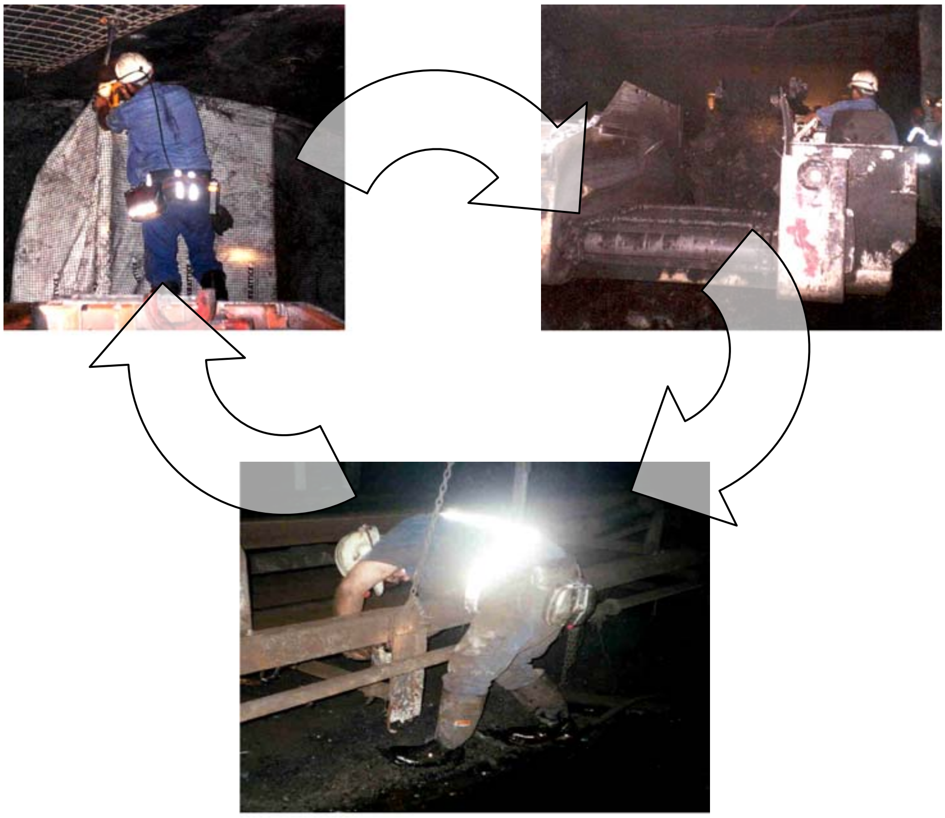
Workload Distribution in Underground Coal-Mining



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Summary

This report describes a study of workload distribution in underground coal-mining funded by Coal Services Health and Safety Trust, undertaken by a research group at Queensland University of Technology. The study focused on the use of strategies to reduce musculoskeletal injury that use various forms of workload distribution, including job rotation, as one part of the hierarchy of controls. Previous research on the practice and outcomes of job rotation in other industries were reviewed, together with aspects of injury causation and fatigue that are influenced by workload distribution.

Deputies in Queensland and New South Wales representing 248 miners were interviewed about the current workload distribution practices at four different mine sites, together with a smaller group of miners. This provided information about the involvement of miners and deputies in decision processes about the allocation of work over the course of a shift, the factors taken into consideration in both allocating work and in determining the nature and timing of rotation to other tasks. Information was also gathered on related issues such as break and sleep quality. The interviewees also provided open-ended commentary on limitations to job rotation in their crews.

A set of field observations were also conducted, which supplemented the interview data and provided information concerning the limitations and opportunities for job rotation within crews.

A modeling exercise was undertaken using information gained in the preceding phases to illustrate the effects of varying crew size and skill levels in crews on the capacity to undertake job rotation over a shift.

A series of recommendations are made with respect to workload distribution practices, in the areas of management and policy, crew-level interventions and training, and research and data management.

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Acknowledgements

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1. Introduction

Despite the increased mechanization of industrial activities, underground coal mining remains a physically demanding occupation. Manual handling tasks in this sector involve repetitive lifting, carrying, pushing and pulling (sometimes of high loads) that can lead to repetitive strain injuries (McPhee, 2004). Injuries often occur as a result of awkward postures, high levels of mechanical stress and high rates of task repetition. According to the *Queensland Mines and Quarries Statistical Report (2004/5)*, sprain and strain injuries comprised 62% of all workers compensation claims in coal mining, and, at just under 40%, represented by far the most frequent type of injury in mining overall. In a recent survey of coal-mining OH&S managers undertaken by the research team (Parker and Worringham, 2004), only dust was ranked as a greater health hazard than manual handling, musculoskeletal injury, and sprains and strains (Table 1-1).

Table 1-1 Ranking of top 5 health hazards across the participating mines

Ranking of health hazards	
Rank 1	Dust
Rank 2	Noise Manual handling/musculoskeletal/sprains and strains Poor ergonomics
Rank 3	Environment Unevenness causing slips, trips and falls Rocks and walls collapsing Equipment Traffic
Rank 4	Diesel fumes Chemicals Hazardous substances
Rank 5	Vibration

Source: Parker et al. 2004

There are many factors influencing the probability and severity of such musculoskeletal injuries. This report focuses on one in particular - the distribution of workload – and more particularly, the distribution of workload between employees. The report presents information about current practices in the underground coal-mining sector, and considers how workload distribution may contribute, along with other forms of control, to limiting or reducing the occurrence of musculoskeletal injuries.

Ideally, workload distribution would be organized to ensure that physical loads never exceed the capabilities of workers. There are several structural factors that influence this, including adequate staffing levels and shift length/rosters that are not excessive, as well as ergonomic changes to reduce physical demands. Each of these well-accepted measures has limitations, however. Staffing levels may be sub-optimal as a result of illness or skill shortages. Shift lengths reflect multiple and complex factors including collective bargaining, transport, accommodation and other logistics. Ergonomic improvements may be constrained by the limitations of the underground environment as well as cost, and can take time to implement even when an ideal re-design has been identified. Therefore, it is important to consider other approaches to mitigating injury, including distributing workload in such a way that it reduces the level of injury-causing factors. One approach, job rotation, shares work tasks across workers over the course of a shift, and can account for the capacities of the worker, the time spent on performing tasks and the physical demands of the task (Carnahan et al., 2000). Unlike some industries with highly prescribed and compartmentalized tasks, such as certain types of manufacturing, underground coal-mining has many unique characteristics influencing workload distribution. Figure 1-1 illustrates some of these differences. As a consequence of these factors, the industry has already evolved its own patterns of job rotation, so that the introduction of job rotation is seldom an issue. Indeed, underground coal-mining has always shown greater sharing of work-tasks than has the open-cut sector with its marked specialisation. Therefore, *understanding the variety of job rotation practices* that are in use and considering *ways to optimize them* are the key goals.

Inevitably, a range of practical concerns dictate task scheduling within a shift. These include the skill-sets and experience of individuals in a crew, the numbers on duty for a given shift, current geological and environmental conditions, pay rates for specific duties, and other factors. Observations from our Coal Services funded project concerned with *"Development of Functional Fitness Measures Related to the Work Practices of Underground Coal Miners"* suggest, however, that current workload distribution may in some instances be less than optimal with regard to exposure to injury risk, and that quite simple modifications could be explored without major disruption of work. Variety in workloads can be achieved through

Manufacturing work

Easily observed, measured, regulated.
Issue is whether to introduce job rotation at all

Underground coal-mining work

Autonomous, distributed, hard to measure.
Issue is how to optimise existing job rotation

Figure 1-1 Contrasts between manufacturing and underground coal-mining in factors that influence job rotation practices.

varying tasks, working at different speeds, avoiding prolonged repetitive short cycle tasks and movements, and increasing the frequency or duration of rest breaks.

Within a job schedule, the timing and sequencing of tasks must strike a balance between productivity demands and the safety concerns of personnel involved in meeting those demands (Carnahan et al., 2000). It is not necessarily the case, of course, that these goals are contradictory. For safe job design, it would be ideal to have a clearly established maximum acceptable work time for a given workload. In laboratory studies, it has been found that there is an inverse relationship between maximum acceptable work time and physical workload. Unfortunately, determining maximum acceptable work times for specific tasks and environments is much more challenging than doing so in laboratory conditions. However, it remains the case that optimising job rotation during a shift should enable loading on musculoskeletal structures that is less damaging.

Effective workload distribution within a crew requires that a range of factors be considered beyond simply the tasks themselves and the work-rest cycle, however. Some of these concern the degree to which members of a crew are qualified to perform and proficient in different work tasks. This issue is considered along with crew levels in a subsequent section.

From numerous discussions with managers, safety officers, deputies, supervisors and miners in the underground coal mining industry, the research team has become aware of the potential for injury associated with inadequate workload allocation and the opportunity and need for the design of effective work rotation schedules as one important strategy for the reduction of strain injury and fatigue. Consequently, the aim of this research was to evaluate current workload allocation strategies and where such practice can be improved, provide information that can be used to assist deputies and miners develop good models for their particular setting.

2. Methods

2.1. Review of relevant research

A first step was to establish those aspects of the problem that have already been investigated in previous research, and to evaluate relevant studies with regard to their scope, depth, quality, and applicability to the underground coal-mining environment. From this process findings which are well established and may be applied in this workforce were identified.

Accordingly, searches of basic science and clinical databases were undertaken of published resources in health, medicine and psychology, together with relevant biomedical science disciplines. Supplementary searches were conducted using other databases and from reference lists of key papers. A series of relevant journal publisher websites were also searched for articles that have been published recently but have not yet been indexed in the major databases. The research reports identified were categorized and key points summarised in a subsequent section.

2.2. Interviews with deputies and miners

Interview question development

Drawing upon observations of long-wall, development and maintenance processes and work tasks, as well as data on physically demanding tasks, the research team developed an initial set of questions aimed at determining the extent and type of workload distribution practices used by crews. These were revised and extended on the basis of comments from a small group of deputies and miners who assisted with the project in its early stages. The final version consisted of a mix of short open-ended questions (some with follow-up questions) and checklists, including some related to the timing, reasons, and personnel involved in decisions about job rotation. The final interview was piloted with other deputies to check its content, wording, and length.

In parallel with this process a similar set of interview questions was devised for miners rather than deputies. There was significant overlap of content, but some questions required rewording (for example, those concerning decision-making), to reflect the miner's perspective. The questions were piloted in a similar manner to those for deputies.

Interview implementation

Members of the research team undertook interviews at four mine-sites in Queensland and New South Wales. These were almost all conducted on-site and in person, however, a small number were conducted via telephone, as some individuals who were willing to participate were unavailable on the day of the researchers' visit. Participation was entirely voluntary, and procedures used complied with the requirements of, and were approved by, the QUT Human Research Ethics Committee. Recruitment of participants used a combination of flyers, talks to work-crews, and approaches by OH&S staff to available staff. While this essentially represents a convenience sample, very few prospective participants declined to be interviewed, and the sample is reasonably representative in terms of employee demographics (see Results section).

2.3. Observations

Members of the research team spent in excess of 80 person-hours at three mine-sites directly observing development, longwall and maintenance operations, particularly noting changes in tasks and their timing. These observations were primarily qualitative, as the need to be accompanied by an appropriately qualified miner and the dispersed nature of much of the work made formal recording of task durations and task switches possible only to a limited degree.

2.4. Modeling of factors affecting workload distribution

Data obtained in both the observations and interviews made it clear that job rotation practices are often constrained by structural factors of crew size and skills. Consequently, simple illustrative models of the effects of these factors were developed. These are described in Section 4.8.

2.5. Limitations of the study

Representativeness

The logistics of repeated travel to mine-sites limited the number of sites that could be included in the sample. Miners and deputies from two mines in Queensland's Bowen Basin and one mine in the Hunter valley of New South Wales participated in face-to-face interviews, with additional data from a fourth (NSW) mine obtained by telephone. It was not possible to determine if there are any consistent differences in workload distribution practices between Queensland and New South Wales. However, the four mines are owned by different companies, are of different sizes, and different mining practices (e.g. longwall, and highwall) and equipment. This diversity suggests that the data may be considered reasonably representative of the industry.

Matching of miners and deputies.

Ideally, all interviews would have paired miners and deputies from the same crews, so that comparisons between responses of the two groups could have been on matched responses. Two factors prevented this: firstly a decision to emphasise deputies as the primary source (thus creating unequal numbers), and secondly, the practical difficulty of obtaining responses from matched entire crews and their deputies, given rostering patterns and the limited time available for interviews pre-and post-shift.

Scope of study.

It was originally intended that, as a final stage, a set of optimal workload distribution practices be collated and piloted in a work-crew in an intervention-style phase. To accomplish this, it would have been necessary to finalise a set of optimal practices early, identify crews in which these practices were *not* used, and implement them over a period long enough to detect changes. However, the priorities of all mines is clearly on maintaining production, and securing such a high level of extended cooperation without disrupting production would have been very difficult. More fundamentally, it became clear as interview data was obtained that the factors affecting workload distribution practices are sufficiently complex, and the specific equipment, work methods and conditions of individual mines sufficiently variable, that any single "optimal" schedule of workload distribution would, even if it could be developed, not necessarily apply to a particular crew.

In consequence, the study was refocused to give greater emphasis to describing and analyzing current practices, to understanding more about those factors that appear to set limits on the extent of job rotation in this industry, and to the development of materials that can be used for training. The recommendations therefore include suggested guidelines for optimising workload distribution that include but go beyond the individual crew level, and, by being less prescriptive and more flexible than a single procedure, may have a better prospect of being adopted than had the original research plan been attempted without change.

