Chapter 1
Introduction

1.1 The Need for Improving Mining Equipment Reliability, Maintainability, and Safety

The history of mining may be traced back to the ancient Egyptians, who operated malachite mines at Wady Maghareh on the Sinai Peninsula and at Timna in the Negev. Today millions of people are employed in the mining industry throughout the world. For example, in the USA alone around 675,000 people are employed in the natural resources and mining sector [1].

Each year billions of dollars are spent to produce various types of equipment for use by the mining industry throughout the world, and this expenditure is increasing rapidly. For example, in 2004 American mining equipment manufacturers shipped around $1.4 billion worth of goods and a year later, in 2005, the figure jumped to $2 billion [2]. Nowadays, the competitive global economy is forcing mining companies around the world to modernize its operations through increased mechanization and automation.

Thus, mining equipment is becoming more complex and sophisticated, and its cost is increasing at an alarming rate. In addition, its safety-related issues are receiving increased attention. This in turn makes it cost ineffective to have backup units nor unsafe units. All in all, in order to meet production targets and tight schedules, the mining companies are increasingly demanding better equipment reliability, maintainability, and safety.

1.2 Mining-equipment-related Facts and Figures

This section presents facts and figures directly or indirectly concerned with mining equipment reliability, maintainability, and safety.

- In 2006, the value of shipments of selected types of mining machinery and related equipment from American manufacturers was estimated to be around $2.5 billion [3].
- The average fatality rate in the US mining industry was 27.7 per 100,000 workers, as opposed to 4.8 per 100,000 workers in all US mining industry sectors during the period 1992–2001.
- Equipment maintenance costs range from 20% to over 35% of total mine operating costs [5].
- Approximately 10% of production time is lost by unplanned maintenance in the Australian underground coal mining industry [6].
- Annual mining deaths in the USA decreased from around 500 in the late 1950s to about 93 during the 1990s [7].
- In 2004, around 17% of the 37,445 injuries in American underground coal mines were associated with bolting machines [8].
- During the period 1995–2001, a total of 11 programmable electronic-related mining incidents were reported in the USA; 4 of these were fatalities [9, 10].
- In open-pit mines in both Chile and Indonesia, maintenance cost is more than 60% of the operating cost [11].
- According to various civilian and military studies, it is possible to reduce preventive maintenance and corrective maintenance task times by 40% to 70% with planned maintainability design efforts [5].
- During the period 1990–1999, electricity was the fourth leading cause of death in the US mining industry [12].
- Usually, the cost of maintenance in the mining industry varies from 40 to 50% of the equipment operating cost [13].
- During the period 1978–1988, maintenance activity accounted for 34% of all lost time injuries in US mines [14].
- During the period 1983–1990, with respect to per-injury data for independent contractor employees in the mining industry, approximately 20% of the coal-mine-related injuries occurred during machine-maintenance activity or while using hand tools [15].
- During the period 1990–1999, 197 equipment fires caused 76 injuries in coal mining operations in the USA [16].

1.3 Terms and Definitions

There are a large number of terms and definitions used in the area of reliability, maintainability, and safety. This section presents some of the terms and definitions considered useful for application in the area of mining equipment reliability, maintainability, and safety [17–21].

- **Accident:** an unplanned and undesired act
- **Availability:** the probability that a piece of equipment/system is functioning satisfactorily at time t when used according to specified conditions, where the total

time includes operating time, logistical time, active repair time, and administrative time

