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OPTIMISED LAYOUT AND ROADWAY SUPPORT PLANNING WITH INTEGRATED INTELLIGENT SOFTWARE

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ABSTRACT

Experience with knowledge-based systems for Layout planning and roadway support dimensioning is on hand in European coal mining since 1985. The systems SOUT (support choice and dimensioning, 1989), SOUT 2, PLANANK (planning of bolt-support), EXOS (layout planning diagnosis, 1994), Sout 3 (1995) have been developed in close cooperation by CdF[1], INERIS[2], EMN[3] (France) and RAG[4], DMT[5], TH - Aachen[6] (Germany); ISLSP (Integrated Software for Layout and support planning) development is in progress (completion scheduled for July 1996). This new software technology in combination with conventional programming systems, numerical models and existing databases turned out to be suited for setting-up an intelligent decision aid for layout and roadway support planning. The system enhances reliability of planning and optimises the safety-to-cost ratio for :

- deformation forecast for roadways in seam and surrounding rocks, consideration of the general position of the roadway in the rock mass (zones of increased pressure, position of operating and mined panels).
- support dimensioning
  - yielding arches, rigid arches, porch sets, rigid rings, yielding rings and bolting / shotcreting for drifts
  - yielding arches, rigid arches and porch sets for roadways in seam
  - bolt support for gateroads (assessment of exclusion criteria and calculation of the bolting pattern)
- bolting of face-end zones (feasibility and safety assessment; stability guarantee).

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INTRODUCTION

With declining ore grades, exhaustion of near surface reserves and rising labour costs the underground coal and metal mining industry in the European Union requires efficient planning tools that will improve its performance since mechanisation has almost approached 100% so that machine development will only give marginal improvements in performance. Major improvements can only be achieved by the re-development of the whole production process through careful and precise mine planning that will utilise simulation and production system's analysis.

Mine planning involves a variety of disciplines, phases and operations and a multitude of parameters to be considered (e.g. for designing a support system at least 10 parameters must be evaluated that include rock mass structure, rock strength properties, stress analysis, geometry of excavation, rock- support interaction analysis, mine life etc.). Errors in planning are frequent. Within the German coal mining activities they are estimated to be at least 10% in the decisions taken. As a consequence to that mine workings, as an example, are located in highly stressed zones, which means subsequent expensive repairs and maintenance. Furthermore planning errors cause production losses, affect safety and might have environmental impacts by subsidence. These supplementary costs are difficult to quantify.

Accordingly, INERIS and DMT co-operate closely with TU-Aachen and the mining groups CdF and RAG since 1985 on improvements of the planning process in order to avoid the above-mentioned planning errors and resulting costs to a far-going extent.

For fielding and supporting the planning process improved in the intended way, software programs are being developed since the sixties. The more and more widespread use of conventional calculation programs, numerical models, data bases, and programs for 3-dimensional representation of the deposits and the mining infrastructures allow, since the late seventies, significant steps towards improved planning. The planning process was accelerated and made cheaper.

These programs however do not allow consideration being given to the specific know-how and experience of the specialists which is of foremost importance for mine. Therefore, INERIS and DMT work, since 1985, on knowledge based systems for mining. This technique - an artificial intelligence (AI) technique - has been chosen because, in contrast to conventional data-processing algorithms, such a system makes it possible:

- to formalise knowledge and experience,
- to integrate the know-how of the experts and to guarantee that it is coherently implemented,
- to facilitate the updating of this know-how, which is absolutely essential in a context which evolves as the deposit is worked and as technology develops.

Several knowledge-based systems : SOUT (1989), SOUT 2, PLANANK, EXOS (1994) and SOUT 3 (1995) have been developed in close cooperation by CdF, INERIS, EMN (France) and RAG, DMT, TH-Aachen (Germany).

Since early 1996, these knowledge based systems are integrated with conventional calculation programs, programs for 3-dimensional visualisation, databases, and numerical models for rock pressure calculation within an intelligent system for layout and roadway support planning.

Industrial use of this integrated software system is supposed to reduce cost substantially, about all in roadway maintenance, support , and by avoiding production standstill.

SOFTWARE SYSTEMS FOR MINE PLANNING

1 Conventional Programs

A variety of programs for general calculation are a standard use in mine planning since a number of years. Based on longyears underground observation, DMT developed e.g. programs for roadway deformation forecasts. The experience gained in this way and the following treatment of the statistical methods of variance and regression analysis led to empirical formulae describing the roadway deformation as a function of geological (e.g. seam thickness, rock strength) and mining technical parameters (e.g. roadside packing, support backfilling, planning of the roadheading relative to the face advance) and the strata pressure.
Furthermore we should mention here those programs which allow support planning and dimensioning: standing support, bolt support in gates, bolting in baseroads (coalface is starting from base roads) and bolting for securing face ends.