3. Background and Literature Review

Many factors impinge on workload. These include the nature of the work tasks themselves (in terms of their biomechanical and physiological demands), roster patterns, shift length, staffing levels, work culture and practices, and a variety of factors that contribute to fatigue, including sleep patterns and circadian effects. Many of these lie outside the scope of this report, which focuses on the *distribution* of workload. While these other factors are sufficiently important that some of them are briefly reviewed here, the issue of job rotation is emphasized, as it directly addresses the allocation of tasks to workers independent of these other considerations. This section therefore begins by outlining the major mechanisms leading to musculoskeletal injury, which provides a rationale for the role of different forms of workload distribution in preventing injury. Then key studies of job rotation are summarised, including evidence concerning its advantages and disadvantages. In the final part of the review, other related factors impinging on workload distribution are considered.

3.1. Causes of musculoskeletal injury and workload distribution

The goal of this section is to highlight those aspects of injury causation that may in some way be addressed through modifications to workload distribution. It is not intended to be a comprehensive account of these mechanisms.

Kumar (2001) recently prepared an extensive review of the causation of injury to muscle, tendons, ligaments, bone and cartilage, and recognized four principal theories: *Multivariate Interaction, Differential Fatigue, Cumulative Load,* and *Overexertion*. While each emphasizes different factors, Kumar (2001) notes that all four operate simultaneously and interact. Each theory is summarized and their relevance to workload distribution is then presented.

Multivariate Interaction Theory

This theory reflects the widely held view that musculoskeletal injury is precipitated by multiple factors: in the first instance, biomechanical conditions create loads on tissue, the consequences of which are influenced by genetic, morphological and even psychosocial characteristics of the individual. This is an “all-encompassing” theory that recognizes the interplay of multiple external causes and different levels of predisposition, vulnerability and susceptibility, and the consequent strain imposed on tissue that is the direct precipitator of injury.

Differential Fatigue Theory

This view of injury causation starts with the observation that occupational tasks are not always biologically optimal. Many combine the features of being repetitive and/or asymmetrical (e.g. involving rotation). By requiring higher relative levels of activation in some muscle groups and their connective tissues, these become fatigued at a faster rate and to a greater degree than other muscles and their associated structures. With sufficient repetition, these fatigued structures lose the capacity to produce sufficient force and to control joint motions in a coordinated way that protects structures from damage. As a consequence, injury will occur either in the overloaded tissues directly, or on tissues they normally protect, by preventing appropriate load-sharing.

Cumulative Load Theory

This theory emphasises the "duty cycle" of tissues in activity induced injury. All tissues have a stress-bearing capacity that can be reduced by fatigue, and if sufficiently loaded, this may result in deformation and alteration of their viscoelastic properties. The threshold stress at which the tissue will fail is at its highest following adequate recovery, but with sufficient repetition and insufficient periods of recovery, cumulative loading will reduce the threshold to the point where otherwise "safe" loading will result in injury. This form of cumulative load is the product of each load and the loading cycle, and can occur in different combinations. Kumar reports, for example, that in studies of lumbar spine loading by Brinckmann et al. (1987, 1988) and Hansson et al. (1987), tissue failure occurred after 5000 loading cycles for loads between 50 and 60% of ultimate compressive strength (UCS) (the load at which failure occurs for a single cycle), but after just ten cycles when the load was 75% of UCS. Given that individuals cannot maintain exertions close to their maximum for more than a short period, biology appears to offer some protection against injury from high loads over a few cycles, but less protection from those occurring with moderate loads over a larger number of cycles. Rapid cycling, in particular, offers insufficient recovery time and will hasten the injury process.

Overexertion Theory

This resembles Cumulative Load Theory in its basic proposition that injury occurs when tissue tolerance levels are exceeded, but differs in recognizing the influences of force, duration, posture and motion during physical tasks. In particular, injury could occur through *sustained* contractions of particular muscles in awkward postures, rather than principally through repetition of a movement cycle as emphasized in Cumulative Load Theory. However, repetition of such motions may also occur. The theory suggests that overexertion injuries occur when the combined critical threshold "safety margins" for force, exposure time, and posture/motion are exceeded.

Implications for workload distribution

The theories sketched in the preceding sections are not the only ones which have been proposed, but they represent major hypotheses about injury causation, and together, identify both the range of contributing factors and some of the ways in which these factors operate.

At the heart of each theory is the central fact that tissue damage occurs when a *force* or *stress threshold* for the most vulnerable tissue is exceeded. In turn, the threshold is reduced by attributes of the action(s) performed (repetition rate, load, posture, exposure time, asymmetrical or differential loading) and characteristics of the individual. Of direct relevance to the topic of workload distribution are the interactions involving *load, repetition*, and *exposure time*, for each individual work task. A continuum of loading can exist, and injury result from either excessive peak loads or the cumulative effect of lesser loads sustained over a protracted period. These situations are illustrated in a simplified form in Figures 3-1, 3-2, and their implications for job rotation and workload distribution are summarised in Figure 3-6, discussed later.

An injury that results from a peak load could be associated with a single task occurring only once during a shift, with an acute injury resulting from the inability of the muscle, ligament, tendon or other structure to withstand the high forces acting on it. By contrast, prolonged exposure to tasks that by themselves would not result in such acute injury may nevertheless cause progressive damage over time, a shown in Figure 3-2. While there are various engineering strategies that may be applied to reduce the high peak forces seen in some manual tasks, especially those requiring lifting or carrying, the cumulative effect of sustained work with low to moderate peak forces can still elevate injury risk. For a set amount of work, there may still be significant cumulative loading. To use a simple example, if 100kg

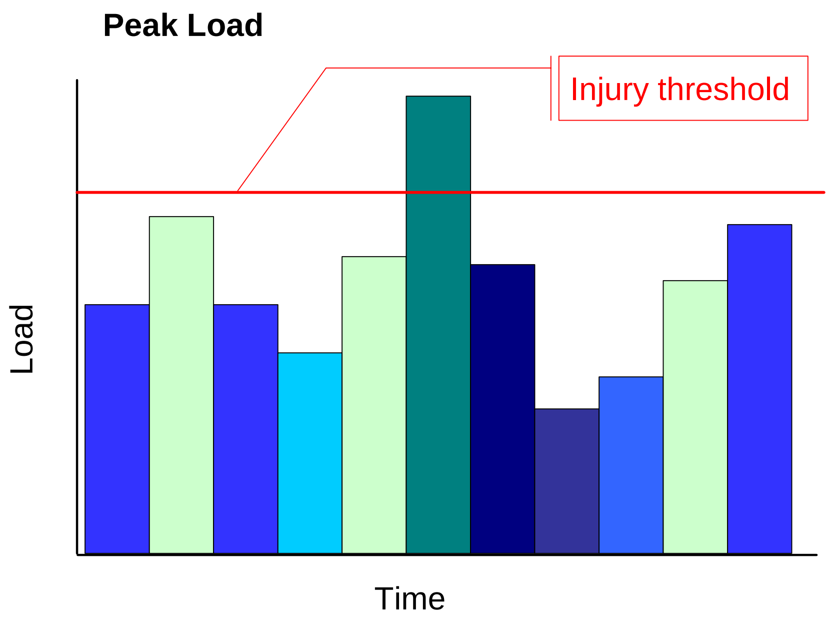

Figure 3-1   Injury caused by peak loading

Each bar represents a single task, one of which exceeds a critical injury-producing load in isolation

of supplies need to be lifted and carried a set distance, there are choices as to how the task is executed, e.g. 5 lifts x 20kg or 20 lifts x 5kg. The latter moves the situation away from high peak loading but may still cause cumulative injury. Many such choices occur in underground coal-mining, as illustrated by some of the items that are delivered by out-bye workers and transported to the development or longwall panels. Some of these typical loads are illustrated in Figure 3.3. Both peak and cumulative spinal loading are independent risk factors for the reporting of low back pain (LBP) (Norman et al., 1998), and any injury-reduction strategy must address both.

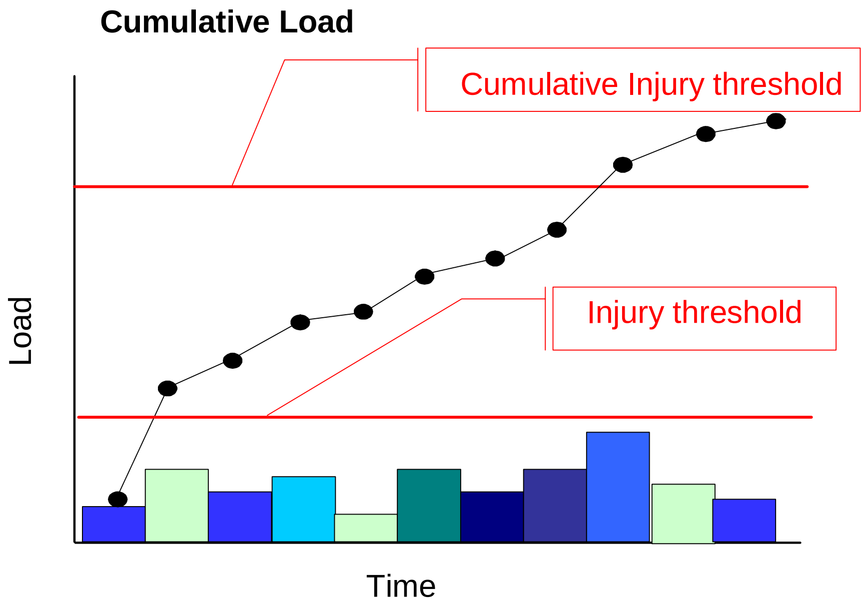

Figure 3-2 Injury caused by cumulative loading

Each bar represents a single task, none of which exceeds a critical injury-producing load in isolation. Injury can be caused by summation of loads over time (black line).

Obviously, a trade-off also exists between loading and task duration, as the preceding load carriage example makes clear. Productivity demands clearly limit the distribution of such tasks across time. Twenty lifts of 5kg will take four times as long as the higher peak load alternative. A complicating factor is that this trade-off between force and duration can also influence the frequency and duration of recovery periods (Christensen et al., 2000). This includes both "micro-recovery" (such as periods of seconds or minutes that occur naturally within many tasks, e.g. on completion of a roof-bolting cycle while waiting for the continuous miner to move into position), or in longer formal rest breaks. As expressed by Wood et al., (1997), who have studied these trade-offs extensively, *"increasing the force increases the time available for recovery but also increases the need for recovery".* For this reason it is extremely difficult to devise optimal work-rest ratios for specific industrial settings (e.g. Lilley et al., 2002). This is especially true when workers undertake multiple tasks.

Figure 3-3 Sample loads in underground coal-mining

(Photos courtesy of Kestrel Mine, Queensland).

3.2. Job rotation as strategy for decreasing the risk of injury

The basic premise of job rotation is to alleviate the physical fatigue and stress on a particular muscle group or groups, ligaments, tendons, joints, or other structures by rotating workers between jobs that involve higher and lower physical demands or between jobs that place physical demands on different structures. The underlying assumption is that by spreading the workload over several physical structures in this way, the injury risk can be lessened. For example, by rotating between tasks that primarily require the action of different muscle groups, the cumulative stress imposed on each can be kept below the cumulative injury threshold, as previously outlined. Job rotation is also claimed to have a number of secondary benefits including reduced boredom and monotony for the workforce, increased motivation and innovation, reduced work stress and associated absenteeism and turnover rates, increased production (cited in Frazer et al., 2003).

3.3. Limitations of job rotation.

High peak forces

While job rotation may alleviate cumulative loading on specific structures, it would be ineffective in mitigating injury attributable to exceptionally high (peak) forces. This is because injury can be caused by even a *single* exposure if the peak forces involved exceed critical values. It is accepted that exceptionally high forces are, by definition, encountered very infrequently. The important point, however, is that the logic of job rotation does not apply in such cases. Indeed, rotating larger numbers of workers through such tasks may simply expose more people to injury (Frazer et al. 2003a). For this reason, other forms of control, including fundamental redesign of the task, should always be used in such cases.

Different tasks using the same muscles, ligaments, joints

Rotation among jobs that involve different operational tasks but which use the same muscle groups or other structures in a similar way cannot be nearly as successful in reducing injury risk, even though the strategy may have secondary benefits such as alleviating boredom and monotony, referred to previously. In most cases of manual handling and manual operation, there is at least some overlap in the structures that are loaded between one task and another. This often involves the trunk and, in particular, muscles of the back, and consequent stresses on the spinal column. Posture is a critical element in the degree of overlap. An erect posture, such as standing or sitting, reduces torques around the lumbar vertebrae, decreases muscle activation required to counteract such torques, and reduces spinal compression. Therefore, switching between, for example, operating the continuous miner and roof-bolting will transfer loads from one set of structures to another more completely than switching between roof-bolting on one side of the miner to doing so on the other (though some equipment makes roof-bolting tasks somewhat less similar on either side than others). A challenge in finding effective job rotation practices is to maximize the differences between consecutive tasks with respect to their demands.

Other factors than the physical demands of the work are also important. For example, Baker et al. (2003) recommend that the scheduling of tasks should be planned to ensure that high risk tasks are performed during periods of highest alertness. Rotation onto a higher demand job when already physically tired is not advisable. Rotation systems should be flexible enough to allow for situations such as this.

