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ABSTRACT

Human factors engineering is considered with regard to the design of safety factors for aviation and highway transportation equipment. Current trends and problem areas are identified for jet air transportation and for highway transportation. Suggested solutions to transportation safety problems are developed by applying the techniques of human factors engineering. (FS)

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THE DESIGN OF TRANSPORTATION EQUIPMENT IN TERMS OF HUMAN CAPABILITIES

The Role of Engineering Psychology in Transport Safety

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The Role of Engineering Psychology in Transport Safety

Ross A. McFarland

I. Introduction

The very extensive movement of people and goods by various forms of transportation constitutes one of the outstanding characteristics of modern times. In certain areas of the world, safety in transit is assuming even greater importance than problems relating to health, food, and shelter. In the U. S., for example, the increasing mechanization of our environment, diverse industrial procedures, and especially the wide use of transport vehicles have resulted in new threats to the well-being of large sections of the population. Thus, the assurance of safety in transportation has become one of the basic requirements of modern life. This is an area in which engineering psychologists can play an important role. In order to understand the problems involved it is first necessary to consider safety in relation to the volume of air and highway transportation, and the associated accident rates.

II. The Current Trends in Aviation

The current trends in aviation point to increasing speeds with presently designed supersonic transports, involving higher operating altitudes, and accommodations for larger numbers of passengers. Also, aircraft for 300-500 passengers per plane are currently under construction. There are also many newer types of planes for flying nearer to the surface of the earth, and for shorter ranges. Helicopters, and (VTOL) aircraft designed for vertical take-off and landing are proving to be highly efficient.

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A. Number of pilots and planes in operation. In U. S. aviation today there are almost 600,000 pilots with current medical certificates. About 390,000 are private and student pilots, 175,000 are commercial pilots and 35,000 are air transport pilots. These airmen are flying 125,000 registered aircraft, of which 2500 are air carrier transports.

B. Volume of air traffic. The number of revenue passengers (i.e. number of tickets sold) in air travel has gone up between 10 to 15 percent each year, as shown in the table below. Passenger travel by air between the U. S. and foreign countries is four times as great by air as by sea; on North Atlantic routes there are 11 times more passengers by air than by sea. The airlines in the U. S. are now carrying larger numbers of passengers in inter-city travel (44 million) than the railroads (14 million) and the motor buses (22.7 million). The scheduled airlines of the U. S. fly approximately one-half of the total number of revenue passengers on a worldwide basis, i.e. in 1966, 110 million, and in 1968, 125 million.

Year	Revenue passengers
1951	42,000,000
1961	111,000,000
1963	135,000,000
1964	156,000,000
1965	180,000,000
1966	196,000,000
1967	230,000,000
1968	250,000,000

In spite of the great increase in the number of revenue passengers using the airlines the percent of the population using this mode of travel is relatively small. The number of separate individuals represented in the 250 million revenue passengers may be only about 25-30 million. Thus, less than one percent of the world population has flown each year on a scheduled airline. In the U. S. this amounts to less than one-half of one percent of the population.

C. <u>The safety record in aviation.</u> The safety record of the scheduled domestic and international air carriers is very favorable. However, there is no meaningful method of comparing the safety records of different forms of transportation because of the lack of a common denominator or baseline. On a worldwide basis, the fatality rate per one hundred million passengers miles in 1967 was 0.25. The absolute number of passengers killed on scheduled services was 665 in 1964, compared with 680 in 1965, 926 in 1966 and 674 in 1967. In non-scheduled operations in 1967 there were 337 passengers killed, a rate 2 1/2 times that for scheduled services since non-scheduled operations amounted to only 1/5 of that of the total scheduled ones.

In private flying in the U. S. the fatality rate is higher than in commercial or business flying; in the latter skilled pilots are usually utilized. In a recent year the relative accidental death rates for pilots per 100,000 hours of flight were calculated at 0.12 for scheduled airline pilots, 1.4 for business pilots, and 10.0 for private pilots. It is obvious that a great deal remains to be accomplished, especially in the field of private flying.

It is of interest to note that the jet engine has contributed greatly to the safety of airline operations. In recent years, for example, jet transports have had almost twice as good a safety record as propeller-driven aircraft.

In scheduled air transportation there has been a concerted effort on the part of all concerned to identify the causes of accidents and to prevent them at any cost. The pilots are well-trained and receive health checks at frequent intervals, and the air transports are very carefully maintained. The public has demanded and is now receiving safe and efficient operations. The lowering of air fares would undoubtedly increase the volume of traffic.