2 Databases for the 3-D representation of the deposit and the mine

In the late sixties, RAG started to gather technical data (in particular in the field of mine surveying) for certain evaluation purposes. These approaches are integrated in the DIGMAP system. This three-dimensional interactive graphic system allows managing and processing the data on existing and planned mine workings and on the deposit. The main activities of that system are mining-specific mapping and deposit evaluation for the survey side of layout planning. Since 1993 that system has been introduced by 100% with RAG.
Several other commercially available databases exists (e.g. SURPAC); CdF is using a company specific 3-D database under AutoCAD.

3 Numerical models

In the context of this application, numerical models are to be understood as representations of the field under investigation - including the mine working- which are in conformity with the dimension and the limiting conditions. In all points of these models the differential equations (or the partial derivations) which govern the physical phenomena involved are solved. This solution is arrived at numerically, by means of various approximation methods mainly associated with appropriate discretisation on the field, a discretisation of certain calculated functions, and to ponominal interpolations of subfields.

A priori this approach is based on analysis and formalisation of the physical reality of the involved phenomena. This approach allows at the present and to certain point to integrate the most complicated aspects of these phenomena as well as their interdependencies, and is trying to be an exact representation of physical reality.
It is possible today, e.g. by finite element methods, to investigate mechanical, elastic, plastic and viscous behaviour, flows, thermal effects, and how to consider anisotropy and heterogeneity.
The capacity of the computer hardware allows, at present, to take on problems applying thousands degrees of liberty either two or three dimensional.

In this field, DMT developed e.g. the software GEDRU, « Gebirgsdruckvorausberechnung : rock pressure forecast » (Figure 1). It is a planning tool which helps to head mineworkings in low-pressure zones of the mine in view of keeping deformation at a minimum.
The calculations are based on three-dimensional finite-differences programs which allow only for vertical shifting. The calculations covers a block with surface area of approximately one square kilometre and a vertical range of 500 meters. This zone may contain up to 10 seams each of them mined or earmarked for mining, over large areas. Coal and rock are supposed to be elastic. In the zones of mining, piecewise, linear correlations between pressure and shifting are assumed (variable by the user according to the kind of stowage practised).

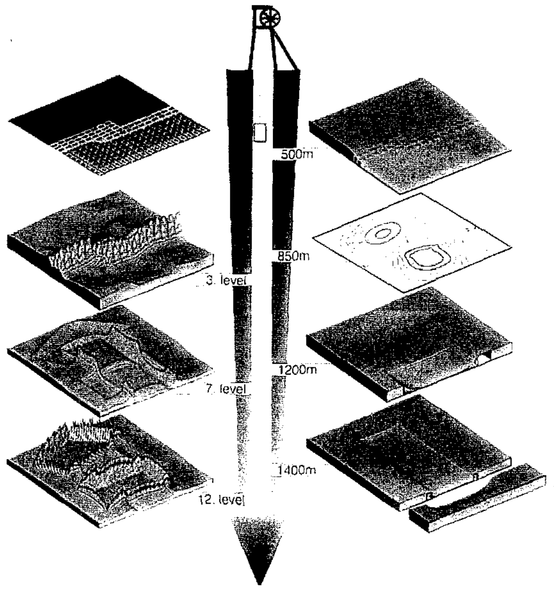

Figure 1 : Rock pressure forecast by the software GEDRU ».

4 Knowledge Based Systems

4.1 Introduction

Before 1983, the task of producing an expert system generally consisted in asking an expert for his expertise and in coding it immediately; every rule represented the reply of the expert to a problem in a given context. The knowledge and the know-how were closely intermixed. This led to systems which were certainly functional but whose development was more or less anarchic and particularly "fragile" and difficult to maintain.

Since 1983, one has talked of second generation knowledge based systems to describe these systems where knowledge is encoded in a declarative form, regardless of the form of use. Models of certain areas are drawn up (classification, design, diagnosis), making it possible to define typical methods of knowledge acquisition for these areas.

The declarations provided by the system so designed are much more than a simple reproduction of the rules. They are also more durable, because they tend essentially to be based on the characteristic principles of an area rather than on point by point heuristics.

It can also be said that, in order to acquire the knowledge of areas of application, one tends to turn to specialists rather than experts (the classic difference between the specialist and the expert being that the former demonstrates his knowledge publicly and through books and publications, whereas the expert's knowledge is essentially of a private nature and is based on personal experience difficult to impart". Since the difficulty in knowledge acquisition is more a problem of interpretation and modelling than the simple transfer to the computer system, collaboration with the specialists in the relevant discipline simplifies this phase.