3.4. Costs associated with job rotation

From an employer standpoint, the main objection to implementing job rotation in the workplace may be a loss of production. Rotation of tasks takes time switching from one job to another, especially if the workplace is spread out and significant travel is required, such as required in underground mining or on large construction sites. Task rotation scheduling is dependent upon the work environment, the nature of the work and the number of tasks suitable for rotation. The skill level of the workers also needs to be taken into consideration. Workers cannot be rotated onto a task for which they do not have the training or the skills or fitness. In order to optimise job rotation it is necessary to also promote multi-skilling in the workforce. Other workload factors to consider in the design of work schedules include mental application and fatigue, monotony or diversity of tasks and social aspects. Additional problems are posed by the effects of an aging workforce, where tolerance for higher workloads decreases with age as a function of spinal compression tissue tolerance (Jager et al., 1991). Gaudart (2000), for example, has noted that older workers performed less job rotation in the French automobile industry, for example, than their younger counterparts.

Boost productivity, cut injuries with job rotation - Up Front

Risk & Insurance, March 3, 2003 by Joshua Clifton

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NATIONAL HAZARD ALERT

AMWU

SHARING THE RISK – JOB ROTATION

Its Bad Health And Safety Practice

Manual Handling is risky business; when workers compensation figures are looked at, lifting is the most common cause of injuries.

Unfortunately, employers often use job rotation to decrease the risk of injury. It cannot work if the worker is rotated through a lot of risky jobs.

Job rotation can be particularly dangerous when extra hours are worked or staff are absent and the rotations are less frequent.

If manual handling risks exist[1], then the work MUST be changed to minimise the risks to health and safety.

Figure 3-4 Simplistic views of job rotation tend to over-emphasise its advantages and its disadvantages

(Sources: Clifton, 2003; AMWU, 2006)

Unfortunately, information about job rotation includes publicity that tend to emphasise either its positive effects or by contrast, focus on its potential problems. Examples of each are shown in Figure 3.4., the first from a professional insurance industry journal, the second an alert issued by the Australian Manufacturing Workers' Union (see also Worksafe, Victoria, 2003). In both cases, however, the more detailed information provided in the complete text acknowledge the limitations (in the first case) and the situations in which job rotation can play a role (in the second), so that the "headline" claims in each case over-simplify the reality. The following section examines the empirical evidence on job rotation to date, with the goal of providing useable guidelines.

3.5. Evidence of effects of job rotation

The first observation is that job rotation is a relatively widely used strategy for minimising occupational musculoskeletal injury. In the United States, a study of manufacturing companies in the Midwest found that 43% of companies used job rotation (Davis and Jorgensen, 2005). Although several objectives were cited by respondents, the main goals reported were to reduce exposure to risk factors for work-related injuries and to reduce work related injuries. When questioned about the benefits realised from introducing job rotation, a mean rating of 4.09 on a 5 point scale (in which 1 = “not at all”, and 5 = “very much”) was given for the item “decreased incidence/symptoms of work-related injuries, surpassed only by a score of 4.19 for that of “increased skill of the employees”. Locally, in our survey of OH&S staff in Australian coal-mining, job rotation was reported as being used by 70% of responding mines (Figure 3.5.), the second most frequently reported strategy for avoiding excessive physical demands of work (Parker et al., 2004). The survey did not, however, probe the particular forms of job rotation in operation.

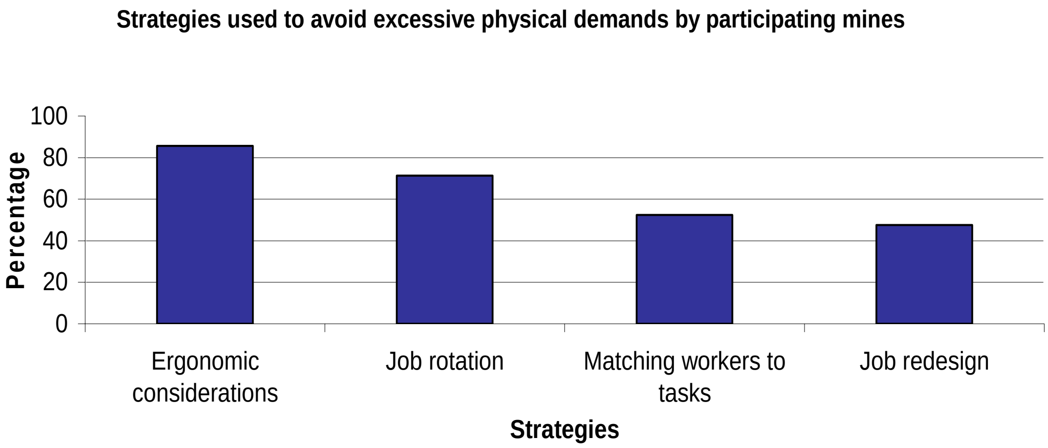

Figure 3-5 Job rotation amongst strategies reported by OH&S staff for dealing with physical demands of jobs

Source: Parker et al, (2004)

Studies reporting the efficacy of job rotation are small in number. Many unions and government departments already advocate the application of regular job rotation in the workplace to counteract fatigue and injury risk and provide guidelines for doing so (e.g. US Department of Labor Mines Safety and Health Administration, 2003; Triggs and King, 2000; Ellis, 1999), so it is surprising that so little research exists regarding the outcomes of job rotation in occupational settings thus far. One reason may be that the effects of job rotation are often difficult to obtain because the type and extent of job rotation – especially the demands on different structures – are difficult to quantify (Frazer et al., 2003a and b). Some studies focus less on the efficacy of the practice than on methods to set up job rotation schedules. For example, Carnahan et al. (2000) developed and tested algorithms to produce job rotation schedules designed to reduce injury risk. Lifting tasks were assessed for injury risk according to the Job Severity Index (JSI) with task rotation schedules subsequently designed based on the index. The JSI is a unitless ratio of weight lifted compared to worker capacity, and takes into account the weight of the object, the rate of lifting and the horizontal distance of the object from the ankles at the start of the lift (Liles, 1986). The aim was to create a safe job schedule where the object weight, horizontal distance and repetition rate varied over time. Gender and lifting capacity of the individual were taken into account.

Mathematical approaches to establishing job rotation have also been reported by Tharmmaphornphilas (2003), albeit for noise exposure rather than musculoskeletal injury.

More recently, Drinkaus et al. in two related papers (2005a and b), report evaluations of methods for determining the job risks for multi-task jobs, including the use of an upper extremity load measure, a modified Strain Index and the NIOSH composite lifting index, that may be of value in assessing the loads faced by workers who engage in several tasks.

Overall, it is premature to advocate any particular method for setting up optimal rotation schedules. The current literature is far from complete, but the studies do point to the importance of establishing appropriate indices if job rotation is to be based on a formal process. Currently, such formal, prescribed rotation schedules would not seem to apply to underground coal-mining as the allocation processes are far more informal and distributed than those examined in the preceding studies.

Job rotation as a risk factor in industrial workers

Roquelaure et al. (1997) report one of the only epidemiological case-control studies in which the factors investigated included job rotation. Sixty-five television manufacturing plant workers (10 female, 59 male) with carpal tunnel syndrome and sixty-five matched workers without this diagnosis were compared to determine the relative contribution of work-related and individual risk factors. Workers with previous musculoskeletal injury were excluded. The “odds ratio” for lack of job rotation was 6.3, in other words, those whose work did *not* include job rotation had a probability of having carpal tunnel syndrome 6.3 times higher than those whose work involved job rotation. Several other factors, including force exertion and repetition, were also identified as risk factors, and these factors were found to exert a combined effect. Although job rotation was found to be an important factor in decreased incidence of carpal tunnel syndrome in this study, it cannot be completely dissociated from other risk factors present in this population, nor could it be determined if it had similar effects on other forms of injury. In a review of studies concerning carpel tunnel syndrome, Lincoln et al. (2000) noted that the absence of job rotation was implicated as a causal factor in several studies, but commented on the methodological flaws that characterised many of the studies and that prevents any unequivocal conclusion about these risk factors.

Musculoskeletal disorders, muscle function and job rotation in supermarket cashiers

In one study of female supermarket cashiers, Rissén et al. (2002) evaluated the blood pressure, electromyographical activity of the trapezius muscle (which covers the upper back, the neck, and the shoulder), as well as the rate of reported musculoskeletal disorders and pain, and perceptions of work. These observations took place before the introduction of job rotation between cashier work and a mix of cashier work and tasks in the various supermarket departments. The latter took place between 3 and 4.5 years later. The measures which showed a significant change were a decrease in systolic blood pressure, an decrease in trapezius muscle activity on the left side of the body, and an increase in the reporting of “positive arousal” with respect to work. The authors noted potential shortcomings of the study, including the relatively small sample size (n=31), but also commented that the improvements recorded are opposite to the trends of increased work stress and sick leave observed in the Swedish workforce overall in that period. Thus the study showed modest but real benefits of a job rotation system.

Low back pain reporting and job rotation in simulated automobile assembly tasks

Frazer et al. (2003a) evaluated job rotation strategies in a laboratory study in which two automobile assembly tasks were simulated in a biomechanics laboratory (one task having low physical demand, the other high physical demand). The evaluation involved rates of reported low back pain (LBPR), and vertebral loading patterns, with measures of lumbar vertebrae peak shear force and cumulated moment over a shift.

When one of two analytical methods was used - time weighted average (TWA) (Smith et al., 1991), no major effect of job rotation was found. TWA is determined as an average of the risk between jobs. For example, if job 1 has a high (40%) injury risk while jobs 2 and 3 both have a substantially lower risk (10%), the TWA injury risk over a shift, assuming each job is performed for an equal duration, is 20% (Frazer et al., 2003). When performed in the absence of job rotation, Job A had a significantly lower injury risk than did Job B, as indicated by the LBPRI for each (Job A 0.46; Job B 0.81). However, when time was split evenly between the two jobs, the injury risk was 0.72 using the LBPRI method. Both scores are lower than the injury risk seen when only performing Job B and higher than the injury risk seen when only performing Job A, indicating that job rotation does act to spread the workload.

Further analysis by Frazer et al. (2003a), however, using different proportions of time in each job, showed that even short durations in a high load job can significantly increase the injury risk for those usually performing an easier job. While Job A in isolation had an LBPRI of 0.46, this jumped to 0.61 if the worker rotated onto Job B for only 1% of the time during a shift. This is due to the immediate exposure to the high peak loads associated with the more demanding job. This second analysis implies that the rise in the reporting of LBP was greater for those who rotated into the more demanding job than the corresponding drop in LBP reported by those who rotated out of the demanding job. The study was limited by the fact that both jobs involved significant use of the low back musculature, thereby not allowing for alleviation of fatigue in the vulnerable muscle group or joints. This highlights a limitation of job rotation as an injury prevention strategy. In many industries, the principal tasks often involve lifting or carrying, which makes use of nearly all major muscle groups, especially the low back musculature. Finding appropriate tasks which do not stress these muscle groups may be easy in some settings, but very challenging in others.

Effort, fatigue, pain, sick leave and job rotation in refuse collection

A third industry in which a series of linked studies of job rotation has been carried out is in refuse collecting. Kuijer et al. (1999) analysed the effects of job rotation in refuse collecting and street sweeping, jobs which used different muscle groups as the prime movers but still involved the low back musculature to a large degree. Job rotation was found to significantly lower both perceived effort and fatigue, compared to refuse collectors who did not rotate. However, this may be attributed to the lower overall production when rotating, since the rotating workers' daily average of 572 (± 208) refuse bags handled was less than half of that seen when not-rotating (1556 ± 229 bags). This finding indicates that a lower overall workload, as indicated by the lower work output, may be the reason for the lower perceived effort and fatigue in rotating workers. This in turn may have been caused by an artifact whereby the non-rotating workers performed more work.

Kuijer and colleagues have subsequently reported two more investigations of job rotation amongst refuse collectors. The first focused on job rotation between collecting two-wheeled containers and driving a refuse truck (Kuijer et al. 2004). The second study, Kuijer et al. (2005) followed up on the first stage of this study after one year, and compared a group who initially did not rotate but switched to rotation, with those who did or did not rotate throughout. The need for recovery, measured on a self-report scale, decreased significantly in those who had rotated throughout the study compared to the other two groups. On the other hand, both rotating groups reported a significantly higher prevalence of low back and neck complaints. The authors acknowledge two factors that affected their study and prevent any simple interpretation of these prevalence reports. Firstly, the rotating groups reported no more sick leave, secondly, none of the groups were randomly selected and there was some evidence of a "healthy worker effect" in which those without back pain tended to be found in the non-rotating group. Conversely, a history of back or neck pain may have led new drivers to choose to rotate, biasing the results.

Productivity and job rotation in small business operations

Finally, in a study by Kogi et al. (2003), job rotation was implemented by means of better work organisation in small businesses in the Philippines, with workers avoiding repetitive tasks in association with adding more frequent and better quality breaks. Comfortable resting areas were added to the work environment to improve the quality of the break and facilitate recovery. Work groups were also given more autonomy over the timing of job rotation, allowing workers to change jobs when fatigued in the limbs and back. An increase in production was also noted from the job rotation system. The greater level of autonomy for the workers may also lead to higher job satisfaction and self-efficacy.

3.6. Summary of evidence concerning the efficacy of job rotation.

Together with the epidemiological study by Roqulaure et al (1997), these four studies, of small business employees, supermarket cashiers, simulated automobile assembly tasks, and refuse collection, have quite mixed outcomes. Some physiological measures as well as self-reports improved with job rotation, while others showed the opposite. The authors themselves acknowledge the difficulties of properly evaluating job rotation effects in real life, and the methodological problems associated with these studies make it unwise to conclude that job rotation is either clearly beneficial or clearly harmful. A reasonable interim position is that there is evidence that it can be either beneficial or harmful, with the nature of the tasks involved in the rotation and their sequencing being important determinants. There is a very clear need for more carefully designed studies in this area.

