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by Frederick C. Gamst

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Human factors in the diesel-electric locomotive is the subject of a study in applied ethnology and applied physical anthropology. Working from the viewpoint of locomotive crew members, the study's principal objective is to aid in designing locomotives that will enable crews to work efficiently and safely. Thirty recommendations are made to this end. After a discussion of applied anthropology, general characteristics of present-day locomotives and operations of the crew in the locomotive are covered. Recommendations and background information are presented in the following areas: (1) arrangements of cab displays of warning devices and mechanical indicators, (2) arrangement and design of controls, (3) locomotive structure, (4) impacts, (5) exterior signaling for the locomotive, and (6) vibration on the locomotive.

KEY WORDS: applied anthropology, railroad safety, locomotive as a work place, locomotive structures and functions, human factors, human engineering, industrial ethnology

INTRODUCTION

The research results reported here are part of a long-term project in industrial ethnology focusing upon railroad operating employees, their work, and their work settings, such as the locomotive.

This article broadly concerns applied anthropology, but because the label is not used in a uniform way, we should say something about this aspect of anthropology. Customarily, summary and survey writings on applied "practical" anthropology pertain only to what is actually an applied ethnology; that is, a planned or directed change in the behavior of members of a particular group (Malinowski 1929; Myres 1931; Herskovits 1936:216; Loomis 1943; Lord Hailey 1944; Richards 1944; Lantis 1945; Evans-Pritchard 1946; Mair 1957; Swartz and Ewald 1968:459-495; Foster 1969; Beals and Hoijer 1971:600-617; Ember and Ember 1973:353-369). Thus

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only one of the four traditional fields—ethnology (or cultural and social anthropology), archeology, anthropological linguistics, and physical anthropology—of the discipline of anthropology is customarily covered. Of the term applied anthropology, Margaret Mead says:

> Although the term has been used more extensively for the work of social or cultural anthropologists in government, industry, race relations, and the technical assistance field, it may be more generally applied when a specialist in any field of anthropology, culture, linguistics, physical anthropology, or archaeology draws professionally on his discipline to solve some practical problem. (1964:32)

Applied anthropological linguistics has led to fruitful changes in the teaching of languages to students. Applied archeology is concerned largely with salvage work of surveying and excavating cultural remains in an area about to be transformed by anything from a dam to a parking lot.

Applied physical anthropology, a term used by its practitioners, has long been highly developed and productive in the United States (*American Journal of Physical Anthropology* 1948; Newman 1953). Lecturers in introductory anthropology courses sometimes note in passing that a few physical anthropologists, in their practical work, design seats. In this comment they probably obliquely refer to Ernest A. Hooton's study of seats on railroad passenger cars (1945). Applied physical anthropology goes back further than this practical aid to commuters in the northeast, to the period of the Civil War with its "army [physical] anthropology," necessarily practiced by nonprofessional anthropologists as there were no professionals then. By the time of World War I, applied army anthropology was well developed and professionals such as Hooton and Alesh Hrdlichka collected "[physical] anthropological data" during the selective service draft of 1917-1918 and the demobilization of 1919 (Davenport and Love 1921:1-63). Anthropometrical measurements of soldiers were taken for varied potential uses, including the quartermaster's supplying of properly fitting uniforms.

Physical anthropology applied to the military expanded in scope by World War II (Damon and Randall 1944; Randall, Damon, Benton, and Patt 1946), had its counterpart in Great Britain (LeGros Clark 1946), and continued to develop after the war (Damon 1955; Hertzberg, Emmanuel, and Alexander 1956; Snyder 1961; Hertzberg and Burke 1971). By the time of World War II, emphasis had changed from the previous gathering of anthropometric data to the study of the space-geometry of machine operators' body motions and to the wider study of man-machine systems, particularly aircraft. Such applied physical anthropology overlaps with engineering, and has also been labeled as research in human factors, human engineering, biotechnology, dynamic anthropometry, and engineering anthropology. It concerns the designing of equipment suitable to human needs and capabilities (McFarland, Damon, and Stoudt 1958:1). As it overlaps with medical research, it is, therefore, also a part of medical anthropology. Not only military but also civil man-machine systems, which are often closely related, have been the post-World War II subjects of applied physical anthropologists (Damon and Crichton 1965; Damon and McFarland 1955; Damon, Stoudt, and McFarland 1963, 1966, 1973; Snyder, et al. 1968). More recent research, such as that of Richard Snyder, studies man's adaptation and reactions to the "astroecological environment of space" (a concern of bioastronautics, or astrobiology). Significantly, one of Snyder's professional positions has been that of Chief, Physical Anthropology Branch, Department of Survival Research, FAA. In short, a large area of research in applied physical anthropology exists, of which many "applied anthropologists" (read "ethnologists") are only partially aware.

The label "applied anthropology" was used in the title of this article in a sense acknowledging the variety of this part of the integrated discipline of anthropology. As noted earlier, the present research and its findings result from a larger and continuing project in industrial ethnology, and it is, therefore, in large part an applied ethnology. Many of the techniques and procedures of the applied physical anthropologist, however, have been used within the basic participant observation, which takes place in many areas of his traditional interest as exemplified in the literature just cited. Thus, this paper is one in applied *anthropology*—basically ethnological, but also physical.

The method of ethnology has as its distinctive characteristic continuous, almost fully participating observation which is lengthy in duration—normally a year or more (to allow for effective socialization of the ethnologist into the group under study). As the ethnologist immerses himself in the life-ways and settings of his subjects, he internalizes large parts of the culture he is studying, be it that of Navajo tribesmen or of Yankee longshoremen. (As used in this article, the term ethnology includes social anthropology.)

The ethnologist's primary technique of research is designed to enable him to ask appropriate questions and to observe and participate, with understanding, in the salient experiences of any life-way, including an occupation, because he views the world of the native of that life-way from a perspective that is at once that of the native and that of the ethnologist. Such a perspective is particularly illuminating in the ethnological study of industrial organizations and the "natives" of these, since most of the myriad occupations in our society, with its innumerable divisions of labor, are all but unknown to the average person, including the researcher embarking on a project of industrial study. Further, the largely qualitative nature of human factors research within industrial ethnology is not unique to this subfield of anthropology. Results of this kind are at times also achieved elsewhere; for example, in the human and mechanical engineering of aeronautics, "It is a recognized fact that pilot opinion is one of the most significant factors in determining important design decisions on our new aircraft" (Cooper 1957:47).

In the design of my research project, I decided to report on human factors in the locomotive cab (Gamst 1975a) and on the entire locomotive (this article) because these two studies were logically among the "first things" to present before reporting further on the social field of railroading in North America. Other first things include railroad signaling (Gamst 1975b) and a lengthy discussion of the nature of industrial ethnological research (Gamst *n.d.*). Those interested in the methodological strategies and techniques of data gathering underlying the present article should consult this last paper.

Because of my experience in and extensive technical knowledge of railroading, this industry serves as the field from which data are gathered and ideas are tested to arrive at ethnological generalizations applicable to all occupational institutions and roles. (Of course, some of the findings of the research project, as in this article, pertain solely to the railroad industry.) I am especially interested in the social organization and cultural patterns of occupational groups and in the consequences of changes, such as automation of technique and rationalization of social interaction, that affect them. Additional interests include the testing of the appropriateness and utility of applying ethnological theory and research methods to a modern Western industrial setting.

Other techniques of research used in this study to augment the primary participant observation should be mentioned. Unstructured interviewing of key informants was used to assess reliability and analysis of data as well as to explore more esoteric kinds of information not within the common experience; for example, being on a "runaway" train. Structured interviews, with a set of standardized questions asked of those encountered in the fieldwork, were used to assess the reliability of data. Also used was an extensively pretested questionnaire concerning engine service and railroading in general. This contained two hundred and twenty-five questions and was mailed to engine service employees on three railroad districts. Though quite lengthy, the questionnaire received a very high rate of return, and, among other things, enabled the comparison of data from one district to another. Relevant documents were also analyzed. These included railroad operating bulletins and rules, mechanical and air brake rules, trade union documents on operations and locomotives, and technical publications on locomotives and their appurtenances. Physical anthropological data were gathered on reach envelopes of operators, motor skills required during

operations ranging from routine to complex, location of controls and indicators in relation to normal postures of the crew members, noise and vibration and other noxious agents in the locomotive, signaling of the locomotive to the outside environment, and such factors as fatigue and safety. Of course, many of these physical anthropological data were intertwined with the ethnological data gathered through the techniques just mentioned.

Much of the information presented in this article was collected or developed during my six and one-half years in all types of railroad engine (locomotive) service from mid-1955 until the beginning of 1962. This experience included yard, through freight, local freight, passenger, and helper (pusher) service, and service as a hostler, over three large and two small railroads, covering a good part of the West. Diesel-electric, steam, turbine-electric, and electric locomotives were worked on in this service. I also held minor trade union positions and took considerable technical instruction in my craft, including a lengthy correspondence course on the mechanical aspects of locomotives. The rest of the information presented here comes from subsequent fieldwork from 1970 through 1973 and from contacts maintained with railroaders from 1962 through 1969. Although the data were gathered principally on the three larger railroads referred to above, the findings of this article relate to all North American railroads because of uniformities in railroad equipment, operating rules, and work (labor) rules. Minor ethnological field surveys of railroading in Africa (Gamst 1969, 1975c) and in Europe contributed to my overall understanding of North American conditions.

The diesel-electric locomotive is a work setting that has received scant attention in human engineering research. The design of its cab (control compartment) and arrangements of its controls and indicators have developed largely from origins in steam locomotives, but with some influence from electric transit vehicles such as street cars. Little concern for the physical limitations or convenience of the operators went into the design of the diesel. While making recommendations for rationalization of design, this article discusses the human factors of the diesel's operations, structure, arrangement of controls and instrument displays, and layout of other interior and exterior elements. Such rationalization could and should have been undertaken over two decades ago during the transition from (external combustion) steam locomotives to (internal combustion) diesels and is long past due. Two noteworthy exceptions to the dearth of human factors research on the locomotive cab have just been completed by the Canadian National Railway and the Association of American Railroads (AAR).[1] The research and recommendations reported in this paper are further contributions to a trend started by these two pioneering investigations. Recommendations for improving the locomotive as a work place are found throughout the article, are prefaced by the word *should*, and are grouped at the end of the paper in a summary. The recommended rationalizations of the work place are designed to aid future planning for modification of existing diesel-electric locomotives and for the building of new locomotives, which will enable crew members to work efficiently and safely in a reasonably comfortable work setting. Findings and recommendations are appropriate for the purely electric locomotives that will undoubtedly begin to replace diesel-electrics in many of their applications over the coming decades.

