Ergonomics in the Design Process

Presented by Justin O'Sullivan CPE, Principal, Ergonomics for Work; ergowork@bigpond.net.au

Introduction

Given the type and nature of injuries in underground mining, the key roles and necessary independence of operators and the very difficult environment, ergonomics plays a fundamental role in the design of underground mining equipment. It is clear that optimal performance, minimal fatigue and minimisation of errors are crucial to a productive and safe process. Ergonomics plays a key role in all of these areas by ensuring that the dimensions, clearances, space, layout, efforts, visibility and other factors, incorporated in the equipment design, are matched to human capabilities and limitations.

Engineers work hard to ensure that the equipment is designed for the purpose, is capable of withstanding the stresses, is productive and cost effective. However, in many cases, the design is a slight modification or progression of existing designs and without a significant focus on the human factor. In my experience engineers often see the human as the weak link in a good design and one element which is difficult to control and can involve unpredictable outcomes.

Ergonomic data, about humans and their interactions with tasks, can help take some of the mystery out of the human factor and provide engineers with useful specifications to be incorporated in the equipment design. This presentation discusses the types of contributions ergonomics can make to the design of underground equipment, along with some examples.

Ergonomists and Ergonomic Data

According to the International Ergonomics Association ergonomists **contribute to the design** and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people. Ergonomists, in practice, have to address real world problems and seek the best compromise under difficult circumstances while aiming to provide cost effective solutions, according to Stanton et al.[1]

In my experience ergonomists also have other goals, particularly in regard to assisting with design:

- Find and apply data on human performance relevant to the design and demands;
- Assist the designer/engineer by way of ergonomic specifications;
- Assess risk quantitatively, comparing current and intended designs;
- Set clear solution goals and specifications which can act as a design standard;
- Often provide a neutral or objective opinion utilizing ergonomic data.

Examples of ergonomic data and their application are discussed below.

Anthropometry

Anthropometry is the science which deals with the size and shape of people within a population (Standards Australia Handbook 59-1994). The application of anthropometry, in design, is to incorporate the relevant human dimensions, aiming to accommodate at least 90% of potential users, taking account of both static and dynamic factors. Static factors are such things as height of a lumbar support on a seat backrest, the seat pan depth, the doorway size for access, etc. Dynamic factors relate to movements of the body, reach distances, movement patterns, viewing angles (where a person has to move their head to view from one point to another as part of the process).

Photo 1: Roof Bolting

A critical example of anthropometry, in this case, is viewing and reaching angles in roof bolting. In this case a miner was suffering chronic neck pain (Photo 1). Analysis

[1] **Stanton, N** et al, Editors, Handbook of Human Factors and Ergonomics Methods, CRC press, 2005.

of the work revealed typical neck extension in the order of 40-45° as well as maximum reaching to insert the bolt and resin. The height of the floor of the continuous miner was found to be such that most people would need to adopt near to 40° neck extension to view the bolt hole as well as significant reach in order to reach forwards and upwards when inserting bolts and resin. The solution involved determining the appropriate floor heights, and forward reach distances to the bolters, in order achieve a suitable degree of neck extension based on typical frequency and duration. The ergonomic data included eye movements vs neck movements, the part of the neck involved in the neck extension, human dimensions for eye height and reach capacity, likely forces applied and other factors. The result was a recommendation to raise the floor of the miner 100-200mm and extend the floor forwards 200mm toward the bolters (Photo 2).

Biomechanical Stress Analysis

Biomechanical factors take in all factors related to musculoskeletal stress, including postures, movements, forces, durations and frequencies. There is relevance to all aspects of underground mining even the walking demands placed on Deputies.

Photo 2: Refurbished Miner – raised and extended floor to assist roof bolting

Ergonomic data is available in relation to muscle strength, joint range of motion, movement patterns, endurance, repetition and speed, for example, a rapid movement can be perhaps 30% weaker than a slow movement.

An example of a particularly non-ergonomic situation, where there appears to be little account taken of biomechanical stresses, is the changing of rollers on gate road converyors (Photo 3). Here the problems relate to limited space, unpredictable forces, tight deadlines, awkward postures, poor visibility and inability to use both hands comfortably in the circumstances.

Photo 3: Changing of rollers

A further example is shuttle car design where there are common problems with seat heights, pedal reach distances, viewing angles and other factors (Photo 4-6). Shorter workers may be required to half stand up whilst driving or lean outside the confines of the vehicle to see. Even tall workers can have problems with the viewing angles as well as problems fitting their knees between the tow opposing seats.

