EMTECH: Mine emergency support technologies

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Summary of the project:
Recent mine incidents, both within the EU and elsewhere, have highlighted the role that emergency support systems and technologies have in ensuring the survival of the mine workforce. The large, deep complex mines of the European Union are presenting increasing challenges for the industry. There are currently deficiencies in situational awareness and supporting communication and evacuation measures available after a major accident. Crucially required technical progress in these fields will significantly enhance EU incident provision and emergency preparedness. This will both help to ensure that the workforce is protected and secure the infrastructure of coal production.

Keywords: evacuation, safety, mines, CFD, simulation, STEPS, Geocontrol.

1 WP2 – Incident Status and Decision Making Support

1.2 Modelling and prediction of products of combustion transport (Task 2.2)

The work reported in Task 2.2 concerns the modelling work on smoke transport. The objective was to simulate a fire model underground in Pozo Carrio Colliery, Spain in order to obtain a prediction of the smoke movement and its interaction with the ventilation system of the mine. The information obtained concerning smoke transport was then integrated with the evacuation simulation. The CFD model inputs were predicated on the results obtained from various real-scale fire tests. This enabled the simulation solver to be verified and optimised. The simulation scenario was reduced to critical zones of interest; the fire zone, the area where mineworkers are normally working, the zone where the refuge will be located and the galleries from the work areas to the refuge station or onward to exit from the mine. To develop the simulation model in computationally complex zones (including the fire zone, the refuge and the intersections between galleries where the air flow changes its direction abruptly) it was necessary to generate a homogeneous mesh based on 0.15 m cubes.

It was recognised that various combustion-related parameters, such as fire characteristics and real flow conditions inside a mine would need to be studied before the modelling could be developed. In order to adjust and validate the fire modelling to be used, different tests were performed in the fire test gallery at Santa Barbara, located at Leon, Spain. The mine where the fire test gallery is located is also similar to the typical structure of Hunosa's current coal mines, with working levels divided into sub-levels, with a main entrance and exits to the surface via the upper levels.

As a first step, resources were concentrated on commissioning the test facility to run the tests. The necessary instrumentation and sensors were acquired and located in different points of the ventilation circuit of the main test drift and surrounding workings. As part of this process, any necessary computers, electronic I/O modules, cables, transducers were upgraded. In the fire test gallery, nine sections were available for fire experimentation, four sections of which are located ahead of the burning pool, and five after the pool. In each section, three thermocouples are placed to measure temperature. In section 9, there is one gas analysis station, properly constructed and protected from the high temperatures of the flue gases. The station equipment included a flue gas analysing system, O_2, CO, NO_2, NO, SO_2 gas sensors and temperature measurement.

Three tests were carried out, differentiated by airflow introduced into the tunnel. As a result of these tests, concentrations of gases and temperature profiles within the test tunnel were obtained. These provided an essential input into the CFD model to verify the outputs and give feedback to improve the model. A second activity focused on the analysis of the ventilation network at Pozo Carrio Colliery, where the refuge prototype was to be installed. The objective here was to simulate a fire model inside the coal mine in order to obtain a prediction of the smoke movement and its interaction with the ventilation system of the mine. The information obtained concerning the smoke transport would then input directly into Task 2.4 ‘Evacuation modelling and safe egress routes’.

The airflow Q (m^3/s), dry bulb temperature (T_{DB}), wet bulb temperature (T_{WB}), pressure P (Pa) were measured at a number of places in the mine ventilation circuit. With these data, the ventilation network was analysed with dedicated software, ‘VENTILA’. Additionally, information related to the equipment in galleries was obtained in order to calculate the amount of material that could be involved in a fire, which sections and the placement of communication equipment (e.g. phones, intercoms). These data were taken into account in the CFD modelling. Another key point was to determine the influence of fire source location within the model. Several places were considered; the most probable and the most dangerous, leading to a location that fulfilled both conditions, near the end of the conveyor belt run and next to a ventilation shaft.

As points of detail, the simulation model incorporated the following features and assumptions.