This procedure, in conjunction with systematic use of object-oriented methods enable one today to design systems which use modules developed for other applications, even if they were originally intended for areas bearing little similarity. The intention is even to take over knowledge bases.

With new architecture it is possible to address the problem of heterogeneous specialist knowledge arising from the difference in the theoretical solutions proposed for a given case, and also the problem of the heterogeneous specialist knowledge arising quite simply as the result of the difference between the experts asked. Reference is made then to multi-expert systems.

The graphic instruments normally available for most computer systems have simplified the creation of user-friendly interfaces to a great degree.

In the final analysis the systems do not stand alone: they can communicate with standard applications (calculation and spreadsheet programmes) more suitable for numerical calculations and with the companies databases. This integration in the "classic" computer system of the user simplifies the introduction of systems in practical terms. The system is thus more practice based and easier to handle.

4.2 The “art of mine“

The shape and management of a mining concern is more an "art" than a process or configuration of processes. The areas of knowledge which are of relevance have many different layers. The “art of mine“ is a promising area of use for artificial intelligence methods, and especially methods which enable one to develop knowledge-based systems.
Where classic optimisation procedures only provide partial solutions, the expert systems help integrate the wide variety of areas of knowledge addressed to solve the problems arising. Designed as intelligent systems to help in decision-making, they perform an auxiliary function for mine operators without "replacing" specialists, as was attempted in the early 80s.
In fact, the development of research into expert systems such as we have referred to above was in fact only belatedly taken into consideration in our SOUT project; the obvious reason is the fact that the development was the work of engineers and researchers involved mainly with the geotechnics of mines and rather than the work of artificial intelligence professionals.

HISTORY OF THE PROJECT « KNOWLEDGE BASED SYSTEMS FOR MINING »

The « knowledge-based systems for mining » project was started in 1985 and it may be said that, in terms of artificial intelligence and its applications, it went through the following three periods :

1 The beginnings: the myth of the artificial expert (from 1985 to 1988)

In 1985, at the time of the great epoch of artificial intelligence, and expert systems in particular, Charbonnages de France (CdF, the French coal board), decided to commission CERCHAR[7] to devise and implement an expert system to help with the choice of mining support structures with the idea, quite widespread at the time, of "replacing" the experts on supporting structures. This is how the SOUT project was born [Waterman 86].

2 The disappointment: Analysis of the failure of the first phase (1989 to 1992)

At the end of the 'eighties it came to be noticed that the expert systems were having difficulty keeping their main promise ("replacing the experts"), and a general feeling of disappointment set in. The SOUT project did not escape this. Apart from a cruel lack of user-friendliness and a lack of integration (no direct interfacing with existing databases, little direct access to analytical or numerical computation programs) it was quickly observed that there were few chances that SOUT would "replace" the support expert. The SOUT 0.1 system remained in this state until 1992.

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[7] Centre d'études et recherches des Charbonnages de France, now INERIS.

3 The reality: An Intelligent Decision-Supporting System (from 1992)

Since the beginning of the 'nineties, we have witnessed a new development of artificial intelligence and a redefinition of the role of expert systems; they are now regarded as help and support systems rather than systems designed to replace the experts.

A collaboration has been set up between INERIS, and our colleagues in the German coal-mining industry: the DeutscheMontanTechnologie (DMT, German mining technology, DMT). This collaboration, and the research and engineering works carried out since 1992 are described in detail in the section which follows.

EVOLUTION OF THE PROJECT SINCE 1992

Version 0.1 of SOUT, completed in 1988, has unfortunately continued to be little used and little effort has been devoted to maintaining it. The new interest since July 1992, in expert systems in the general mining field, and in SOUT in particular, has enabled us a) to keep an up-to-date eye on the technology in the field of expert systems and b) to improve the data-processing implementation of SOUT considerably.

This has enabled us to "professionalise" the SOUT 0.1 experimental prototype produced for an university doctoral thesis [Baroudi 88] and come out with version SOUT 2.0, which represents genuine robust, ergonomic and "ready-to-use" software.

At the same time the systems EXOS (TU-Aachen and DMT) and PLANANK (INERIS and DMT) were developed for allowing a diagnostic of layout and roadway planning and for the dimensioning of standing and / or bolting support.

1 Computer re-programming of the expertise

Version 0.1 of SOUT was intended mainly to demonstrate the value and feasibility of an expert system in the mining industry.

Although this SOUT version 0.1 contained excellent expertise in the fields of geotechnics and mining operations, it did not take full advantage of the new methodologies of expert systems. Nor did the data-processing implementation meet the current requirements regarding ease of use and robustness. The interfaces were not very user-friendly; incorrect use of the prototype, or the introduction of unplanned data caused the program to "crash".