CHARACTERISTICS OF PRESENT-DAY LOCOMOTIVES

Almost all of the locomotives used today on North American railroads are diesel-electrics in which a *diesel engine* drives a *main generator* producing electricity to power electric *traction motors*, one of which is geared to each axle of the locomotive. (A few locomotives have one or two *idler* axles, without motors, used for distribution of weight.) At the engineer's *control stand* in the cab, after the proper setting of various switches and levers, as the throttle is opened from idle position to positions 1 through 8, the main generator is electrically connected to the traction motors through an *electrical* (switching) *control cabinet*. With each throttle advance the engine increases its r.p.m.'s, delivering more mechanical power to the generator which then furnishes more electrical power to the motors propelling the locomotive.

Many diesels are equipped with a regenerative *dynamic brake*, a system in which the traction motors and the generator exciter are connected electrically, for retarding the locomotive and its train. The motors are electrically reconnected from the control stand (through low voltage circuits in the control cabinet) as electric generators which produce power dissipated as heat in roof-mounted resistor *grids* cooled by a fan. All locomotives used in passenger service, regardless of terrain, *should*, but do not now, have a dynamic brake as a low-speed backup in case of a full or partial failure of an air brake system.

Locomotives of all kinds have an *automatic air brake* system (for use of brakes on locomotives and cars) and an *independent air brake* system (for use of locomotive brakes independently of automatic [all-of-train] brakes). Passenger trains today are retarded by independent and automatic air brakes that have been in existence in varying forms since the end of the nineteenth century. Passenger trains powered by locomotives normally no longer have in addition the *electro-pneumatic*, high-speed control braking system first generally used in the 1930s, which is an additional expense to install and maintain. This additional braking system is controlled, along with the standard automatic system, by one of two distinct

brake valves in one housing operated by a common handle, and by a shifter lever used to select the brake valve and system to be operated. The superior electro-pneumatic system, which *should* be used on all passenger trains, gives instantaneous uniform electrical application of train air brakes and includes a regulated use of the high braking forces required for high-speed operations, without exceeding the lower braking forces necessary at lower speeds. The regulated electro-pneumatic forces are the greatest possible to impose upon the wheels without causing them to slide.

A small percentage of the locomotives used in North America is (straight) electric. What I have said and will say about diesels generally applies to them, except that their prime mover is not a component engine but a power station that supplies electricity through overhead lines or third rails.[2]

On January 1, 1974, railroads of North America owned 33,257 diesel-electric locomotive units. These units had a total of 65,962,244 horsepower (Osthoff 1974). The range of maximum loaded weight per unit is from 44 to 270 tons, with almost all units being in the 115-ton and over range. Unit length ranges from 45 to 100 feet. Height above the rail ranges from 14 to 17½ feet and width is 10 to 10½ feet. A typical cab is 10 feet wide by 6 or 7 feet long. Most units may be used in *consists* of from two to eight (or even more) units operated in multiple.

A locomotive consist of three 3000-h.p. units pulling a 5000-ton train on level tangent track at 58 m.p.h. with its throttle fully opened will consume about 500 gallons of diesel fuel oil per hour. Such a train has 1.8 h.p. per trailing ton. Many fast time freights have 2.5, 3, and even 4 h.p. per trailing ton, with correspondingly higher rates of fuel consumption. Locomotive diesel fuel costs around $.25, or more, per gallon. Thus fuel costs on most road runs are far greater than the wage costs of the engineer.

Generally, compared to trucks, trains are four times as efficient in their consumption of energy. For every one gallon of fuel a locomotive burns in hauling freight, a truck hauling the same load burns four. Trains are about sixteen times as efficient as commercial aircraft in their fuel consumption. Furthermore, the electric locomotive and electric rail transit equipment are the only land transport vehicles able to use nonpetroleum fuels such as coal and nuclear fuel (converted to electricity). Thus some form of electric locomotive transport can, with technology already in dependable service, provide the energy-conserving haulage just noted without consuming any of our diminishing petroleum resources. Electric transportation need not compete for fuel with industries totally dependent upon petroleum, such as fertilizer manufacture, air transport, personal auto transport, and manufacture of plastics.

The cost of a unit ranges from about $200,000 to $500,000, and the average road unit costs $350,000. The value of the freight cars and their

1. Engine EMD Model 12-567B
2. Main Generator & Alternator
3. Generator Blower
4. Auxiliary Generator
5. Control Cabinet
6. Air Compressor
7. Traction Motor Blower
8. Instrument Panel
9. Controller
10. Speedometer Recorder
11. Air Brake Stand
12. Cab Heater
13. Seat
14. Hand Brake
15. Fuel Tank Vent With Flame Arrestor
16. Lube Oil Filler
17. Engine Water Tank & Lube Oil Cooler
18. Engine Control & Instrument Panel
19. Load Regulator
20. 34" Fan & Motor
21. Radiator
22. Horn
23. Exhaust Manifold
24. Sand Box
25. Fuel Filler
26. Head Light
27. Batteries
28. Fuel (1200 Gal.) & Water (1350 Gal.) Tank
29. Main Air Reservoir
30. Air Intake & Shutters
31. Boiler Water Filler
32. Engine Room Ventilating Fan
33. Air Intake For Grids
34. Fuel Tank Gauge
35. Door (Plain)
36. Emergency Fuel Cut-Off
37. Dynamic Brake Hatch
38. "AC" Contactor Cabinet
39. Boiler
40. Air Compressor Aftercooler
41. Toilet
42. Battery Charging Receptacle
43. Sanding Nozzles
44. Blue Flag Bracket
45. Air Brake Rack
46. Water Cooler
47. Fire Extinguisher
48. Hinged Sash
49. Fixed Sash
50. Sand Box Filler
51. Boiler Room Shutters
52. Number Box
53. Boiler Air Intake
54. Boiler Stack
55. Battery Box Vents
56. Water Tank Vent
57. M.R. Pipeline Filter

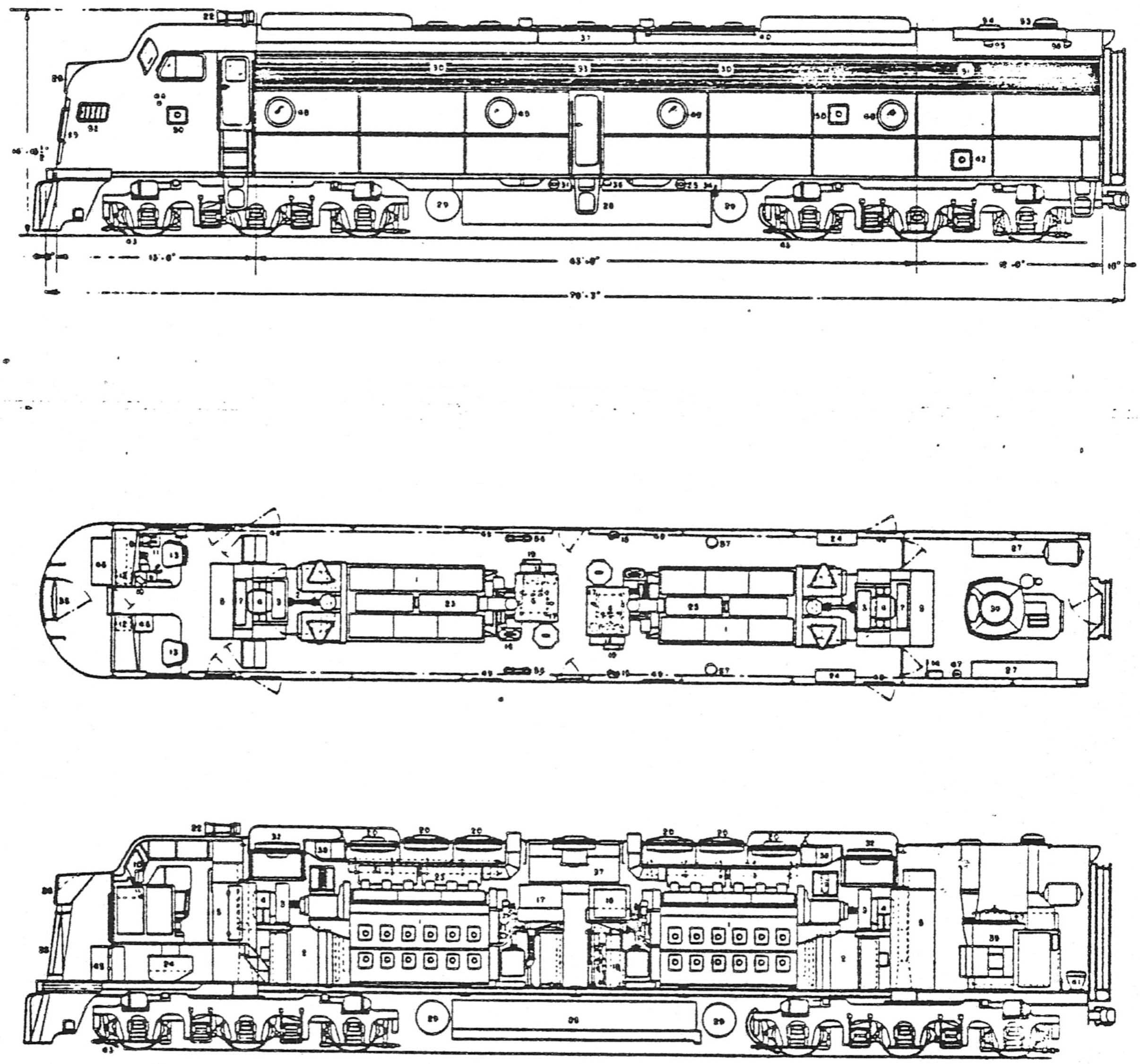


FIG. 1. ARRANGEMENT OF EQUIPMENT IN A CARBODY UNIT. This unit has two 1200 h.p. power plants instead of the normal single plant. The center axle on the front and rear trucks is an unpowered idler. A deflector style pilot with coupler cover is located forward of the front truck. The anticlimber device is the forwardmost ribbed part of the frame immediately above the pilot. (Source of illustration: N T S B Report No. NTSB-RAR-72-5, page 4.)

contents pulled in a freight train can easily total millions of dollars. Sometimes just a few carloads of special equipment may be worth millions. The value of a passenger train with a few hundred passengers is, of course, incalculable. A new passenger car costs from $100,000 to $450,000. Thus not only the locomotive, but also its trailing load represents a considerable investment to be safeguarded.

Electrics and diesels have three major designs, (1) *carbody*, (2) *road switch*, and (3) *yard switch*, accounting for almost all of the locomotive units in service in North America. Locomotives of all designs are either *A units*, with cabs, or *B units*, which have no cabs and which are used as booster units in a consist. Usually, carbody units are used in passenger and in through freight service, road switch units (originally designed for local freight) are used in all classes of service, and yard switch units are sometimes used outside of yard service in local freight and occasionally in helper service on grades. The majority of these units may be interconnected with electric cables and air hoses for multiple-unit operation from the cab of the lead unit. (Outside the scope of this article is the now infrequent but growing use of *remote multiple-unit control systems*, which allow the engineer in the cab of his lead, or "master," unit to control through coded radio signals the locomotive functions on remote, or "slave," units located elsewhere in the train.)