- **Failure:** the inability of an item/piece of equipment/system to operate within specified guidelines
- **Failure mode:** the abnormality of item/equipment/system performance that causes the item/piece of equipment/system to be considered as having failed
- **Hazard:** the source of energy and the behavioral and physiological factors that, when not controlled effectively, lead to harmful incidents
- **Hazard rate:** the ratio of the change in the number of items that have malfunctioned to the number of items that have survived at time t
- **Maintainability:** the probability that a failed system/piece of equipment/item will be restored to its satisfactory operating state
- **Maintenance:** all actions necessary to retain an item/piece of equipment/system in, or restore it to, a specified condition
- **Mean time to failure (exponential distribution):** the sum of the operating time of given items divided by the total number of failures
- **Mean time to repair:** a figure of merit depending on item/equipment/system maintainability equal to the mean item/equipment/system repair time; in the case of exponentially distributed times to repair, mean time to repair is the reciprocal of the repair rate
- **Mine:** an excavation from which minerals or ore is extracted
- **Mission time:** the time during which an item/piece of equipment/system is performing its specified function
- **Open-pit mining:** a form of operation designed for extracting minerals that lie near the Earth's surface
- **Ore:** any natural combination of minerals
- **Redundancy:** the existence of more than one means to accomplish a specified function
- **Reliability:** the probability that an item/piece of equipment/system will carry out its specified mission satisfactorily for the stated time period when used under specified conditions
- **Reliability model:** a model used to assess, estimate, or predict reliability
- **Safety:** the conservation of human life and its effectiveness and the prevention of damage to items/equipment/systems as per stated requirements
- **Safety assessment:** the quantitative/qualitative determination of safety
- **Safety process:** a set of procedures followed to enable the safety requirements of an item/piece of equipment/system to be identified and met
- **Unsafe condition:** any condition, under the right circumstances, that will lead to an accident

1.4 Useful Information on Mining Equipment Reliability, Maintainability, and Safety

There are many different sources for obtaining mining equipment reliability-, maintainability-, and safety-related information. This section lists some of the most useful sources, directly or indirectly, for obtaining such information, under a number of distinct categories.

1.4.1 Journals and Magazines

- Journal of Quality in Maintenance Engineering
- Reliability Engineering and System Safety
- IEEE Transactions on Reliability
- International Journal of Reliability, Quality, and Safety Engineering
- Professional Safety
- Hazard Prevention
- Accident Analysis and Prevention
- Reliability Review
- Journal of Fire Safety
- Reliability: The Magazine for Improved Plant Reliability
- Quality and Reliability Engineering International
- RAMS ASIA (Reliability, Availability, Maintainability, and Safety (RAMS) Quarterly Journal)
- National Safety News
- Engineering and Mining Journal
- Australian Mining
- Mining Magazine
- Engineers Australia
- Mining Technology
- Soviet Mining Science
- International Journal of Surface Mining & Reclamation
- Mining Congress Journal
- Coal Age
- Transactions of the Canadian Institute of Mining and Metallurgy
- CIM Bulletin
- The Mining Engineer
- Engineering Failure Analysis

1.4.2 Conference Proceedings

- Proceedings of the Annual Institute on Mining Health, Safety, and Research
- Proceedings of the Annual Reliability and Maintainability Symposium
- Proceedings of the ISSAT International Conferences on Reliability and Quality in Design
- Proceedings of the European Conferences on Safety and Reliability
- Proceedings of the International Conferences on Probabilistic Safety Assessment and Management.
- Proceedings of the International Conference on Reliability, Production, and Control in Coal Mines, 1991
- Proceedings of the Annual Meetings of the Society for Mining, Metallurgy, and Exploration
- Proceedings of the International Symposium on Mine Planning and Equipment Selection
- Proceedings of the American Mining Congress-Coal Convention, 1991
- Proceedings of the IEEE Annual Industry Applications Conferences