All researchers agree that a job rotation structure should not involve back-to-back high stress jobs or tasks, especially not where the same muscle groups are being recruited. This has led some researchers to devise methods to implement job rotation with these constraints in mind. An example of this is the study reported by Henderson (1992), who developed a rotation system for a poultry processing plant by ranking every task by physical demand, on a scale ranging from low physical stress up to unacceptably high physical stress. Tasks in the latter category were not to be performed at all and ergonomic redesign was required. No back-to-back series of high stress tasks were allowed and each high stress task needed to be preceded by a low stress task.

The diverse and very incomplete nature of research into the effectiveness of job rotation makes it difficult to summarise in a definitive manner. While there is some evidence of effectivenesss when tasks differ sufficiently, there is also evidence that injuries may be unaffected or even increase, particularly if the tasks involved in job rotation are not sufficiently different. Tasks with very high forces and stresses should be addressed through measures other then workload distribution as they may cause injury with minimal exposure. Low force tasks for short periods, minimal repetitions and/or durations may not require much change. Job rotation has the potential to produce beneficial outcomes when applied for the remaining tasks, with the provisos that it is not used when individual tasks have very high forces, and that jobs selected for rotation are sufficiently different with respect to structures used. This concept is illustrated in Figure 3.6, which identifies three situations: those in which combinations of force and exposure are not high enough to warrant job rotation, those in which forces are sufficiently high to rule out job rotation as a safe and effective measure, and those in which beneficial effects of appropriate job rotation may be expected.

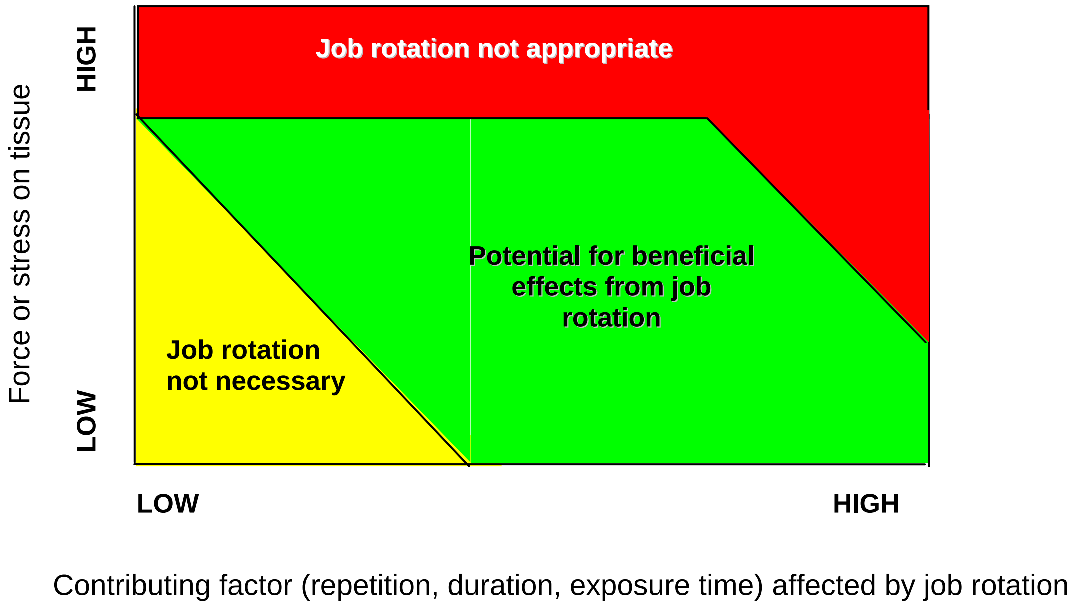

Figure 3-6 Probability of injury: Interaction of stress or load on tissue and contributing factor related to workload distribution

4. Interview and Observation Phase

4.1. Demographic characteristics of participants

Figure 4-1, 4-2, and Tables 4-1 and 4-2 present a demographic profile of the deputies and miners who participated in this phase of the study, as well as their estimates of specific characteristics of their own crew. Thirty-six deputies provided data, leading crews representing a total of 248 miners. A smaller sample of miners were interviewed (n=18) for comparison. Deputies were emphasized because they have formal and overall responsibility for work allocation. Note that the reports of deputies and miners on comparable items (e.g. crew size) are not identical because they were selected from overlapping but different samples of crews. There was, as expected, wide variation of age and experience in the mining industry in both groups, and crew size (2-10). Not surprisingly, deputies tended to be

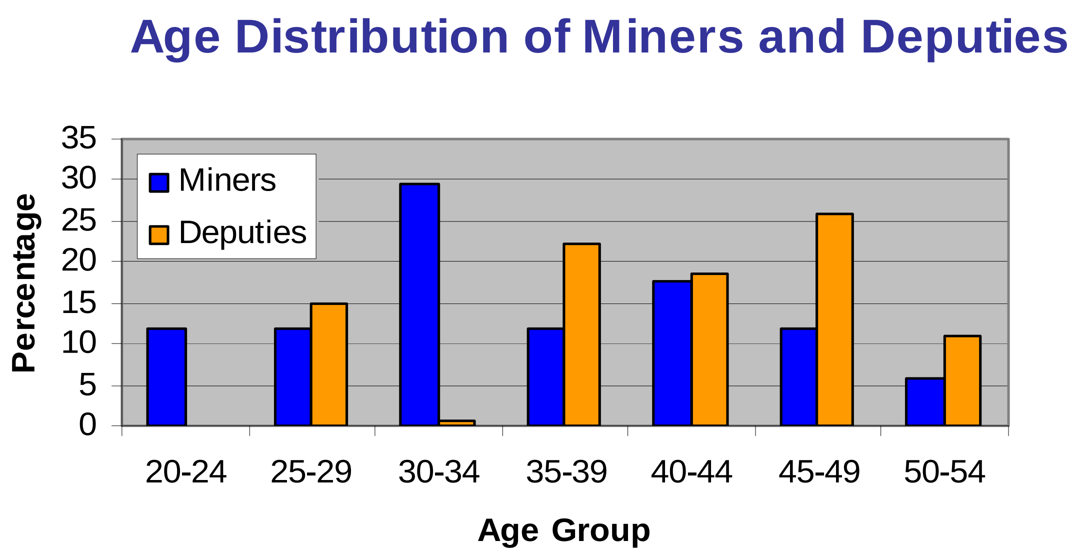

Figure 4-1 Age distribution of interviewees

older than miners overall and to have had about three more years experience in the industry (Table 4-1). Factors that relate indirectly to workload distribution and its effects include shift length, rest break length, sleep length, quality of recovery following rest breaks and sleep, and fitness. It was beyond the scope of this study to obtain detailed data on these factors. For example, the ratings of fitness levels of fellow crew members (Table 4-2), suggest that that on average just under five of the crew (average size 7.8) are rated as very fit by their colleagues, but the objectivity of this information is necessarily limited. Of note, however, was that workers rated their rest breaks (average duration 0.7 hr) as being of higher quality (on a simple 3 level scale) than the quality of their sleep between shifts, which averaged 6.5 hr overall and less than 6 hours the previous night, showed large variability, and was rated as average or poor by half the respondents. Although sleep and breaks during work cannot be compared directly, the relatively low rating for sleep was noteworthy. The rest break and sleep quality ratings are shown in Table 4-3.

Table 4-1 Profile of deputies and ratings of crews by deputies

Variable	Average	Minimum	Maximum
Years in occupation	13.8	2	34
Years as a deputy	6.6	0	25
Years employed at current mine	5.7	1	11
Number in crew	6.9	3	10
Age of youngest crew members	25.4	18	35
Age of oldest crew member	46.7	34	60

Table 4-2 Profile of crews as rated by miners

Variable	Average	Minimum	Maximum
Years as a miner	10.6	0.5	26
Length of shift (hrs)	12.1	10	13
Number in crew	7.8	3	13
Number in crew rated as having low fitness	1.3	0	4
Number in crew rated as having moderate fitness	1.9	0	6
Number in crew rated as having high fitness	4.7	1	8
Typical work break duration (hrs)	0.7	0,5	1
Average hours of sleep	6.5	3.5	8.5
Hours of sleep last night	5.8	2	10

Table 4-3 Self-ratings of rest break and sleep quality (%)

	Rest break Quality	**Sleep Quality**
Poor	0	19
Average	19	31
Good	81	50

In summary, information about workload distribution presented in the following sections was based on a set of deputies and miners who represent primarily production and development, have an age profile comparable to that of the overall workforce, with deputies being somewhat older and having more industry experience. Crew sizes varied widely (3-10), with modal values of 7-8. Miners generally rated their fellow crew members as very fit, mostly rated work break rest as of good quality, but with rating overnight sleep (of relatively short average duration) as of good quality.

4.2. Ratings of evenness of workload distribution and involvement in decisions

This interview phase of the project was designed to obtain data on a range of issues related to workload distribution in crews. Responses to questions covering several aspects of decisions about workload distribution, for example, who is involved in these decisions, factors that are taken into consideration, and timing of any rotation of tasks, are presented next.

Sixty percent of respondents reported that they felt their current workload distribution across members of the crew during a shift to be “somewhat evenly” or “evenly” spread across workers (Figure 4-2). One quarter of respondents, however, rated this spread as “somewhat uneven” or “very uneven”. Many factors are likely to enter these judgements. The ideal of all members of a crew perceiving workloads to be evenly distributed is almost certainly unattainable. However, it is significant that a sizeable minority of respondents (1 in 4) felt that this distribution was at least somewhat even.

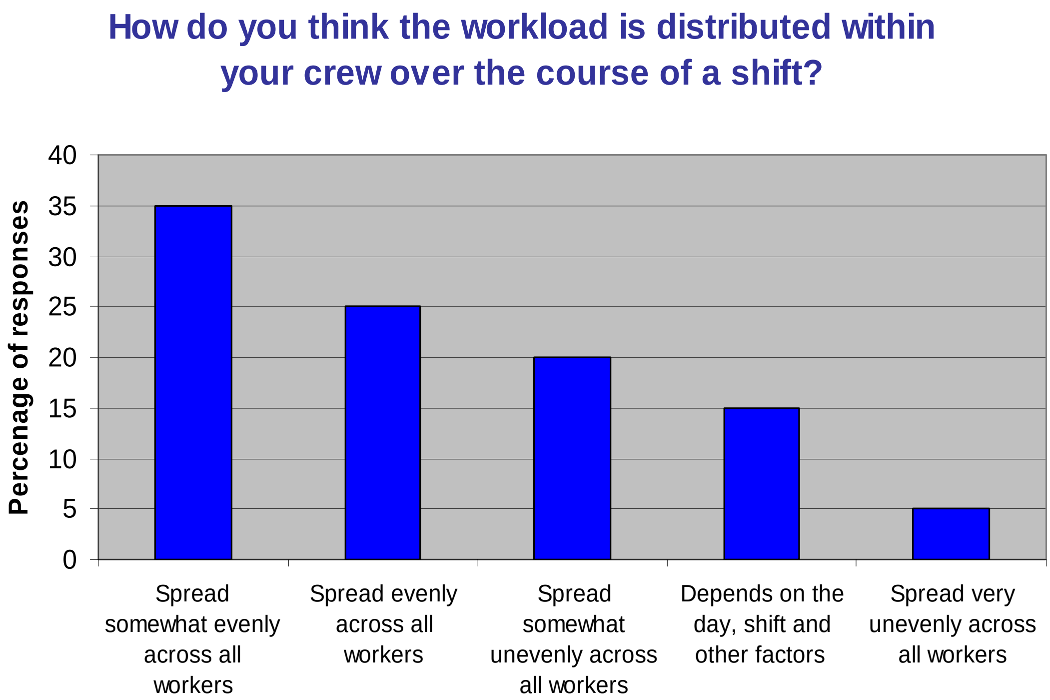

Figure 4-2 Ratings of evenness of workload distribution within crew across shift

All but 5% of respondents reported that decisions about workload distribution were made collectively, with the difference being only in whether these decisions involved small or large groups or the entire crew (Figure 4-3).