Carbody units have side walls and a roof extending the entire width and length of the locomotive frame except where the roof line dips down a few feet in front of the windshield of the automotive-styled cab. The depressed roof line and narrowed side walls round off into the front of the locomotive, the *nose compartment*, situated forward of the cab (see figure 1).

The cab of the common and versatile road switch design is usually situated about one-fifth of the way back from the front of the frame. The side walls of the cab extend the full width of the frame, but so-called *long* and *short hoods* (since the early 1950s, normally to the rear and front of the cab, respectively) are set in about 1½ to 2 feet from the sides of the frame (see figure 2). Since the late 1950s, nearly all road switchers have been built with the short hood cut down to about two-thirds of its former height to insure better forward visibility for the locomotive engineer operating without a locomotive fireman-helper (see figure 3). Like the nose compartment of a carbody unit, the short hood usually contains auxiliary equipment. The long hood, like the space behind the cab of the carbody design, contains the diesel-generator set, air compressor, cooling system, and other equipment. Regardless of design, this space is called the *engine room*. Diesel noise is painful (above 130 decibels) within the engine room of a carbody unit at full throttle operation (for example, during necessary on-the-road trouble-shooting or inspections). Standing in the engine room next to a locomotive's diesel running wide open is an awesome, ear-

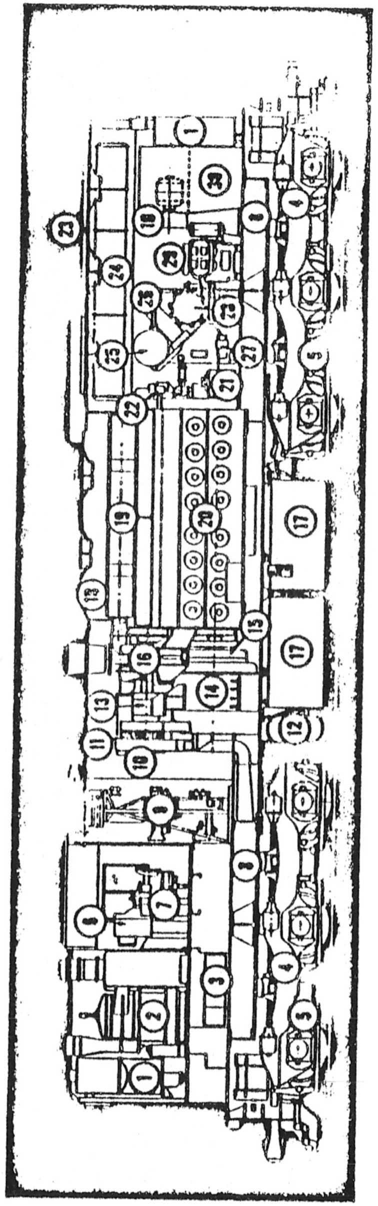


FIG. 2. ARRANGEMENT OF EQUIPMENT IN A 2400 H.P. ROAD SWITCHER DESIGN with long (engine room) hood to rear and short full-height hood forward of the cab. The flash boiler (2), seldom present in this design, allows the unit to be used in commuter passenger service. All axles are powered. (Illustration courtesy of Electro-Motive Division, GMC, La Grange, Illinois.)

1. Sand Box
2. Steam Generator
3. Storage Battery
4. Truck
5. Traction Motor
6. Locomotive Controller
7. Air Brake Controls
8. Air Duct
9. No. 1 Electrical Cabinet
10. Traction Motor Blower
11. Generator Blower
12. Air Reservoirs
13. Auxiliary Generator
14. Main Generator
15. Alternator
16. Turbocharger
17. Fuel and Water Tanks
18. Dynamic Brake Hatch
19. Exhaust Manifold
20. Diesel Engine
21. Lube Oil Strainer
22. Governor
23. Engine Cooling Fans
24. Radiators
25. Engine Water Tank
26. Lube Oil Cooler
27. Fuel Pump
28. Lube Oil Filter
29. Air Compressor
30. No. 2 Electrical Cabinet

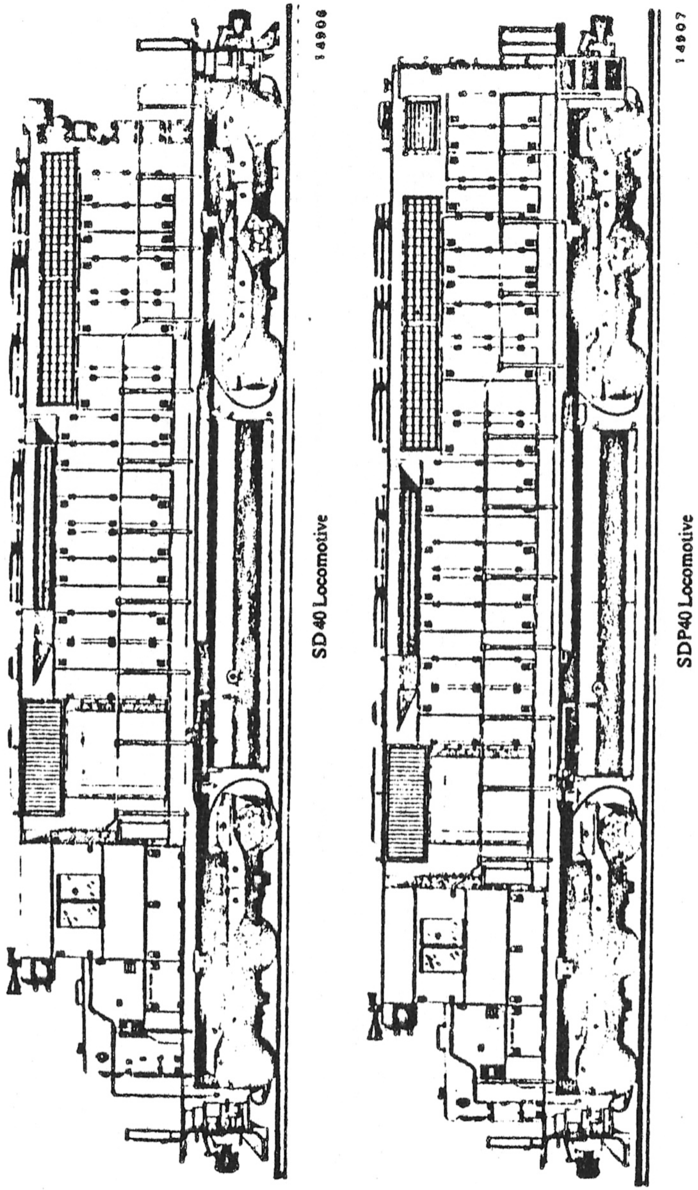


FIG. 3. NEWER TYPE OF 3000 H.P. ROAD SWITCHER DESIGN with short hood cut to half-height. The SDP (Special Duty Passenger) design has the long hood extended further back to include a flash boiler. (Illustration courtesy of Electro-Motive Division, GMC, La Grange, Illinois.)

shattering experience. In hot summer operations, the heat radiated from such an engine is enough to burn the skin of the face, and an engine crew member shields his face with a rag while passing by or working in its vicinity.

Yard switch units are similar to road switch units except that their long hood is the only hood, and is on the forward end. The rear of the cab is a vertical windowed wall, protected by an extension of the frame for a few feet, which forms the rear of the locomotive (see figure 4).

Some units of all three designs contain *flash boilers* to provide steam for passenger car heating and hot water and, frequently, for operation of air conditioning devices. Steam, an anachronism in railroading surviving from the earliest days of the Industrial Revolution, *should* be eliminated from all locomotives and passenger cars as soon as possible. The live steam, supplied at a pressure of up to 225 pounds, is potentially dangerous to anyone nearby in an accident, and is a constant source of minor burns to railroaders. An *AP* release of December 29, 1973, regarding the rescue of passengers from the wreck of Amtrak's *Coast Starlight*, said, "Rescuers in one car were hampered by clouds of steam from a ruptured line." Furthermore, steam is a very inefficient means of powering temperature control mechanisms in passenger cars compared to electricity, which has powered common rail passenger service since the 1930s. Failures of the often "temperamental" boilers can cause discomfort to passengers, as one did on December 31, 1973, on Amtrak's *San Francisco Zephyr*, which had frozen water pipes, unheated cars, and frozen toilets. An irate passenger lamented, "We sat there in those cars, no heat, no nothing." In the United States and Canada since the late 1950s, only "rides" provided by operating rail transport "museums" have had passenger service powered by steam locomotives. In the 1970s these are the only appropriate places for the joining of rail operations and steam.

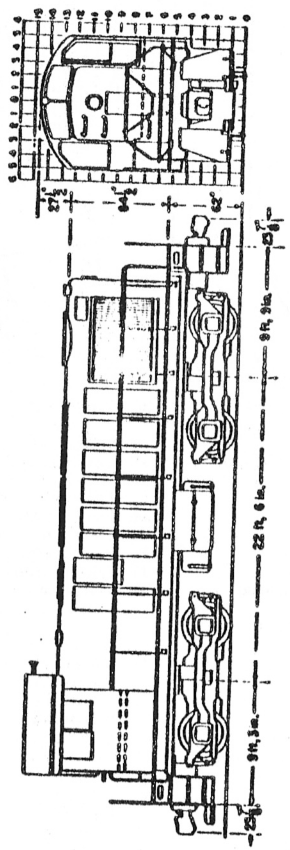
OPERATIONS IN THE LOCOMOTIVE

Just as the "patrol vehicle serves the policeman in many different ways" (Clark and Ludwig 1970:67), so does the locomotive serve railroad operating personnel in many different ways. (1) In the switching of railroad cars, the locomotive cab serves as a switching control center operated by the engineer. (2) In the movement of trains over the road, it serves as a train control center. (3) The cab is sometimes used as a compartment for transporting passengers (usually operating personnel or officers being sent in railroad service to another terminal). (4) The entire locomotive, including exterior platforms, serves as an office where the engineer and other crew members do "paper work" concerning locomotive maintenance, dispatching of trains, planning of switching, and allocation of service to shippers. (5) It is an eating and rest area, when the locomotive is stopped during

1000-HP SWITCHER

115 Tons on Drivers
60 MPH Maximum Speed

One GT-553 Generator; Four GE-731 Motors;
75:16 Gear Ratio; 40-in. Wheels



TRAILING TONS* IT WILL HAUL SAFELY

Speed MPH	Tractive Effort	Time Limit	GRADE—COMPENSATED FOR CURVATURE						
			Level	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%
5.0	50,000	4 min.	....	3325	1925	1335	1010	805	660
7.5	36,500	90 min.	....	2385	1370	940	705	555	450
10.0	28,000	90 min.	5765	1790	1020	695	514	400	320
15.0	19,800	Cont.	3805	1210	680	455	328	248	190
20.0	15,000	Cont.	2640	864	480	310	218	158	115
25.0	12,000	Cont.	1905	644	350	220	149	100	69
30.0	10,000	Cont.	1435	495	266	160	100	63	....
35.0	8,100	Cont.	1030	360	185	104	58	....	....
40.0	6,600	Cont.	730	255	120	59	....	....	....

