Advances in Industrial Ergonomics and Safety II
Edited by Biman Das
Taylor & Francis 1990

ERGONOMIC DESIGN GUIDELINES FOR UNDERGROUND COAL MINING EQUIPMENT

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INTRODUCTION

Thirty-five years ago underground coal mining equipment consisted of simple rugged machines powered by electric motors and hydraulics. These machines cut, dug, loaded, and transported coal from the mine face to the surface. Mine maintenance personnel, armed with hand tools and a knowledge of hydraulics and electricity, maintained these machines in the working sections of the mine. Over the years the basic mining machine evolved into powerful, complex mining systems. To boost productivity, the size and horsepower of the machines increased dramatically. To increase throughput, new machines such as continuous miners, long wall systems, and continuous haulage were introduced. To improve personnel safety and health, safety and environmental control systems were tacked onto the machines. Despite the safety improvements and new systems, mining equipment maintenance costs have continued to escalate and the percentage of maintenance related injuries have remained stubbornly high.

Equipment maintenance costs in U. S. underground coal mines range from 25% to over 36% of total mine operating costs (Conway and Unger, 1989a). A British study, supporting this figure, reports that equipment maintenance costs accounts for 30% of British coal mine operating budgets (Ferguson, 1985). With coal mining profits squeezed, mine operators are searching for ways to contain equipment maintenance costs. These efforts traditionally focused on reducing maintenance staff size, spare parts inventories or maintenance intervals.

In addition to costs, equipment maintenance accounts for 30% of all lost time injuries in underground coal mines (Conway and Unger, 1989b; Conway and Elliott, 1988; National Academy of Science, 1982). Despite extensive Federal and State research and ongoing mining company safety programs, there has been no decrease in maintenance accidents over the last ten years.

With few exceptions, no significant ergonomic or maintainability design improvements are observed in surface or underground mining equipment over the last twenty-five years (Conway and Unger, 1989a and Conway and Sanders, 1982). This is particularly true with respect to the design of equipment for maintenance. In fact, personnel safety and equipment maintainability have decreased due to increased equipment size and added-on safety and environmental systems. Likewise, few new maintenance tools, procedures, automatic test equipment, or technology based aids were made available to support equipment maintenance. The result has been a continuing escalation of maintenance costs and equipment downtime and a consistently high percentage of maintenance injuries.

ERGONOMIC DESIGN REVIEW

An ergonomic/human factors design review of operational underground coal mining equipment was conducted under a U. S. Bureau Of Mines funded project (Conway and Unger, 1989a, 1989b). The objectives of this study included: (a) assessment of the extent to which ergonomic and maintainability design concepts are incorporated into current mining equipment design, (b) the identification of ergonomic design deficiencies contributing to maintenance injuries and costs, and (c) the preparation of an ergonomic based maintainability design guide specifically for underground coal mining equipment.

A survey of mining machines in nine large (over 1 million tons per year) and smaller (150,000 to 1,000,000 tons) U. S. mines operating in high seam (over 142 cm) and low seam (76cm to 142cm) coal was completed. The sample included conventional, continuous, and long wall operations. The survey included the following categories of equipment: shuttle cars, scoops, roof bolters, continuous miners, long wall systems, undercut machines, face drills, utility vehicles, and personnel carriers.

During site visits, scheduled and unscheduled maintenance tasks for each category of equipment were identified. The steps required to complete the maintenance action were noted along with task completion times. Maintenance accident records were analyzed to identify equipment factors contributing to the accidents. The equipment was then examined to identify design deficiencies contributing to the accidents or that impeded maintenance actions. Maintenance personnel, supervisors and mine management were interviewed to confirm the findings, to identify other design deficiencies and elicit recommended design improvements.

Six large and smaller mining equipment manufacturers were visited during the study to identify equipment design practices and constraints. Several major manufacturers reviewed and critiqued findings and the draft design guide.

DESIGN INDUCED PROBLEMS

The study identified a range of design-induced safety and maintenance problems. The results are reported in Conway and Unger (1989b). Summarized below are the major categories of design deficiencies.