1.4.3 Books

- Blanchard, B.S., Verma, D., Peterson, E.L.: Maintainability: A Key to Effective Serviceability and Maintenance Management. Wiley, New York (1995)
- Cox, S.J.: Reliability, Safety, and Risk Management: An Integrated Approach. Butterworth-Heinemann, New York (1991)
- Dhillon, B.S.: Design Reliability: Fundamentals and Applications. CRC Press, Boca Raton, FL (1999)
- Dhillon, B.S.: Engineering Maintainability. Gulf Publishing, Houston, TX (1999)
- Dhillon, B.S.: Engineering Safety: Fundamentals, Techniques, and Applications. World Scientific, River Edge, NJ (2003)
- Goetsch, D.L.: Occupational Safety and Health. Prentice-Hall, Englewood Cliffs, NJ (1996)
- Grant Ireson, W., Coombs, C.F., Moss, R.Y. (eds.): Handbook of Reliability Engineering and Management. McGraw-Hill, New York (1996)
- Hammer, W., Price, D.: Occupational Safety and Engineering. Prentice-Hall, Upper Saddle River, NJ (2001)
- Moubray, J.: Reliability-Centered Maintenance. Industrial, New York (1997)
- Shooman, M.L.: Probabilistic Reliability: An Engineering Approach. McGraw-Hill, New York (1968)

1.4.4 Organizations

- American Society of Safety Engineers, 1800 East Oakton St., Des Plaines, IL, USA
- World Safety Organization, P.O. Box No. 1, Lalong Laan Building, Pasay City, Metro Manila, The Philippines
- Reliability Society, IEEE, P.O. Box 1331, Piscataway, NJ, USA
- The American Institute of Mining, Metallurgical, and Petroleum Engineers, 8307 Shaffer Parkway, Littleton, CO, USA
- Society for Maintenance and Reliability Professionals, 401 N. Michigan Avenue, Chicago, IL, USA
- Society of Logistics Engineers, 8100 Professional Place, Suite 211, Hyattsville, MD, USA
- Society for Machinery Failure Prevention Technology, 4193 Sudley Road, Haymarket, VA, USA
- National Safety Council, 444 North Michigan Avenue, Chicago, IL, U.S.A.
- American Society for Quality, Reliability Division, 600 North Plankinton Avenue, Milwaukee, WI, USA
- System Safety Society, 14252 Culver Drive, Suite A-261, Irvine, CA, USA

1.4.5 Standards

- MIL-STD-785, Reliability Program for Systems and Equipment, Development and Production, US Department of Defense, Washington, DC
- MIL-STD-1629, Procedures for Performing Failure Mode, Effects and Criticality Analysis, US Department of Defense, Washington, DC
- MIL-HDBK-217, Reliability Prediction of Electronic Equipment, US Department of Defense, Washington, DC
- MIL-HDBK-781, Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification, and Production, US Department of Defense, Washington, DC
- MIL-STD-882, Systems Safety Program for System and Associated Sub-system and Equipment-Requirements, US Department of Defense, Washington, DC
- IEC 60950, Safety of Information Technology Equipment, International Electro-Technical Commission (IEC), Geneva
- MIL-STD-470, Maintainability Program for Systems and Equipment, US Department of Defense, Washington, DC
- MIL-HDBK-472, Maintainability Prediction, US Department of Defense, Washington, DC
- MIL-STD-471, Maintainability/Verification/Demonstration/Evaluation, US Department of Defense, Washington, DC

- IEC 61508 SET, Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems Parts 1–7, International Electrotechnical Commission (IEC), Geneva

1.4.6 Data Information Sources

- RAC EEMD1, Electronic Equipment Maintainability Data, Reliability Analysis Center, Rome Air Development Center, Griffiss Air Force Base, Rome, NY, USA
- Government Industry Data Exchange Program (GIDEP), GIDEP Operations Center, US Department of the Navy, Corona, CA, USA
- National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA, USA
- Safety Research Information Service, National Safety Council, 444 North Michigan Avenue, Chicago, IL, USA
- Defense Technical Information Center, DTIC-FDAC, 8725 John J. Kingman Road, Suite 0944, Fort Belvoir, VA, USA
- National Aeronautics and Space Administration (NASA) Parts Reliability Information Center, George C. Marshall Space Flight Center, Huntsville, AL, USA