- The simulation used a reduced scenario set of the Pozo Carrio mine, which is very large.
- The simulation used an estimated heat release rate (HRR) of 6 MW.
- The fire was located in sub-plant 4, which is 55 metres from the refuge. This location is coincident with one motor of the conveyor belt, which transports mineral out of the mine.
- The ventilation air had a flow value of 1.8 m/s.
- The ventilation door, located near the refuge, was closed in its normal position.
- The fire was simulated as a source of energy and mass, with the fire source represented by a heat release rate fixed inside a given volume. This value is not influenced by the ventilation.
- A reduction of 30% in the HRR has been applied in order to consider the energy lost by radiation near the fire.
- A 20 minute long simulation was employed.

The essential physical aspects of the simulation scenario are shown in the two figures below Fig. 1 and Fig.2, including the available escape route options.

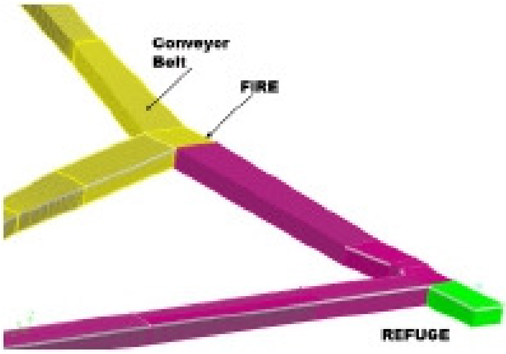

Figure.1: CFD simulation of mine fire, essential features

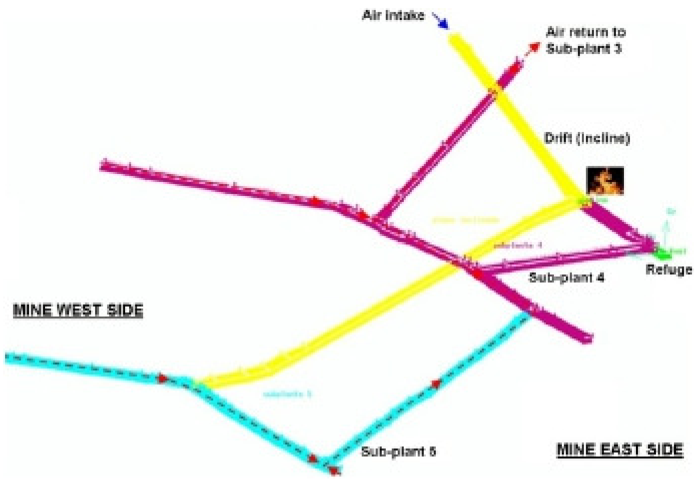

Figure 2. CFD simulation of mine fire, mine gallery relationship, evacuation route options

The geometry of the model includes sub-plant 4 and sub-plant 5 with their connecting galleries and the drift (inclined plane) which is a clean air ventilation gallery. The geometry and the mesh were simplified to reduce the required solver power of the software for modelling less important volumes of mine roadway. The lower 300 m of the drift was represented in the model. The created geometry does not include the vault shape of the gallery since this would generate an overly complex mesh. However the cross-section value used matches the mine value since this feature combined with the air velocity is the basis of the ventilation system analysis and of the smoke movement within the model. Consequently the generated mesh is homogeneous. The fire was analysed against three important parameters – temperature, visibility and toxicity.

Discussion of Modelling Results

In evacuation situations there are two factors that have critical influence on the oxygen cost and available wearing duration of the self-rescuer equipment – physical demands of evacuation and the mine thermal environment. From the point of view of the safety of the evacuating mineworkers, the minimum duration available from the self-rescue devices was assumed to be 20 minutes, which was assigned as the simulation time. The temperature limit was assigned to be 80°C, this value indicated by NFPA and PIARC recommendations. The analysis of the smoke movement illustrates how the hot smoke affects the tenability of moving along specific evacuation routes. Discussions with Hunosa specialists confirm that this is a worst-case analysis, since the build-up rate of previous underground fire incidents has been somewhat slower in practice, allowing more time to escape via various routes. Within the analysis, after about three minutes from the fire starting, the smoke has not arrived within the sub-plant 5 zone; the sub-plant 4 and its intersection with the gallery that ascend to the sub plant 3 also remain free of smoke. However, five minutes from the start of the fire it is not possible to traverse from the east side of sub-plant 5 to the refuge or the exit of the mine. If the door located near the refuge were to remain closed, it would be possible to exit from the west zone of the sub-plant 5 to the sub-plant 4 and then to the gallery which goes to the sub-plant 3 during the entire 20 minutes of this fire simulation.