Accessibility

Inadequate component accessibility represented the largest single design deficiency in terms of reported injuries and excessive maintenance task completion times. Access problems resulted from: (a) inadequate access opening size and placement, (b) poor layout of components requiring Removal and Replacement (R/R) of non-failed parts, (c) inability to access mounting bolts or connectors, or to use required hand tools, (d) inability to access components or hoses mounted inboard where they simply cannot be reached in lower seam mines. For example, R/R of a single hydraulic line on one roof bolter, which should require only 10 minutes, requires from 3 to 4 hours due to poor machine design and inadequate component accessibility. On one continuous miner, three or more non-failed components are remove simply to change one hydraulic line.

Component-Machine Interface

Component interface problems centered on: (a) inadequate component-machine interface design to help personnel in R/R heavy components and (b) the inability of maintenance personnel to use lifting devices to handling 100 to 1,000 pound components.

Routine Maintenance

Inadequate machine design hinder maintenance personnel efforts to quickly R/R high failure rate components (e.g.; pumps, water lines, hydraulic valves) and perform scheduled lubrication, adjustments and inspections.

Fault Isolation

Inadequate design for fault isolation decreases the ability of maintenance personnel to determine the cause of system failures resulting in excessive trail and error troubleshooting, maintenance errors and increased personnel risk.

Damage Prevention

Inadequate machine design for component protection result in unnecessary component damage and increased maintenance burden.

Lack of Resources

Design of maintenance tasks require the use of special tools or lifting devices typically not available at underground maintenance locations. Hence, maintenance personnel "jerry-rig" tools to handle 100lb to 1,000lb components.

Design Complexity

Unnecessary equipment complexity results from poor machine layout and the crowding of components into compartments without regards to the need to maintain them. Designs were found that multiplied the number of frequently replaced connectors or components simply as a design convenience resulting in increased maintenance burden.

DESIGN RECOMMENDATIONS

A comprehensive ergonomic and maintainability design guide for underground mining equipment was prepared. The guide covers mobile and stationery equipment used in underground mines with seam heights down to 76cm. Interested readers can refer to Conway and Unger, (1989b) for specific mining equipment design recommendations and to Sanders and Peay (1988) for general human factors design guidelines for underground mining equipment. A summary of the accessibility design recommendations is presented below.

LOCATION OF MAINTENANCE POINTS

A maintenance point (MP) is defined as any point where two components come together or where a component is mounted on the machine. In the mine environment, the physical location of the MP impacts personnel safety, equipment downtime and maintenance costs. In lower seam mines (e.g.; under 142cm), it is difficult to access components from the top or bottom (underside) of the mining machine due to the restricted roof clearance over the machine. MPs located in the center of the machine are difficult or impossible to access. Hence, visual and physical access must be from the sides or the ends of the machine. The concept of the primary and secondary maintenance zone is suggested as a design tool for equipment designers and evaluators.

Primary Maintenance Zones

The Primary Maintenance Zone (PMZ) is defined as the area extending from the outer edge of a machine inboard (inward) a distance of 45cm (18 inches). The PMZ extends around the machine as illustrated in Figure 1. All scheduled maintenance and service points should be located within the PMZ. This includes: (a) lubrication and inspection points, (b) fluid fill points and (c) adjustment points. In addition, high frequency of failure components and connections (e.g.; hydraulic valves, water lines, etc.) and replaceable wear points should be in the PMZ.

