RESOURCE REQUIREMENTS FOR TUNNEL EXCAVATIONS A GENERALIZED COMPUTER MODEL

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ABSTRACT

Desmg of tunnelling requires the knowledge of many machine/ rock parameters such as rock types, machine capacity, penetration rate, maintenance schedule, etc. Capital investment, resource requirements (labour, material, etc.) and project scheduling will all play an important role in defining the eccncmics of the overall project.

This paper reviews current approaches to designing drilling, blasting, mucking and transportation systems for development of tunnels for mines. A generalized computer model lists the resources needed for different sizes of tunnels in varying rock conditions.

ÖZET

Tünel tasarımı; kayaç tipi, makina kapasitesi, delme hızı, makina bakım programı gibi bir dizi makina/kayaç parametresi üzerine bilgi gerektirir. Sermaye yatırımı, kaynak gereksinimi (işgucu, malzeme, vs.) ve proje planlaması bu konudaki bir projenin tanımlanmasında önemli rol oynayacaktır.

Bildiride, madenlerde tünel açımıyla ilgili delme, patlatma, toprak kaldırma ve taşıma *sistemlerinin* tasarımında mevcut yaklaşımlar *gözden geçirilmekte, çeşitli kayaç şartlarında farklı boyutlardaki tüneller için gereken kaynakların dokumu, genelleştirilmiş bir bilgisayar modeli yardımı ile yapılmaktadır.*

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1. INTRODUCTION

The driving drifts (tunnels) is a very important aspect of underground mining. It is not unusual for the percentage of rock broken during development in a mine, for example sublevel caving, to be as much as 25% of the total (Holmberg, 1982). If one also considers the amount broken for transport, ventilation and exploration drifts, it can be easily understood that the planning and excavation of drifts play a major part in the total economics of the mine.

Increased mechanisation and distances between the shafts and the working areas (average 6.2 km in W. Germany, Athaus, 1985) and also negative impacts on air conditions, when steadily moving to deeper areas, demand larger tunnel areas and longer distances for transportation and carrying new mining equipment. With modern machines, the hard work involved using hand held jack hammers is gone, and a better environment is achieved.

The question, "which method should be used in tunnelling today?" has recieved more attention with the progressive advancement of the tunnelling technology. A wide range of tunnelling options is now available. Depending on the ground conditions, a contractor may opt to excavate using conventional techniques with hydraulic or pneumatic drills, tunnel boring machines, slurry type machines or roadheaders (Eroackway, 1982). Despite the many advantages of using tunnel boring machines, drilling and blasting is normally prefered in most hard mining applications. The trade-offs between the two systems of fragmentation are numerous, highly interactive and tedious to compute manually (Sharp, 1983).

The prime objective of this paper is to develop a model for desk top computer system that will enable the mining engineers to respond to input for drilling and blasting approach.

The parameters considered for the model development are tunnel size, compressive strength of the rock and drilling, blasting, mucking and transportation systems.

2. DRILLING AND BLASTING

2.1. Number of Shotholes Required

The number of holes needed for each rock type is difficult to estimate accurately without field tests. Besides, the rock varies along a tunnel and the number of holes may have to be changed correspondingly. However, it should be worth while trying to optimize the specific drilling, especially in long tunnelling projects.

The number of blastholes needed to distribute the charge mainly depends on,

— type of rock,
— type of explosive,
— hole size (or bit diameter),
— smooth blasting requirements,
— type of cut,
— blasting vibration restrictions (Tamrock, 1982),
— desired material size after blasting.

Hole sizes from 3C.0 mm, 38.00 mm are often considered to belong to the small hole-method, while 41 0 mm 64.0 mm hole sizes belong to the larger-hole method. Figure 1 shows the relationship between number of holes, tunnel area, bit diameter and type of rock.

In the graph, compressive strength (Compst) is examined as one of the parameters that affect the number of blastholes requirement. The other one is bit diameter.