For the last ten minutes of the simulation the temperature conditions remain relatively steady. The temperature conditions which are needed to reach the refuge through the door, which is located near to it, or the exit mine, through the gallery that ascends to the sub-plant 3, are tenable throughout the 20 minutes of simulation. The inaccessible zones due to high ambient temperatures are the zones near the fire, the area in the intersection between the drift and sub-plant 4 and the zone located between the refuge and the fire. It is not possible to evacuate to the exit through sub-plant 4, the only access to the exterior then being through sub-plant 3. Analysis of the temperature contours shows a short back layering, where the critical velocity of the smoke is lower than the air velocity in the ventilation gallery. The distribution of the smoke takes the same path as the clean air through the ventilation system down to the deeper sub-plants (levels) of the mine. Ten minutes after the beginning of the fire, the smoke has filled all the geometry of the model, there is not smoke stratification and the visibility is zero.

Conclusions of Analysis

The principal objective of this work has been to realise a simulation model, based on commercial CFD code that can be used to predict smoke movement in the mine. With the analysis of the results of the simulation it was determined that smoke products are transported to all areas covered by the mine fire scenario within ten minutes of the fire beginning. The results show the possibility of high temperatures (greater than 80°C) in the zone of the refuge, although this is considered a worst case scenario. High temperatures are not observed throughout the drift, which is the main air intake. At distances greater than 40 m from the fire up the drift, the temperature values are close to ambient values. Only near the seat of the fire are temperatures observed to be higher than 80°C.

High temperatures are however observed downstream of the simulated fire. In sub-plant 4 the temperatures are higher than 80°C and it would quickly become impossible to use this route to leave the mine. On the other hand, in sub-plant 5 and between sub-plant 4 and the gallery that ascends to the sub-plant 3, temperature values are no higher than 30°C providing a tenable route (at least in thermal environment terms) to leave the mine. However, it is recognised that the ability of evacuees to think clearly when exposed to smoke decreases with increasing smoke density and the heat associated with hot smoke.

The modelling and fire simulation carried out for Pozo Carrio mine confirm that the research approach of using a fire source represented by a HRR fixed inside a volume, leads to realistic temperatures except very near to the fire, around 5–10 m from the fire seat. In this zone the analysis requires a more sophisticated treatment. It is also observed that smoke is transported throughout the mine, which loses buoyancy and descends when in contact with cooler air and cold walls. In this case visibility is often close to zero and only the miners training and their knowledge of the environment can allow them to reach a place of safety.

However, in terms of emergency planning, there are only two zones which would be cut off due to the high temperatures of the smoke; one of them being the ‘cul-de-sac’ at the easterly part of sub-plant 5. To evacuate from this district, the mineworkers should cross the intersection between sub-plant 5 and the gallery that ascends to sub-plant 4. This zone reaches a temperature value of 80°C five minutes after the fire commences. The other zone that is cut off is the refuge external area, which fills quickly with hot smoke with a temperature greater than 80°C some five minutes after the fire commences. Under the specific fire conditions this would not allow the miners to approach the refuge.

The modelling has been supported by extensive analysis of case studies of previous fire incidents, which generally suggest slower rates of fire growth. It is also recognised that the model scenario of a developed fire in an intake represents a worst case. However, all emergency planning and risk assessment activities must account for such scenarios.

2 Evacuation modelling and safe egress routes (Task 2.4)

In Task 2.4, the main objective was to simulate the evacuation process within Pozo Carrio coal mine under fire conditions, taking into account the CFD simulations carried out. The evacuation times were calculated using an advanced Simulation Programme, STEPS conveniently adjusted with real displacement velocities and considering the boundary conditions of temperature and smoke. Details of the numerical code are given in an appendix to this report. Once the simulations were undertaken, it could be established whether nominal places of safety of underground were suitably sited, or whether they could be relocated to improve the overall security of the mine. After analysis of the results, improvements in evacuation times were identified by implementing better fire detection systems, especially in the areas of greatest fire risk. Additionally, enhanced ways to raise the alarm with mineworkers could further improve these times. It was considered that these two aspects together could reduce total evacuation times by two to three minutes. In order to address worst case fire scenarios, it was also considered advisable to include an additional SCSR donning station in the sub-level.