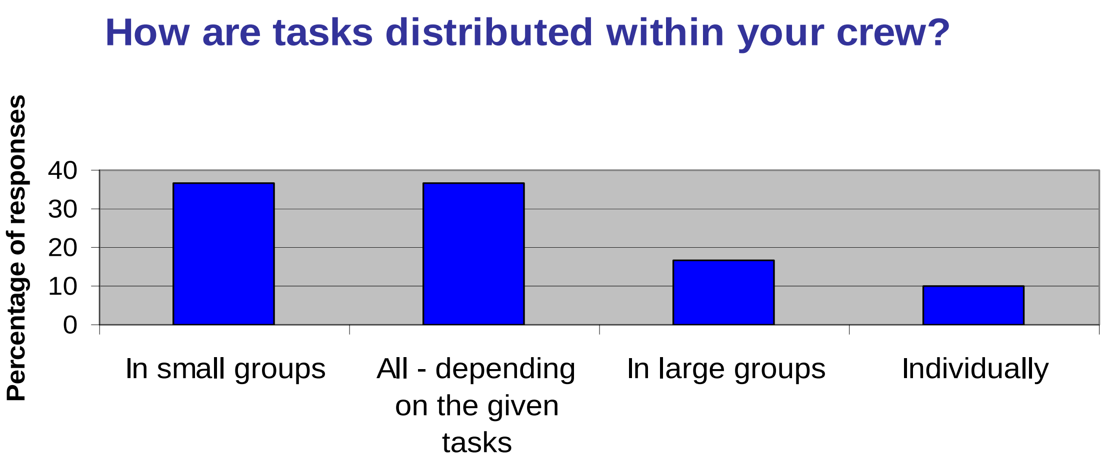

Figure 4-3 Size of group involved in workload distribution decisions

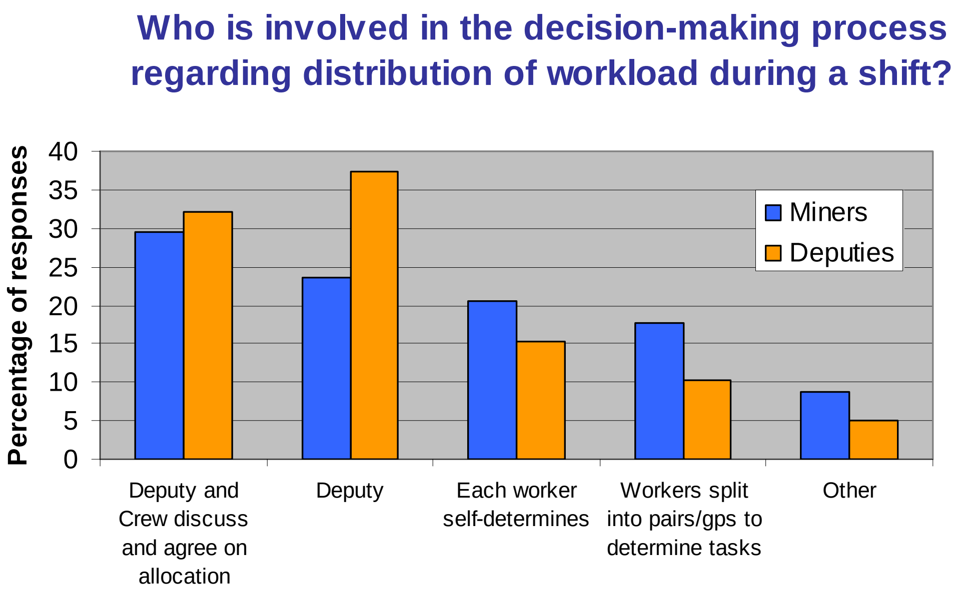

Figure 4-4 Roles of those making decisions concerning workload distribution

When the roles of those involved in these decisions was examined in more detail, the roles of the deputy and crew members becomes more evident (Figure 4-4), with a range of procedures being used from simple task allocation through to more self-determination. A difference between miners and deputies emerged, however, in that miners rated the deputy's involvement in these decisions as being at a lower level than did the deputies. This discrepancy could have many causes, including the possibility that deputies perceive themselves as being involved in the decision by implicitly approving the outcome of self-selection of tasks, i.e. not having to intervene and make changes in what the crew decides amongst themselves.

4.3. Factors influencing workload distribution decisions

More than a dozen factors were rated by deputies as factors that were taken into account when deciding how to allocate tasks at the beginning of a shift (Figure 4-5). Not surprisingly, “skills and training of crew members” was reported more than twice as frequently as any other factor This bears on the requirements for miners to be appropriately qualified ("ticketed") for specific equipment and procedures, with some jobs (shearer driver on longwall and continuous miner operator on development) being important cases. Qualifications impose significant limits on the capacity to allocate tasks across a crew, in ways that are examined in a separate section (4.7).

Other important factors were worker fitness and the even distribution of work over the shift, the need for self-determination of work, and production goals. While more subtle than ticketing (a miner is or is not a holder of a ticket for a job, but fitness is a matter of degree and is harder to ascertain), fitness was not surprisingly a consideration, given the heavy physical demands, awkward postures, and other requirements of some tasks.

The high rating accorded to fitness by deputies in allocating tasks somewhat contradicts the data reported in the previous section, that miners see their fellow crew members as predominantly possessing high fitness levels (Table 4-2). Where this the case, it might be expected that deputies would not rate this factor as second only to skills and training as determinants of work allocation. Consistent with the data reported above, self-selection of tasks continued to be taken into account by deputies in these decisions.

Work environment variables, such as availability of equipment or practicality of tasks were seen as important influences, as was the process of self-selection, i.e. crew members determining for themselves when they were ready to rotate.

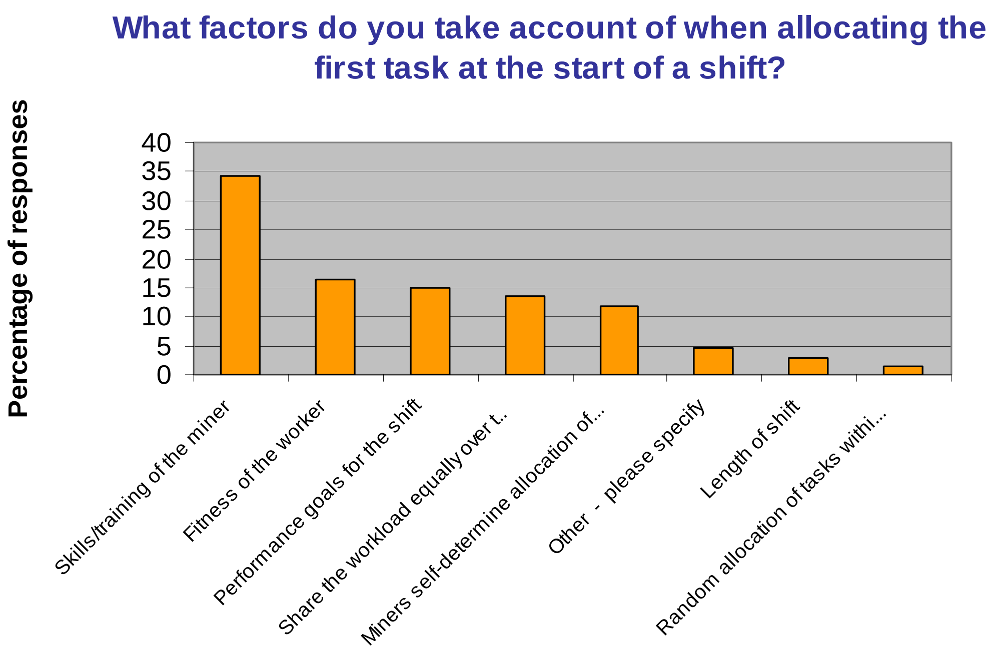

Figure 4-5 Factors used by deputies to allocate first task on a shift

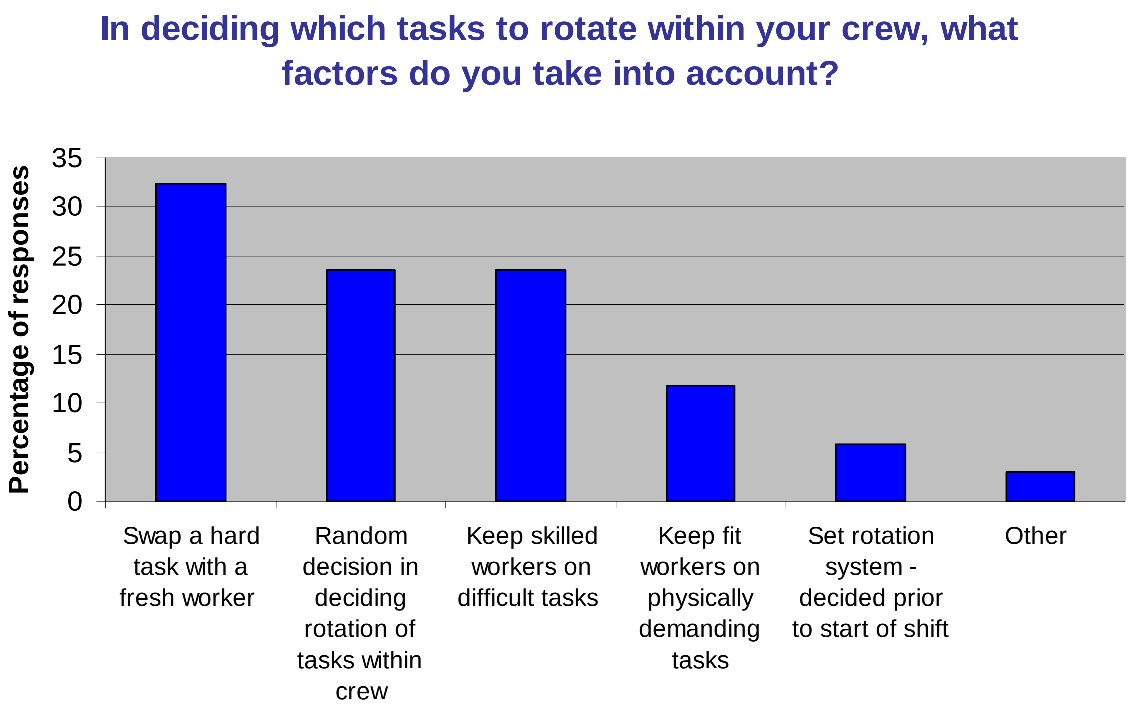

Figure 4-6 Factors used by miners in deciding which tasks to rotate

A similar question posed to miners concerned the factors they use to determine *which* tasks to rotate (Figure 4-5). "Swapping a fresh worker into a hard task" was the single most frequently reported item. This was reported more than twice as frequently as the goal of keeping a fit worker on a physically demanding task. This suggests that some tasks are considered too demanding to simply leave to a fit miner and that a key goal of job rotation as currently practiced is simply to share the most demanding jobs around the crew. While fit workers are not necessarily kept on physically demanding tasks, however, the same was not true for skilled tasks, as keeping a skilled worker on a difficult task was a factor reported twice as frequently. This may reflect constraints of ticketing and skills, an issue explored in a subsequent section of the report. The fact that random decisions about rotation were also reported relatively frequently suggests that some rotation is not determined as much by a particular match of person and task, but simply to provide variation.

More than a dozen factors were rated by interviewees as factors that were taken into account when deciding when to rotate tasks (Figure 4-7). Not surprisingly, work environment variables, such as availability of equipment or practicality of tasks were seen as important influences, as was the process of self-selection, i.e. crew members determining for themselves when they were ready to rotate. Both deputies and miners reported that perceptions of worker boredom were also commonly used. This is important since boredom effects can be largely independent of fatigue levels.

There were some differences in the perceptions of deputies and miners, however. Deputies reported using their perception of crew member fatigue levels much more than estimated by miners themselves (Figure 4-7). There could be many explanations for this. An obvious possibility is simply that fatigue levels are hard to judge by observation, since they would cause discomfort to the individual before becoming apparent to others. This would lead to deputies simply underestimating fatigue in their crew.

Miners more often reported taking into account the level of fatigue of those currently on physically demanding jobs. To the degree that jobs are rotated, (and very few interviewees reported never rotating), all or most members of a crew could be expected to undertake the

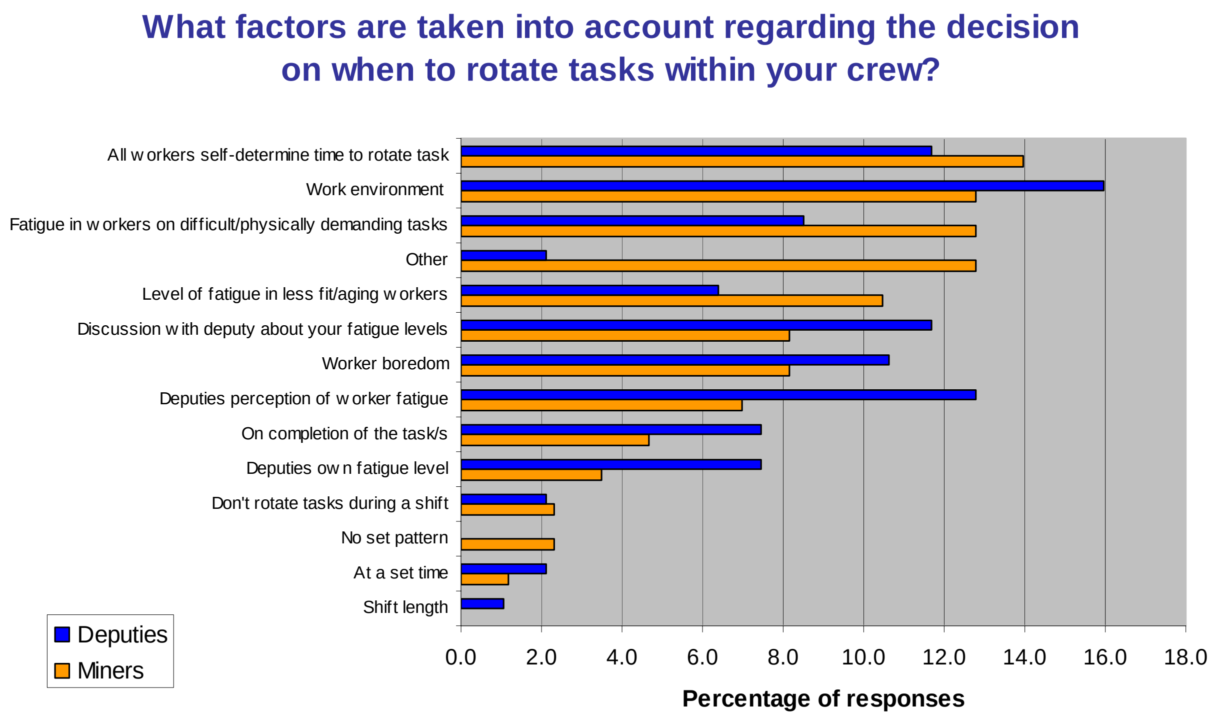

Figure 4-7 Factors used by miners and deputies to determine the timing of task rotation

hard jobs often enough to be very aware of their characteristics. Deputies may undertake them less frequently or not at all, and thus rate them as less demanding.

