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Preliminary investigations into the loco-man factor on the Indian Railways

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After a brief consideration of the existing literature pertaining to the ergonomic analysis and design of locomotive drivers' cabins, the present paper describes the results of a questionnaire survey among 26 electric locomotive drivers in India, with some recommendations. A preliminary analysis of the controls and displays in the cabin has been presented.

Introduction

The design of the locomotive driver's cabin, and that of the arrangement of controls and displays in it, have evolved over several decades, largely from origins in steam locomotives. The driver has to monitor a large number of parameters, each of which provides a direct feedback by related displays in the cabin. Signals and other restrictions are among the external factors that affect his responses, while the behaviour of the train itself is determined by weight, weight distribution, car combinations, and even weather conditions. Locomotive drivers are therefore subjected to various types of stress – physiological, psychological and environmental; yet they have to make critical decisions under such conditions, decisions on which numerous lives and property worth thousands of pounds depend.

Indian Railways

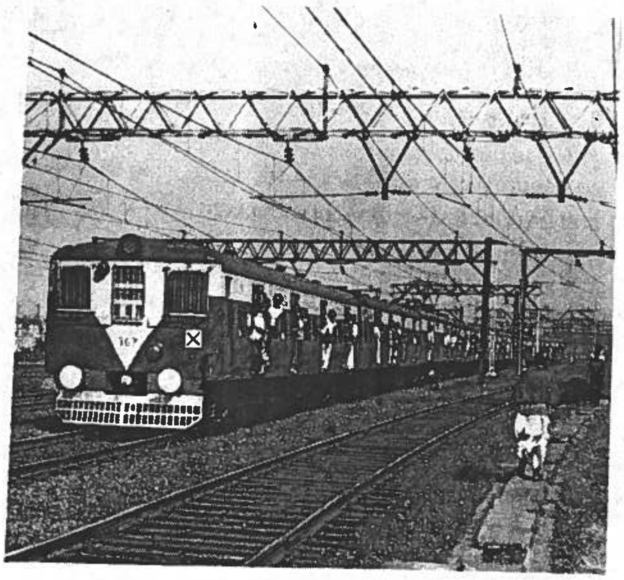
The Indian Railways is the biggest single industry in the country, from the point of view of capital invested and labour employed (over 1·52 million men). In terms of route mileage, India, with 60 093 km (in 1980) occupies the sixth place in the world. Electric traction was first introduced in 1932.

Rationale

Though manufactured in India, most of the locomotives are of foreign design. No design compensation has been made for

(1) the different population of men who drive them (anthropometric measurements differ significantly (Sen, 1964)), or

(2) for the vastly different Indian climate in which they are driven.



Typical scene on Indian Railways

No studies have been published, until now, on these aspects of the design of Indian locomotives. In this context, it is interesting to note that as much as 60% of all railway accidents in the country have been ascribed to the human (loco-man) factor (South Eastern Railway Safety Organisation, 1979).

Objectives

The objectives of the study (which is still continuing) are to perform an in-depth ergonomics evaluation of the existing design of the electric locomotive cabin (see below), and to furnish design recommendations (both on a short and long-term basis).

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Table 1: Comparative review of literature relating to driver cab design

Year	Author(s)	Country	Type of loco	Area	Remarks
1957	Schwab	USA	High-speed diesel	1) Analysis of fatigue and stress factors 2) Recommendations	First documented interest in the subject.
1972	Andrew and Manoy	England	–	1) Anthropometric survey of footplate staff 2) Comparison with text-book data	Only published data of its kind.
1973	Coombs	England	Steam	1) Ergonomic factors of the man/machine interface. 2) Some details of modern (non-steam) control positions.	A retrospective study.
1975	Gamst	USA	Diesel-electric	1) Design and analysis of the controls and displays 2) Quality of the environment	Recommendations include one for the provision of conveniences in the cabins (recommended 18 years ago by Schwab, apparently without effect).
1976	Robinson *et al*	USA	Diesel/diesel-electric	1) Analysis of locomotive cabin environment 2) Delineation of functional requirements 3) Projections of future require-ments 4) Recommendation of design alternatives.	Presents a 3-tiered functional analysis and a systems/sub-systems analysis. These analyses give rise to an objective approach to design recommendations.
1977	Powell and Cartwright	England	Electric	(similar to above)	Some design projections discussed.
1978	Heino *et al*	Finland	Electric and diesel	1) Physical factors (noise, vibration, thermal climate) 2) Chemical factors (diesel exhaust constituents) 3) Ergonomics of works postures and movements	
1978	Hannunkari *et al*	Finland	–	Questionnaire study highlighting driver responses, disease patterns and mortality.	
1979	Branton	England	–	1) Skills of train driving 2) Detailed consideration of braking behaviour 3) Driver models 4) Practical recommendations.	Task analysis and recommendations directed at understanding and developing the drivers' skills.