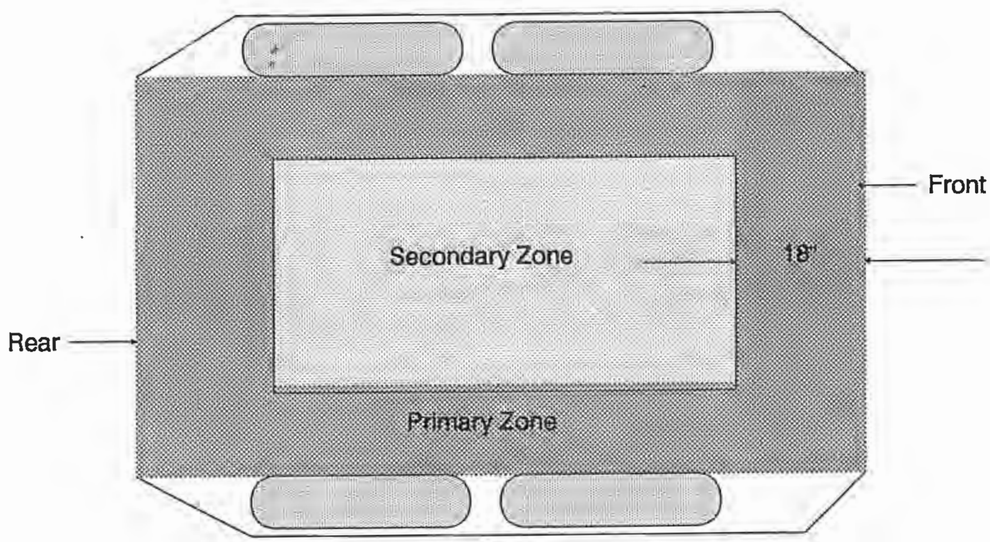

Figure 1: Primary maintenance zone.

Secondary Maintenance Zone

The Secondary Maintenance Zone (SMZ) is defined the area extending from the inner edge of the PMZ to the machine centerline. Only components requiring no routine maintenance should be located in the SMZ. Adequate direct visual and physical access must be provided for all MPs in the SMZ.

Tertiary Maintenance Locations.

A Tertiary Maintenance Location (TML) is defined as a MP located outside the PMZ and SMZ. TMLs may include a lubrication points on the end of a roof bolter boom or a tensioner on a conveyor system. The TML should be designed to permit full visual and physical access to the maintenance point. Where possible, the TML should be located under

LEVEL OF ACCESSIBILITY

Two levels of accessibility should be considered during the design process: visual and physical access. Visual inspection is the most frequent maintenance task. Accessing a component on a mining machine to inspect it often accounts for over 25% of the task completion time. Physical access to the MP is the next most frequently performed maintenance step. Maintenance safety and task completion times can be improved if all MPs and frequently replaced components are directly visible and accessible to the maintainer. Table 1 lists recommended visual and physical access locations for MPs on machines used in lower seam mines.

VISUAL ACCESS

Visual inspection is also the first step in any maintenance task. Hence, maintenance points should be visible to the maintainer. Where practical, MPs should be located in the PMZ and should be visible without removing access covers or other components. Hazardous or energized components may be mounted behind protective covers in the PMZ, but should provide direct visual access for the maintainer after the protective cover is removed. Visual access should provide line of sight inspection of all relevant locations on the component or connection.

Table 1: Recommended MP Locations

Location	Physical Access To Maintenance Points	Visual Access To Maintenance Points
Recommended	Machine Exterior-PMZ	Machine Exterior-PMZ
	Machine Exterior-Under Fender	Machine Exterior-Under Fender
	Machine Exterior-Open Compartment	Machine Exterior-Open Compartment
Acceptable	Machine Exterior-End of Vehicle	Machine Exterior-End of Vehicle
	Machine Exterior-Closed Compartment	Machine Exterior Closed Compartment
		Machine Cavity - Opening
Least Preferred	Machine Cavity-Top Opening	Machine Cavity-Top Opening
	Inside Operator's Compartment	Inside Operator's Compartment
	Machine Exterior-Behind Other Components	Machine Exterior - Behind Components
Undesirable	Machine Top-Under Access Cover	Machine Top-Under Access Cover
	Inside Machine Feature (e.g.; Boom Frame)	
	Under Machine-Exterior	Under Machine - Exterior
	Interior Machine Cavity - No Direct Access	Interior Machine Cavity-No Direct Access
	Interior Machine Chassis	Interior Machine

When a component is located in the SMZ, it should be mounted outboard (exterior side) of the machine frame and should be directly visible to the maintainer. If a MP must be located inboard (inside the frame), it should be positioned to permit direct visual access from the side or the end of the machine. This visual access may be through covered or uncovered access opening. The maintainer may be in a stooped, kneeling or crouched position while viewing, but his/her head should be upright.