III. Problem Areas in Scheduled Jet Air Transportation

The application of human factors principles in improving safety revolve around the major causes of the accidents. For example, in modern jet flying there may be unusual environmental stresses due to the intensity of light and rapid changes in light conditions. The influence of glare in relation to rapid changes in altitude and cloud formation must be anticipated. If a pilot is flying in very bright sunlight he may descend rapidly to conditions of relative darkness before dark adaptation can occur. There is also the possibility of injury from solar flares and radiation while landing,cockpit configurations of future models may place limitations on the pilot's vision or field of view. Finally, the distance traveled in relation to human response times must be kept within tolerance limits.

A problem of great current concern, and falling within the engineering psychologist's field of interest relates to the high incidence of accidents during approach and landing (Gerathewohl and Gannett, 1969). During 1959-1966, in the free world, in jet revenue operations 60 accidents occurred in a total of 199 during approach. There were 36 additional ones during landing. Of those accidents attributable to pilot error in the above period, 43 took place during approach and 12 in landing. The unfortunate aspect of this situation is that the pilot is usually more fatigued at the end of a long flight and his judgment and decision-making capabilities may be less than optimum. From the point of view of the engineering psychologist it is obvious that to prevent aircraft accidents involving collision with high terrain more information and better training in operating procedures must be introduced to give the pilot quick and unequivocal answers to the following questions. (1) Where am I? (2) What is the safety height? (3) How far away and in what direction is my next landing? And (4) When shall I get there and do I have enough fuel? With an adequate human factors research program all of these areas are subject to satisfactory control and safety of operation. (Ruffell Smith, 1968) The answer to all of these problems fall within our present capabilities if human engineering principles and available equipment could be introduced and the pilots trained to use them.

IV. Areas for Study in Private Flying

One problem relates to the inadequate training of many who participate in private flying. An outstanding deficiency is insufficient training, especially in instrument flying. Another area for improvement relates to the design of small aircraft to prevent spinning and to provide better stability and control. Also, accepted crash-survival design features are not fully incorporated in the construction of many current light planes. Another design problem concerns the flight capabilities of some of the newer jet powered small aircraft which are capable of flight at high altitudes. Without pressurization, the pilots and passengers will require oxygen and the designers of light high performance aircraft must provide for pressurized cabins as the most satisfactory solution.

Recent studies tend to indicate that private pilots should be more adequately indoctrinated in regard to the factors influencing their physical fitness and safety in flight. Many private pilots are flying without oxygen at altitudes above 10,000 feet for two hours, and 12,000 feet for one hour, thereby exceeding the current federal regulations. (McFarland, 1968)

Although airline pilots observe the regulations in refraining from drinking alcohol for eighteen hours before flight, there is an increasing amount or evidence that many private pilots drink excessively before flying. Precise

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information on this subject can only be revealed through blood alcohol determinations. Current evidence suggests that about one-third of the fatal accidents in private flying may involve excessive drinking.

V. Current Trends in Highway Transportation

In the field of highway transportation the enormous volume of traffic and the poor safety record are well-known. In 1967, there were close to 100 million registered vehicles being driven by approximately 103 million licensed drivers. By 1975, it is expected there will be more than 118 million vehicles on the highway, operated by 126 million drivers, and accumulating a trillion and a quarter miles of travel in a year.

In regard to the safety record, the number of fatalities from motor vehicle accidents exceeded 40,000 in 1962, and has increased each year since. In 1967, there were 53,100 fatalities, and the preliminary estimate of the National Safety Council for 1968 is set at 55,000 deaths. In addition to fatalities, there are large numbers of persons each year receiving injuries which are disabling beyond the day of the accident. In 1967, such injuries were received by approximately 1,900,000 persons. These fatalities and injuries constitute an enormous drain upon the human and financial resources of the country.

It is significant to note that the largest number of fatalities take place in the younger age ranges. In 1966, one motor vehicle death in 5, or 22 percent, was a male between 15-24 years of age. This amounted to 12,000 youths and this number will reach about 15,000 by 1970. If one takes the ages of those killed in motor vehicle accidents and relates them to the expected years of life otherwise remaining for these persons, it can be estimated that in 1966, more than 1.9 million life years were thus lost prematurely. By 1975, the number of persons in the 15-24 year-age group will increase about 30 percent. The fact that this age group has had elevated and growing accident rates has important implications in the overall efforts to solve the motor vehicle safety problems.