In SOUT version 2.0 [Thoraval & al 94], [Sbierczik & al 95] we placed the emphasis on programming with NexpertOject®[8], using the accepted practices in artificial intelligence, while taking into account of recent research results in this field and incorporating the expertise of SOUT 0.1.

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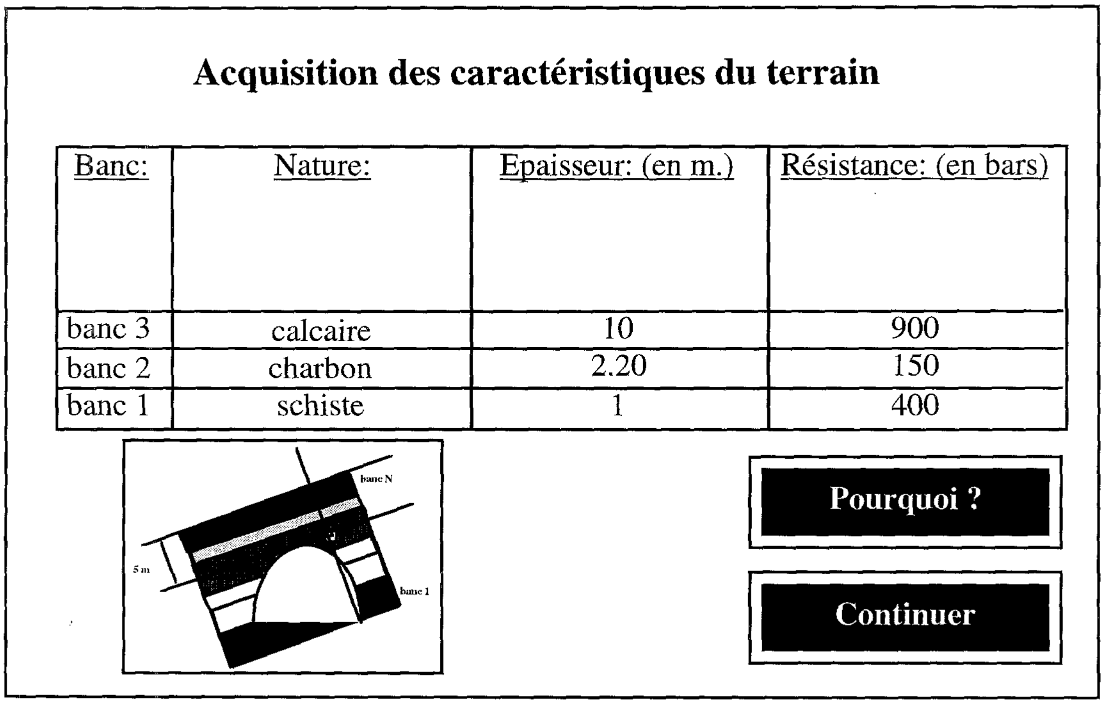
[8] NexpertObject® is an expert systems shell developped by Neuron Data®

Finally, with Toolbook®[9] we have created true user-friendly graphical interfaces, taking maximum advantage of the possibilities offered by the mouse, scrolling menus, graphic screens, push buttons etc. (cf. Figure 2).



Acquisition des caractéristiques du terrain

Banc:	Nature:	Epaisseur: (en m.)	Résistance: (en bars)
banc 3	calcaire	10	900
banc 2	charbon	2.20	150
banc 1	schiste	1	400

Figure 2 : Acquisition of the basic data concerning the roadway and the strata [10].

A particular effort has been made during the development of version 2.0 of SOUT to illustrate the argument interactively and to explain and gives reasons for the results of the system (Figure 3). Users in fact only have confidence in the results if they can obtain proof of them. This is very important in order that the tool becomes accepted and, above all, used. Another asset is the fact that the product can be used for training purposes.

Thus by pressing, for example, the "?" button of Figure 2, we can be given reasons for SOUT's conclusion (cf. Figure 3).

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[9] Toolbook® is an interface development toolbox developped by Asymetrix®

[10] Acquisition of characteristics of the strata :

Layer :	Nature:	Thickness: (in m)	Resistance: (in bars)
layer 3	limestone	10	900
layer 2	coal	2.20	150
layer 1	shale	1	400