It was of note that deputies reported using their own fatigue level as in indicator that jobs should be rotated significantly more often than miners thought they did ($\chi^2 = 4.17$, $p < 0.05$). If this reflects conditions that affect the whole crew (heat, humidity), or if deputies are participating in those tasks, this would be a useful criterion. However, depending on the nature of the work, a deputy might be significantly more or significantly less fatigued than the members of the crew and the deputy's fatigue level.

4.4. Open-ended comments on limitations on capacity to rotate jobs

The following comments were made with regard to factors that limit the ability of crews to engage in job rotation:

D2: *Crew size*

D3. *Management, production.*

D4. *As long as the individuals can choose what they wanted to do, i.e. what task.*

D7. *Regulations of mines – have work instructions that have to be followed. Individual workers (some follow guidelines more closely).*

D8. *Insufficient manning (recruitment issues). Turnover of workforce (haven't got all tickets).*

D9. *Workers wouldn't like to go back to 8hr shifts, less days off. More days at mine.*

D10. *Personalities. Crew train up to get skills.*

D11. *Number of workers. Look at risk assessments. Some things can't change.*

D12. *The inadequate numbers – out of 9, lucky to get 6 0ften cover for job. Development big problem.*

D13. *If all there not a problem. Can't operate below 5 people – slowing down. Guys don't want to rotate – culture coming out. Unions hrs, crews/work – not complaining - My domain. Worked hard to get a miner driver. Need more skills.*

D14. *Good to have new workers' ideas.*

D15. *Workers' ability, workers' training.*

D16. *Crew – critical level 5. Need 8/9 people for proper rotation. Can swap whole crew between face and out-bye. Sometimes tickets – who can do what.*

D17. *Not enough people – 2 crews at 6 hours.*

D18. *Bolting most physical task – especially offside bolters. Drivers easiest. Miner driver needs to be qualified. Lack of crew/lack of tasks to rotate.*

D26. *Four sections per shift: 1 pr section – swap around.*

D33. *Manning levels – hard when have to do prep work and normal production work. Get task done by end of shift/let next crew know what next task is.*

D36. *Keeping manning up – 6-7. 9 - have to find work, more work to watch. Have to keep happy. Morale. Depends on how much done.*

D19. *Need similar skill levels within crew. E.g. Eimco driver gets sick of job but no-one capable of taking over.*

D20. *Skill level, number in crew, strength.*

D21. *Skill level, Numbers in your crew (manning), shift type (day vs. night), personalities – trust, attitude.*

D22. *Skill levels; manning (if only 2 people).*

D26. *None – all skill levels equal in crew therefore can do all tasks. Get the job done, move onto next task.*

D24. *Skill levels, priority importance of tasks; ability (fitness/strength/emotional (personal) issues); earn your 'stripes' reward/punishment.*

The most frequently mentioned factors were clearly crew size (mentioned in 50% of responses, and skill levels or ticketing (mentioned in 42% of responses). No other single factor received consistently high rates of comment.

4.5. Summary.

The interview data confirmed that crews already practice forms of workload distribution and job rotation in response to the physical demands, skill requirements and organizational and environmental constraints of the job. It was clear that all aspects of workload distribution, while ultimately the responsibility of the deputy, are determined by interactions not only between workers and deputies, but within the work crew itself. While most respondents rate these allocation decisions as being at least somewhat even, one in four felt them to be somewhat or very unevenly spread across workers. There was some evidence that deputies perceive the factors affecting workload distribution decisions differently from miners. Skilled workers were reported as being kept on skilled tasks more often than fit workers were reported as being kept on physically demanding tasks. Respondents in the interview phase noted limitations in skills and insufficient crew size as principal factors constraining job rotation.

4.6. Field observations.

Three development panels and two longwalls were visited in the study and directly observed. The development crews were practicing "in-place" methods. The following observations highlight aspects of these tasks relevant to workload distribution and job rotation only. It is assumed that possible ergonomic controls are explored as a normal part of risk assessment. Only normal development (i.e. gateroad and cut-throughs) and longwall retreat activities were observed: periodic tasks such as longwall moves were not occurring at the time of the observations. However, various outbye installation tasks (e.g. mounting 4” water pipes), supply activities (mostly with Eimcos and varying amounts of manual handling) and maintenance (changing rams, flight chain, electrical work on the pantechnicon). Moving monorail and belt structure were observed for a lesser period, as were roller changes.

Observations of development crews

The main factor influencing job rotation is the specific cycle of cutting with the continuous miner (CM), loading shuttle cars, bolting, roof support and ancillary activities. During a single cycle with the most common equipment (e.g. ABM20), there is limited opportunity for the “off-side” bolter and the CM operator (who generally also undertakes bolting on the near side of the CM) to rotate. Switches can only occur when the CM is not cutting or tramming. Similarly, while the normal production cycle is being followed, shuttle drivers also were noted to remain on the same vehicle with only periodic breaks. Workers involved in cable-handling, bringing up supplies, and tasks such as hanging ventilation tubes have more opportunity to rotate tasks between themselves. Although actual cutting occupies only a small percentage of a shift, the critical role played by the CM operator often keeps this worker on task for the entire period between crib-breaks. Many crews have no more than two workers ticketed for the CM, which restricts the capacity to move between tasks. Shuttle-car driving was also observed to involve relatively low levels of job rotation, with up to six hours of driving reported by one crew.

The effects of relatively long periods operating the CM are primarily indirect. The CM operator has a less physically demanding task than some (though prolonged standing can bring about discomfort, and neck or other pain related to the remote control may occur, and CM operators who also bolt are exposed to the demands of that task as well). In the operations observed, roof bolters tended to remain on task for periods in excess of thirty minutes, depending on whether they had to bring up supplies or assist in other tasks.

The skill level required of CM operators makes this a “high status” activity, although this factor varies considerably between crews. Blumberg (1980) noted that (albeit it in the different mining environment of late 1970s in Pennsylvania) 70% of job-switches he observed were from tasks viewed as low status to those thought of as higher status, and that seniority ($r = -.44$) and age ($r = -.37$) were significant predictors of *not* switching jobs (seniority was no longer a predictor when age was partialled out). He recounts the only case

of a “miner helper” moving to operate the continuous miner was because the labour agreement required this in order for miner helpers to be eligible for the top rate of pay.
In addition to status, however, practical considerations play a role: less experienced operators will take longer to perform tasks and may decrease production to some degree.

The other characteristic of development crews that was both mentioned and, to a lesser degree, observed, is that these crews may often be short on crew numbers, which greatly reduces job rotation options.

Breakdowns or other problems (waiting for supplies) were observed to have opposite effects with respect to workload distribution. On some occasions they allowed additional rest, although this was unpredictable, but it was also observed to require a worker who had just carried out one demanding task to assist with another (field maintenance) unexpectedly.

Members of crews observed described bolting as one of the most uncomfortable tasks, yet often the same individual works at this task for half the shift at a time, or even the entire shift. This can involve handling upwards of 45 roof bolts and associated mesh, with significant leaning and bending, often carried out in confined conditions with awkward manoeuvres of the bolts and mesh required. This includes a significant component of asymmetric handling and overhead work.

Roof-bolting appears to be a good candidate for increased levels of job rotation on crews where this is not practiced. The loads are awkward, but not by themselves excessive. The sustained postures and repetition are major factors contributing to the injury risk of this task, in combination with the fact that the maneuvers and postures are often asymmetrical. A recent biomechanical evaluation using 11 experienced bolters (Plamondon et al, 2006) found a NIOSH lifting index of 1.4 for this task, and identified longer bolts, limitations on foot placement, and the asymmetrical nature of the task as principal concerns. Cornelius and Turin (2002) identified a series of ergonomic problems and possible modifications after observing roof-bolting operations and interviewing 12 bolters, but did not specifically consider issues of task duration, rest breaks, or rotation. In addition to ergonomic improvements, the hazard imposed by this task could be partially offset by more frequent switching between bolters and those engaged in supply work, cable-handling and other tasks. Figures 4-8 and 4-9 show bolting to be considered to have relatively low intensity, but it was rated as the most frequently carried out action in all parts of the underground sector other than walking, standing, and carrying loads, and the repetition can be reduced significantly through job rotation.

Observations of longwall crews

Crews observed in longwall operations tended to be larger than those on development: crews of 7-10 being typical. A mix of activities was observed including shearing, maintenance, and belt and monorail moves. As a limited amount of longwall activity could be observed directly, additional information was provided by discussions with longwall crew members. It was apparent that practices of job rotation vary quite widely. The research team was told of crews that practice complete rotation every second shear to those in which very little rotation occurs at all over a shift. More typically, rotation after crib breaks or on each shift was reported. Some tasks require a tradesperson, and it was reported that an electrician will often work at the maingate. During regular production, rotation of operators can achieve goals in addition to modifying exposure to musculoskeletal injury.

Longwall operations require periodic belt moves, typically twice per shift, together with associated moves of the pantechnicon and monorail. These operations have been identified both by our own research (see Figures 4-8, 4-9, Parker et al., 2004) and that of others (Burgess-Limerick et al., 2006) as involving particular physical demands. Taking apart, moving and installing belt structure poses difficulties of access, awkward working postures, and a range of lifting, carrying and other manual handling activities. With monorail sections weighing in the order of 65 kg, installing and removing and handling monorail is also a potentially injurious task. Practices for these activities vary, but comments were received that there could be more frequent role changes than usually took place for belt move tasks. In addition it was commented that in some mines there is a practice of bringing in members of the outbye crew to undertake part or all of the belt move, while in other settings, longwall crews switch directly from production activities to belt and structure moves.

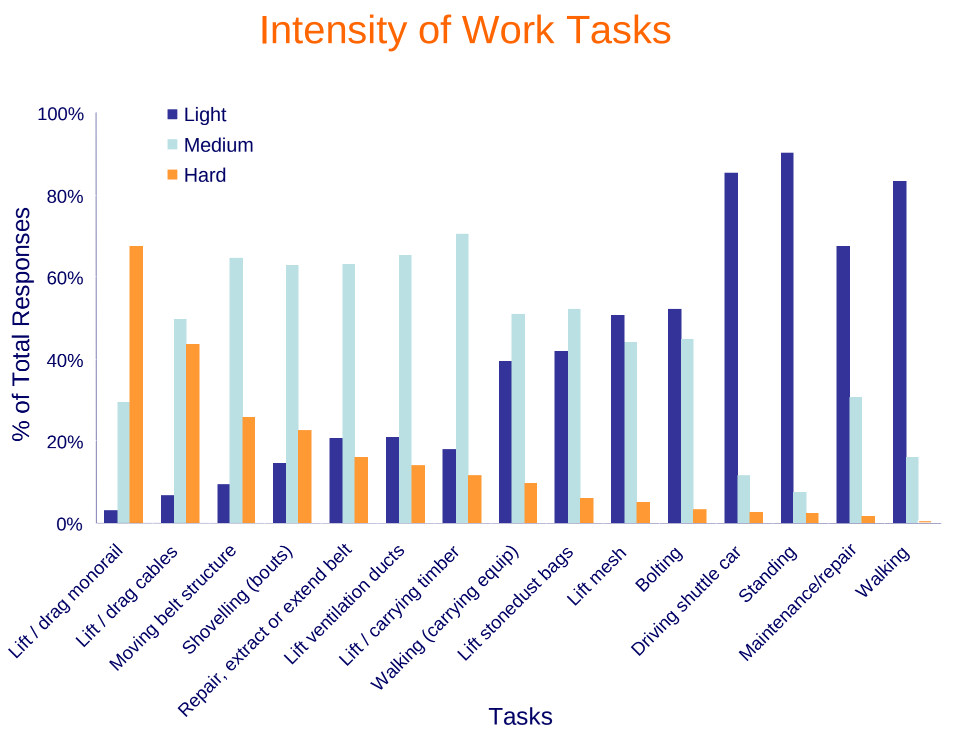

Figure 4-8 ***Self-rated intensity of work tasks in underground coal-mining. (Parker et al. 2004)***