The present paper aims to present a preliminary report on

(a) the conditions prevalent in the cabins of electric locomotives now in use on the Indian Railways, and

(b) the functional, physiological and psychological requirements/stresses on the drivers,

in so far as these are related to the design of the cabin and that of the controls and displays in it.

Review of literature

The literature pertaining to ergonomics of train driving and driver's cabin design has been listed in Table 1.

Types of locomotives

Differing functional requirements

Table 2 shows the different types of locomotives in use in India, in terms of motive power and type of vehicle hauled. The type of vehicle hauled influences the functional requirements of the locomotive and the design of its cabin. For example:

(a) locomotives used for shunting duties do not run at high speeds (hence emergency brakes, speedometers are not priority items) but require bi-directional movement and good, immediate fore-and-aft visibility,

(b) goods locomotives need proper displays of traction motor current (during starting),

Table 2: Present locomotive types used in India in terms of motive power and functional requirements

Motive power	Functional requirements			
	Passenger traffic (mail/express)	Passenger traffic (local/passenger trains/EMU)	Goods traffic	Yard operations/ shunting
Diesel-hydraulic	√	–	–	–
Diesel-electric	√	–	√	–
Diesel-mechanical	–	–	–	√
Electric (25 kV AC)	√	√	√	(*)
Steam	–	√	–	√

√ – used

(*) – used when shunting engines not available to take empty coaches (rake) between starting station and yard.

(c) mail/express trains run at high speeds and require good braking arrangements, and design of emergency controls should make for reduced reaction times,

(d) short passenger trains run predominantly during the day, while mail/express trains run during both night and day, leading to more stringent lighting requirements in the latter.

Comparison with US Railways

Robinson *et al* (1976) performed a similar analysis with respect to the US Railways. (No similar comparative analysis with respect to British or Japanese Railways have been published). They identified four locomotive types (turbine, diesel-electric, electric and diesel-mechanical), and three types of functional requirements (passenger, goods and yard operations). Apart from turbine engines (not in use in India), all the other locomotive types are used for each of the three applications. Presumably because of the existence of subway networks, there are no EMU locals or short passenger trains and there is only one category of 'Passenger traffic', corresponding to the present 'Passenger traffic : mail/express'.

Selection of locomotive type

In India, steam locomotives are being phased out, while diesel-mechanical locomotives are used strictly for yard/ shunting operations and diesel-hydraulic locomotives are extremely limited in number. Table 2 shows that the 25 kV AC electric locomotives are involved in the greatest number of different applications. The cost of maintaining a diesel locomotive is three times greater than maintaining an electric counterpart, and electric locomotives incur lower operational costs per mileage than those run on diesel (Hammond, 1968). Robinson *et al* (1976) (p 51) have projected a greater demand for electric traction due to a possible energy crisis particularly relating to oil. Furthermore, from March 1981, Indian Railways have switched to electric traction (from diesel-hydraulic) for its prestigious 'Rajdhani Express', allowing the addition of three coaches to the consist with concommitant economic benefits. The electric locomotive (WAM 4 type 25 kV AC) was chosen for this study in the light of these considerations.

Material and methods

The information was gathered (by the authors) in three ways:

(1) interviews with drivers and traction staff,
(2) administration of a questionnaire, and
(3) observations during runs (on electric locomotives).

This part of the study was carried out on the South Eastern Railways, which has 9·9% of the total Indian Railways route mileage, but larger portions of employee strength and traffic density (precise figures not available) (Table 3).