From Figure 1, it is also possible to estimate the quantity of explosive required per round or per cubic meter of advance for the particular rock to be blasted and the face of the tunnel has then to be drilled systematically so that the drilled holes can contain this quantity of explosive. Each hole is charged with a column length of explosive two thirds of its depth.

This graph is constucted for the two sizes of drill bit diameter. One is less than 40.0 mm and the other is gigger than 40 o mm

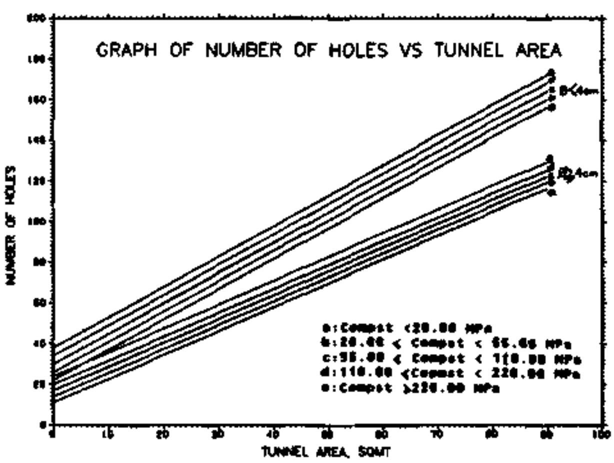

Figure - 1 Graph of number of holes vs tunnel area

As it can be seen from the graph, the weaker the rock (or the less compressive strength) or the bigger the bit diameter, the fewer the holes normally required. The rock type is the critical factor in estimating drilling and blasting effectiveness and economics.

2.2. Rock Characteristics

The classification of rocks for drilling, serves as a job property. It estimates various operating and performance parameters through the medium of index properties and/or visual inspection. Drilling performance can be related to the classification of the rocks to be excavated. In the model Deere-Miller Rock Classificaton (Table 1) iş used in order to estimate penetration rate, drillabilty of the rock and bit life

2.3. Machine Characteristics

There are several types of boring and drilling machines distinguished by the primary breakage motion, percussive, rotary and rotary-percussive. There is also the down-holedrill (D-H-D) type, a percussive drill with the drive machine located directly behind the bit.

Major components of drill machines are the cutting bit, drill pipes or drill steels feed and thrust mechanisms, power sources and the mounitng.

2.4. Bit Life

Bit life is influenced by two mechanisms, breakage and abrasion. As drilling proceeds, the bit losses its sharpness. For high silica rock, resharpening is necesssary after advances of 50 0 ft (15.24 m) to 100.0 ft (30.48 m.) and during this interval penetration rate reductions range from about 5% to 15% respectively (Adler, 1983).

As drilling proceeds, along with periodic resharpening, material is worn by chipping and abrasion, which also reduces the bit gauge.

2.5. Penetration Rate

Rock penetration depends on breakage which must be correlated to a particular failure criterion. Since drilling is dynamic, an energy criteria is used. Toughness is the area under stress-strain curve at failure, and recognizes the role of the strain energy. Table 2 illustrates the performance parameters which were presented by Adler, 1982.

Table 1 - Deere-Miller rock classification (Adler, 1982)

Rock Strength Class	Compressive Strength (psi)	Modulus Ratio	Description
Very High	> 32,000	200-500	Quartzite Diabase Dense Basalts
High	16,000-32,000	200-500 (> 500)	Majority of igneous rocks, stronger metamorphic rocks, well cemented sandstones, hard shales, majority of limestones and dolomites
Medium	8,000-16,000	200-500 (< 200)	Shales, porous sandstones and limestones, schistose metamorphic rocks
Low	4,000-8,000	200-500 (< 200)	Porous or low density rocks (friable sandstone, porous tuff), clayshales, rock salt
Very Low	< 4,000	< 200	Weathered or altered rocks of any lithology

Table 2 - Performance parameters (Adler, 1982)

Rock Toughness Class	Drill Performance Parameters					
	Penetration Rate (fph)				Bit Life (ft.)	
	Percussive	Rotary	Rotary-Percussive	D-H-D	Percussive or D-H-D	Rotary or R-P
Very High	20 - 40	10 - 30	15 - 30	15 - 30	500 - 1500	500 - 1500
High	30 - 50	20 - 30	15 - 50	15 - 30 (60)	500 - 1500	500 - 2000
Medium	30 - 60	30 - 70	40 - 80	-	1500 - 4000 (No D-H-D)	2000 - 5000
Low	85 - 120	70 - 150 (300 - 400)	70 - 160	-	4000 - 10,000 (No D-H-D)	5000 - 20,000
Very Low	Auger, dig, rip, cave, etc.					