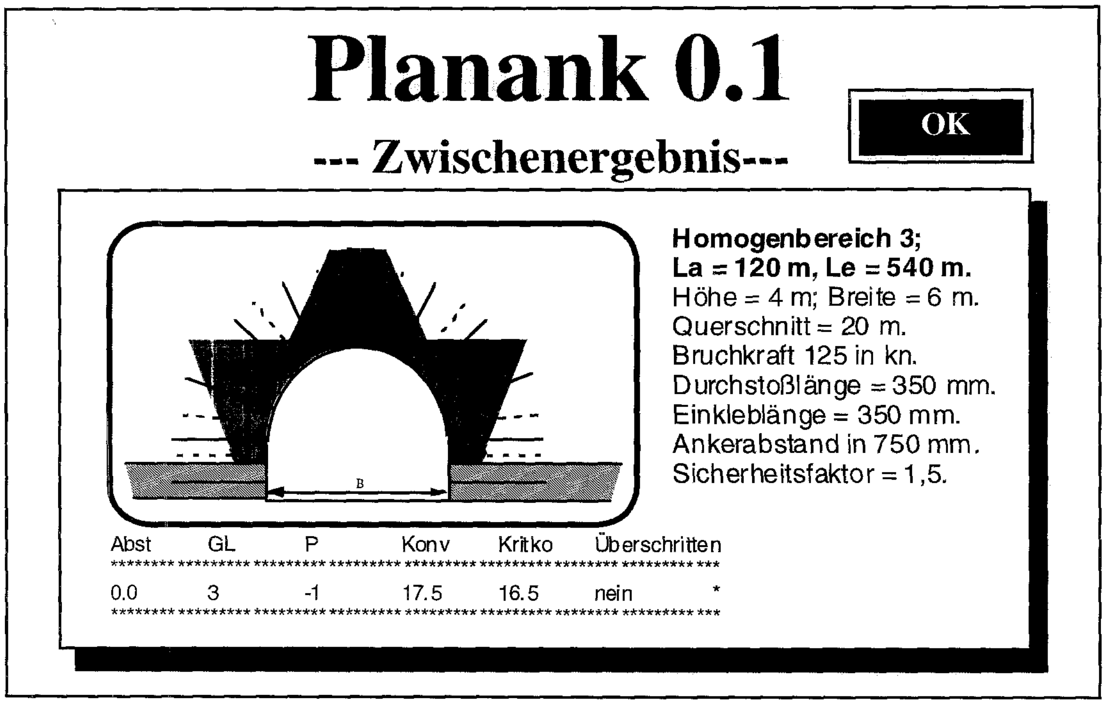
Why?
Continue

3 The system PLANANK 0.1

In 1994, DMT decided, in close collaboration with INERIS, to create the expert system: PLANANK (Planning of an Anchor Support system, Figure 4). The ultimate purpose of the project is to incorporate, within a single system, all the knowledge available to the German coal industry on bolting of mining galleries with a view to producing a complete software package dealing with all aspects of bolting, and capable of being directly used by engineers.

In accordance with the above objectives, this system contains the knowledge of German experts on the subject of the bolting of gate roads in mines. This knowledge proved to be complementary and not contradictory to that contained in SOUT. Furthermore, the PLANANK 0.1 system has been especially adapted for German conditions :

- it takes account of the special geological features of German deposits (thin seams, highly stratified formations...),
- it directly integrates specific computation programs produced by DMT for the calculation of the length and density of the bolts,
- and it meets the statutory German requirements for anchor bolting systems.