Photo 4: Shorter worker operating the shuttle car

Photo 5: Shorter worker leaning out to see ahead

The ergonomic advice given included detailed dimensional specifications with an adjustment range to accommodate 90% of operators and to allow for appropriate viewing angles, good lumbar support (most T backrests available do not have a good lumbar support), raising of the floor to improve heights of the seat, repositioning the seat relative to the pedals (Figures 1, 2, 3).

Photo 6: Taller worker operating a shuttle car still with obstructed viewing angles and limited knee room

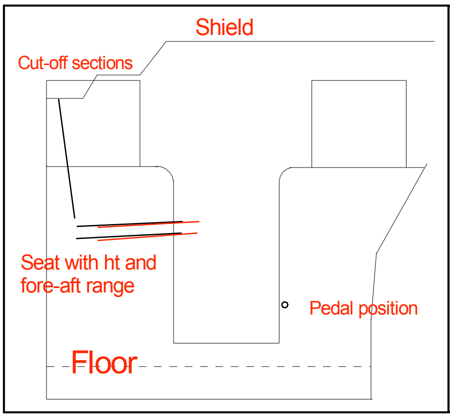


Figure 1: CM layout

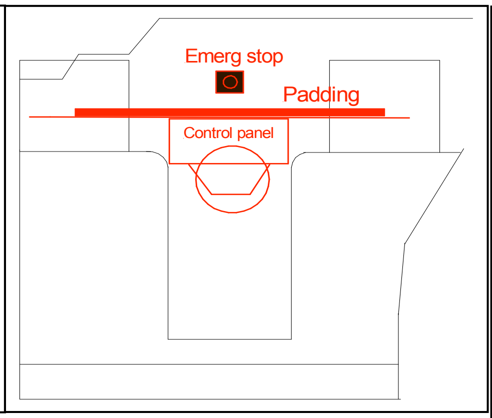


Figure 2: CM steering wheel position

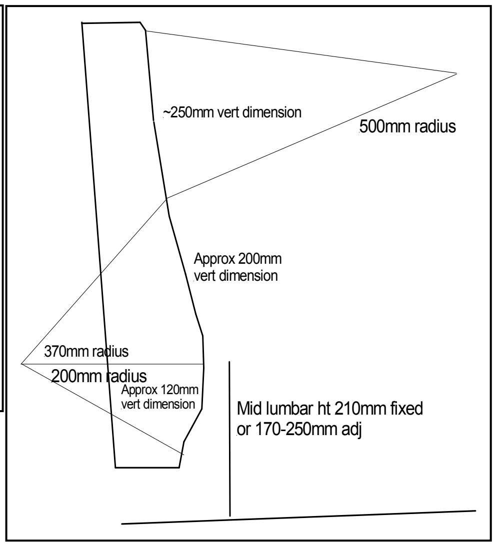


Figure 3: CM seat profile

A new miner being constructed is being designed to include a swivel seat, swivel through 180°, with toggle controls on the armrests which would have a switching mechanism built in so that tilting the toggle lever to the left steers the machine left while tilting to the right steers the machine to the right no matter which way the operator is facing. An important ergonomic factor here is the armrests must move up and down with the suspension seat so that support of the forearms is maintained in order to maintain control of the toggle levers and prevent sudden and uncontrolled movements during operation.

Slip and Fall Prevention

A significant area of ergonomics is the analysis and control of slip/fall risks including slips and falls on a level surface and the design of access ways and ladders etc. An example is the access on a continuous miner where the analysis found significant problems related to the step heights, lack of poor slip resistance, a significant step across distance to the tail and lack of slip resistance on the platform around the edge of the tail (Photo 7).