The main achievement of this task has been to establish a very high correlation between the observations from evacuation drills and the simulation models, particularly where the evacuation simulations were repeated to incorporate very precise geometrical data. Refinements made to the evacuation simulation model permitted other arbitrary mine layouts to be analysed without having to carry out corresponding evacuation drills. The process to calculate the evacuation times involves the following stages.

1. Mine selection
2. Establish evacuation routes
3. Selection of simulation software

4. Mineworker characterisation
5. Incorporation of CFD output data
6. Analysis of the evacuation process

It was found that smoke was a key factor influencing the evacuation time. Practical studies confirm that evacuation speed can be reduced to around one third of its nominal value when the visibility distance is three metres or less. In order to adequately account for this speed reduction in the evacuation simulations, a dedicated analysis was carried out for sections of the mine where smoke was considered to be present whilst mineworkers evacuated the mine. One modelling issue that arose in the study of the evacuation process was how to best maximise the zonal coverage of the supporting CFD output data. The process of mesh generation can act as a constraint on the analysis process due to limitations of solver automatic mesh generation algorithms. Developments in solver techniques have resulted in enhanced mesh elements and mesh connectivity. However further work is required to increase the scope of the modelling in order to examine efficiently a number of scenarios and cases underground. An alternative approach could involve the use of simplified fire studies with CFD simulation employed for the principal evacuation route.

One of the key aspects of Task 2.4 was to determine evacuation times under different boundary conditions of a real mine, where there are shafts and tunnels at different levels, so that the calculations performed in the simulations can be validated, if necessary with evacuation drills. Pozo Carrio Colliery, in Asturias was selected since it provides a physical arrangement with different levels, ventilation shafts, mustering points and other elements that influence an evacuation to a point of safety. In order to develop the evacuation modelling, the evacuation routes established in the Pozo Carrio Colliery Emergency Plan were analysed, taking the times estimated for different starting points from the workplaces and passing via the refuge location. The escape times and escape speed in each stretch were measured under normal conditions with two mineworkers with good cardio-vascular fitness walking together at the same time noting that...

- In case of an emergency the time taken to walk through the galleries in the mine may be different from the range of times measured.
- The evacuation time can be considerably extended due to possible confusion, reduced visibility, stress and eye irritation.

The above points are a central requirement to determine the realistic evacuation rates that permit correct evacuation model calculations. The method must also consider average worker physical qualities, the ‘difficulty’ of the escape route (height, clearances and obstacles, slope, requirement for climbing) and any impairment to visibility. The evacuation rate parameter is fundamental towards setting the distance between self-rescuer changeover stations against known characteristics of the self-rescue apparatus, where for example SCSRs are tested with a ventilation demand of 35 l/min.

The main problem determined here was that mine conditions exceed the standards considered realistic within commercial software, such that it is necessary to adjust (or calibrate) evacuation speed according to real values observed in a variety of evacuation exercises. Towards meeting this requirement of determining a representative and realistic evacuation speed function for the mine workforce, several dedicated exercises were conducted by Hunosa, UK Coal and CSRG (the latter undertaking a large set of measurements). In terms of the specific outcomes and observations regarding the evacuation modelling, the following points are noted.

1. Commercial software runs obey NFPA standards. In this standard, evacuation speed is set between certain values with regard to criteria such as slope or visibility, however none of these parameters matches the real conditions inside a mine (with gradients of up to 14% in Spain, for example).
2. Assumptions regarding mean speed during evacuation and climbing slopes has been predicated on information provided by the coal operators. This is considered reasonable.
3. Another key requirement is to comprehend the procedure of evacuation from a mine, since the routine may introduce periods of time that are not foreseen in the evacuation model. By way of example, the first stage in response to a fire is to try and extinguish the fire if the workforce is near enough and have the means to safely do so.
4. Mustering at a meeting point or refuge and communication with key decision-makers may also need to be carried out, prior to initiating a district or general evacuation.

The first simulation considered evacuation speed as a constant. Subsequent model runs employed a model with variable speed related to the mine gradients present together with data from the mine evacuation exercises. As a further enhancement, the model was amended to account better for the interaction between mineworkers and their respiratory protective devices. The time taken to don their devices and the placement of these devices was taken into account in order to make the evacuation simulation as realistic as possible. This also incorporated an estimate for mean fire detection times. he evacuation simulations were validated using data from evacuation drills conducted by the coal mine operators. Pre-incident workforce deployment information also needs to be incorporated, since this is critical information in the early stages of a rescue operation.