Planank 0.1

--- Zwischenergebnis---

Homogenbereich 3;
La = 120 m, Le = 540 m.
Höhe = 4 m; Breite = 6 m.
Querschnitt = 20 m.
Bruchkraft 125 in kn.
Durchstoßlänge = 350 mm.
Einkleblänge = 350 mm.
Ankerabstand in 750 mm.
Sicherheitsfaktor = 1,5.

```
Abst      GL        P         Konv      Kritko    Überschritten
******** ********* ********* ********* ********* ******** ********* ***
0.0       3         -1        17.5      16.5      nein          *
******** ********* ********* ********* ********* ******** ********* ***
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Figure 4 : The DSS : PLANANK 0.1[12].

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[12] Intermediate result
Homogeneous range 3; La = 120 m, Le = 540 m.; Height = 4 m; Width = 6 m; Cross-section = 20 m
Breaking force 125 in kn. Penetration length = 350 mm; Cementing length = 350 mm; Distance between anchor bolts 750 mm; Safety factor = 1.5 Dist. / GL / P / Conv. / Crti. fact. / Exceeded / No

4 The system EXOS

The main objective of the knowledge based system EXOS is to realise a diagnostic of layout planning and dimensioning of roadways.
The diagnostic of gateroads start with the criterion « position within the strata ». It is checked whether the parameters which strongly influence the strata pressure effects are considered (e.g. strength and composition of the associated strata). Subsequently, working boundaries and pillar edges in the roof as well as faults are investigated.

Under the criterion « influence of working faces » the strata mechanical influence of working faces on the roadway is analysed with consideration being given to earlier and synchronous mining in other seams and working of both seams alongside the roadway. Subsequently the controllability of the roadway is investigated (the convergence to be expected is assessed, convergence-reducing measures are proposed).
Eventually, the intended support is examined (e.g. the support techniques: rigid arch, yielding arch, and porch-set support).
The diagnosis of base roads is analogous to gate roads with the main difference in the influence of the working faces in the same seam. As a main difference between roadways in seam and drifts there is the criterion position within the strata. For support dimensioning, the support systems yielding ring support and rigid ring support are investigated in addition.
A diagnosis report, including, if necessary, several recommendations to improve the examined layout planning situation, constitutes the overall result.

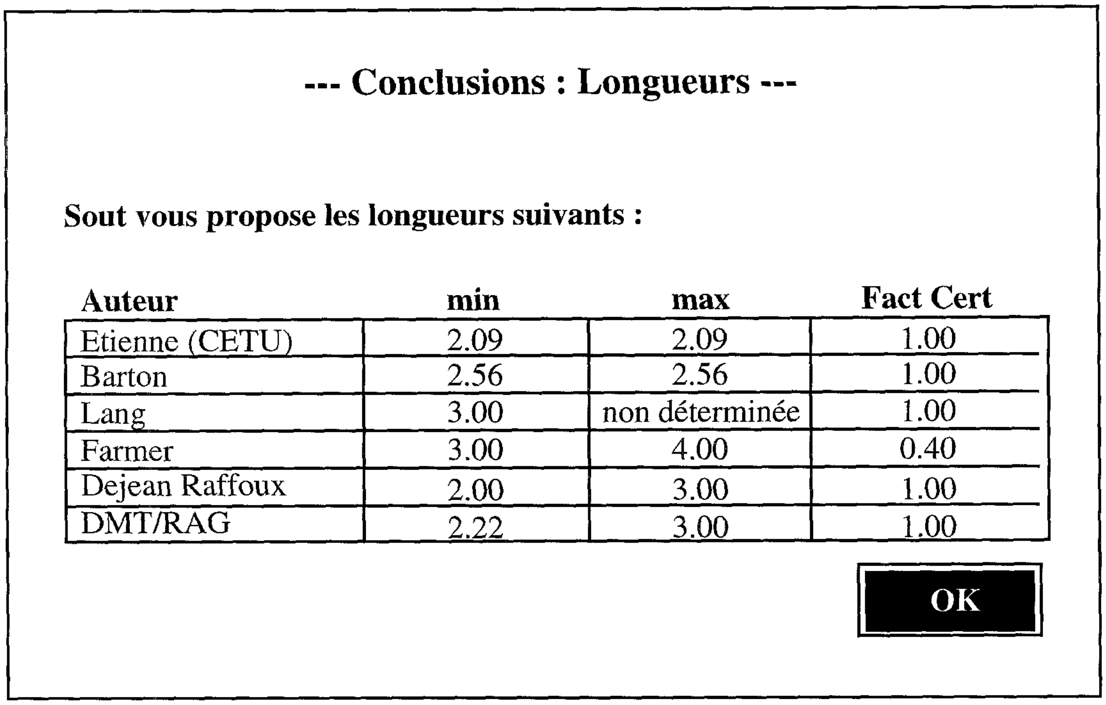
5 The SOUT 3 Franco-German multi-experts system for roadway support planing

Based on the **SOUT** 2.0 expert system and the Planank 0.1 expert system, an expert system for the planning of bolting supports for a haulage road [Kouniali 95], a Franco-German multi-expert system for the calculation of bolting supports in mining galleries was developed.

As was stated above (cf. § 1.5), the multi-expert approach makes it possible to model the knowledge and know-how of several experts within a knowledge base containing the rules of reasoning used by specialist engineers in the field to define and calculate the bolting scheme in question. Such a system made it possible to integrate the complementary knowledge and experience of several proven specialists and to provide a quite unique tool for the training of engineers of different disciplines (cf. Figure 5).

The objective of this multi-expert system has been to integrate the knowledge and experience of French and German experts in the bolting field in order to be able:

- to store the knowledge and know-how of these specialists for their own benefit and that of others,
- to provide continuous training of engineers and foremen within CdF, RAG and DMT,