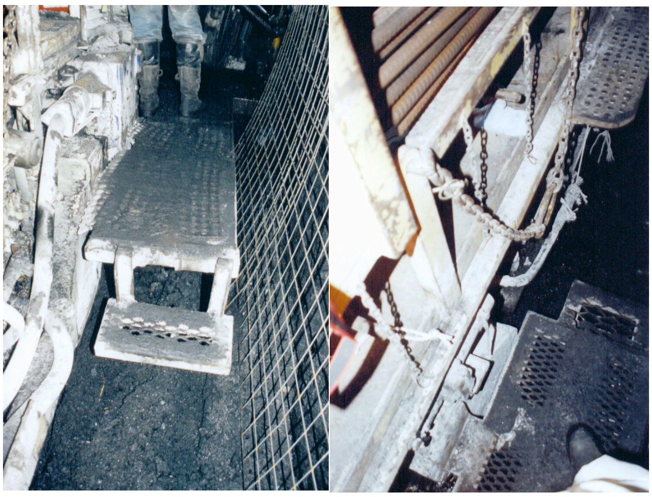


Photo 7: CM access/egress

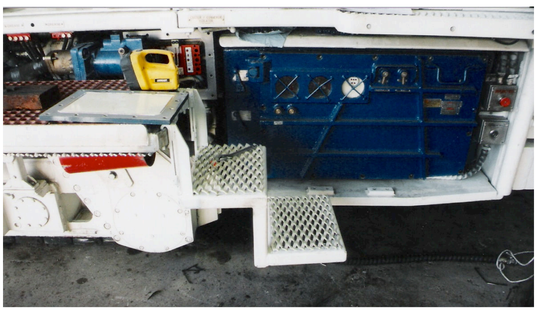


Photo 8: Refurbished CM access steps prior to fitting of slip-resistant nosing strips

Analysis of incident data among the development crews found that 20% of incidents arose from access/egress on and off the miner. A more detailed analysis by Burgess – Limerick has found an even greater percentage of the incidents are related to access and egress. The ergonomic specifications for a refurbished miner included altered dimensions on the access steps, a lower bottom step height, application of slip-resistant nosing strips on the steps and on the tail.

Control Room Ergonomics

In the control room situation there is a mixture of office and visual ergonomics as well as cognitive and computer-human interaction. The ergonomist has the role of assessing and providing specifications for the layout, the heights, the viewing angles and distances, character heights and contrasts on the screen as well as various other factors. An important issue, shown by research, is the need to support the whole forearm when using the mouse in order to greatly reduce musculoskeletal efforts in the forearm, shoulder and neck.

Photo 9: Old Control Room

In this example, at a hard rock mining situation (Photo 9), the control room had been designed in a rudimentary fashion resulting quite inappropriate dimensions, poor postures, poor viewing angles and other problems. Solution specifications included the designing of a new three-person console, a new layout for the existing room, a layout allowing easy viewing to the outside to rest the eyes and full forearm support (Figure 4, Photos 10, 11).

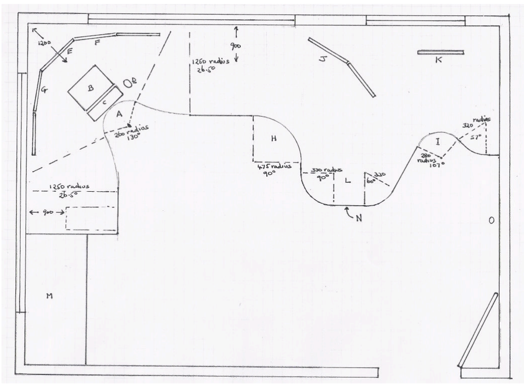


Figure 4: Drawing of new control console

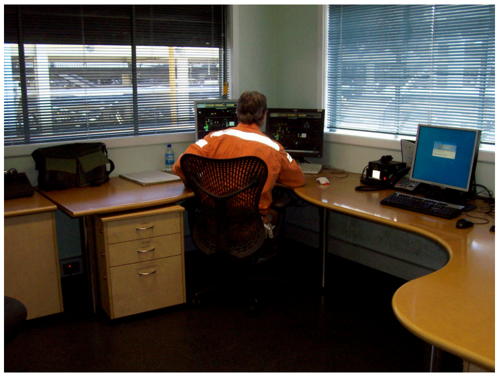


Photo 10: Main conrollers Position (prior to completion)

Photo 11: Secondary Control Position

New Miner Project

Ergonomic specifications were requested for a new ABM 25 Miner for BMA Crinum Mine with the aim being to assist the engineer, Alan Bruce, in determining suitable dimensions, forces, layout factors and other aspects of the design. Specifications were provided in regard to the following:

- Floor height;
- Monorail storage and handling;
- Mesh handling;
- Cassette storage and handling;
- Roof bolting;
- Rib bolting;
- Access/egress;
- Guarding and mechanical safety issues.

In regard to working height, the intended floor height was 993mm, with the floor to roof height being 2300mm. Analysis of various tasks, such as roof bolt insertion, viewing angles for roof bolts, monorail installation indicated that most males would find the reach distance difficult and neck extension would be excessive. Basic anthrometric data was extrapolated to allow consideration of the effect of the roof height; some examples are shown in the figures below.