*Based on Davis train resistance formulae for standard 4-axle cars with an average weight per car of 40 tons

FIG. 4. TYPICAL DESIGN OF YARD SWITCHER with long hood forward of the cab and no compartment behind the cab. (Illustration courtesy of Alco Corporation, Schenectady, New York.)

meals and other designated periods of inactivity. (6) Finally, the locomotive is an informal meeting place for conversations and is then regarded as a clubhouse sacrosanct to certain working men.

The crew of a train or of a yard locomotive is made up of railroaders in engine service and in train yard service. The engine crew today consists of a single locomotive engineer. Mandatory in the past on all diesels, but rare today, is a second engineman, the locomotive fireman (helper). He assists the engineer in his duties, thereby learning the craft of engineer into which he is eventually promoted after passing the required examinations. A conductor, who is in charge of the entire crew and responsible for its operations, and two brakemen (in train service) or switchmen (in yard service) constitute the train/yard crew, which complements the engine crew in either train service (over the road) or yard service (in the terminal areas).

When cars are switched in road service, and usually in yard service, the engine crew is alone in the cab, while the others are on the ground throwing switches, coupling and uncoupling cars, riding cars and braking them to a stop with handbrakes, and passing hand signals to all crew members. The conductor coordinates these and other activities, and locomotive movements, by his hand signals, during switching. While he is running on the main line in road or yard service, a (head) brakeman or switchman is in the cab with the engineer. In road service the conductor and rear brakeman, who is also the flagman, ride in the caboose at the rear of the train. For the main line runs of short duration in terminal areas, other yard crew members either ride on the cars being hauled, on the outside platforms of the locomotive, or in its cab.

While switching cars, the engineer must continuously or frequently lean, on a window-sill armrest, out of the cab's right side window, facing forward or to the rear. In such operations, he normally can use only one hand for most controls. On the majority of locomotives, these are located in or near a control stand to his left as he faces forward in his workspace, which is known as "the right-hand side of the cab." In running over the road and through yards and terminal areas, the engineer sits up straight in his seat and can apply both hands to the controls while watching ahead. During road operations he watches the right-of-way for various objects: numerous kinds of signals, other trains, and obstructions such as motor vehicles on crossings and people and animals on the tracks. While he is operating freight trains at speeds from 50 to 70 m.p.h., these objects at first may be not quite distinguishable on the horizon and then seconds later resolve themselves as they flash past the locomotive. Most certainly, as the old railroad adage says, "The eagle eye [engineer] must keep his hand upon the throttle and his eye upon the rail."

The locomotive fireman (helper) has a workspace on the left-hand side of the cab. When no fireman is in the crew, a brakeman or switchman occupies his workspace and acts as a lookout. A fireman is always present on locomotives used in road passenger service. In this service the head brakeman assists the conductor back in the coaches, and the full engine crew is thus alone on the locomotive. The fireman serves as a lookout on the left side of a train or switching movement and as a back-up lookout for the engineer; he reminds the engineer of requirements imposed by bulletins, by the employees' timetable, by the telegraphic train orders and messages given them by *operators* at wayside stations, and by many kinds of signals; he runs the locomotive under supervision; and he maintains the power and other output of the machinery on the units of the locomotive.

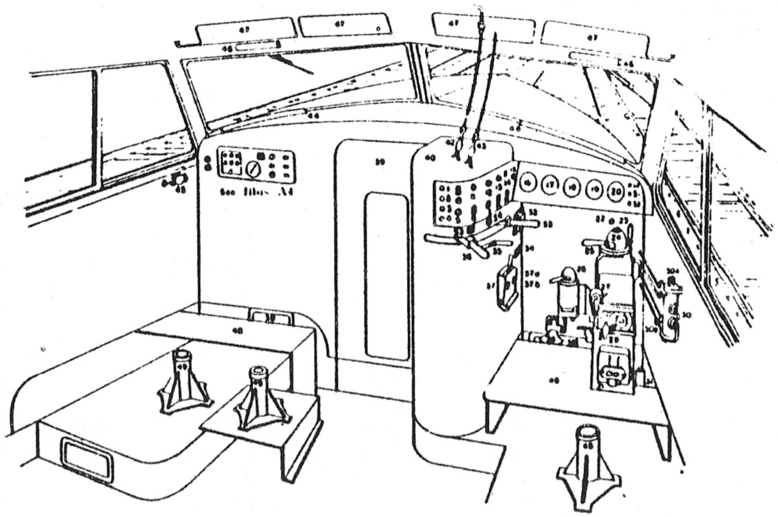
In the past, many railroads had a third engine crew employee on passenger diesels, who was known as a *maintainer*. Passenger locomotives were equipped with an *attendant call button* at the control stand so that the engineer could signal the maintainer by means of bells in the enginerooms of his units. The maintainer did not come from the ranks of enginemen (engineers, hostlers, and firemen), who along with trainmen, switchmen, and others are employees of the operating department (having to do with the operation of trains and yard locomotives), but from the mechanical department employees engaged in the repair, maintenance, servicing, and building of railroad rolling stock. The maintainer's position is analogous to that of those flight engineers on aircraft who come not from the ranks of pilots, but from the mechanical ground support forces.

The maintainers were gradually phased out by railroad management, especially after managers no longer gave high priority to maintaining high standards of passenger service. The 1937 National Diesel Agreement between the railroads and the Brotherhood of Locomotive Firemen and Enginemen required the assignment of a locomotive fireman (helper) on all diesel-electrics and other locomotives, except those weighing less than 45 tons on the driving wheels. (Hence the existence of a small number of 44-ton center-cab diesels used in light industrial switching, usually by industrial firms.) As a result of the Report of the Presidential Railroad Commission of 1962, firemen are now in the terminal part of their phase-out (through severance, attrition, and promotion to engineer) in all jobs except those of passenger fireman, hostler, and engineer-trainee. Hostlers move and service locomotives in roundhouse and shops areas. The Commission concluded:

> . . . that firemen-helpers are not so essential for the safe and efficient operation of road freight and yard diesels that there should continue to be either a national rule or local rules requiring their assignment on all such diesels (1962:45).

The dissenting report of Commissioner S. C. Phillips strongly disagreed with the above conclusion (1962:189-235) and Commissioner A. F. Zimmerman would not sign the report (1962:271).

In any event, when the fireman is no longer present, his work, including



Engineman's Compartment

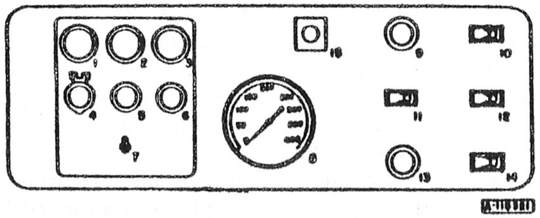
A-H33148

1. Hot Engine Indicating Light (red)
2. Low Lube Oil Indicating Light (yellow)
3. Hot Journal (red)
4. Boiler Flame Out Indicating Light (blue)
5. Attendant Call Button
6. Headlight Circuit Breaker
7. Headlight Dim Switch
8. *Order Light Switch
9. Emergency Engine Stop Button
10. Control Circuit Breaker
11. *Gauge Light Switch and Rheostat
12. *Heater Switch and Rheostat
13. *Defroster Switch and Rheostat
14. Generator Field Switch
15. Windshield Wiper Control Valve
16. Load-Braking Indicator
17. Speed-transition Indicator
18. Suppression Gauge
19. Main and Equalizing Reservoir Gauge
20. Brake Cylinder and Brake Pipe Gauge
21. Equalizing Piston Portion
22. Rotair Valve
23. Air Brake Signal Whistle
24. Automatic Brake Valve
25. Automatic Air Brake Handle
26. Independent Brake Valve
27. Bell Ringer Valve
28. --Deadman's Foot Valve
29. Train Control and Safety Control Cock
30. Sander Valve
    a. Time Sanding
    b. Instantaneous Sanding
31. First Service Cock
32. Wheel Slip and Brake Warning Buzzer
33. Throttle Handle
34. Electro-Pneumatic Air Brake Circuit Breaker
35. Reverse Handle
36. Selector Handle
37. Mars Headlight Control Switch
    a. Oscillating Motor Switch
    b. Jog Switch
38. *Cab Heater
39. Door to Hood
40. Control Stand
42. Whistle Pull Cord
43. Whistle Valve Pull Cord
44. *Defroster Openings
45. Conductor's Valve
46. *Windshield Wipers and Motors
47. *Sun Visors
48. Foot Rests
49. *Seat Stands
50. Sanding Indicator Light (blue)
52. Brake Warning and Wheel-Slip-Indicator Light (white)
53. Selector Position Window
54. Throttle Position Window

*These controls and devices are duplicated at fireman's and engineman's positions.

FIG. 5. CAB INTERIOR OF CARBODY TYPE PASSENGER UNIT. Engineer's workspace is at right with a "balanced" set of control levers. Fireman's workspace is at left. (Illustrations from Colt Industries' Fairbanks Morse Engine Division.) Figure 5a shows detail of fireman's control panel.

the maintenance of machinery, is now divided between the head brakeman or a switchman and the engineer. The fireman's workspace on a passenger locomotive is equipped with indicators and switches for operation of the flash boilers and an emergency brake valve (see figure 5). On freight and yard locomotives only an emergency brake valve is ordinarily provided. On a few yard units the engine control panel is in front of the fireman. On all locomotives, air pressure in the automatic brake system and train speed indications cannot be monitored from this workspace even though the information is necessary to those on the left-hand side.



1. Boiler Flame-Out Signal Light (blue)
2. Hot-Engine Signal Light (red)
3. Low-Oil Pressure Signal Light (yellow)
4. Train Steam Line Shutoff Push Button
5. Soot Blower Push Button
6. Separator Blow-Down Push Button
7. Steam Generator Master Switch
8. Steam Pressure Gauge 0-400 Lb. Scale
9. Defroster Switch and Rheostat
10. Hood Light Switch
11. Order Light Switch
12. Classification Light Switch
13. Heater Switch and Rheostat
14. Number Light Switch
15. Gauge Light Switch and Rheostat

FIG. 5a. CONTROL PANEL AT FIREMAN'S POSITION. Detail of figure 5.