1.5 Problems

1. Discuss the need for improving mining equipment reliability, maintainability, and safety.
2. List at least seven facts and figures concerned with mining equipment reliability, maintainability, and safety.
3. Define the following terms:
   - Open-pit mining
   - Hazard rate
   - Reliability
4. List the five most important journals that publish mining-equipment-reliability-related studies.
5. Compare mining equipment reliability with its maintainability.
6. List at least four sources that can be useful for obtaining mining equipment reliability-, maintainability-, and safety-related information.
7. List at least four of the most important standards on reliability, maintainability, and safety.
8. Define the following terms:
   - Safety
   - Failure
   - Accident

9. What is mean time to repair?
10. Compare equipment availability with equipment reliability.

References

1. Division of Information Services, United States Bureau of Labor Statistics, 2 Massachusetts Avenue, Washington, DC
2. Chadwick, J., Higgins, S.: US technology. Int. Min. September, 44–54 (2006)
3. Manufacturing and Construction Division, US Census Bureau, US Department of Commerce, Washington, DC
4. Iannacchione, A., Mucho, T.: 100 years of improvement in aggregate worker safety. Stone Sand Gravel Rev. pp. 28–34 (March/April 2003)
5. Unger, R.L., Conway, K.: Impact of maintainability design on injury rates and maintenance costs for underground mining equipment. In: Improving Safety at Small Underground Mines, compiled by R.H. Peters, Special Publication Report No. 18–94, US Bureau of Mines, Washington, DC, pp. 140–167 (1994)
6. Clark, D.: Tribology – its applications to equipment reliability and maintainability design in the underground coal mining industry. In: Proceedings of the Institution of Engineers Australia Tribology Conference, pp. 38–44 (1990)
7. Historical Data on Mine Disasters in the United States, US Department of Labor, Washington, DC. Available online at www.msha.gov/msainfo/factsheets/mshafacts8.htm
8. Burgess-Limerick, R., Steiner, L.: Preventing injuries: analysis of injuries highlights high priority hazards associated with underground coal mining equipment. Am. Longwall Mag., pp. 19–20 (August 2006)
9. Sammarco, J.J.: Addressing the safety of programmable electronic mining systems: lessons learned. In: Proceedings of the IEEE 37th Industry Applications Society Meeting, pp. 692–698 (2003)
10. Fatal Alert Bulletins, Fatal Grams and Fatal Investigation Reports, Mine Safety and Health Administration (MSHA), Washington, DC (May 2001). Available online at www.msha.gov/fatals/fab.htm
11. Hall, R.A., Daneshmend, L.K., Lipsett, M.G., Wong, J.: Reliability analysis as a tool for surface mining equipment evaluation and selection. CIM Bull. 93, 1044, 78–82 (2000)
12. Cawley, J.C.: Electrical accidents in the mining industry, 1990–1999. IEEE Trans. Ind. Appl. 39, 6, 1570–1576 (2003)
13. Forsmann, B., Kumar, U.: Surface mining equipment and maintenance trends in the scandinavian countries. J. Mines Minerals Fuels August/September 266–269 (1992)
14. MSHA Data for 1978–1988, Mine Safety and Health Administration (MSHA), US Department of Labor, Washington, DC
15. Rethi, L.L., Barett, E.A.: A summary of injury data for independent contractor employees in the mining industry from 1983–1990. Report No. USBMIC 9344, US Bureau of Mines, Washington, DC (1983)
16. De Rosa, M.: Equipment fires cause injuries: recent NIOSH study reveals trends for equipment fires at U.S. coal mines. Coal Age pp. 28–31 (October 2004)
17. MIL-STD-721, Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety, US Department of Defense, Washington, DC
18. Omdahl, T.P. (ed.): Reliability, Availability, and Maintainability (RAM) Dictionary. ASQC Quality Press, Milwaukee, WI (1988)
19. Naresky, J.J.: Reliability Definitions. IEEE Trans. Reliabil. 19, 198–200 (1970)

20. Dictionary of Terms Used in the Safety Profession, 3rd ed., American Society of Safety Engineers, Des Plaines, IL (1988)
21. McKenna, T., Oliverson, R.: Glossary of Reliability and Maintenance Terms. Gulf Publishing, Houston, TX (1997)