Visual access openings should permit inspection of the MP from the side or end of the machine. Visual access openings should be located above the machine centerline to permit ease of viewing as suggested in Figure 2. Openings that must be located below the machine centerline should be sufficiently large to permit viewing of the maintenance point from a kneeling or prone position.

Visual access openings should not be located on the top or the underside of machines used in mines with seam heights of under 152cm. If the visual access opening must be placed on the top of the machine, it should be located as close to the side or end as possible. Do not locate visual access openings behind components that must be removed in order to complete a visual inspection.

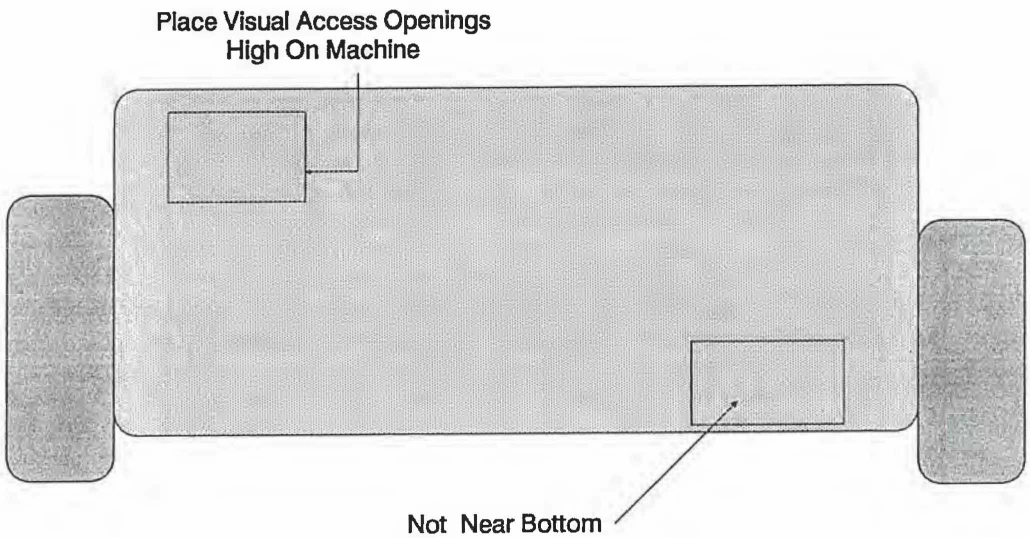

Figure 2: Recommended location for visual access openings.

Protective Covers

Access covers should be designed for rapid removal and replacement from the side or the end of the machine. Do not install access covers behind components that must be removed to complete a maintenance task. Windows should be installed on solid access opening covers, cabinet doors or other protective enclosures housing components requiring continuous, daily, or periodic visual inspections.

Visual Inspection Distances

time of the visual inspection. If the inspection point is more than 90cm (18 inches) from the eye location, the maintainer should be able to move his/her head to within the required 90cm viewing distance. If a cap lamp is required to provide illumination for the inspection, it must be included in the above provision.

PHYSICAL ACCESS

Physical access is the second step in most maintenance tasks. The level of access required varies as a function of the task (Conway, 1986). Single or two handed access may be adequate if: (a) the MP is within the PMZ and (b) the maintainer can observe the component during the maintenance process. Partial or whole body access is required for maintenance tasks if: (a) the maintenance point is more than 90cm (18 inches) from the edge of the machine, or (b) the maintenance point is in an interior machine cavity, or (c) visual access is limited from the side or the end of the machine.

Routine service points should be directly accessible by the maintainer. Access can be achieved by: (a) locating the service point in the PMZ or (b) providing an access opening sufficiently large to permit the maintainer to access the point with required tools.