ARRANGEMENTS OF CAB DISPLAYS OF WARNING DEVICES AND MECHANICAL INDICATORS

A pilot of an airplane or the driver of a truck has in front of him displays for the monitoring of status changes in his prime mover(s) and appurtenances, as did the engineer of a modern steam locomotive. Surprisingly, to the contrary, the engineer of a multiple-unit diesel is operating "blind," with little monitoring of trailing units and with poorly arranged displays of instruments in the lead unit from which he operates all units. Furthermore, in contrast to the pilot, the engineer has no means of checking his warning devices to see if they are operative. The driver of a 1974 Toyota automobile equipped with an auxiliary sensor panel of eleven warning lights has more indicators visible to him in his normal driving position than does a locomotive engineer on most units. One experienced engineer with over thirty years of engine service and almost the same amount of time as both an active and a reserve Air Force pilot of multi-

engine heavy bombers summed up the difference of the displays on the aircraft and the diesels. He said, "I was accustomed [on aircraft] to scanning my instruments, forward of my seat in the cockpit, while I was flying. This [scanning] kept me on top of everything. When the first diesels came, I was surprised that many of the gauges and warning lights were not visible to the engineer running his engine."

It is generally accepted in human engineering that the warning signal lights of a machine are less effective as they are moved out of the field or angle of vision of the operator to be warned (Morgan, et al. 1963:92). An engineer has to keep track of many lights located 180 degrees from his normal position, on the back wall of the cab, or even in the separated engine room behind the cab. A general alarm bell rings on all units when any of certain signal lights indicates an operating status outside of the normal range, on any one unit or any one power plant of a unit with two such plants. Warning lights monitoring conditions on trailing units or on the second of two power plants in a lead unit are almost never *trainlined* (interconnected and hence communicated, in this case to operating workspaces on the lead unit) and thus their signals are unknown until someone goes back to read them. When the alarm bell is ringing because of one malfunction on one unit, there is no way to know when an additional malfunction occurs.

The numerous color- or color-and-alphanumerically-coded signal lights located on an *engine control panel* on the rear cab wall of road switchers, and on this wall and in the engine room of carbody units, are not trainlined.[3] At least one fairly common operating problem, the tripping of the engine overspeed protective device, is not monitored by a signal light. A number of indicators with moving pointers and fixed indices are also found on the panel alongside the lights, and are also not trainlined.[4]

The decision to place these warning lights and indicators outside of the engineer's line of vision was largely economic. To trainline the signal lights and indicators from unit to unit and to move them around to the front of the engineer (requiring running their wiring across the length of the cab) would increase the cost of the unit. On yard switchers, and on the oldest road switchers, both of which have the long engine room hood forward, these warning lights and indicators are necessarily on the cab's front wall, because the shortest path for wiring and lines from the engine room and control cabinet is to the front of the cab. On a few carbody units, several of these lights were displayed in the front of the cab (see figure 5), an example of several presently-needed rationalizations of design which were used on at least a few types of locomotives in the past.

The first paragraph of the introduction to the operating manual of a highly successful and commonly used locomotive states: "All of the operating devices, manual and visual, normally used by the engineman [engineer] during locomotive operation are located near the operator's position. Most of these devices are located either on the control stand or on the engine control panel." What is not stated is that on most locomotives this "normally used" control panel, with its warning lights and indicators, is located behind the engineer's head as he faces forward during operation of road locomotives, except on those units where it is entirely out of sight in the engine room.

Indicators and warning lights monitoring conditions on *all* power plants, traction motors, and running gear of all units in a consist *should* be displayed if on the lead unit, or repeated if on a trailing unit, on a panel within the normal field of vision of an engineer facing forward while operating his lead unit. These indicators and lights could be to the front, left-front, and right-front of the engineer. Certain warning lights and control switches might be advantageously located overhead in the ceiling of the cab as in aircraft design, if front panels become too overcrowded with indicators and control switches. Most of these indicators would normally display only stable readings, as the readings are of special interest only when they change from the desired value. A stable reading would be indicated by warning light off, or dark, and a deviant reading by light on. Because today most engineers operate without the assistance of a fireman-helper and in the future almost none will have this assistance, it is vital that the engineer in his workspace be able to monitor statuses of all important components on all of the units in his consist. Automation in the form of trainlined control switches and other controls to correct trainline signaled operational problems *should* be given high priority in the design of the next generation of locomotives.

Of course, many important indicators and signal lights are presently fairly well located to the engineer's left and left-front. But one vital indicator, the speedometer face of the *speed recorder*, is canted at an angle so that its indications are visible only to the engineer and not to the other crew members on the left-hand side of the cab. These crew members have explicit instructions to see that the engineer observes the numerous kinds of speed restrictions imposed by the railroad operating and airbrake rules and by federal and local laws. They are not provided with the information necessary to fulfill their duties, however. The speed recorder *should* be positioned so that its indications are visible throughout the cab.

Other major indicators at the engineer's workspace are either two or three *duplex air gauges* each indicating a pair of functions pertaining to the air brake systems. One of these, showing locomotive brake cylinder and train brake pipe pressure *should* be duplicated on the left-hand side of the cab, at a negligible cost, so that the engineer's control of the train can be effectively monitored by other crew members when necessary. A *brake pipe flow indicator* (gauge) is found in relatively few cabs. It *should* be in

all cabs because the engineer has no other way to monitor the vitally important flow of air in the brake pipe running the length of his train—to know whether the automatic air brake system is charged, leaking badly, beginning to leak, being activated from elsewhere on the train, or restricted because of ice buildup in freezing weather. An important signal light at the control stand shows operation of the *pneumatic control* (or *power cutoff*) *switch* and is not color coded. This light is illuminated during emergency, safety control, and locomotive overspeed control application of air brakes, and indicates that the "PC" switch in the control cabinet is open and has reduced all diesel engines in the consist to idle speed.

During tractive propulsion and dynamic braking, a *current load meter* on the control stand indicates the strength of either of these two forces with a reading of the amperage, the amount of electrical current, supplied to one traction motor on the lead *truck* of the lead unit. Problems relating to the load meter and recommendations for its improvement are found in another publication (Gamst 1975a). Problems and recommendations regarding the *wheel slip/slide* light are also found in the publication.

Two additional warning lights not now found on locomotives, which *should* be present with flashing red signals, pertain to moving a locomotive from its initial terminal point. Older units have *electro-pneumatic* switching gear in the electrical control cabinet, and this will not operate and move the locomotive until a *control air pressure* of at least 90 pounds is pumped up. This minimum pressure provides adequate braking control while the main reservoirs are pumped up to their normal 140-150 pounds. Newer units have *electro-magnetic* switching gear, not dependent upon any minimum air pressure on the locomotive. Thus these units may be powered and moved before any air braking pressure is built up. One of the two proposed flashing red signals (to be mounted above the independent brake valve, which ordinarily must be released before a unit will roll) *should* come on when control circuits are energized before 100 pounds of pressure is built up. Similarly, units are sometimes inadvertently moved from ready tracks with their brake cylinders cut out (for inspection and maintenance by the roundhouse forces). This condition should be indicated by the second flashing red light, which should monitor all units in a locomotive consist.

That no warning light should be bright enough to blind the operator is a canon of human engineering (Morgan, et al. 1963:92). On some older units, especially yard switchers, the wheel slip light is so large and so bright, in its location directly in front of the engineer, that its indications have the effect of a flash bulb going off in his face in the dark cab at night. As one might suspect, this condition leads to the masking of the warning light with paper, black paint, or tape. Of course, the greatest problem in display of warning devices on locomotives is not overexposure, but no exposure.

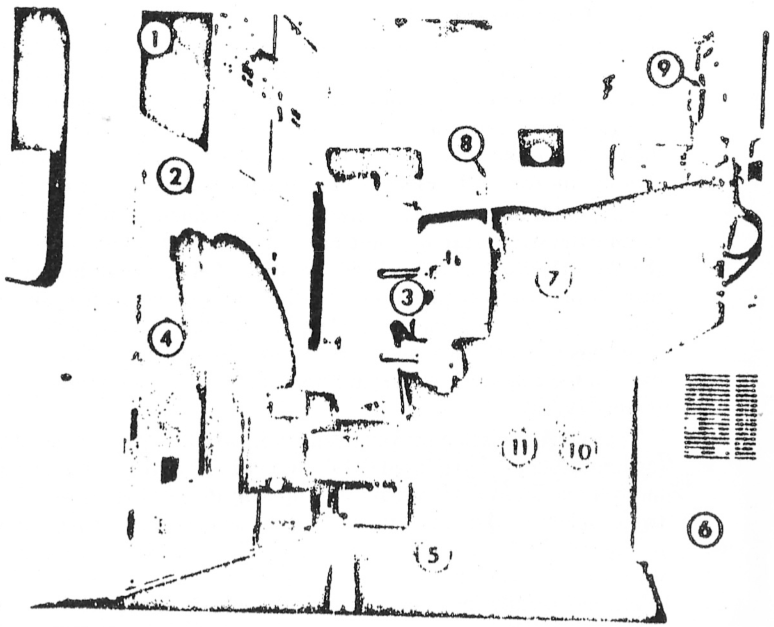
ARRANGEMENT AND DESIGN OF CONTROLS

Larger Controls

The introduction to a comprehensive study in applied physical anthropology entitled, "The Anthropometry of the Manual Work Space of the Seated Subject" states, "Controls and switches must not merely be within reach, they should also be placed in the best possible spatial position relative to the operator" (Dempster, Gabel, and Felts 1959:28). As we shall see, on a locomotive the controls and switches are not even "within reach" most of the time. In human engineering discussions of general rules to be observed in the layout of a workspace, one of the cardinal rules is that controls must be "balanced," arranged so that no one limb is overburdened and each limb will be used most effectively (Morgan, et al. 1963:282; Van Cott and Kinkade 1972:346). Another, related, rule is that when a major control must at times be operated by either hand, the control should be in front of the operator midway between his hands (Morgan, et al. 1963: 282-283).

Since most carbody units have been retired and scrapped and few new ones are being built, the vast majority of existing units is of the road and yard switch types. In contrast to the carbody units, on these two types all of the controls are located to the left of the engineer as he faces forward (see figure 6). These include the automatic and independent brake valves, throttle, reverse lever, selector lever, whistle lever/cord, bell lever, sanding lever, and headlight reversing and dimming switch. (Many yard switchers and some road switchers have the sanding valve and headlight switch mounted to the right of the engineer.) Generally speaking, the right hand must be crossed over or in front of the left hand for coordinated use of all of these controls. This arrangement is satisfactory in yard service, where the engineer frequently runs his locomotive without use of bell, whistle, automatic air brakes, or headlight dimmer. He runs his locomotive with one hand while watching signals from switchmen as he leans out of a cab window with his other arm on a window sill arm rest. Thus, "balancing" of the locations of brake valves and operating levers is not advantageous in yard service, where a locomotive might be running in reverse part or much of the time with the engineer leaning out the side window.