After adjusting the evacuation speeds for the simulation software application STEPS with correspondence to data derived from real evacuations and other specific studies, all the simulations were carried out using high accuracy reference source data. However, one of the more important aspects to permit comparison between the results of the CFD fire simulation and the evacuation simulation is to determine how the sequence of events develops from the beginning of the fire to the beginning of the evacuation process. Sometimes, especially in slowly developing fires, the fire start time cannot be readily defined as, for example, on a conveyor belt in which friction is occurring. In fast developing fires, this time is self-evident as it matches the rapid appearance of flames. In the CFD simulation, the fire commences within the simulation when a constant Heat Release Rate of 6 MW over a surface of 6.5 m^2 is achieved, which takes five minutes to fully develop in terms of power and smoke release. As a final element of the simulation studies, further consideration was given as to how movement through smoke during evacuation affects the overall speed of evacuation. This is clearly an important parameter, and which has a close relationship with the studies conducted within Task 2.3 and Task 3.4.

Various empirical tests confirm that the speed of locomotion when visibility is zero can be reduced to less than one third of the speed which can be developed under conditions of normal visibility. Studies of the impacts of irritating and non-irritating smoke were examined. As to be expected, there is a strong influence concerning the ocular irritation level experienced from the smoke and its impact on overall progress. Given the cross section of the mine, it is anticipated that smoke products will in a worst case scenario be transported in a fully de-layered form without significant stratification, greatly impairing visibility.

2.1 Evacuation Modelling: STEPS Numerical Code

This appendix provides further details of work carried out in Task 2.4 to develop a general-purpose numerical simulation model of a mine evacuation.

The calculation basis of the STEPS numerical code is NFPA 130 'Standard for fixed guideway transit and passenger rail systems', used in default mode but with appropriate modifications to account for mineworkers' behaviour during the evacuation process. Briefly, the modelling procedure includes the following steps.

2.1.1 Geometry definition

The first step to be taken when considering an evacuation analysis is to generate a geometric calculation model, generally attaching drawings. The next step is to introduce into the model evacuation routes and blockages, creating a realistic 3D model that may be used for calculations. Each item of the model, such as a door or slope, is assigned as an 'exit' in accordance with width and walking speed as regulated in NFPA 130. The infrastructure geometry is important, hence the requirement for correct definition.

2.1.2 Mine load definition

The mine load depends on the mine process which will be analysed. In this case, a load factor of 70 people was selected. This parameter needs to match the local deployment situation, noting the possibly of significant variance throughout the EU and North America.

2.1.3 Simulation parameter definition

Mine load placement, response time, form of emergency, visibility, mineworkers' skills, doors open/closed are the parameters set before running the model. The simulation will operate on a set of rules that define mineworkers' possible behaviours. The rules will cover classes of information necessary to create a realistic simulation. These classes of information will include, but are not limited to

- Human factors – e.g. physiology, psychology, level of training.
- Physical factors – e.g. mine location, ventilation systems.

Once the model is fully designed, data that should be stored for further analysis are determined, such as miners' load, number of people that use the different egress routes, the number of people that manage to exit from the model, and so on. Finally, redundant simulations are made to avoid, through mean and error analysis, typical fluctuations of a transitory, random simulation. The evacuation routes available at the mine consist of two 1.2 metre wide 'corridors' that lead to evacuation galleries. In a panic situation it is recognised that congestion could arise in a small clearance situation and that further scenarios with larger clearances (representative of larger mines) may be required.

Human behaviour modelling and fluid mechanics model

Fluid mechanic analogues are often used as a technical basis for predicting human behaviour in case

of evacuation. The principles involve time estimated from several expressions that connect empirical data with fluid mechanics, as follows.
People trying to escape from an emergency area keep a free area between themselves and the walls and other unanimated objects whilst they pass near them. This is similar to fluid concept of boundary layer. The width of this layer may vary from 10 cm to 40 cm. Thus, effective width is the real width minus two times the width of the boundary layer. To enumerate the number of people present within the model, estimates were provided by partners for the number of mineworkers present inside the mine in the case of various incidents. As a first approach 70 people were allocated to the model.