Note: Do not use rotary when rock $Si0_2$ content exceeds 50%.
( ) extreme values

Calculation of Hole Depth and Advance Rate

Typs of cut:
— parallel cut,
— burn cut,
— V-cut (Wedge cut),
— various fan cuts (Tamrock)

In the cut, the holes are arranged in such a way that the delay sequence permits the openmg to gradually increase in size until the soppping holes can take over. The holes can be drilled in a series of wedges (V-cut), as a fan, or in a parallel geometry usually cantred around an empty hole.

The choice of the cut has to be made with respect to the type of available drilling equipment ,the tunnel width, and the desired advance. With V-cuts and fan cuts where angled holes are drilled, the advence is strictly dependent upon with of the tunnel (Holmberg).

The principle behind a parallel cut is that small diameter holes are drilled with great precision around a larger hole. The larger hole (empty hole) serves as a free face for the smaller holes, and the opening is enlarged gradually until the stopping holes take over. In this paper, the type of the cut is assumed to be a burn cut.

It is accepted that the advance rate is restricted by the diameter of the cut hole and the deviation for the small diameter blastholes.

Good economics demand maximum utilization of the full hole depth. The equation for the hole (H) is expressed by Holmberg as:

$H = 0\ 15 + 34.lXd — 39.4Xd^2 (m)$ (1)

where d is the empty hole diameter in meters.

Advance rate (I) is;

$I=0.95Xd$ (2)

Equation 1 and 2 are valid only for drilling deviation not exceeding 2%.

3. MUCKING SYSTEMS

In the computer model, two types of mucking systems are considered by examining the tunnel face area, type of muck and job conditions. One of them is Overshot loader (OL) that fills a front mounted by crowding and bucket lifting, passing the loaded bucket over the machine. At the point of discharge, the bucket is stopped suddenly and the load leaves the bucket following the throw trajectory past the rear of the loader. The largest rail bound loaders can clean roadways as wide as 4.0 m from a single track. Wider headings require multiple trackage and the bucket of OL ranges from 0.14 m^3 to 0.59 m^3. The small rail bound loaders can work efficiently in headings as small as 1.8x1.8 m and as large as 14.00 m^2 (Sundeen, 1982).

The other type of the mucking system is Load-Haul-Dump Unit (LHD). LHD vehicles combine certain characteristics of conventional front-end loaders and dump trucks, specially designed for materials handling in underground mining and tunnelling. The design intent is to provide one vehicle with one man, with the vehicle loading itself, hauling the load over or inclined haulageways and dumping the load.

In the model, mucking system is chosen intertactively based on the input tunnel area. For various tunnel areas, the type of mucking system required to be adopted, is given below;

Tunnel Area (m2)	*Mucking System*
^ 3.24 to 8.52	Overshot Loader
> 8.52 to 14.00	Overshot / LHD
> 14.00	LHD

3.1. Productivity of the systems

Productivity of OL varies greatly, depending upon the physical limitations of and in the working area Under optimum conditions, small loaders in a typical rail heading load out from 25.0 to 30 0 m^3/hr, large loaders with up to 0 59 m^3 bucket can laod as much as 110.0 to 120 0 m^3/hr CSundeen, 1982).

LHD productivity depends upon an understanding and application of a number of variable factors that are known as the "job conditions".

The job conditions are a group of factors that affect both the productivity and of the vehicles and the ultimate cost of moving materials. They are divided into three groups-, excellent, average, and severe. As the job conditions approach to excellent, the greater will be the productivity and the lower will be the cost.

