rock core measured in percentage by a rock core greater than 100mm drilled along core hole. It is degree of fracture or jointing of rock mass. Lower than 50% of RQD value states as weathered quality of rock whereas above 75% is termed as good quality of rock. This is clearly understood by the table below [10].

Table 2. RQD Based Rock Classification

| Rock Quality                        | RQD (%) |
|-------------------------------------|---------|
| Very poor (Completely Weathered Rock)| ≤25     |
| Poor (Weathered Rock)               | 25-50   |
| Fair (Moderately Weathered Rock)    | 51-75   |
| Good (Hard Rock)                    | 76-90   |
| Very good (Fresh Rock)              | 91-100  |
c) Joint Spacing
It is the spacing between two layers of rock created due to brittle fracture under tensile loading condition. Joint sets have great impact on the cutter of the TBM hence its consideration while selecting the TBM is very reasonable [11].

d) Surface
This parameter checks for the surface condition.

e) Ground condition
This parameter checks for the ground condition including water content.

5. Algorithm for TBM Selection
Steps 1 to 9 explains various cases and steps involved to make the selection of TBM

1. Start
2. Enter the UCS
3. Case 1
   3.1. Is (UCS > 250) if Yes proceed to 3.2 else goto Case 2
   3.2. Is (RQD > 90) if Yes proceed to 3.3 else goto Case 2
   3.3. Is (JS > 2) if Yes proceed to 3.4 else goto Case 2 [ JS = joint spacing in mm]
   3.4. Is surface very rough if Yes proceed to 3.5 else goto Case 2
   3.5. Is Ground Dry if Yes proceed to 3.6 else goto Case 2
   3.6. Extremely Hard rock and Gripper TBM will be used.
   3.7. Stop
4. Case 2
   4.1. Is (100 < UCS < 250) if Yes proceed to 4.2 else goto Case 3
   4.2. Is (RQD < 90) if Yes proceed to 3.6 else goto 4.3
   4.3. Is (75 < RQD < 90) if Yes proceed to 4.4 else goto Case 3
   4.4. Is (0.6 < JS < 2) if Yes proceed to 4.5 else goto Case 3
   4.5. Is surface less rough if Yes proceed to 4.6 else goto Case 3
   4.6. Ground is Damp, Very hard rock, Single or double shield TBM can be used
   4.7. Stop
5. Case 3
   5.1. Is (50 < UCS < 100) if Yes proceed to 5.2 else goto Case 4
   5.2. Is (50 < RQD < 75) if Yes proceed to 5.3 else goto Case 4
   5.3. Is (0.2 < JS < 0.6) if Yes proceed to 5.4 else goto Case 4
   5.4. Surface is highly weathered proceed to 5.5
   5.5. Is ground wet if yes proceed to 5.6 else goto case 4
   5.6. Strong rock, Single or double shield TBM can be used
   5.7. Stop
6. Case 4
   6.1. Is (25 < UCS < 50) if Yes proceed to 6.2 else goto Case 5
   6.2. Is (25 < RQD < 50) if Yes proceed to 6.3 else goto Case 5
   6.3. Is (0.06 < JS < 0.2) if Yes proceed to 6.4 else goto Case 5
6.4. Surface is slick sided proceed to 6.5
6.5. Is ground dribbling if yes proceed to 6.6 else goto case 5
6.6. Medium Strong rock, EPB TBM can be used
6.7. Stop

7. Case 5
7.1. Is \((5 < \text{UCS} < 25)\) if Yes proceed to 7.2 else goto Case 6
7.2. Is \((5 < \text{RQD} < 25)\) if Yes proceed to 7.3 else goto Case 6
7.3. Is \((\text{JS} < 0.06)\) if Yes proceed to 7.4 else goto Case 6
7.4. Surface is soft proceed to 7.5
7.5. Ground is flowing, weak rock, EPB TBM can be used
7.6. Stop

8. Case 6
8.1. UCS < 5
8.2. RQD < 5
8.3. Very weak rock, SS TBM can be used
8.4. Stop

9. End
User returns to case 1

6. Conclusion
The Expert system generated using the above algorithm generates the satisfying results based on geographical parameters. More parameters are being added in phase 2 to make it more advanced and reliable. A complete user interface for the one such case is being shown in the ‘Figure 4’, to have a gest of how software is going to publish the result.

![Figure 4. User Interface for Case 1](image_url)
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