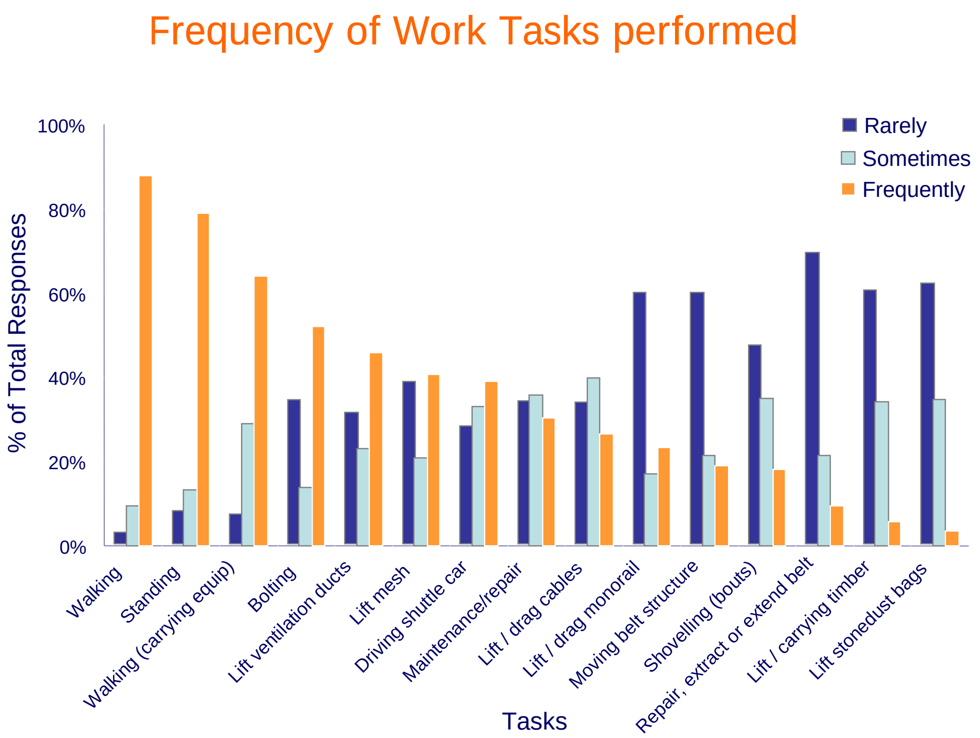

Figure 4-9 ***Self-rated intensity of work tasks in underground coal-mining. (Parker et al. 2004)***

4.7. Job rotation and exposure to hazards other than musculoskeletal injury

Noise, heat and dust are significant problems on both longwall and development. The United Kingdom's Health and Safety Executive (2006), for example, in a report from the Occupational Health in Mines Committee, explicitly recommend job rotation as a means for decreasing exposure to heat in underground mining, *"to limit exposures within a set team size job rotation is likely to be necessary and consideration should be given to additional training requirements to allow multi-skilling"*. The report notes that heavy manual tasks, which they exemplify with tasks that include building conveyor belt structure and cable pulling, will increase the requirements to mitigate heat.

Kizil and Donoghue (2002), for example, report that shearer operators have the greatest exposure to dust, and boot-end operators the least, with chock operators and deputies having intermediate levels of exposure. Of interest here is that miners classified as "face workers", i.e. those who rotated between shearer operating and chock operating, had exposure levels that did not differ significantly from those of chock operators, which in turn was significantly lower than shearers. This is consistent with the notion that rotation may be of benefit with respect to dust exposure as well as musculoskeletal injury. Similar arguments may be made with respect to noise, which also vary in the different sections of longwall operations. Caution is needed with this practice as the same potential problem identified by Frazer (2003a), namely that rotation can simply expose some people to increased levels of injury, may also apply with regard to noise, as argued by Weinrich (1999).

4.8. Modelling of Job Rotation

The published data and findings from the current study make it clear that the factors influencing workload distribution - as well as its potential benefits and drawbacks - are varied and complex. It is clear that no single system can be applied to determine the "optimal" level and method of workload distribution. For example, the fact that decisions about this issue are strongly perceived as a shared function of deputies and miners, and involve both consultation and some degree of self-selection, precludes the use of a "formulaic" approach to the allocation of work tasks.

Despite this consensus that the process is not a purely objective one, it does not mean that specific aspects of workload distribution cannot be better understood by some quantitative analysis. In this section, we present the results of modeling which was designed to shed light on some of the fundamental constraints on workload distribution - whether or not such distribution is viewed as desirable - and without regard to the process by which tasks are allocated. A majority of participating deputies and miners noted that limits on the distribution of work tasks are set, to a significant degree, by factors such as the qualifications and numbers of crew members available on a given shift. These were clearly evident in the open-ended comments of deputies to the question "What factors limit job rotation on your crew?" (Section 4.4).

To understand the effects of these limitations more fully, the model examined a hypothetical development crew, using four different scenarios. Of necessity, these are somewhat simplistic, but nevertheless capture significant features of crew composition. One specific goal of the modeling was to generate an index of job rotation. This index, Worker Job Rotation Index (*W JRI*), is the average proportion of a shift a crew member would spend on each major task. A second index, Job Rotation Index (JRI), is the average proportion of a shift a task is undertaken by different crew members.

Four scenarios were developed. Table 4-4 below illustrates Scenario 1, in which there are 5 crew members (represented by the lower case letters in the leftmost column) and five major tasks (represented by the upper case letters in the top row). The five tasks are: left bolter, right bolter, shuttle car driver 1, shuttle car driver 2, and continuous miner driver. The scenario could be readily extended to six, seven or more crew members (for example, to represent cable hands and miners allocated to supplies/outbye work). In scenario one, the least qualified miner and experienced miner is ticketed to ' 1'. Able to undertake only one of the five tasks, a second miner is ticketed for two tasks and so on, with the most qualified miner ticketed for and able to undertake any of the tasks. Ticketing is indicated by the presence of a "1" in a cell to represent the intersection of worker and task in Table 4-4.

Table 4-4 Ticketing for hypothetical development crew.

A value of 1 indicates that the worker is qualified to undertake the specified task

Worker	L Bolt	R Bolt	Shuttle 1	Shuttle 2	Miner
a	1	1	1	1	1
b	1	1	1	1	1
c	1	1			
d	1	1	1	1	
e	1	1	1	1	

Table 4-5 Task allocation for hypothetical development crew

Five workers and five main tasks are illustrated. Values are proportions of shift spent on each task. JRI: Job Rotation Index, calculated as the average proportion of that job allocated to workers. W JRI: Worker Job Rotation Index, calculated as the average proportion of the shift each worker spends on each task. In each case, 1 would indicate one worker spends entire shift on one task.

Worker	L Bolt	R Bolt	Shuttle 1	Shuttle 2	Miner	Sum	W JRI
A			0.25	0.25	0.5	1	0.33
B	0.25		0.25		0.5	1	0.33
C	0.5	0.5				1	0.5
D	0.25	0.25	0.25	0.25		1	0.25
E		0.25	0.25	0.5		1	0.33
Sum	1	1	1	1	1		
JRI	0.33	0.33	0.25	0.33	0.5		

Table 4-5 shows the distribution of tasks which would be followed in order to achieve the most even task allocation possible for that scenario. Only one possibility exists in this case: since only one person can perform all tasks, he is allocated the task that none of the others can perform. In a real situation, this might be a skilled activity such as driving the miner. In the example, the next most qualified miner must undertake the remaining task that none of the others can perform, and so on down to the least qualified individual. This pattern of allocation is shown graphically in Figure 4-8.

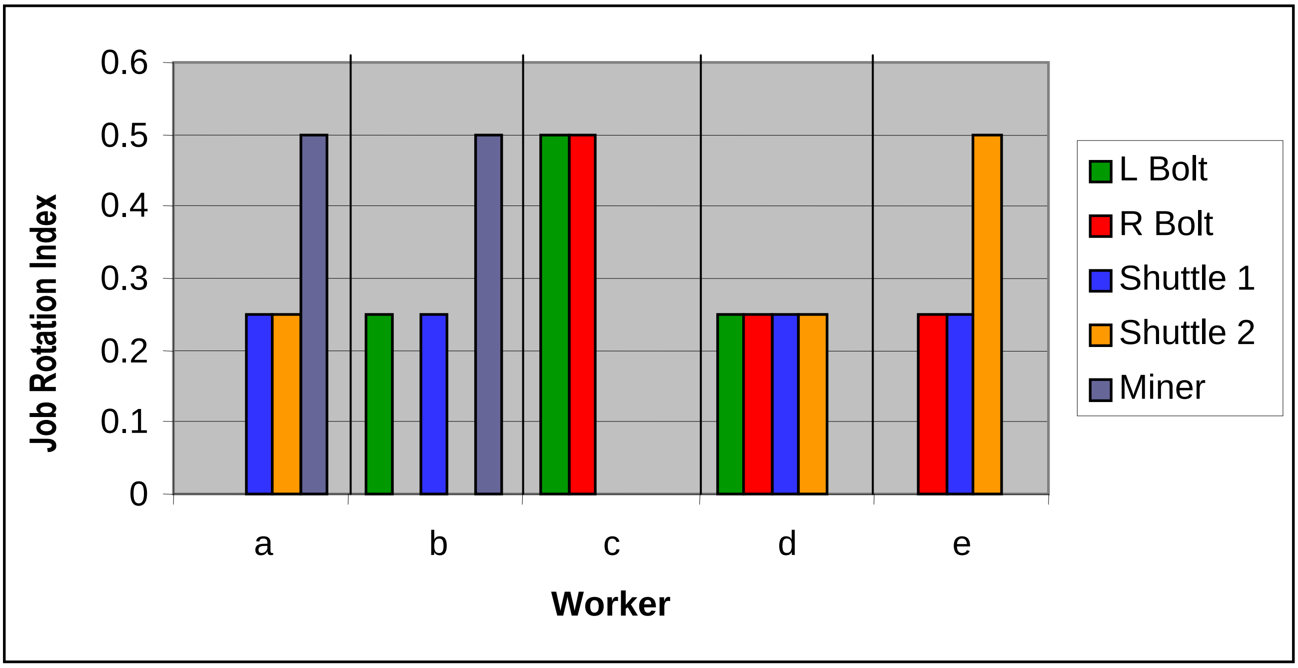

Figure 4-10 Task allocation corresponding to table 4-5

The next tables and figures illustrate a possible allocation of tasks for Scenario 2, in which it is assumed that crew size remains unchanged but a single worker (C), receives training and ticketing for the shuttle cars and the continuous miner. Table 4-6 shows this change. The increased skill level of this one individual enables several possible reconfigurations of task allocation, of which one is shown in table 4-7 and Figure 4-9.

There are three key points illustrated by this example. First, in addition to the significant improvement in the allocation of tasks for Worker C, whose W JRI drops from 0.5 to 0.25, "knock-on" benefits accrue to other members of the crew despite their remaining at the same skill level. For example, Workers B and E also have the capacity to rotate between tasks more frequently, with W JRI values dropping to 0.25 from 0.33. Second, this underestimates the "freeing up" of the rotation schedule, since Worker C was originally required to bolt for the entire shift, with the switches only occurring between left and right

Table 4-6 Additional ticketing for hypothetical development crew

A value of 1 indicates that the worker is qualified to undertake the specified task.

Worker	L Bolt	R Bolt	Shuttle 1	Shuttle 2	Miner
a	1	1	1	1	1
b	1	1	1	1	1
c	1	1	1	1	1
d	1	1	1	1	
e	1	1	1	1	

Table 4-7 Modified task allocation for hypothetical development crew

Worker C is now trained to undertake two additional tasks (shuttle driving and continuous miner operation).

Worker	L Bolt	R Bolt	Shuttle 1	Shuttle 2	Miner	Sum	W JRI
a			0.25	0.25	0.5	1	0.33
b	0.25	0.25	0.25		0.25	1	0.25
c	0.25	0.25		0.25	0.25	1	0.25
d	0.25	0.25	0.25	0.25		1	0.25
e	0.25	0.25	0.25	0.25		1	0.25
Sum	1	1	1	1	1		
JRI	0.25	0.25	0.25	0.33	0.335		

sides of the miner. In the modified schedule, while he still has two bouts of bolting, there is the opportunity to separate them with one or two other tasks. Finally, the example shows that increasing skill sets in a crew can make better use of existing skills in the remainder of the crew. If a given worker is confined to a smaller set of tasks than those for which he is ticketed because of the limitations of another worker, then the training he has undertaken has been underutilized.

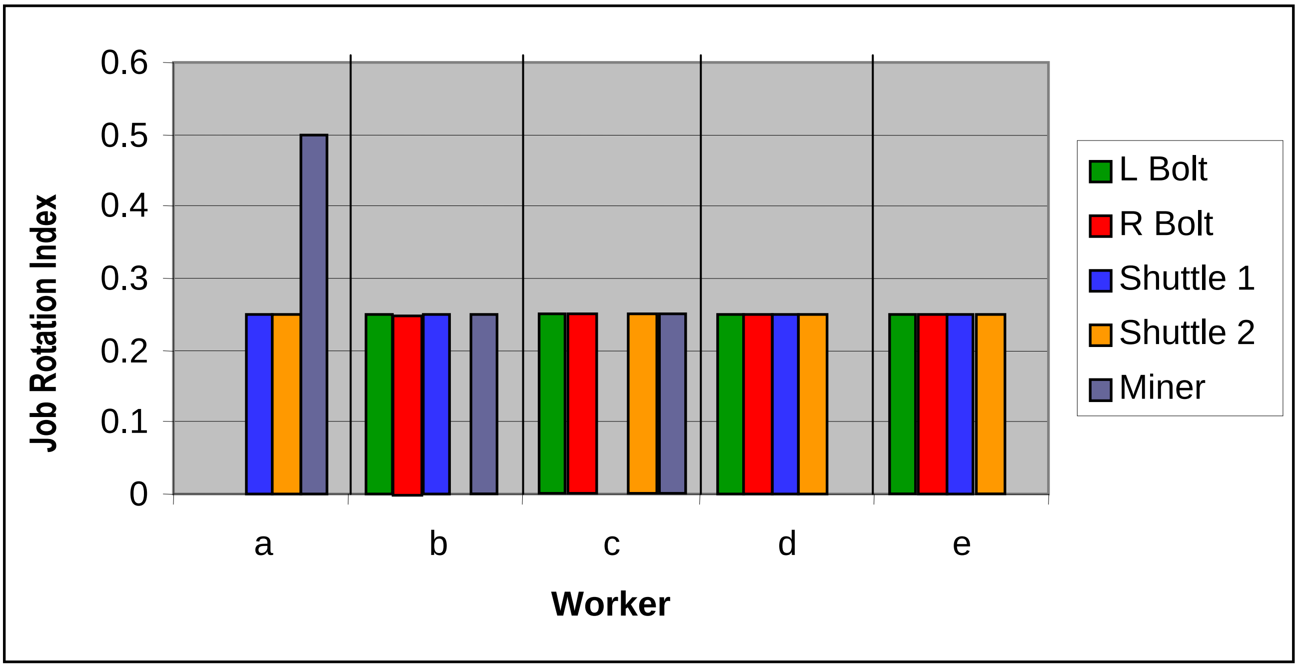

Figure 4-11 Modified task allocation for hypothetical development crew (additional training)

This allocation reflects a possible schedule enabled by the additional training depicted in Table 4-7

The second example illustrates the effects of adding a crew member, as opposed to undertaking additional training. In this case, an additional worker, F, is added to the crew, and is qualified for bolting and shuttle car driving. It would be possible, of course, to give this additional worker new tasks. In this simple example "outbye" refers to a range of support tasks that could not be undertaken by a crew of 5 – this could include bringing up additional supplies, acting as a cable hand, grading, and other functions. While the new worker could be allocated these additional tasks only, and the new job would receive the equivalent of one full-time worker, the other crew members would not benefit with respect to their tasks. In Table 4-8 and Figure 4-12, an allocation is illustrated which allows each of the other crew members additional rotation, bringing the average W JRI from 0.35 down to 0.26. This again demonstrates that the benefits of increasing crew size beyond the minimum can extend to all members of the crew if an appropriate rotation is selected.