Having chosen a mucking system, the program calculates number of cycles per round, total working time, etc. in order to estimate required resources.

4. RAIL HAULAGE SYSTEMS

The principle application of rail haulage in underground mining is in the movement of ore or coal production from near the production areas to a shaft or processing plant and removal of development rock In some cases, such production haulage may end a shaft pocket or slope belt conveyor transfer station depending on the type of mine and the geological placement of the mineral being mined.

4.1. Rail Haulage

The basic reasons for choosing rail haulage are high tonnage production per shift and long distances (Buckeridge, 1982). Projecting a main line haulage for comparision with other systems requires a choice of many variables which are interrelated, such as production rate per shift (or per round for a tunnelling operation), transportation distance, gradients, rail mine cars, high tonnage demands consideration of wider track gauges and area of haulageway. «

The choice of train size'governed by tonnage per round, physical factors of loading and dumping, cycle time and the number of trains that can be operated and safely controlled,

4.2 Size and Specification of Locomotives

Finding the size and specifications for a locomotive may require the consideration of many factors. The first and most important step is to decide on the required locomotive weight necesssary to develop the tractive effort to move the train load. Maximum grade and the load are the input for this calculation.

A locomotive with steel tires on clean dry steel rails can produce a running tractive effort of 26% of its weight. A locomotive should be able to produce approximately 15% more tractive effort than required by the trailing load in order to provide a reasonable acceleration rate (Buckeridge).

4.3. Type of Locomotive

A choice of three types of locomotives is considered diesel, trolley and battery. The first step in choosing an appropriate type is to examine the factors that govern the operation of the haulage system. These include size, disposition, length, gradient and stability of roads, arrangement of pit bottom and duty in terms of time, load and mine car capacity (Green, 1953). Following working principles will sometimes lead to one or other type of locomotive.

a A road which is subject to movement of either floor or roof is unsuitable for trolley locomotives.

b. A road of small size may require enlarging to provide necessary clearance for trolley locomotives, and the cost of this may well be prohibitive.

c. A road with severe gradients is unsuitable for battery locomotives. It may be suitable for trolley locomotives.

d. Deep hot mines may be unsuitable for diesel locomotives.

e. In a mine where sense of smell is important, diesel locomotives may be undesirable (Green).

In the computer model ,type of locomotive is suggested according to interactively answered questions by considering the working principles The statutory gradient limit for locomotive haulage is 1 in 15 (Lunnon, 1976).

5. COMPUTER MODEL

UGDEV is a FORTRAN77 program, developed to calculate required resources of a tunnelling operation. The flowchart of the program is illustrated in Figure 2. The main features of UGDEV are summarized below;

i — It calculates number of blastholes for a given tunnel area, bit diameter and compressive strength of the rock, estimates power for an electro-hydraulic drill rig that can cover the face.

ii — For known rock conditions and type of drilling (Rotary or Percussive), it estimates penetration rate, drilling and blasting time.

iii — The program selects mucking system by considering the area, job conditions and type of muck, calculates mucking cycle and mucking time.

iv — For rail transportation, it calculates weight of locomotive that is capable of carrying the material which is encountered after a round by considering gradient of the road and suggests one of trolley, battery or diesel locomotives for known underground working conditions. Also for calculated weight of locomotive, acceleration, retardation and tractive effort are calculated as well as required weight of rail.

v — Finally, for a given tunnel length, area and working time, the model estimetes required resources such as labour (operation, maintenance), explosive consumption, fuel electricity, detonators etc. It then plots graphs. For this purpose, some routines from the common plotting library at Imperial College were utilized.

6. PROBLEM SENSITIVITY

Ability to change and rerun a problem quickly gives the user the opportunity to investigate how small (or large) changes in specific parameters will affect the overall results.

6.1. Problem Parameters

To illustrate how the model was used, Table 3 gives a set of user defined parameters used in this paper to show how the various problem parameters interact with another.

Following are the basic assumptions to compile the data in Table 3.