Questionnaire

Most of the questions were of the open/subjective type. The broad headings under which these were grouped are:

(1) the drivers' backgrounds, and general information like experience, medical history, welfare facilities received, etc,
(2) work organisation (working hours, shift details, leave)
(3) duties and procedures (at start, during run, end of run, and in emergencies)
(4) signals and signs to be monitored and exchanged (similar to above),
(5) visibility factors (windshield, glare, weather conditions, etc),
(6) the cabin environment (including heat, dust, noise, vibration, work-space and seating),
(7) special skills like internal representations of track sections, monitoring of track, braking behaviour, etc, and
(8) accidents and critical incidents.

Bias

A strong impression was formed that the drivers were biased in the following main ways:

(1) to give an exaggerated impression of their skills and abilities,
(2) to exaggerate the bad points of the work conditions,
(3) to make the job seem more difficult than it might be.

These factors are likely to influence different responses differently (according to the nature of the questions), and tend to cancel out where all are applicable.

Table 3: Category, age and experience of the drivers (subjects)

Grade	Description	No of subjects		% of total staff strength (on SE Rly)	Age (years) (Mean ± SD)	Total years of experience (Mean ± SD)
–	Driver inspector	1				
Special	For superfast trains	2		8·0	40·7 ± 2·93	17·9 ± 3·83
A	For Mail/Express trains	13	16 total			
C	For Goods trains	3		0·25	34·3 ± 2·26	11·7 ± 3·23
Assistant	Fireman/co-driver	7	10 total			
ALL SUBJECTS		26		0·62	38·2 ± 4·11	15·5 ± 4·68

Results and discussion

The important conclusions drawn on the basis of this preliminary study are presented below, along with some of the questionnaire responses (included in the appropriate sub-sections) and discussion. The figures indicate the percentages of positive responses to the different choices (marked alphabetically).

Training and rules

Training received: (a) insufficient : 3·8%
(b) just adequate : 0
(c) thorough : 96·2

Drivers receive extensive theoretical and practical training (learning loads). However, this consists mostly of technical aspects of the locomotives, the Rules, and familiarisation of the track section on which the trainee will operate. The actual skill of train driving is absorbed during this "learning load" period by a "process of incidental learning akin to osmosis" (Branton, 1979). "The rules governing their duties and procedures are exhaustively formulated, and would prevent any accident if rigidly adhered to. However, this would also tend to bring all traffic to a standstill. Subtle pressure from superiors whose interest is the maintenance of traffic flow, (thus overriding protests from drivers regarding missing parts, poor brake-power, etc), subjective and individual assessment of the risk-factors in critical situations, and often sheer negligence, is a major reason for rule-breaking drivers."

Links

Locomotive drivers studied do not follow any 'shift' in the conventional sense of the term, but follow 'links'. These 'links' are a predetermined sequence of trains which will take a driver from his home station to different destinations and back. According to the train timings, drivers get up to 24 h rest in between runs (minimum 8 h).

People exhibit circadian rhythms in some of their body systems and naturally their efficiency, alertness, etc, will definitely be influenced in some way or other by the interaction between the circadian rhythms and the irregular work timings. The majority of the drivers (84·6%) considered the link system to be the most disturbing aspect of their occupation, particularly with respect to social and family life. Hannunkari *et al* (1978) have reported that about 50% of active drivers rated 'irregular working hours' as the worst aspect of their work, and that this has led to hypertension, stomach troubles and other disabilities. It is unlikely that the 'link' systems can be totally done away with; one must attempt to rationalise the timings with reference to the circadian rhythms and social requirements.

Overhead equipment

Apart from observing the track and signals, the driver must also keep an eye on the overhead equipment (both the current carrying catenary wire and also the supporting structures). This is mainly because of the occasional presence of foreign bodies on the wire which might snare the pantograph.

Assistant drivers

Drivers are unanimous that the presence of assistant drivers is essential, for a multitude of functions.

Signals

Drivers' responses when asked about maximum distances at which signals can be sighted and correctly recognised under various conditions are given in Table 4. The values represent the percentage of the total number of drivers

Table 4: Percentages of drivers reporting visibility of signals under the stated conditions

	(a) less than 10 m	(b) approx 100 m	(c) approx 1 km	(d) more than 1 km
during day:				
good weather	0%	0%	20%	80%
light rain	0	0	42·3	57·7
heavy rain	30·8	53·8	15·4	0
fog	88·5	11·5	0	0
during night:				
good weather	0	0	30·7	69·3

questioned who selected the answer in the respective column. They could select only one of the four choices.