The people density (as persons per square metre) may then be calculated. If this ratio is less than 0.54 persons/m^2, the mineworkers would escape at their own pace, independent of the others' speed. If however the density is greater than 3.8 persons/m^2, then personal interaction is such that individuals cannot evacuate until the crowd passes any bottleneck again reducing density. Between these two limits, evacuation speed can be considered as a lineal function,
$S = k - a \cdot k \cdot D$, where

S= Evacuation speed in m/s

D= People Density in persons/m^2

k= constant. In case of a slope, a door or a corridor, k=1.40

a= constant. If speed is in m/s and Density in persons/m^2, then a=0.266

These are general parameters used in building evacuation simulations. Given the special conditions under which evacuation in a mine take place, other factors need to be considered such as...

Positive factors

- Mineworkers usually know their way inside the mine to a high degree of familiarity.
- Mineworkers are well trained and know exactly how to behave in case of an emergency.
- Mineworkers' physical condition exceeds the standard of the general populace.

Negative factors.

- Visibility is reduced.
- Gradients are very steep.
- Psychrometric conditions can become very unfavourable.

The possible effects of all these factors were considered during the study. Once speed is determined, the next factor to calculate is specific flow, it being the ratio between people that passes through an area in a period of time. Thus,
$Fs = S \cdot D$, where

Fs= specific flow in persons/s•m^2

S= evacuation speed in m/s

D= density in persons/m^2

Joining the two previous equations,
$Fs = (1 - a \cdot D) \cdot k \cdot D$
Thus, maximum flow occurs when density is 1.9 persons/m^2. Real flow is the product of specific flow and effective width,

$Fc= Fs \cdot We$

Joining the two previous equations,

$Fc = (1-a \cdot D) \cdot k \cdot D \cdot We$

Now, the time needed to pass through a certain point in an evacuation route can be evaluated as

$Tp= P/Fc$

Where Tp is the time needed to pass, and P the number of persons. Thus,

$Tp=P \cdot /((1-a \cdot D) \cdot k \cdot D \cdot We)$

Transition Points

There are many transition points inside an evacuation route, such as narrowings, joinings, and critical points. Considering similarity with fluids, an alternative form of Bernoulli's principle can be used, $\sum Fsi \cdot Wei=\sum Fsj \cdot Wej$, where,

i, j mean before and after a transition point, respectively.

4.2.4 Speed settings on STEPS

The Max Speed field is used to specify a maximum walking speed for the edited People Type. When one defines subsequent walking speeds in the list, this parameter is used as the basis for all of them. The maximum walking speed can also be defined directly in metres per second by entering it into the field, or it can be picked from a distribution. It is acknowledged that walking speed underground is also complex function of surface roughness. Walking conditions can be adversely affected where there is floor lift, wet conditions or walking on tracks. The distribution list enables the desired distribution to be selected. Each time a new person of the edited People Type is created in the simulation, its maximum walking speed will be randomly picked against the specified distribution. The first entries in the list come from the predefined distributions library section. The entries after the separator are the distributions defined in the model by the user. Once the maximum walking speed has been defined, several other parameters can be specified to model the effect of the environment on people's speed during the runs. The generic equation used in STEPS to model walking speed is as follows.

$$V=\min(\alpha_{slope} \times \alpha_{proximity} \times \alpha_{density} \times \alpha_{local} \times V_{max} + V_{local} , V_{smoke})$$

The Use slope calculation checkbox can be checked so that STEPS automatically takes into account the influence of slopes on walking speeds. When this option is activated, STEPS calculates the variable α_{slope} each time a person moves. It is necessary to specify the Up slope factor (β_{up}) and Down slope factor (β_{down}), which are used as follows.

- Assign θ as the angle of the slope for a specific move.
- When the person is going up: $\alpha_{slope} = \beta_{up} / \sin\theta$
- When the person is going down: $\alpha_{slope} = \beta_{slope} / \sin\theta$

The Use Speed/Distance Curve checkbox can be checked so that STEPS automatically takes into account the influence of person inter-distance on walking speeds. When this option is activated, STEPS calculates the variable $\alpha_{proximity}$ each time a person moves. It is needed to specify a Speed/Distance Curve in the list when this option is activated. This Curve gives $\alpha_{proximity}$ versus the distance to the closest person ahead. The first entries in the list come from the predefined speed distance curves library. The entries after the separator are the Curves defined in the model by the user.

