temperature and humidity, or to harmful dusts, fumes, and gases. Human error or failure may occur in many of these situations, and environmental conditions or operating practices may predispose the workers to accidents.[2]

In addition to the established methods of combating industrial accidents, such as safety-education programs and special safety equipment, there is a relatively new discipline, commonly called human engineering, which can reduce accidents by relating the mechanical design of the equipment to the biological and psychological characteristics of the operator. It seems reasonable to require that machines be designed from the man outward, with the instruments and controls considered as extensions of his nervous system and body appendages. This implies that machines and working areas must be built around the operators rather than placing the workers in a setting without due regard for their requirements and capacities. Unless machines are so constructed, it is hardly fair to attribute so many accidents to human failure, as is usually done.

If this point of view is carried out in practice, fewer accidents should result, training costs should be reduced, and the necessity for extensive redesign of equipment after it is put into use should be eliminated. This principle holds true whether an employee is operating motorized equipment on the highway, flying an aeroplane, operating a lathe or punch press, or carrying out any of the numerous mechanized duties of a manufacturing plant.[3]

1. Designing for Human Capabilities and Limitations

Although it was pointed out first almost 50 years ago that the design of tools should take into account the variations in the physiques of different workers, relatively little has been done since along these lines.[4] By and large, the employee today must still adapt himself to the tools and equipment provided him and to the methods of work prescribed for everyone. However, the gains that result from adapting the equipment and working methods to the individual are of demonstrated significance. This does not mean, as is sometimes believed, that equipment and methods need to be developed for each individual, but rather that optimum conditions can be discovered for groups of workers. Thus, the best arrangements can be set forth with reference to human capabilities.

Machine speeds during certain industrial operations, for example, are sometimes clearly un-co-ordinated with the capacities of the operators. With slow speeds the worker may become impatient, while fast speeds may disturb him because of his inability to keep up. In either case accidents may result. As the speed of work increases beyond a point, a disproportionately greater increase in

[2] R. A. McFarland, Chairman, Proceedings of the President's Conference on Industrial Safety, March 23, 24, and 25, 1949, *Bull.* No. **112**, Bur. Labor Standards, U. S. Dept. of Labor, 1949.

[3] R. A. McFarland, Human engineering: a new approach to driver efficiency and transport safety, *Soc. Automotive Engrs. Trans.*, **62**, 335–345 (1954).

[4] F. W. Taylor, *The Principles of Scientific Management*. Harper, New York, 1911.

errors (and therefore, presumably, of accidents) has been observed. This may be especially true for older workers.

It is recognized also that as work becomes more physically demanding a greater number of accidents may be expected. The importance of severity of work as a factor in safety is frequently underestimated. Ordinarily, with more strenuous operations the speed of work falls off considerably toward the end of the working day. Thus, in many instances the opportunity for accidents is also reduced, and when the safety of jobs is compared in terms of the number of accidents incurred, differences may be obscured or minimized. If the accident rate is taken in terms of the number of accidents incurred per unit of work completed, quite a different picture may emerge. In one case, for example, while the rate of accidents increased only 50 per cent from the beginning to the end of the working day in a less demanding factory job, it increased 275 per cent for a more demanding job.[5] In such a situation the need for consideration of ways and means for reducing physical demands, such as through increased leverage and booster systems, is obvious.

One of the most important concepts of human engineering is thus the design of equipment in terms of human capabilities and limitations. We have learned that difficulties arise when mechanization becomes too complicated for human operators. Therefore, everything must be done to design the equipment and to set up the operating procedures to facilitate the greatest possible efficiency and safety. More precisely stated, first, the engineer must have an understanding of the sense organs and the characteristics of human perception if satisfactory information is to be supplied from sounds and lights in the operation of equipment. In general, man is a poor monitor of equipment. Second, the engineer must not place unreasonable demands upon the operator in regard to the physical responses involved, for example, in reaching or operating a control or lever or in clearly differentiating between two or more controls. Otherwise, an inadvertent operation of a switch or control may occur. Third, the engineer must consider that the operator of equipment is frequently suffering from temporary impairment of functions, such as fatigue, thus causing inefficiency, and that there may be changes in function as a result of aging. Finally, the physiological and environmental conditions such as temperature, humidity, toxic gases, and other factors must be considered, or physiological limits may be exceeded.[1]

B. PRINCIPLES OF ADVANCE ANALYSIS

The initial phase of any human engineering program in industry should consist, wherever possible, of an advance analysis of all possible faults in equipment and working areas. If defects are present, it is only a matter of time before some operator fails and has an accident. Advance analysis assumes an operational job analysis that should include a survey of the nature of the task, the work

[5] J. Goldmark, M. D. Hopkins, and P. S. Florence. A comparison of an eight-hour plant and a ten-hour plant, *Pub. Health Bull.* No. **106**, 1920.