Tunnel definition	Rock properties
Length =300.0 m	Rock density = 2.5 t/m^3
Area =10.0m2	Compressive st = 65 0 MPa
Geology = a ^erage	

Drill jumbo characteristics
Type of jumbo = electro-hydraulic
Number of booms = 2
Utility of jumbo = 95%
Availabilty =90%

Drilling characteristics	Rail transportation
Type of drilling = rotary	Type of loco = diesel
Cuthole diameter=6.0cm	Gradient =1 in 27
Bit diameter =3.5 cm	Number of wheels = 4 (locomotive)

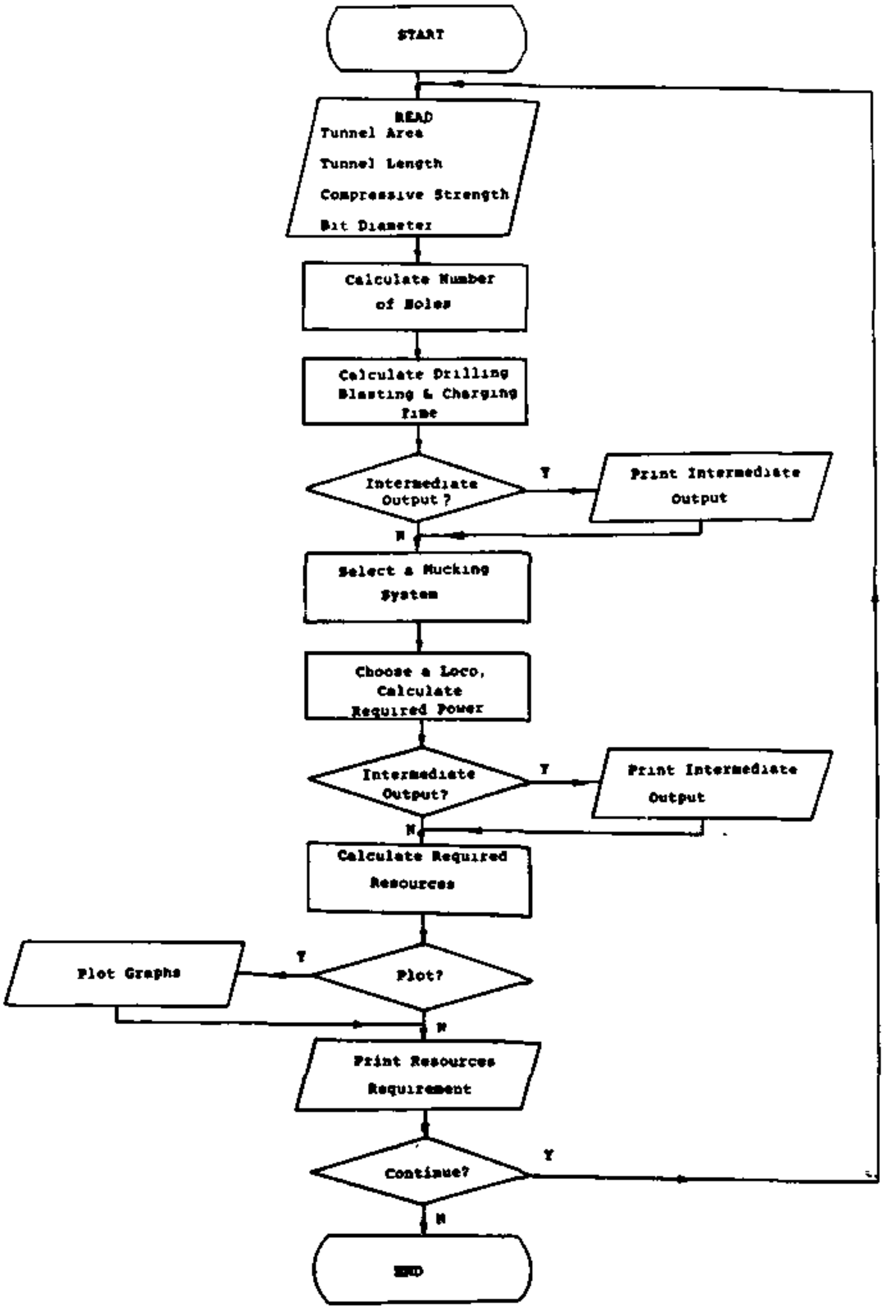

Figure 2 - Generalized flowsheet of resource requirements for tunnel excavation program UGDEV