- to have a tool to aid decision-making in the absence or temporary unavailability of human experts.



--- Conclusions : Longueurs ---

Sout vous propose les longueurs suivants :

Auteur	min	max	Fact Cert
Etienne (CETU)	2.09	2.09	1.00
Barton	2.56	2.56	1.00
Lang	3.00	non déterminée	1.00
Farmer	3.00	4.00	0.40
Dejean Raffoux	2.00	3.00	1.00
DMT/RAG	2.22	3.00	1.00

Figure 5 : Results of SOUT concerning the possible length of the bolts[13].

INTEGRATION INTO A COHERENT SOFTWARE PACKAGE : ISLSP

1 Definition

ISLSP (Integrated Software for Layout and Support Planning) is an "intelligent" decision support system (IDSS) for layout planning and roadway support dimensioning in underground mining with the principal purpose of optimising the safety-to-costs ratio.

The system comprises five independent software components developed on the basis of various software technologies. These software components co-operate :

a) DIFLAN : a conventional program for digitalising mine surfaces and for generating feed data for strata pressure forecasts. (Figure 6)
b) GEDRU : a program for strata pressure forecasts developed on the basis of numerical models (Figure 1)
c) PABBAS : a conventional program for roadway deformation forecasts
d) EXOS is a knowledge-based decision support system (DSS) for diagnostics in layout and roadway planning.
e) SOUT : a knowledge-based support system (DSS) for the selection and the dimensioning of roadway support systems in underground mining with the principal purpose of optimising the safety-to-costs ratio. (Figures 2 to 5)

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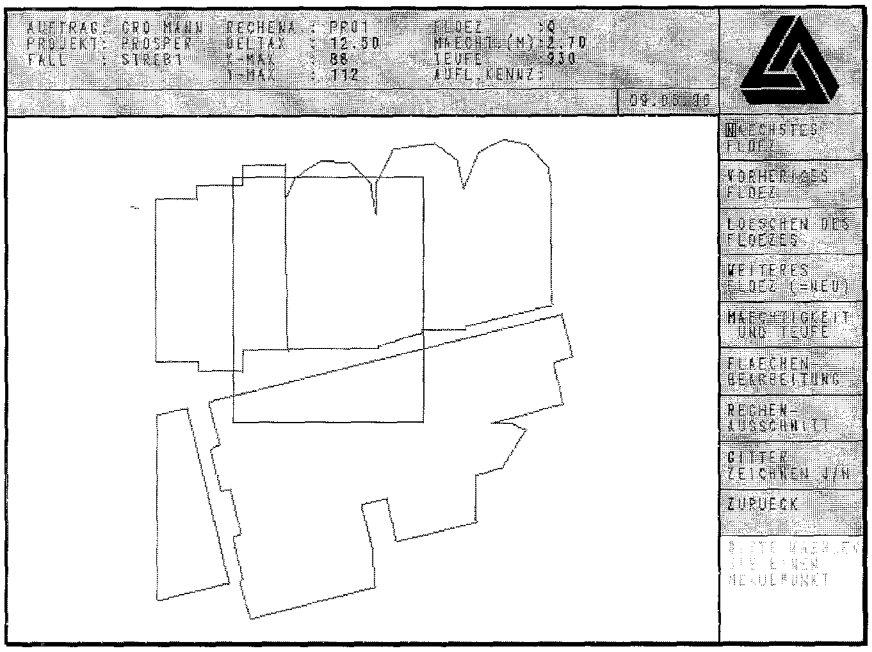
[13] Conclusions: Lengths
SOUT suggests the following lengths:



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AUFTRAG : GRO MANN   RECHENA. : PR01      FLOEZ      :Q
PROJEKT : PROSPER    DELTAX   : 12.50     MAECHT.(M):2.70
FALL    : STREB1     X-MAX    : 88        TEUFE      :930
                     Y-MAX    : 112       AUFL.KENNZ:
                                                     09.05.96
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Figure 6 : The conventional program DIFLAN for digitalising mine surfaces.

2 Layout and Roadway support Planning with ISLSP

Planning with ISLSP comprises five main steps (Figure 7)

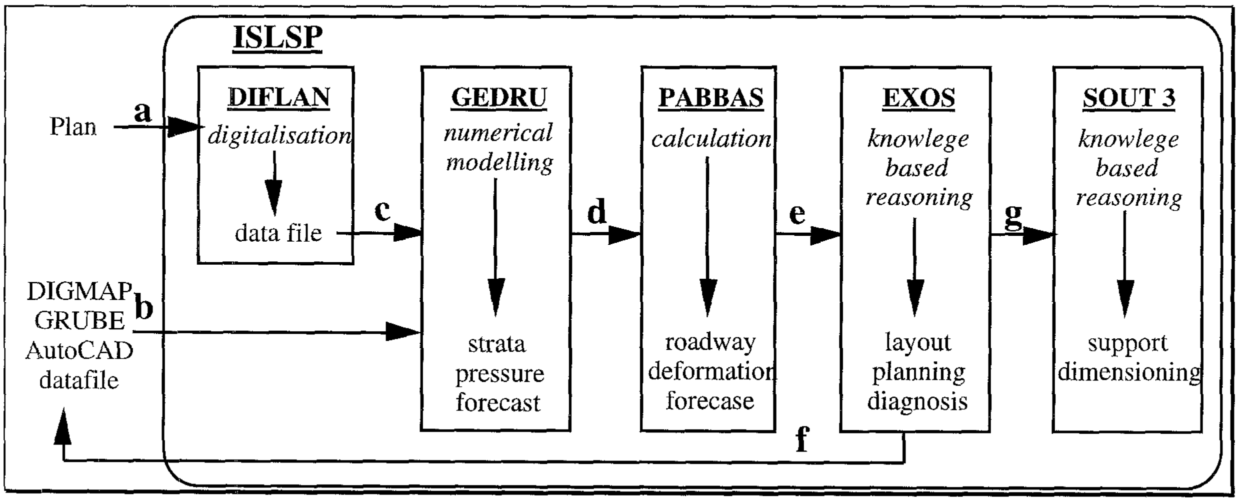

Figure 7 : Layout and roadway support planning with ISLSP.

a) Generally the first layout variant is drafted "manually" on the basis of optimised machine-technical connection of the roadways and the coalfaces to the existing infrastructure of the mine. This variant is on hand then either "on paper" or in digitalised form in DIGMAP-, GRUBE- or AutoCAD data file. By means of DIFLAN, planned on paper are digitalised.
b) The data on hand with DIGMAP (RAG), AutoCAD (CdF) or GRUBE(TU-Aachen) data files can be put in directly.
c) By means of the layout variant 'fed' in this way, a strata pressure forecast is established by means of the GEDRU program,

d) and a roadway convergence forecast by means of the PABBAS program.

e) The data processed in this way (layout planning, mine infrastructure, deposit, strata pressure and roadway convergence forecast) are then cycled automatically to knowledge-based system EXOS which runs diagnostics of the layout planning with respect to strata mechanics . If the result of this diagnostic work qualifies the layout variant as unfavourable, automatically proposals for improvement are drafted.

f) The user may then improve layout planning by means of the calculated recommendations.

g) If the result of the diagnosis is satisfactory to the user the latter can demand support planning. The knowledge-based System SOUT 3 then calculates type and dimensions of support.

3 Planned developments