In road service, a more rational arrangement (and one mentioned by freight and passenger engineers as being "comfortable") is found in most carbody units (see figure 5), where the automatic brake valve is to the right-front and the independent brake valve is to the center-front. This older balanced arrangement distributes controls between the two hands. It also places the frequently used independent brake valve between both hands. This arrangement would lessen the contortions often required in operation of controls in fast-paced, high-speed road service, where most or all of the controls noted above may have to be operated simultaneously



1. Engine Control Panel
2. Circuit Breaker Panel
3. Air Brake Controls
4. Switch and Fuse Panel
5. Safety Control Pedal
6. Cab Heater
7. Locomotive Controller
8. Air Horn Lever
9. Speed Recorder
10. GRD/FAULT Reset Button
11. Attendant Call Button

FIG. 6. LOCOMOTIVE CONTROL STATION. Controls are arranged to engineer's left on a new road switcher. (Illustration courtesy of Electro-Motive Division, GMC, La Grange, Illinois.)

or within a few seconds of one another. The older balanced arrangement has its origin in the layout of early streetcar controls, where a lever approximating the throttle was found on the left-front of the motorman and an air brake valve was on his right-hand side. This arrangement was repeated in the General Electric gasoline-electric rail cars of the 1910s, which were forerunners of the diesel-electrics, and in the straight electric locomotives of the early twentieth century.

After they are no longer useful in road service, the older, lighter road switchers of moderate horsepower are often retired to yard service. Because of their potential for eventual service in yards, it might not be economical to have all new road switchers equipped with balanced controls—unless two sets of air pipe connections for the brake valves were built into the locomotive under the engineer's workspace, one to the left and one to the center-front and right-front. With two separated sets of connections, locations of independent and automatic brake valves could be changed with the permanent change from road to yard service. Another means of balancing controls would be to move the throttle and dynamic braking selector levers further to the right in the engineer's workspace. Anthropometric investigation in the design of rational cabs is needed. This investigation *should* include the problems of balancing controls for road service and the location of controls with respect to the reach envelope of the engineers.

The problems of the reach envelope are succinctly stated in the summary to an extensive research report entitled "Anthropometry in the Design of the Driver's Workspace," which says that, "Difference in human body size may have serious implications for the comfort, efficiency, and safety of vehicle drivers" (McFarland, Damon, and Stoudt 1958:20). Numerous problems of reach envelope and posture required by positions of controls exist in the engineer's workspace and are discussed in another publication (Gamst 1975a).

The new Association of American Railroads' (AAR) Standard Controller (or control stand), introduced in 1972, is not a mandatory feature on new locomotives and few units now have it. Requiring its installation would eliminate two problems in dynamic braking. First, controls with similar functions do not operate in the same direction. The handles of air brake valves are, and always have been, moved counterclockwise to increase braking force. In the relatively recently introduced electrical dynamic braking, braking force is increased by moving a lever in a clockwise direction, which is the same direction as increased throttle movement for increased propulsion. The incompatibility in operation of braking devices *should* be eliminated. The second problem is that although the dynamic brake and throttle levers were originally separate from one another, in the late 1950s they were combined. The selector lever that formerly controlled dynamic braking and other functions remained on the control stand after the combining of control of dynamic braking and tractive propulsion in the throttle lever. Previously, the throttle had no braking function. Because the selector lever is still present for its minor nonbraking functions, it *should* regain its control of dynamic braking, but with a counterclockwise application. It has such an application in the new AAR control stand. With separate braking and propulsion levers, an engineer could never pull back on the throttle lever (as he now can on the majority of locomotives having dynamic brakes) with either braking or propulsion in mind, and effect the opposite function.

The standard AAR control stand is a significant step toward a vital rationalization—standardization of all major and minor controls, warning devices, and indicators in order to facilitate efficient and safe operations. Further standardization, as far as practicable, is needed in the locomotive cab and engine room.

Yet another cardinal tenet of human engineering is the prevention of

accidental activation of controls (Morgan, et al. 1963:261; Van Cott and Kinkade 1972:346). Some yard switch locomotives are still in service with throttles that are not notched along their quadrant of movement. The quadrants thus do not prevent rapid accidental opening of the throttle by the force of a very rough hard coupling into another piece of rolling stock while moving forward. A far more common potential for accidental activation is found in the protruding handle of the now standard No. 26 automatic air brake valve and is discussed elsewhere (Gamst 1975a).

LOCOMOTIVE STRUCTURE

Problems of the structure of the diesel locomotive fall into two major areas: crashworthiness during impacts, and integrity with regard to admission of dangerous substances such as flames, smoke, and caustic or flammable liquids and gases. Nearly all of a steam locomotive was forward of the cab and this provided a tremendous buffer to impact with other railroad equipment, highway vehicles, and so forth. The cab, however, rarely had integrity even against the icy winds of winter weather.

Aside from the yard switchers, which as often as not are operated in reverse with the cab leading, all carbody units and most road switchers are operated with only a nose compartment or a short hood, usually cut down to a point below the cab windshield, between the crew in the cab and any number of potential disasters. The railroad accident reports of the Interstate Commerce Commission and of the National Transportation Safety Board are replete with examples of the tragic aftermaths of breached locomotive cabs. Many accidents could have less destructive consequences through provision of better designed, stronger locomotives. Improved exterior signaling for the locomotive, discussed below, will also reduce certain kinds of accidents.

More of the considerable weight of a unit *should* be devoted to inert protection of its crew. The underframe, engine room machinery, and trucks account for most of this weight. (A truck is a flexible frame bearing from one to four pairs of wheels and their axles. It is attached to a unit's underframe by a vertical center pin about which it turns. Onto the truck are mounted air brakes, springs, and, on locomotives and self-propelled cars, traction motors.) When weight reductions were made necessary because of additional equipment on certain switcher units, some railroads successfully removed most of the weight from the underframe beneath the running boards on either side of the long hood. Similar weight reductions may be made elsewhere in underframe and trucks so that the weight can be reallocated to inert protection of crew members. Of course, weight alone does not equal structural protective strength. Greater weight does, however, permit more and larger structural members. Proper design of these members and of their interrelations ultimately provides the protective strength.

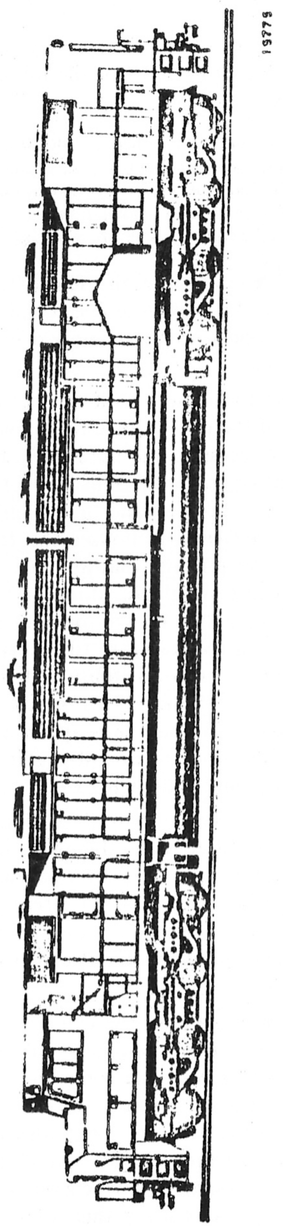


FIG. 7. DDA40X LOCOMOTIVE. A SEMI-ROAD SWITCHER with its full-width-of-the-underframe nose compartment. This behemoth of the rails is 100 feet long, weighs 270 tons, and generates 6600 h.p. from its two power plants in the double length (engine room) long hood. (Illustration courtesy of Electro-Motive Division, GMC, La Grange, Illinois.)

See Photos of Slim Somerville's accident

At times, wrecks are so severe that the short hood nose and cab are sheared from the underframe (with the crew inside the cab). Wrecks in which the entire upper portion is sheared from the underframe are not unknown. The consequences of these and lesser collisions *should* be mitigated by much heavier collision posts strategically located in the presently light upper framing of a unit's superstructure, which rests upon the massive underframe. The steel beams of the upper framing in the short hood nose and cab *should* be both heavier and more closely spaced than at present. These framing beams *should* run around the front and rear window panes and into the roof of the cab. They *should* also be a part of a front cab wall made of steel plate, of half-inch thickness, dividing the cab and the compartment forward of the cab. The entire cab and short hood nose *should* be made integral with the underframe through framing beams, collision posts, and heavy plating. Buttressed by massive collision posts, the front and sides of the short hood/nose *should* be made of steel plate of about one-inch thickness instead of the present one-eighth-inch. Alternatively, nose design could use steel sheeting and upper framing of standard strengths and thicknesses. These would compress or telescope on severe impact, up to a heavily buttressed and plated wall midway between the front of the nose and the front of the cab. Such a design would be comparable to the telescoping end vestibules of standard North American rail passenger cars (with their stenciled warning, "DO NOT STAND IN THE VESTIBULES").

As a design, the short, half-height hood as we know it today *should* be abandoned, because it exposes the front cab wall to hazards from the outside for several feet on either side of the hood. Instead, following a pioneering design introduced on the Union Pacific Railroad in the 1950s and 1960s,[5] a modified carbody type cab and its full-width-of-the-underframe nose compartment *should* be wedded to the useful road switcher configuration behind the cab. For want of a more felicitous name I shall call this new type the *semi-road switcher* (figure 7). Along with some kind of heavier construction, the full-width nose provides much better protection to the crew in the cab. Without the heavier construction, the protection would be only moderately improved.

Additionally, an extra-heavy snowplow type or other deflecting type of *pilot* ("cow catcher") *should* be on the lower-front and lower-rear of new units. Installing such a pilot design will do away with present vertical pilots equipped with foot boards upon which men sometimes stand while the unit is moving. Foot boards on the ends of units *should* be eliminated in any event to obviate a work practice which remains dangerous, whether or not it is prohibited by railroad operating rules. As in past construction of carbody units and as on certain steam locomotives, the front *coupler* on new road units *should* be covered by a heavy gauge *coupler cover* with a door for access to the coupler by trainmen during switching with the front of the locomotive (see figure 1). A pair of warning-signal lights, visible to the engineer, *should* let him know the fully-open/fully-closed status of this door, preventing the smashed coupler doors of yesteryear. The hidden coupler was once used for esthetics more than for safety. But securing it behind the smooth massive face of the pilot and its coupler cover prevents the snagging of automotive vehicles by the locomotive during grade crossing accidents. In such accidents, a hit and snagged vehicle may be dragged for as much as a mile, or alternately may be held by the coupler in a position that causes the locomotive to "climb up" over the vehicle before derailing itself and its train.

Many collisions are made more severe when a piece of railroad rolling stock (such as a freight car), struck by a locomotive, climbs up over the underframe of the unit. The car then rams and shears into the compartment forward of the cab, and then into the cab, and then into the engine room, according to the force of the impact. More engineering research *should* be done on improving the anticlimber device now located across both ends of only a few units. These horizontally ribbed steel beams wrapped around the unit's ends are scarcely distinguishable from their prototypes on turn-of-the-century streetcars. Improved anticlimbers *should* be installed on all units.