Because highway accidents are non-homogeneous in nature and non-repetitive in regard to underlying factors, research on the causes of these accidents has presented many difficulties. However, some broad associations between characteristics of drivers and their accident rates have been revealed from the application of epidemiological methods in this field. Thus, 1) numerically speaking, accidents are an affliction of youth, with young males predominating. This seems to be based on inexperience and lack of training, and on the temperaments and attitudes characteristic of youth; 2) emotional problems, and poor social adjustments are frequently found in persons having repeated accidents; 3) alcohol in excessive amounts is now estimated to be a causal factor in 50 percent of fatal accidents, and there is evidence that about half of these involve drivers who are problem drinkers or alcoholics; 4) medical conditions, apart from alcoholism, appear to be relatively unimportant in accident causation, except in the older driver age range. (McFarland, 1968a)

It has become clear that accidents can result from many interacting causes in which the driver, his vehicle, and the highway may be involved. As noted above, the epidemiological method used in the study of disease processes is also applicable to the analysis of the causes of accidents. The mathematical and engineering approach, in terms of operational or systems analysis, has also proved to be useful, for similar reasons.

At the present time, however, there is little objective evidence in regard to the preventive measures which might result in the greatest benefit for all concerned. It would appear to be unwise to concentrate largely or exclusively on the driver. Current interest in Washington has centered on deficiences in the design of vehicles. Studies of aircraft accidents have shown that restraining devices and protection from the physical forces involved in crashes often result in survival. Thus, preventing the accident on the part of the driver may be of the greatest importance, but certainly more attention should be paid to the characteristics of the vehicle, and the design of modern highways in improving the overall record. Engineering psychologists can make significant contributions in the control of these factors. (Domey and McFarland, 1963; McFarland, 1963)

VI. Problem Areas in Highway Safety for Engineering Psychologists

It is apparent from the foregoing that the problem of safety in highway or ground transportation involves consideration of virtually the entire population. The drivers and passengers in accidents may be young or old, able or inept, or impaired by emotional disturbance, fatigue, or alcohol. Thus it is important to design vehicles more safely or in ways which provide better protection against injury when accidents occur. Also, features should be introduced which do not require active, voluntary participation on the part of individuals. Such an approach has been successful in reducing disease through the control of the viruses or agents of disease. Examples are the chlorination of public water supplies to prevent typhoid, and mass innoculation against the polio and measles viruses. Can an understanding of how injury-producing energy is applied to the body in automobile crashes and a knowledge of the injury thresholds of the body tissues lead to the design of barriers to effectively prevent the energy exchanges which exceed threshold strength? How effective have the crash-injury protection features which have been introduced in automobiles proved to be?

An interesting analysis of the benefits of the current safety features in cars has been made by the National Safety Council. They point out that [illegible]00 of the 53,000 fatalities in 1967 were pedestrians, and hence would not be influenced at all by the safety features within the vehicles. Of vehicle occupant fatalities, 5,700 died in collisions deemed non-survival regardless of safety features, such as in collisions with trains, or involving fire or explosion. Another 18,000 fatalities occurred in accidents deemed non-survivable because of the severe impact forces at high speeds. If one further estimates a saving of 5,000 lives through the voluntary use of seat belts, this leaves 15,000 or 28 percent of the total fatalities. This number therefore constitutes the group in which the current in-built safety features, now required by federal law, might be expected to have an influence.

A. <u>Some Specific Problems in Automobile Safety</u>

With the passage of the National Highway Safety Acts of 1966, a great deal of attention is being given to improving the safety of the modern automobile. The results of these research programs should be studied in relation to some of the items discussed below.

1. <u>Design of restraint systems.</u> The value of seat belts, and especially of the shoulder-lap belt configuration has been well demonstrated. Some safety belts, however, are not designed for ease and comfort in use. For a tall person, for example, the shoulder strap may go across the throat and neck. The design must also permit the shorter driver, when restrained, to reach the

dashboard controls and the brake. It is apparent that restraining devices must be designed on the basis of operational tests in each model.

2. Sizing Considerations. The distribution in body size of the driving population is an important consideration in the design of the driver's seating and the location of the operating controls, especially in relation to the very large and very small drivers. For example, how can the little old lady under 5 feet who is restrained with a shoulder strap be able to reach the controls, or see over the dashboard and hood without seat adjustability? Also, in what way is the driver over 6 feet tall handicapped?