The Use Speed/Density Curve checkbox can be checked so that STEPS automatically takes into account the influence of local density on walking speeds. When this option is activated, STEPS calculates the variable $\alpha_{density}$ each time a person moves. It is needed to specify a Speed/Density Curve in the list when this option is activated. This Curve gives $\alpha_{density}$ versus the local density around the person. The first entries in the list come from the predefined speed density curves library. The entries after the separator are the Curves defined in the model by the user.

The Use Smoke Data checkbox can be checked so that STEPS automatically takes into account the influence of smoke on walking speeds. When this option is activated, STEPS calculates the variable V_{smoke} each time a person moves. The concentration of smoke is set through sample planes. It is needed to specify a Speed/Smoke Curve in the list when this option is activated. This Curve gives V_{smoke} versus the smoke concentration in the person's cell. The first entries in the list come from the predefined speed smoke curves library. The entries after the separator are the Curves defined in the model by the user.

The Walking Speeds group of commands is used to specify various walking speeds for this People Type. These speeds will be used when defining Paths and Planes through their index. Each walking speed in the list is made of two numbers α_{local} and V_{local} defined in the equation above. The list of walking speeds shows all the speeds that have been defined for the edited People Type. The Local Factor field is used to specify α_{local}. The Local Speed field is used to specify V_{local}.

2.1.5 Example results

Whilst a large ensemble of simulation runs is required to analyse any particular application, an indication of example results is provided below in Table
1, which accounts for a subset of the test parameters.

Table 4.2.5-1 : Comparison of walking simulations

$\alpha_{slope} = \beta_{up} / \sin\theta$, $V_{max} = 0.9$. So if $\theta = 16°$ then sin 16 = 0.2756 and with $\beta = 0.146$, $\alpha = 0.53$, $V = 0.9 \times 0.53 = 0.477$ m/s

Mine Paths	**Measured**	**Constant v = 0.52 m/s**	**B = 0.146 v = 0.9 m/s**
1 to 5	06:00	07:00	07:05
5 to 6	06:00	06:30	06:36
6 to 7	09:00	07:30	08:35
7 to 8	08:00	06:30	07:25
TOTAL TIME	**29:00**	**27:30**	**29:41**

Table 1.Comparison between real simulation, constant speed virtual simulation and variable speed simulation

The combination of an ensemble of runs results in an example evacuation profile as given below in

Fig.3. Theevacuation modelling studies, as discussed, considered a wide variety of circumstances and parametersettings for Pozo Carrio mine. Whilst modelling requires high quality input data, supported byverification or validation, it was observed that the evacuation modelling approach showed good agreement with real data derived from evacuation exercises. Data on these exercises is given below. The use of numerical evacuation modelling tools shows considerable promise and potential as part of emergency planning activities.

2.1.6 Input data from evacuation exercises

There was requirement for determining a representative and realistic evacuation speed function for the mine workforce. Towards this objective, several dedicated exercises were conducted by Hunosa, UK Coal and CSRG. These are reported below, together with brief explanatory comments.

UK Coal Mining Ltd., Daw Mill Colliery

UK Coal staff undertook several egress exercises. The prevailing conditions were...

- No smoke or combustion products were present during the exercise.
- Effective Temperature was below 30°C.
- The walking speed was 55 m/min (~0.92 m/s).
- Mineworkers wore heavy footwear and an SCSR.