Cab window panes are often too large (sometimes extending across the entire width of the short hood) and are too thin to provide enough strength to maintain the integrity of the window during impact with heavy foreign objects. Present window panes are often a half-inch thick at the front of the cab and a quarter-inch thick at the sides and rear. Strength of window panes *should* be increased with "shatterproof" panes of the kind used in cockpits of combat aircraft or with laminated safety glass of thicknesses between ¾ inch and one inch. Also, to cover the area now screened by large single sheets of glass, a number of smaller panes *should* be used to maintain the vital integrity of the windows. Shatterproof polycarbonate window panes have been used on some Penn Central locomotives. Although the panes have great strength and resistance to impact, they have the disadvantage of being more easily abraded than glass. This results in a loss of visibility from the cab.

It may be that powered emergency cab closure devices are needed to close all windows, doors, and air vents of all kinds in, under, in front of, and behind the cab during the few seconds of warning before a potentially disastrous accident. Such devices would all be operated from controls on both the right- and left-hand sides of the cab and could be overridden by separate "escape" opening devices at each powered closure. The closure devices, which *should* be a subject of human factors research, would aid in protecting the heavily armored cab from invasion by dirt and gravel from the roadbed and from other dangerous outside substances.

Powered closure of the cab prior to an emergency would probably greatly reduce casualties in the kind of accident the following report (concerning a carbody unit) discusses:

> The cause of fatalities to engine crewmembers and the official was the entrance of burning gasoline into the control compartment [cab] and engine [room] compartments which burned the occupants of the control compartment, made escape into the engine compartment useless, and forced the occupants to jump from the control compartment while the train was still moving at a speed too high to insure survival (NTSB 1971:18).

Investigation *should* be made into the feasibility of installing a fire extinguishing system on at least all A units, to minimize casualties during a fire. Cabs and engine rooms now have only a hand-held type of chemical fire extinguisher.

Most of the semi-road switchers built to date have a platform enclosed by handrails, in front of the nose, above the pilot. The platform is reached by side steps and gives access to the nose and cab through a centrally located door in the front of the nose. This and other front doors on locomotives *should* be made heavier and more impact-resistant. The front door on most semi-road switchers houses the front headlight. Engineers operating these units have told me that at times during night runs a crew member will exit the cab through this door in order to throw a mainline switch that is being approached by the locomotive and its cars. When he does so, the headlight and its beam are turned ninety degrees to the side, and the engineer thereby loses his visibility and runs past the "heading in" (to the siding) switch. A recent (1973) modification of the semi-road switcher by the Canadian National Railway takes the headlight out of the front door by moving the door to an off-center position. A stable headlight is necessary on any unit; thus lights *should* not be mounted in doors.

The locomotive truck, while structurally strong in itself (weighing 20 to 30 tons), is not very firmly attached to the underframe on all units and thus separates itself from the locomotive in severe derailments, when the frame's locking plates prove to be of insufficient strength for holding the truck. Detachment increases the severity of a derailment. Provision *should* be made to have trucks more permanently attached to the underframes of all units.

A final approach to protection of the cab against collision is that of the Southern Railroad, whose road switchers still have controls and other equipment arranged to run with the long hood forward, thus affording massive steam-locomotive-like protection during collisions and other accidents. Some visibility is sacrificed, but on fast through freight trains this slight loss of visibility may well be inconsequential and more than offset by the security provided by the classic locomotive configuration. Human factors research *should* study this solution to collision problems.

IMPACTS

Sustained linear acceleration of a locomotive along a track rarely is noticeable enough to affect the exercise of duties or the comfort of crew members in the cab or other compartments. A crew member (usually the engineer or the fireman-helper) frequently finds it necessary, however, to work on the open running-board or end platform of a unit in order to locate and correct operating difficulties while moving on-the-road. Although the practice is prohibited by operating rules of most railroads, this outside "trouble shooting" is commonly done to stay on schedule and "get over the road." It is a highly dangerous practice during even moderate sustained acceleration or at any speeds over 40 m.p.h. because a man can be blown or jolted off his platform.

Cessation of motion in impacts, not acceleration or velocity, is the great hazard of railroading. Despite continued research, the present state of knowledge of impact tolerances for humans is still incomplete. "The tolerances of the human component of the abruptly decelerated system are related to the elastic and tensile limits of the tissues involved, as well as to profound physiologic, psychologic, and metabolic effects" (Snyder 1973:221). Strong physiologic and psychologic effects may result from just the threat of impact, for example, after crew members in the cab have experienced one or more severe impacts with railroad rolling stock or highway vehicles. One engineer related how, after hitting several automobiles in just a few months, he began involuntarily to ease out of his workspace when a driver tried to beat him to the grade crossing. "I became car shy," said the engineer.

Owing to the nature of railroad switching operations, when locomotives switch *rolling stock* (usually freight cars, but also passenger cars, cabooses, locomotives, and work equipment moved on the track) both inside and outside of switching yards, impacts upon units and their crews are common. Most frequently these are the relatively mild "rough joints" experienced when coupling cars together. "Hang on, we're going into a rough joint!" the engineer will shout across the cab upon seeing a "washout" ("stop as soon as possible—imminent danger/hazard") hand signal given by crew members on the ground. They have allowed the engineer to shove a heavy "cut" (string of cars), normally without operative air brakes, against another cut while moving during switching at moderate speed. These impacts usually cause little or no damage in the cab, especially when crew members are seated and expect them.

Potential danger is ever present, however, as when an expected or unexpected rough joint causes a man to fall against the many hazardous objects in the cab. Sharp edges, protruding knobs, levers, and metal plates, and lack of recessed and padded surfaces (where applicable) in the locomotive cab make the mildest of impacts, or even rail dynamics within the normal range of variation, hazardous. Potential danger is exacerbated by lack of safety/seat belts on any kind of railroad rolling stock, though it is true that an engineer or fireman-helper leaning out a side window would find seat belts inconvenient or very hampering.

More severe but less frequent couplings, sometimes called "bell ringers" because they cause the normally air-actuated clapper of the locomotive bell to strike and ring the bell, may "knock the wind out of" crew members and propel thermos bottles and other objects across the cab. The most severe couplings are rarer but, when they occur, they can throw a man from his seat, crack cab windows, damage locomotive and cars, and even break the glass drinking-water jug loose from its sheet-metal moorings, depositing dangerous glass shards on the cab floor. Water jugs made of ordinary breakable glass *should* never be found on rolling stock.

There is a second class of locomotive impacts in railroad operations, other than in couplings. These impacts, in which one piece or a cut of rolling stock could be stationary, may or may not cause a *derailment* (when rolling stock leaves the rails) or a *wreck* (when serious structural damage is done to rolling stock). This second class includes "cornfield meets" (head-on collisions between two locomotives), "rear enders" (overtaking collisions—often of a locomotive against a caboose), and "Wabashes" (sideswipes between rolling stock on converging tracks). The comments already made on hazards and severity of impact during couplings, of course, apply here.

A third class of impacts occurs during collisions with highway vehicles. Except when a heavy vehicle, such as a loaded cement or gravel truck, is hit, the impact is usually not severe; automobiles are often barely felt. A danger of secondary impact is always present, however, if the lead unit or any other part of the train climbs up over a highway vehicle and derails.

A fourth class of impacts, the effects of which need not be separately covered, is that of derailments involving defects in the rolling stock or track itself.

EXTERIOR SIGNALING FOR THE LOCOMOTIVE

So far I have been concerned with the interior and the structure of the locomotive; its exterior, aside from structure, is also vital in determining interior conditions. Exterior warning signaling is especially important. Audible and visual signaling is used to warn pedestrians, animals, highway vehicles, and operators of railroad rolling stock of the approach of a locomotive.

Air Horn/Whistle. Supplied by an *air compressor* driven by the diesel engine, the air pressure in the *main reservoir* of a locomotive is 140 to 150 pounds, and a considerable blast on the air horn/whistle can be created by this pressure, for the sounding of a good number of standard coded whistle signals. Unfortunately, the standard (highway) grade crossing signal cannot be sounded loudly enough or distinctly enough to warn all motorists. They are enclosed in their vehicles "engineered to eliminate outside noises" and filled with stereophonic sound. They cannot hear the whistle of an approaching train, which may take more than a mile to brake to a halt at certain combinations of tonnage and speed.

So that motorists and pedestrians can more readily distinguish between the air horn of a locomotive and the usual deep, raspy horn of a large truck, all locomotive horns *should* have a standardized chime tone. A pleasant tone similar to the steam whistles of steam locomotives has been achieved with a seldom-used, because more expensive and optional, five-barreled air horn available for several decades. To penetrate into the interior of a modern vehicle designed to minimize outside noise, the locomotive air horn *should* be made still louder than at present. Moving the horn from the cab roof to elsewhere on the top of the unit would help protect crew members' ears. An already available two-position (loud and soft) horn valve will allow the engineer to whistle more softly for grade crossings when conditions permit (e.g., over deserted urban crossings at 3 A.M.) and in yards and other congested, low-speed railroad sites of operations. Generally, the faster the speed of a train and of its potential automotive target, the louder the horn must be to provide warning sufficiently in advance of their possible meeting. It may not be practicable to give fully adequate warning by air horn in the case of a passenger train traveling at 100, or more, m.p.h., and an auto traveling at 60, or more, m.p.h. Degree of loudness, characteristics of chime sound, and trainlining of control of the air horn for simultaneous sounding of all horns on all A units in a consist *should* be subjects of human factors research on the locomotive. The locomotive bell apparently cannot be improved. Its tolling is audible at low locomotive speeds. During high-speed operations with wide open throttle, it usually cannot be heard at all, even as the locomotive flashes by. The use of the bell is often required by law regardless of locomotive speed.

Headlights. Save for the oldest units with headlights having a bulb, every unit has the standard twin sealed-beam front and rear headlights with brightnesses of dim, medium, and full. The headlight is not only used for illumination in the dark, but it is also a standard train signal which "must be displayed to the front of every train by day or night" and which must be dimmed or extinguished according to various railroad operating rules. The headlight also warns motorists and pedestrians of a locomotive's approach.

A single sealed-beam *oscillating headlight* with the same strength as a beam of the standard headlight is additionally found on some locomotives of some railroads. With its unique figure eight pattern of motion, this light clearly distinguishes a locomotive from any other source of light and calls the attention of non-railroaders to the approach of a locomotive not otherwise noticeable (for example, when a train overtakes an automobile before crossing in front of it on a diagonal grade crossing, or comes onto a grade crossing from between buildings whose walls reflect the oscillating beam but not a fixed beam). The oscillating headlight can also be used in its fixed position when the standard headlight is inoperative, and it oscillates its beam around curves in the path of the locomotive, thereby providing better forward visibility at night. Built into the casing of the oscillating headlight is an oscillating red emergency light. At the time of an actual or possible derailment, it automatically signals trains on adjacent tracks not to pass the train whose locomotive displays this gyrating red beam, until it is known that their tracks are clear. Train safety would undoubtedly be improved if red and white oscillating lights were found on all locomotives running on main lines and over grade crossings. The standard headlight has a narrow beam and even the overall beam of an oscillating headlight is relatively narrow despite its gyrating path. If the oscillating light were canted at a larger angle to the center line of the unit than at present, its warning to motorists approaching the track at right angles would be more effective.