Vertical Reach Capacity for Gripping Standing on Tip-Toes	
5th percentile:	2055mm
50th percentile:	2185mm
95th percentile:	2315mm

Vertical Height of Males with Shoes and Helmet Worn	
5th percentile:	1720mm
50th percentile:	1835mm
95th percentile:	1950mm

Vertical Reach Capacity for Gripping	
5th percentile:	1980mm
50th percentile:	2110mm
95th percentile:	2240mm

Conclusions reached included the fact that the roof would be out of reach of 5th and 50th percentile males (if having to reach to the mesh itself in order to hook on monorail brackets), the method for monorails needed to extend reach by 250mm for small males. The force applied would determine the actual reach distance limitations. Practical guidelines given included the capacity to reach forwards from the chest and to reach forwards in front of the toes (allowing for the front edge of the platform for roof bolting).

In regard to roof bolting, the original design included a 550mm forward reach to the bolters which was taken into account in determining the reach capacity for males at 550mm forwards of the shoulders. This showed a reach capacity (vertically) of 1635mm for 5th percentile and 2052mm for 95th percentile (tall) males. The required reach was a nominal 2000mm, allowing for a need to reach to 300mm the roof for easy insertion for bolts and resin etc.

Viewing angles were also considered, allowing for bolt holes to be 500mm forwards of the eyes and the 2300mm height resulting in 39-53° upward viewing angles for small to large males. In allowing for some upward movement of the eyes themselves it was considered that neck extension would be 38° or more for small males. The specification given was to limit neck extension to 25° maximum for all workers.

The overall result was a recommendation to raise the floor height by 200mm which was achieved by installing the first adjustable floor on a continuous miner.

Installation of monorail was examined to consider the force to slide one piece of monorail into another at a maximum reach distance. The strength capacities were provided for movements across overhead or in a fore – aft direction for this type of action, using one arm as well as considering the weight of the monorail sections themselves.

Another key issue was the need to slide mesh from a pack on top of the machine forwards and over above the roof bolters. (Figure 5) On the original design it was found that the height of the top of the pack would be 1925mm which exceeded the reach capacity of small males at 300mm forwards of the shoulders, and was near to the reach capacity of average males.

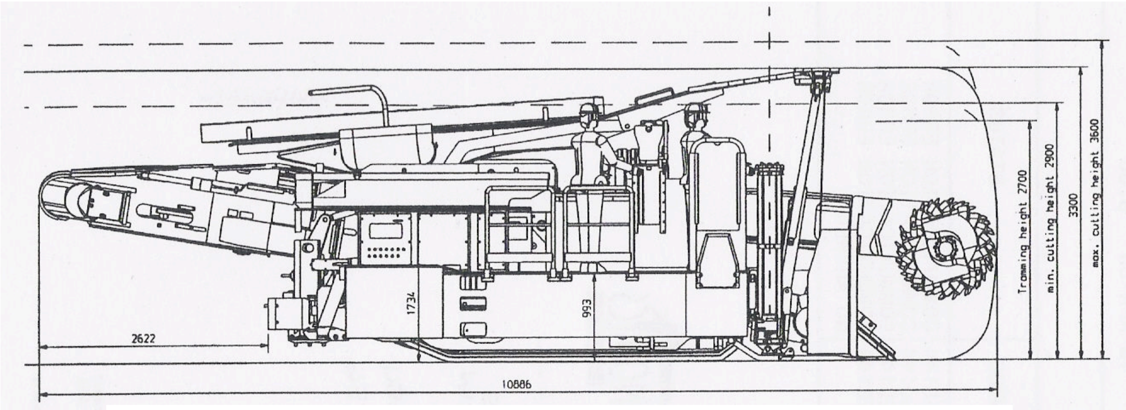


Figure 5: Continuous Miner (ABM25) with pack of mesh on top

The forward reach distance was also found to be a problem. The recommendation included raising the floor height 200mm and limiting any sliding force to 10kg. A further improvement was achieved by having the platform for the mesh designed to swivel toward the right side of the machine in the most forward position to allow the right side worker easier reach to commence the sliding motion and slide the mesh across to the right side first with assistance then provided by the worker on the left side.

Access/egress issues were also considered where it was recommended that the miner have a stairway style configuration with a handrail and slip-resistant nosings, ensuring that the rises were consistent and within a suitable range, based on AS1657, and the bottom step height would be no more than 400mm above ground level. The latter specification was achieved by having the steps able to be folded up for the flitting phase.

In summary, some of the particularly helpful features of the miner are as follows:

- An adjustable floor height to accommodate a larger range of users;
- Handrails to minimise the risk off falling of the side;
- A stairway style access way with good dimensions for easy access/egress and slip-resistant nosings;
- A mesh tray which swivels around to the right for easier reach, also assisted by the raised floor;
- Rib mesh holders, just outside the guardrail;
- A 450mm forward distance between the platform and roof bolters;
- Push button miner bolter controls;
- Improved space in and around the bolter console.