Previously information in regard to body size has been available only on specialized groups, such as truck drivers and military personnel. At the present time static measurements have been obtained on 1000 men and women representing the general driving population in a project at Harvard. Dynamic arm reach measurements have also been made on 200 subjects selected to include the shortest 5th percentile of women and the 95th percentile of men, as well as those in the intermediate range. The extent of arm reach while sitting restrained by a conventional lap and shoulder belt was recorded photographically in a systematic exploration while reaching in different directions from the body and in vertical planes. The measurements are then "read" from the film on an electronic analyzing device. This is linked to a computer which prints out the data comprising not only the individual "reach envelopes" but also for group values. This project should provide basic information in the formulation of federal standards on the location of controls in automobiles. The data will also provide the automotive manufacturers with design criteria which have been experimentally derived from a wide range of automobile drivers.

3. <u>The design of steering control columns.</u> The collapsible steering column has been designed to reduce injuries sustained by drivers from impact against the steering wheel in crashes. The preliminary findings suggest that this development is having a beneficial effect. The actual value of this new design feature can be determined only by comparing the fatality rate in automobiles equipped with collapsible steering columns with those not so equipped. However, the elimination of the steering column entirely might prove to be a more effective solution. There is no reason to believe that directional control of a vehicle is better achieved by a steering wheel than by other devices which may be operated by hands or feet and not involve the hazard of a column in front of the driver's chest.

4. <u>Design of braking systems.</u> The operating efficiency and reliability of braking systems have been greatly improved over recent years. However, such features as the optimal location of accelerator and brake pedals for quickest response have not been determined experimentally by engineering psychologists, or others, although improvements might result from such an approach. Available evidence suggests faster performance when the brake pedal is located alongside and slightly lower than the accelerator pedal. Also, the question of optimal feedback from power steering and power braking systems awaits further exploration.

5. <u>Design of dashboards.</u> Redesign of dashboards to include energy absorbing padding, and to eliminate protruding knobs has had some effect in reducing the severity of injuries. However, some of the recessed control knobs in certain current models cannot be operated by a gloved hand.

6. <u>Design of head supports.</u> The effectiveness of head supports in the prevention of whiplash injuries is an area where operational testing snould have

preceded the formulation of design criteria. Current studies are suggesting the importance of the location and height of the support in relation to the center of gravity of the head. For example, Coermann at the Max Planck Institute in Dortmund, Germany, is finding in simulated collisions (using fresh cadavers as subjects) that the head must strike the headrests squarely at the center of gravity of the head. Otherwise serious injuries may occur. This raises a question of suitable adjustability for tall persons, and of the design of headrests to prevent interference with vision. These findings provide a good example of why operational studies should precede the passing of regulations.

7. Design of crash injury protection. Another important area of research relates to the protection of vehicle occupants against injury either through restraining devices or energy absorbing equipment of all kinds, including the structure of the car itself. Human tolerances to injurious parts of the car must be established through biotechnical studies in order to provide design criteria.

8. Design for improved visibility. This area relates to restrictions on the field of view through windshields and window areas, and on the visibility provided by mirrors. An example is afforded by the tinted windshield. The lower margin of the tinting should be above the eye level height of the driver. Otherwise visibility through the windshield is impaired while driving at twilight or at night. And how can present mirror systems be improved to provide more adequate monitoring of events at the sides and to the rear? Other problems relating to visibility involve vehicle lighting systems, and provisions for signalling and intercommunication between one vehicle and another.

9. Medical problem areas. Two examples in this field relate to alcoholism and aging. The effects of alcohol are well-known, and recent

investigations have provided evidence for revising upwards the estimates of the role of excessive drinking in causing serious and fatal accidents. The problem of the aging driver has not received extensive study. This field needs exploration through experimental methods. For example, measurements could be made of the time it takes to look from the road to the rearview or side mirror and take appropriate action, including braking. The older driver eventually reaches a limit in the speed of response and in taking appropriate actions, and the question of what age range is appropriate for disqualification from driving is one which should be resolved on the basis of experimental evidence.

VII. Designing for Passenger Safety in High Speed Ground Transportation

Current developments in regard to high speed ground transportation systems for the transportation of large numbers of people raise a number of questions within the province of the engineering psychologist or human factors scientist. Some of these areas are outlined below.