Table 3 - Sample problem

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+   UNDERGROUND MINE DEVELOPMENT   +
+                                  +
+     BY T.T.OZAN & H.E.K.ALLEN    +
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              INTERMEDIATE CALCULATIONS

   INPUT          ---------------------------          OUTPUT
   ------              NUMBER OF HOLES                --------

AREA  (SQMT.)         = 10.00     NUMBER OF HOLES                =    44
COMP.STRENGTH(MPA)    = 65.00
LENGTH OF TUNNEL      =  300.00
BIT DIAMETER(CM.)     = 3.50
                     DRILLING & BLASTING
                     -------------------

TYPE OF DRILLING        = ROTARY   PENETARATION RATE(M/MIN)      =  .31
DIAMETER OF CUT HOLE(M)=  .060     EXPECTED BIT LIFE(M.)         = 1351.9
AVAILABILITY OF JUMBO   =  .90     DEPTH OF HOLE,M               = 2.1
UTILITY OF JUMBO        =  .95     DRILLING TIME(MIN.P.RND.)     = 168.89
                                   CHARGE&BLASTING TIME(MIN)     =  27.26
                                   ADVANCE RATE(M)               = 2.0
NUMBER OF BOOMS         = 2
                                   POWER OF JUMBO  KW.           =  12.00
                                   POWER OF CARRIAGE MOTOR       =  18.00
                                   TYPE OF EXPLOSIVE             = POLAR AJAX
                           MUCKING
                          ---------

OP.TIME(OVERSHOT,MIN)   =          TYPE OF LOADER                = LHD
TYPE OF MUCK            =          BUCKET VOLUME(CUB.MT)         = 2.7
JOB CONDITIONS(LHD)     = AVERAGE  THEORET.PRODUCTIVITY          =
ROCK DENSITY(TON/CUBMT)= 2.5       NET PRODUCTIVITY(%)           =
DENSITY OF LOOSE MTRL   = 2.1
LHD AVAILABILITY        =  .90     NUMBER OF CYCLES(LOADER)      =  11
LHD UTILITY     (%)     =  .95     MUCKING TIME(P.RND)           =  16.2
NO OF SHIFTS PER DAY    = 3        MATERIAL CARRIED(T/RND)       =  48.79
WORKING HOUR A SHIFT    =  7.0
SPEED OF LHD(KM/HR)     = 13.0

                     RAIL TRANSPORTATION
                     --------------------

GRADE OF ROAD(1 IN )    =  27.0    WEIGHT OF LOCO(TON)           =  2.72
ROL.RES.(KG/TON)        =  9.06    MAX.TRACTIVE EFFORT(KG)       =   679.27
RATIO,CAR WEIGHT/LOAD   =  .20     RETARDING FORCE(FULL)(KG)     =  1194.30
WEIGHT OF CAR(TON)      =  .8      RETARDING FORCE(EMPTY)        =   771.23
MAX.SPEED OF LOCO(KM/HR= 10.00     ACCEL.FULL TRAIN(M/SCSC)      =  .2
                                   ACCEL.EMPTY TRAIN             =  .1
                                   DISTANCE TO ACCEL.(MT.)       =  19.28
                                   DISTANCE TO STOP(MT.)         =  29.85
                                   NUMBER OF CARS                = 13
                                   WEIGHT OF RAIL(KG/M)          =  5.96
                                   NUMBER OF WHEELS(FOR LOCO)    = 4