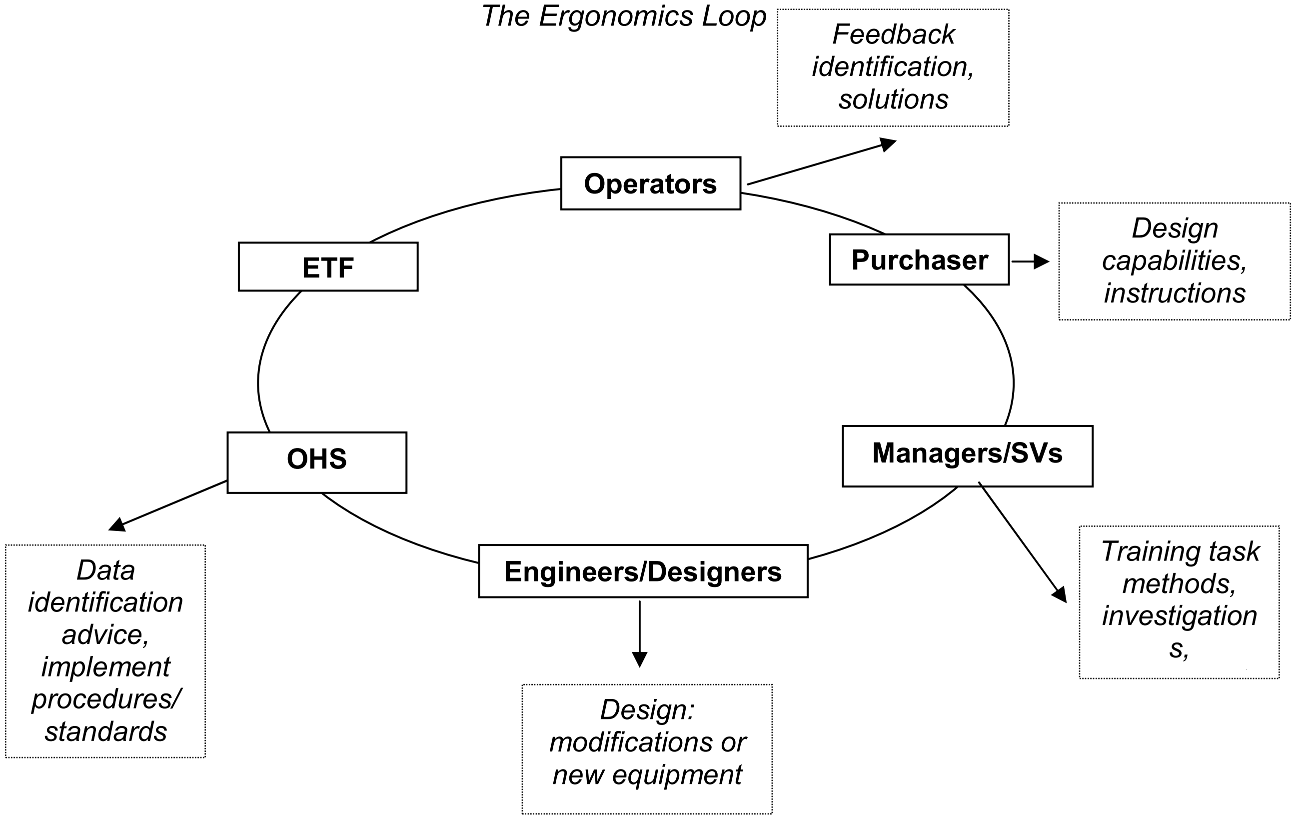

The Design Process and System

In order to effectively apply ergonomic specifications to the design of equipment underground or in any situation, it is necessary to have good consultation with users and operators, a good working relationship with engineering personnel and an effective process. Such a process can be simplified as below

- Determine Objectives/Purpose
- Determine all functions to be performed (by machine, human software)
- Identify functions to be allocated to humans
- Perform in depth task analysis and workflow
  Identify relevant human performance data, outlining specific limitations and capacities
- Lay down design specifications based on human performance and Ergonomic Criteria
- Determine the viability or feasibility of ensuring design meets specifications; if not, reallocate functions and revise design.

Various parties have a role in the process which is illustrated in the ergonomics loop, including an Ergonomics Task Force made up of operators and hopefully engineering and safety personnel (ETF).

The Ergonomics Loop



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