A *rotating* (amber) *light* of moderate brightness, similar to those on emergency road vehicles, is located on the cab roof of some locomotives. This is useful for industrial switchers working across urban streets under circumstances where the oscillating white light might be too bright. It should not be a replacement for the oscillating light. Human factors research *should* be conducted to ascertain the margins of safety provided by oscillating white and red headlights on A units. (The Southern Pacific Company has made extensive applications of these lights.)

Exterior Paint. Certain road vehicles have a standard exterior "signal" paint scheme that makes them not only highly visible, but instantly recognizable as, for example, a school bus or a fire engine. Despite folk songs about the "*red* caboose" (which is quite rare), railroad rolling stock has no standardized signal-color paint scheme and, worse yet, most equipment is inadvertently camouflaged with paint that merges with the background. Locomotives *should* warn of a railroad movement by their very presence, aside from headlight, whistle, or bell. Instead of the economically maintained colors of slate, anthracite, dark brown, and brownish red so common on locomotives, highly visible schemes *should* be used; for example, the "school bus yellow" used by the Union Pacific for the past forty years. Additionally, on all locomotives, without exceptions, the cab and entire front and the rear end *should* have a single standardized, reflectorized signal paint scheme. Luminous varieties of brilliant yellow green or of Air Force anti-collision orange are possible candidates for this "I-am-a-locomotive" signal. Railroad managers who might feel that their corporate, image is best presented to the public by dull greys, coal blacks, and somber browns on their locomotives, apparently do not recognize the value of a pizazzy paint job as a signal to the public connoting vitality instead of a moribund state of affairs.

The Daimler-Benz Corporation has recently completed experimental research to determine which vehicle colors contrast best with varying backgrounds under varying weather conditions (Andres 1973). Not only are the common locomotive blacks, browns, dark blues, and greys found to be camouflage-colors providing poor visual warning signals, but even red is in this category. All of these colors are approximately half as visible as luminous orange. Fluorescent colors reflect more light than normal colors and therefore contrast more with backgrounds in weak light. Luminous orange, white, and light yellow are the most visible colors. A two-color surface with a high degree of contrast between the colors is effective, provided each of the two has a large area of coverage, instead of one being relegated to small details of design, or for that matter, to narrow stripes, customarily found on locomotives with industrial safety striping. Paint must be maintained in a bright condition and not allowed to fade or become covered with dirt and grime.

VIBRATION ON THE LOCOMOTIVE

When engine crew members hear for the first time of my study of their work setting, their most common comment is, "Tell them [the public] about the vibrations in the cab," or, "Tell them what that constant vibration does to us." During meal periods on older (looser) units, the engineer often shuts down the diesel engine. At this time one hears an audible sigh of relief and someone will comment on the pleasant feeling associated with cessation of the vibration ("I'm glad that GOD DAMN engine is off!"). An old friend and former co-worker of mine wrote me in September 1973 that one of his legs had become progressively more numb over the past year or so. He wrote that the railroad's physicians, "examined me and told me that my condition was due to the position [posture] I was in on the engine [for over thirty years], implying that the cause was due to constant rubbing and vibrating [while seated in the cab]." The engineer's disability has progressed to the extent that he will never again run a locomotive.

Further physiological research is needed for our full understanding of adverse effects of vibration in vehicles:

> Major vehicular resonances generally occur in the range of 1 to 30 cycles per second (Hz). Man's performance capability is known to be affected by frequencies in that range. Further, whole body and organic resonances occur in this range with potentially adverse effects for physiological responses and subjective tolerance. (Hornick 1973:297)

Until the time when we understand better the pathologies originating in cab vibration, steps should be taken to suppress these tremors.

Although ever-present on all diesels, the trembling is particularly vexing on those that have been well used. After many years of vibration produced by a 15- to 20-ton diesel engine, the attachment of the cab to the underframe loosens. Rubber mountings between the cab and the rest of the locomotive would dampen cab vibration. Properly designed, sprung, and padded seats with full-length contour back and movable padded armrests would help the engineer and other crew members.

Other aspects of the quality of the environment of the locomotive, including noise, visibility, ventilation, noxious agents such as fumes and sand, and minimal conveniences in the cab are discussed elsewhere (Gamst 1975a).

SUMMARY OF RECOMMENDATIONS

1. All locomotives used in passenger service should have a dynamic brake as a backup in case of failure of an air brake system.
2. The electro-pneumatic brake system should be installed on all passenger trains.
3. Steam and steam-energized equipment should be eliminated from all locomotives and passenger cars as soon as possible.
4. Indicators and warning lights monitoring conditions on all power plants, traction motors, and running gear of all units in a consist should be displayed if on a lead unit, or repeated if on a trailing unit, on a panel within the normal field of vision of an engineer facing forward while operating his lead unit.
5. Automation in the form of trainlined control switches and other controls to correct trainline signaled operational problems should be given high priority in the design of the next generation of locomotives.
6. A brake pipe flow gauge should be installed in all cabs.
7. Two new warning lights should be mounted above the independent brake valve. One would signal when air pressure of 100 p.s.i. is not yet built up on a locomotive. The other would signal when any of the brake cylinders is cut out of operation on any of the units in a locomotive's consist.
8. Anthropometric investigation in the design of rationally-planned cabs should include the problems of balancing of controls for road service and the location of controls with respect to the reach envelope.
9. More of the weight of a unit should be devoted to inert protection.
10. The steel beams of the upper frames in the short hood/nose and cab should be both heavier and more closely spaced than at present.
11. The cab framing beams should run around the front and rear window panes and into the roof of the cab.
12. The framing beams should be a part of a front cab wall made of steel plate with half-inch thickness.

13. The entire cab and short hood/nose should be made integral with the underframe through framing beams, collision posts, and heavy plating.

14. The front and sides of the short hood/nose should be made of steel plates of about one-inch thickness.

15. The short, half-height hood as we know it today should be abandoned. Instead, a modification of the carbody type cab and its full-width-of-the-underframe nose compartment should be wedded to the useful road switcher configuration behind the cab.

16. An extra-heavy deflecting type of pilot should be on the lower front and lower rear of new units. Foot boards on pilots should be done away with in order to eliminate the dangerous work practice of standing on them while the locomotive is moving.

17. On new road units, the front coupler should be covered by a heavy coupler cover with a door for access to the coupler. Open or closed status of the door should be indicated by a pair of signal lights visible to the engineer.

18. More engineering research should be done to improve the anticlimber device located across the ends of some units. Improved anticlimbers should be installed on all units.

19. Strength of window panes in the cab should be increased with heavier glass. Also, to cover the area now screened by large single sheets of glass, a number of smaller panes should be used to maintain the vital integrity of the windows.

20. To aid in protecting the cab from invasion by dangerous outside substances, powered emergency cab closure devices should be a subject of human factors research.

21. Investigation should be made into the feasibility of installation of a fire-extinguishing system on all units with cabs.

22. Front doors, on noses, of locomotives should be made heavier and more impact-resistant.

23. No kind of headlight should be mounted in a door.

24. Provision should be made to have trucks more permanently attached to the underframes of all units.

25. The merits of having road switchers constructed so that they can run long-hood-forward in order to provide impact protection should be a concern of human factors research on railroad operations.

26. All locomotives should have a standardized chime tone to their air horns so that motorists and pedestrians can more readily and quickly distinguish them from the air horns of trucks.

27. Air horns should be made still louder than at present, but should have provision for a two-position (loud and soft) operating valve so that a softer signal may be sounded when practical. Characteristics of air horns should be a subject of human factors research on the locomotive.

28. Human factors research should be conducted to ascertain the margins of safety provided by oscillating white and red headlights on units with cabs.

29. Locomotives should warn of a railroad movement by their very presence (aside from headlight, whistle, and bell), using highly visible paint schemes. The cab and entire front and rear of all locomotives should have a single standardized, reflectorized signal paint scheme.

30. Until we better understand the pathologies originating in cab vibration, steps should be taken to suppress these tremors.

NOTES

I am grateful to my former co-workers and to the National Science Foundation (for Grant GS 3040) and the National Institute of Mental Health (for Grant MH 21783) in their support of my current industrial ethnological fieldwork among railroaders, beginning in 1970. The financial support from the two agencies enabled me to complete my information gathering on the subject of human factors in the cab environment during the summer of 1971, to write the initial draft of this paper during 1972, and to test its findings and recommendations and discuss them with engine service employees during the spring and summer of 1973. Parts of this paper were presented in October 1973 at a colloquium of the Behavioral Science Graduate Program at Rice University. I thank David Schum for discussions of human factors in the design of control compartments. I am especially grateful to the many railroaders who helped me by discussing and commenting upon aspects of this study. I alone, however, am responsible for the recommendations presented here.

1. In the summer of 1973, the Canadian National took delivery of thirty locomotives with a new kind of cab incorporating several changes resulting from their research into cab design, in conjunction with consultation with engine service employees (*Locomotive Engineer*, July 13, 1973:1-2). It is not surprising that my own parallel, but independent, research and experience with the same craft in the same setting recommends several of the innovations already made to some extent by the Canadian National on these new locomotives. The AAR's Standard Controller, although not yet mandatory, appeared in 1972 after several years of research. This controller contains a number of rationalized features, including a superior human engineering design for the dynamic brake control.

Since 1973, the official publication of the Brotherhood of Locomotive Engineers, *The Locomotive Engineer*, edited by W. A. Rice, has been conducting a vigorous campaign to improve conditions on locomotives. Among the strategies of the campaign is the prodding of Federal officials responsible for locomotive inspection and railroad safety so that they will recognize problems stemming from the deteriorating condition of locomotives in the United States. Many of the problems that I have discussed in this article and elsewhere (Gamst 1975a) are also mentioned by W. A. Rice in his writings and by engine service employees in their letters published in the *Locomotive Engineer*. The items published thus far constitute highly significant contributions to human factors studies of the diesel-electric locomotive.

2. The often-made statement that electric locomotives and transit cars are pollution free is only a half-truth, because their external prime mover is not considered.

3. These signal lights indicate: power circuit interrupter is tripped, high voltage ground, turbo (super) charger oil pump operating, batteries not charging, blower failure, blockage in engine air filter, flash boiler failure, automatic water drain open, no voltage relay open, hot engine-cooling water, hot oil/low oil/low water, and excessive crankcase pressure. Some older units also had a signal light to indicate an overheated axle bearing.

4. These indicators include those for: fuel oil pressure, lube oil pressure, lube oil suction, turbocharger air pressure, battery charging (ammeter), control air pressure, and engine water temperature.

5. This design is found on "gallery" type gas-turbine-electrics of the U.P. 61-75 class and on DDA40X semi-road switchers of the U.P. 6900 class.

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