     TOTAL PROJECT LIFE(DAYS)     =  40
     POWER OF LOCOMOTIVE ,KW.     = 18.49
     RAIL TRANS.TIME(MIN)         = 23.92
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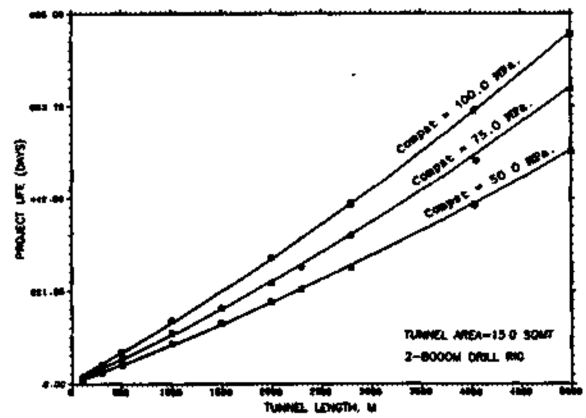

Figure 4 - Graph of project life vs tunnel length

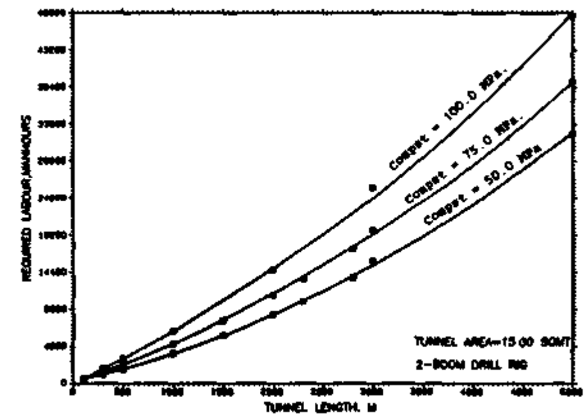

Figure 5 - Graph of required labour vs tunnel length

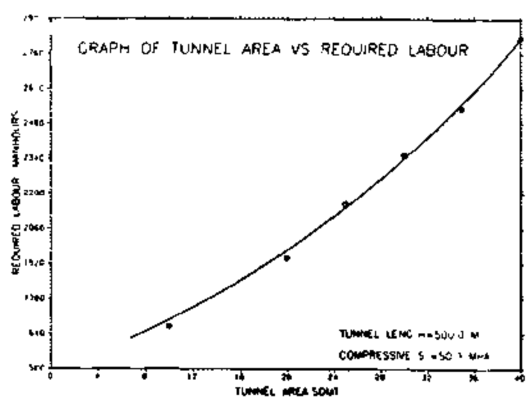

Figure f> - Graph of required labour vs tunnel area

Figure 3 is a graph of project life vs tunnel length. It is observed that at constant tunnel area and compressive strength, the project life increases as the tunnel length increases. The curves become steeper as tunnel length increases. The main reason is the decrease in daily actual working hours due to transportation time spent on travelling to the face. The greater the compressive strength and the greater the tunnel area, the longer the project life.

More resources in terms of labour will be required for longer tunnel length and greater tunnel areas. (See Figure 4 and Figure 5.) Application of more labour and higher capacity machinery than as predicted here could reduce the project life.

Table 4 shows required resurces for the conditions given in Table 3

Table 4 - Required resources

JOB CENTRE	LABOUR(MAN HOURS)				EXPLO. (TON)	DETON-ATOR	FUEL (LT)	ELECT	FILTER	D.BIT	SHANKS	COUPL
	OPERAT.	MAINT	OIL CHANGE	FILTER GREASE								
DRILLING	851.21	33.33	71.33	151.2			1.1	8559	6	11	2	4
BLASTING	74.67				10.12	7226						
MUCKING	82.96	33.33	6.24	13.23			1663		1			
TRANSPORT	122.81	33.33					340					
TOTAL	1231.7	100.0	77.57	164.63	33.8	7226	2004	8559	7	11	2	4

7. SUMMARY

A desk top computer offers an inexpensive tool for testing alternative designs of tunnelling operation for a proposed geologic environment. Comparison of several different pissible changes in an existing mining operation can quickly be evaluated on a computer to rank the alternative changes. The model enables the user to calculate the cost of the operation.

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