The recent and conclusive results of the ISLSP project as an aid to decision-making has urged us - in collaboration with our German (DMT and RAG), French (CdF), Spanish (AITEMIN) and Greek (NTUA and LARCO) colleagues - to contemplate an intelligent system for the planning and simulation of a mining operation.

The planning of a mining operation involves, firstly, a series of decisions which we will classify as "first-order decisions" and which are very closely determined by considerations relating to the geology and history of the deposit being worked: these concern the geometry of the deposit, its regularity, the position and size of the joint-planes, the existence or location of former workings, the existence, location and state of pre-existing infrastructures...

These "first-order" decisions have a bearing, for example, on the cutting of panels, the working sequence, the speed of working... They may be modified at a later date.

These first choices will more or less automatically involve a certain number of consequences (for example, with regard to creations of new infrastructures or distribution of "pressures in the solid rock"..). These consequences are subject to change in the sense that they will occur as the "first-order" decisions are implemented. The whole thing represents to some degree an "initialisation" of the system.

From that point on, the specific working project will require a certain number of "second-order" decisions to be made. The purpose of these is to create the conditions under which the "first-order" decisions can be implemented. These choices concern:

the methods to drive the infrastructures, the support of the roadways and galleries, the mining methods, the support of the workings, the ventilation, ...

A second series of consequences result from these decisions. These have to do with labour, commodities, and the necessary investments, and will determine production levels and costs.

The operators wish to have *an intelligent decision-supporting tool*, permitting advanced *3D modelling*, in order to carry out simulations which provide an insight into the consequences of the planning decisions they have in mind.

It is this kind of an intelligent system for the planning and simulation of a mining operation which we are planning now to create.

CONCLUSION

The design of an knowledge-based system is a complex process which cannot be improvised. The rules of the art involved in the creation of such a system are ultimately the same as those which govern the management of a project whether this be data processing or general engineering. The specific skills relating to the cognitive nature of the project are also difficult to bypass; this is why we have decided to take genuine stock of the fact that the experts and the operators have begun to consider SOUT, EXOS and ISLSP as a tool capable of helping their profession and that they have given their approval to the follow-up projects we have mentioned.

The expected benefits through the large utilisation of integrated knowledge-based planning software are aiming to reduce planning errors and increase planning reliability. At the same time planning costs, particularly for adaptation to new and unpredictable earlier situations, will become cheaper. Repair and maintenance costs of roadways are also expected to be reduced in a significant way, while a reduction in the accident rate is predicted to an unspecified at present figure. More specifically the following results are expected :

1. Improved layout and support planning systems, which will provide greater roadway stability.
2. Reduction of the environmental impact of mine activities until mine closure.
3. Improvement of working and safety conditions.

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