Of course, these examples are simplified greatly and do not account for many of the factors

Table 4-8 Modified task allocation for hypothetical development

Worker F, ticketed for shuttle driving and bolting, is added to the crew

Worker	L Bolt	R Bolt	Shuttle 1	Shuttle 2	Miner	Outbye	Sum	W JRI
a		0.2		0.2	0.5	0.1	1	0.25
b	0.2		0.2		0.5	0.1	1	0.3
c	0.2	0.2				0.6	1	0.33
d	0.2	0.2	0.2	0.2		0.2	1	0.2
e	0.2	0.2	0.3	0.3			1	0.25
f	0.2	0.2	0.3	0.3			1	0.25
Sum	1	1	1	1	1	1		
JRI	0.2	0.2	0.25	0.25	0.5	0.25		

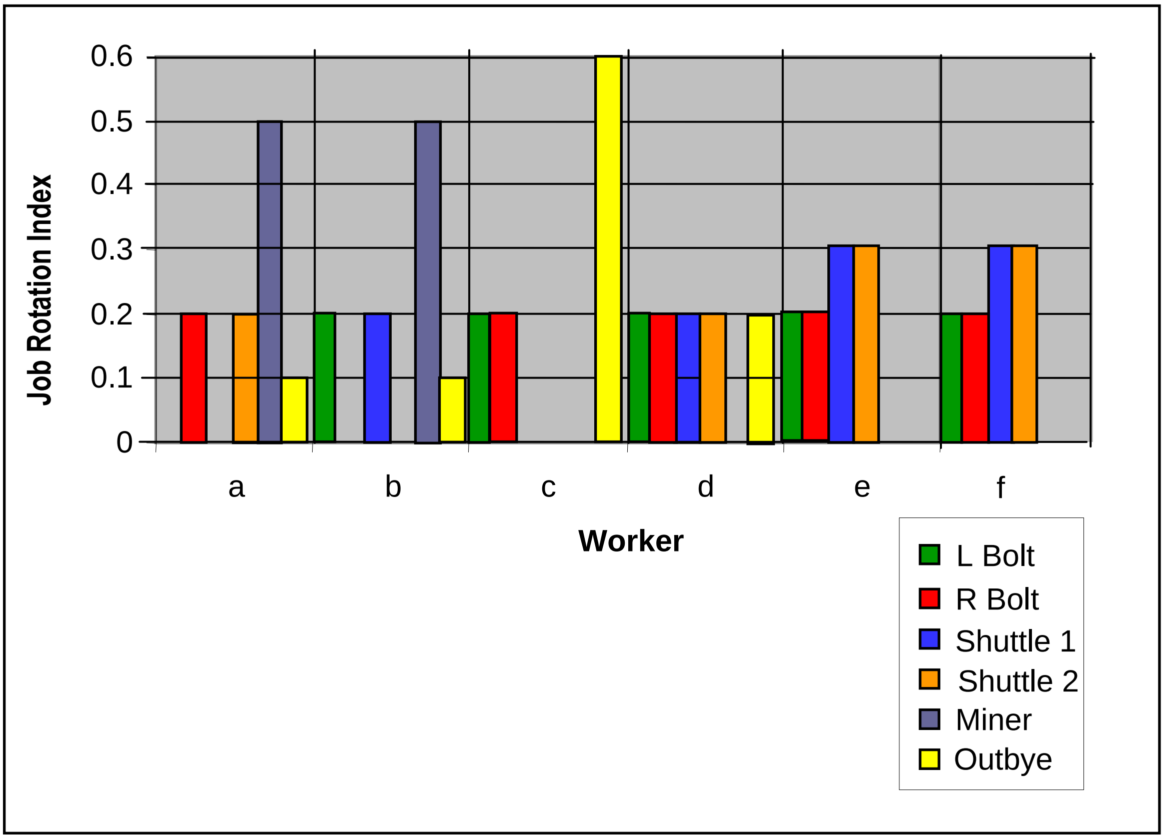

Figure 4-12 Modified task allocation for hypothetical crew (addition of one worker)

This allocation reflects a possible schedule enabled by the additional of one worker ticketed for bolting and shuttle car driving, depicted in Table 4-7 that would influence the allocation of tasks. In particular, they do not describe the timing of rotations, and make rather simple assumptions that all members of the crew can perform at a roughly equivalent level in each of the tasks for which they are qualified. The example is confined to development but could readily be extended to longwall. They do not illustrate the combined effects of increasing crew size and training together, but the "freeing up" of crew members to rotate tasks would be significantly greater than with one alone.

5. Recommendations

5.1. Recommendations for management and policy.

5.1.1. Offside roof-bolting should be considered a priority area for increasing levels of job rotation on development crews.

To the extent that job rotation can contribute to alleviating the risk of musculoskeletal injury, "offside" roof-bolting (opposite the continuous miner operator) would appear most likely to show benefits by exposing individuals to shorter bouts of work. This strategy should not replace engineering controls, including automation or ergonomic improvements. Evidence for this recommendation comes from the ratings of work tasks provided by miners, field observations, the relatively long periods of exposure, high rates of repetition, as well as analyses of this task in the literature.

5.1.2. Belt and structure moves should be considered a priority area for increasing levels of job rotation on longwall crews.

With the same caveats as for the previous recommendation, i.e. that it should not replace efforts to devise ergonomic improvements to the tasks involved, it would appear that belt and structure moves, though occupying only a small proportion of each shift, are an area of work on longwall which could benefit from increased rates of rotation of workers, and, in particular, the use of additional workers from outbye crews where this practice is not already in place.

5.1.3. While considerable benefits may result from improved job rotation, no single 'generic' job rotation practice should be mandated or imposed.

This recommendation recognises two key aspects of Australian underground coal-mining. First, a range of job rotation practices have already evolved in both the development and production (longwall) settings, and it is the improvement and optimisation of these rather than the introduction of entirely new procedures that should be encouraged. Second, both the literature on job rotation and data from the current study make it clear that no "generic" job rotation schedule or system is scientifically justified, because the specific conditions of tasks, crew and environment must be accounted for in evaluating any system of job rotation. *Nevertheless, improvements in practices can still be promoted in ways outlined in subsequent recommendations.*

5.1.4. Any consideration of new training or interventions with respect to job rotation should begin with a proper briefing of relevant Production, OHS & HR managers.

Changes to workload distribution and consequent injury risk through optimising job rotation represent only one small component of a site's hierarchy of OH&S controls. Nevertheless, any new policies or interventions in this area should be made only after a careful review. If a mine-site wishes to explore new strategies of job rotation and workload distribution, it would be valuable for relevant managers to be briefed on these issues. This should include managers involved in decisions about staffing, scheduling and training at a mine site. This strategy is essential if staff are to provide advice and support to crews based on good information.

5.1.5. Managers should evaluate and periodically monitor crew sizes and qualifications, and periodically assess (quantitatively or qualitatively) each crew's capacity to undertake reasonable levels of job rotation

This recommendation follows from the study's findings that highlight the critical roles that staffing levels and qualifications play in workload distribution generally, and job rotation in particular. At a policy level, managers already have to juggle many competing requirements. Before a site considers any training sessions with crews or OH&S staff, it is imperative that mine management consider the implications of differing workload distribution practices. It is, for example, counterproductive to encourage crews to evaluate and improve their own processes if the capacity for meaningful job rotation is restricted by small crew sizes and insufficient skills and ticketing.

5.1.6. To enable adequate job rotation, decisions on staffing and training should be based on information about health and injury of workers and enable forecasting of planned absences

Management need to ensure that adequate integration of data be undertaken to enable short- and medium-term forecasting of crew sizes and the mix of qualifications, so that satisfactory job rotation possibilities exist.

5.2. Recommendations for crew-level interventions and training

5.2.1. Any training or interventions of work crews should emphasise that job rotation is just one strategy amongst many in making work safer, and it should be considered as part of normal risk assessment procedures

In highlighting any specific OH&S issue there is always the risk that it is given an inappropriate emphasis. Crews should not consider job rotation practices in isolation from their normal OH&S responsibilities. In fact, if job rotation is to be effective in reducing the risk of musculoskeletal injury, the identification of any exceptional tasks that carry risk of acute injury (i.e. from peak rather than cumulative loads) through normal risk assessment is essential. Training should make use of authoritative materials (e.g. University of Waterloo workshop, 2004).

5.2.2. Crews should determine and evaluate their own job rotation practices

Underground coal-mining occurs in a unique environment in which crews exercise a considerable degree of autonomy during a given shift. Successful job rotation practices require that this autonomy be respected and built on. For this reason, it is recommended that all decisions and evaluation of job rotation procedures be undertaken by individual crews. This should include the relevant deputy, since the current study suggests that deputies and miners tend to have somewhat different perceptions of current practices.

5.2.3. Crews should be encouraged to make clear and explicit decisions regarding job rotation

The reasons for and decisions about job rotation are often implicit, and can reflect practices which are accepted by the crew but which are not always discussed. As new members join a crew, for example, they may be given little information about why particular tasks rotate and others do not, or what factors a crew takes into account in switching tasks. By openly discussing job rotation practices and making their own procedures clear and explicit, a crew can expect to have greater understanding and acceptance of the system they use. This could be true even if no changes are made to the procedures. This recommendation is based on findings in the study indicating that there is a large range of perceptions about job rotation procedures.

5.2.4. Information about the range of workload distribution practices and pros and cons of alternative procedures should be collected and shared between crews

This recommendation is based on findings in the study suggesting that there is often less knowledge about the job rotation procedures of other crews than might be expected, sometimes even within the same mine. Sharing of this information enables crews to consider their own system and compare its strengths and weaknesses with alternatives.

5.2.5. Training on principles of job rotation should be provided as one component of ongoing health and safety training

Interviews with deputies and miners suggested that most had received little if any formal training about basic principles of job rotation. Even though, following Recommendation 4.1, no single, inflexible system should be promoted, there are relatively simple and widely applicable principles that crews should be given information about. Examples include the use of risk assessment to identify exceptional tasks which should not be mitigated by job rotation, information about acute as opposed to cumulative injury and why different levels of exposure can result in injury in each case, the role of short and long-term recovery in injury prevention, and the use of different markers of fatigue in determining the timing of rotation.

5.3. Recommendations for research and data management

5.3.1. Any interventions concerning job rotation or workload distribution should be independently evaluated.

The value of any intervention cannot be adequately assessed without appropriate data. Several of the preceding recommendations, particularly those which may alter practices in individual crews, should be assessed objectively. For example, in the area of training, it would be important to determine not only whether the training itself was acceptable (materials, methods, etc.), but whether the training had led to any change of practice, and what those changes were. This would in turn allow inspection of injury/incident absence and production data to determine whether the altered practices have been effective.

5.3.2. Injury and incident reporting should incorporate questions about the pattern of workload distribution in effect at the time of the incident or injury.

Several important factors contributing to injury are already noted in most incident reporting systems. It would be valuable to ask for information about what tasks other than the one on which the incident occurred the worker had undertaken on the relevant shift. In this way, it will become possible to identify any patterns regarding job rotation and workload distribution that are associated with injury and incidents, whether negatively or positively.

5.3.3. Future research on job rotation in coal-mining should examine its effects on heat, dust, noise musculoskeletal injury and other hazards together.

Administrative controls are acknowledged to have limitations, but in an area where there are major constraints on engineering controls, they have a place and can be undervalued. It is unfortunate that job rotation, as one such control, has been advocated for mitigating at least four hazards in underground coal-mining, but not been the subject of a study in which its effects on all these hazards are evaluated. While it may not belong in the first tier of control strategies for any one hazard, its value in reducing four significant hazards (to which others, such as susceptibility to fatigue and monotony could be added), deserves a more comprehensive investigation measuring exposures to each hazard in the same individuals.

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