REMOVAL AND REPLACEMENT OF PARTS

All components will eventually have to be repaired or replaced. It is important, therefore, to design the machine for expeditious removal and replacement of every component. To enhance component R/R: (a) layout components so that no other component must be removed to remove the failed component, (b) all components should be R/R in a line perpendicular to the component-machine mounting point, (c) cables, hydraulic lines, water hoses or other items should not have to be removed from non-failed components to remove a failed component, (d) a failed subassembly or part in a major component (e.g.; a bearing) or in a movable machine feature (e.g; a conveyor boom) should be accessible without having to remove other components or to disassemble non-failed machine features.

Parts subject to high stress loadings or wear should be directly accessible without having to disassemble the machine or major parts of the machine. No more than three or four steps should be required to replace a failed part.

HANDLING HEAVY COMPONENTS

To safely and expeditiously R/R heavy mining machine components, it is necessary to incorporate design features and or mechanical assistance for maintenance personnel. Component-machine interface design features may include: (a) locating components in the PMZ where they can be R/R without having to lift it up, over, or around other components or machine features, (b) incorporating hooks, lift points, hand grips or other lifting aids into the design of the component itself, (c) designing the component-machine interface so that the component can guided or slid into correct position without having to lift it, (d) design lips, permanent

Where practical, all components weighing more than 50 pounds should be installed in the PMZ. This location reduces access time, permits the use of handling devices, and the use of powered hand tools. It also reduces exposure to maintenance related accidents and injuries. For components weighing more than 50 pounds, provisions should be made for use of mechanical or powered lifting devices to R/R the component. Lifting assistance is recommended for all components weighing over 100 pounds and located in the SMZ. This mechanical assistance should permit lifting the component off the transport vehicle and lowering it at the installation point. The device also should permit manipulation of the component to align the unit as required for installation on the mining machine.

REFERENCES

Conway, E. J. and Unger, R., 1989a, Maintainability Design Of Underground Mining Equipment - Volume I: Final Technical Report. (Contract J0145034, VRC Corporation), U.S. Bureau of Mines, Pittsburgh, PA, USA, 35 pp.

Conway, E. J. and Unger, R. 1989b, Maintainability Design Of Underground Mining Equipment - Volume II: Maintainability Design Guidelines. (Contract J0145034, VRC Corporation), U.S. Bureau of Mines, Pittsburgh, PA., USA, 161 pp.

Conway, E. J., Elliott, W. and Unger, R. 1988,, Mine Maintenance Material Handling: Volume II - Prototype Device Specification. (Contract H0113018, Canyon Research Group, Inc,) U.S. Bureau of Mines, Pittsburgh, PA, USA, 51 pp.

Conway, E. J., 1986, Human Factors Design Guidelines For Mobile Underground Mining Equipment - Proposed SAE XJ1314. (contract No H0308110, Canyon Research Corporation), Society of Automotive Engineers, Warrendale, Pa., USA, 36 pp.

Ferguson, C.A., et. al, 1985, Ergonomics Of The Maintenance of Mining Equipment. Institute of Occupational Medicine, Edinburgh, 55 pp.

National Academy of Science, 1982, Towards Safer Underground Coal Mines. Washington, D.C., 190 pp.

Sanders, M. S. and J. Peay. Human Factors In Mining. BuMines Information Circular 9182, 1988, 153 pp.

ADVANCES IN INDUSTRIAL ERGONOMICS AND SAFETY

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ADVANCES IN INDUSTRIAL ERGONOMICS AND SAFETY II

Proceedings of the Annual International
Industrial Ergonomics and Safety Conference
held in Montreal, Quebec, CANADA, 10-13 June 1990

The Official Conference of the International Foundation
for Industrial Ergonomics and Safety Research

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Taylor & Francis
London · New York · Philadelphia

Taylor & Francis Ltd, 4 John St., London WC1N 2ET

Taylor & Francis Inc., 1900 Frost Road, Suite 101, Bristol, PA 19007

British Library Cataloguing in Publication Data

International Industrial Ergonomics and Safety Conference
(1990, Montreal, Quebec, Canada)
Advances in industrial ergonomics and safety II
1. Ergonomics
I. Title II. Das, Biman
620.8'2

ISBN 0-85066-748-8

Library of Congress Cataloging-in-Publication Data
is available

Printed in Great Britain by Burgess Science Press, Basingstoke.