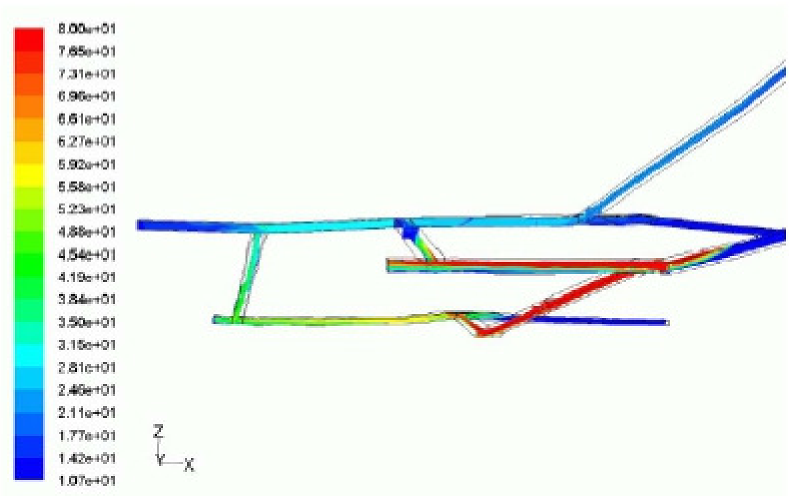

Figure 3: Modelled evacuation times in areas served by Pozo Carrio drift

The results suggest that an average evacuation speed of 0.92 m/s is reasonable assignment in good conditions of temperature and visibility, and which can be maintained for a long period of time.

CSRG District Mining Rescue Station, Wodzislaw

CSRG's evacuation studies included a comparison of theoretical studies with a large number of mine exercises. The individuals were tested in mines in various circuits, with different slopes. Parameters such as age, height, weight and slope were analysed against a range of 52 tests, involving 97 individuals.

Analysis of successive age groups confirmed that different mean movement speeds are observed. For a range of test circuit inclines of between 7° – 10°, a slight deviation between groups is observed and an average speed value of 42.5 m/min was derived. In the range of inclination from 10° to 15°, the difference of mean speed of movement of the participants is reduced to 7 m/min, and then at 11 m/min in the range above 15°, the difference is 3.5 m/min. A summary of these results is shown in Fig. 4.

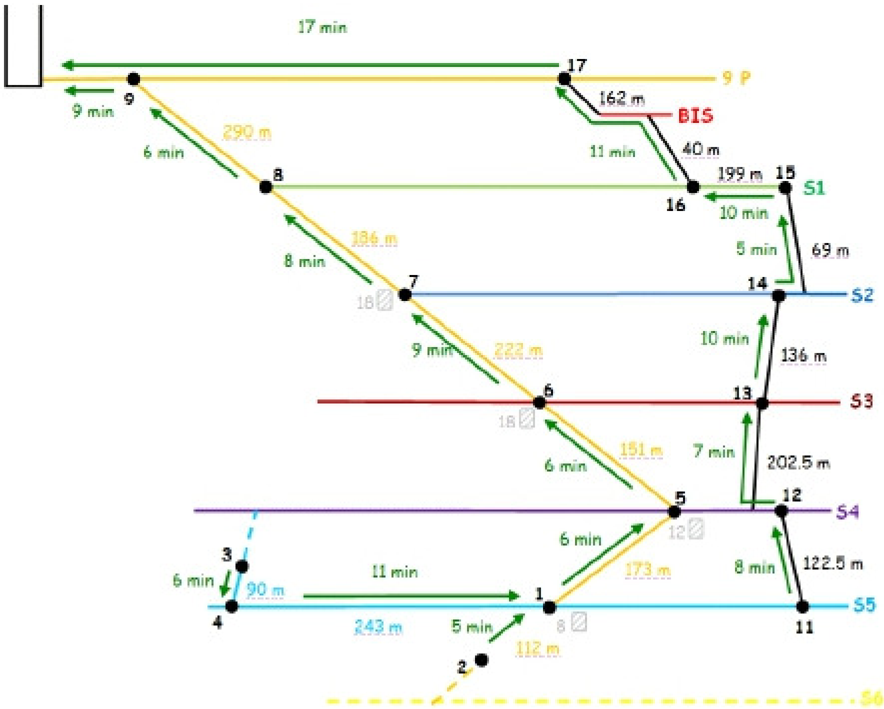

Figure 4 : Summary of evacuation exercise results at Hunosa's Pozo Carrio mine

Regarding BMI, it is observed that the speed for each of the groups declined with increasing slope, however there is a large divergence between the results; attributed to the number of exercises, which hampered proper interpretation of the test results. Further to this, measurements relative to short time segments with a transition of less than 100 metres also resulted in discrepancies. In order to reduce errors, it is proposed that the measurement of segments of transition less than 100 m length should be ignored. The test participants should also be varied in terms of age with a clear sub-division into groups to aid interpretation.

Hunosa Pozo Carrio Exercises

The mean speed obtained was 0.52 m/s (31.2 m/min), and is in broad agreement with the results obtained from CSRG (34 m/min for a 10° slope), largely because most of the Hunosa circuit had a high slope value, of more than 7°.