1. A consideration of human factors in this field will include an advance analysis of 1) the characteristics, physical and otherwise, of the population who will use this form of transportation; 2) the characteristics of the transport system, and of the vehicle itself, and 3) the expected patterns of actions or activities of the passengers when entering, riding in, and leaving the vehicles.

2. One significant subject relates to the rate of change in acceleration, or "jerk". This must be minimized to prevent passenger discomfort. Other problems relate to the discomfort resulting from rapid changes in direction, as in taking curves at high speed.

3. Serious visual problems may result from looking out of windows on high speed trains. Such reactions as flicker vertigo, dizziness, and nausea may be expected.

4. Another area relates to the effects of the air pressure changes which take place when high speed surface vehicles enter and emerge from tunnels.

5. In general, safety problems relate to the prevention of crashes since restraining devices for passengers would be impractical.

VIII. The Application of the Techniques of Human Factors Engineering to the Solution of Transport Safety Problems

Many, if not most, of the safety problems in air and ground transportation can be investigated through the techniques of engineering psychology and related disciplines. Once the problem areas are identified and defined, it is necessary to set up experimental approaches for their solution.

The identification of the problem areas in safety is facilitated through the methods of biostatistics and epidemiology, which have proved effective in the solution of disease problems. These techniques, which involve determining the relative significance of different variables and their interrelationships, are not fundamentally different from what engineers call systems analysis.

In recent years some newer psychophysical methods have been developed in experimental psychology which offer promise in the study of the influence of adverse environmental stresses, or other factors, upon human performance. Deleterious effects upon performance may often be masked by the subjects' "trying harder," and it may be difficult to detect such influences on measures of performance such as overall speed, number of errors, or total output. What appears to be required are tests of performance which reflect deleterious effects in spite of attempts to overcome them, or tests which detect increased effort at the task. The new techniques developed in sensory and perceptual research may be of value in developing measurements of both kinds.

Some of the prime requirements of such tests include (a) a high degree of sensitivity so that small changes are measured, (b) precision of the physical measurements involved in the test, (c) independence of the results from the degree of conscious effort which may be exerted, (d) stability of the function during control experiments when stresses are not applied, and (e) the adaptability to the analysis of complex performance involving insight, decision-making, and the timing of responses. The possibility of developing such tests has been greatly enhanced through the application of systems analysis, and in recent developments in human performance theory.

1. Measures of speed and accuracy combined. One way of adjusting one's performance to offset poor responses might be to sacrifice speed for accuracy or vice versa. Such trade-offs, however, need not indicate degradation in capacity. Until recently, there was no way of combining these two measures. With the development of information theory a non-arbitrary way of combining measures of speed and accuracy into a single "rate-of-information-transmission" measure is available. In this way it is possible to determine the magnitude of task-induced stress.

2. Tests that detect and scale increased effort. Two avenues of research offer tests of increased effort. One of these is concerned with spare reserve capacity and in peripheral attention. The deterioration of performance on a primary task with increased load from a secondary task is a good example of this area of testing. Adverse effects can be measured in terms of steepening gradient of these spare capacity measures. The other area of research

relates to physiological measures of arousal, tenseness, and so forth. A number of techniques for measuring not only muscular tenseness, but also central nervous system activity, and even specific components of neural reaction to signals are well-known to experimental psychologists and sensory physiologists.

The developments of promise in the area of human performance theory and analysis have resulted in part from advancements in communications engineering and computer science. The recent experiments reflect the influence of information and communication theory, and have been concerned with such variables as (1) maximum rate of information transmission, (2) the capacity for visual and auditory short-memory stores, and (3) the trade-off between speed and accuracy of responses. Occasionally the number and complexity of functions have been so great that computer simulation has been required as a technique for exploring the interaction of these functions.

IX. Conclusions

Many of the basic approaches which proved to be so effective in aviation health and safety are equally applicable to the much larger field of highway safety. It is now clearly recognized that highway accidents rarely are caused by single factors but result from a complex series of interrelated causes. This results from a wide variety of interactions including the driver, the vehicle, the highway and the environment. Therefore, the methods of engineering psychology and systems analysis must be used to partial out one important variable or another. This involves an interdisciplinary approach which includes biostatistics, engineering psychology, sensory physiology, anthropology, and systems or operations analysis. (McFarland, 1967)