In difficult conditions the driver is obliged to proceed at extremely restricted speeds and is often aided by auditory signals in the form of impact detonators placed on the track in a coded manner by the station-master or guard concerned. Furthermore, drivers are given precise 'Caution Orders' to supplement the caution signals on the track-side and also to forewarn them about the existence of restrictions. Accidents are, however, caused by incorrect signals or failure to respond to danger signals.

Illumination

Apparently, proper illumination of displays, working surfaces and the cabin in general have been ignored by locomotive designers the world over. Robinson *et al* (p 142) concur that the lighting techniques in the current generation of locomotives is not optimum, while Powell and Cartwright (1977) identify this as a major source of driver frustration.

Arrangements are particularly deficient in relation to night operations. The biggest difficulty is with respect to gauge lighting, (Table 5), which is either missing (internal bulbs) or produces reflections on the windscreen (external bulbs). The apparent conclusion suggested by these figures – that the cabin lighting is acceptable – is misleading. The drivers explained that cabin lighting produces no discomfort as the bulbs are mostly missing! Whatever disturbance occurs is related to having to operate in total darkness, or with torches. Red lights should be provided to allow visibility of working surfaces, caution orders, etc, without losing dark adaptation. There are comparatively less problems with glare due to oncoming headlights at night, as rules require that both drivers dim and brighten their headlights alternately as they approach and cross. However, glare due to low sun is an important problem. It either prevents the driver from monitoring the track ahead or from identifying the aspects of signals. Photochromatic sunshades provided are of only limited usefulness in this regard. Particularly troublesome is low sun behind the driver, when reflections on the signal glass either mask or produce confusion about the signal aspect.

Rear-view mirrors

One of the duties of the driver is to watch the train during runs, to observe:

(1) excess swaying of any coach
(2) hot axle or brake-binding symptoms (smoke during day and sparks during night)
(3) emergency signals from the guard.

There are no rear-view mirrors and drivers have to leave the controls and crane out of the window to observe the train.

Table 5: Illumination of cabin gauges and other lighting problems

	Disturbance due to lighting		
	(a) no	(b) mild	(c) severe
Gauge lighting:	3·8%	19·2%	76·9%
Cabin lighting:	53·8	26·9	19·2
Glare due to oncoming headlights:	92·3	7·7	0
Low sun:	7·7	69·2	15·4

For this reason, observing the train has become almost exclusively a function of the assistant. The provision of suitable mirrors is, therefore, to be recommended.

Necessity for rear-view mirror:

(a) Necessary : 30·7%
(b) Indifferent : 42·3
(c) Not needed : 26·9

Driver safety devices

There are no driver-safety-devices (eg, dead-man pedal) on the type of locomotive studied, perhaps due to the obligatory presence of an assistant.

Indicators

Some drivers voiced their requirements for a *POWER ON* indicator in the cabin. At the moment there is no way of knowing when tension returns in the catenary wire after a power failure (which is a not infrequent occurrence). The present procedure is to reset the circuit breaker, which will trip if there is no tension. The air pressure needed to reset the circuit breaker, (1 kg/cm^2 per attempt) is built up through a small compressor running on the locomotive batteries. This procedure is repeated until the circuit breaker does not trip, often resulting in severe drainage on batteries.

Seats

Several questions were asked about seating and the replies were as follows (in percent):

1. Seats are:
   (a) comfortable : 0%
   (b) adequate : 3·8
   (c) unsuitable : 38·5
   (d) uncomfortable : 57·7
2. When seated, reaching the important controls and reading the important displays is:
   (a) easy : 69·2%
   (b) possible : 23·1
   (c) slightly difficult : 7·7
   (d) very difficult : 0
3. When driving, drivers:
   (a) always sit : 0%
   (b) always stand : 0
   (c) mostly sit : 30·7
   (d) mostly stand : 46·2
   (e) both equally : 23·1
4. During emergencies, or when starting and stopping, drivers:
   (a) stand only : 84·6%
   (b) sit only : 0
   (c) both sit and stand: 15·4
5. If the answer to the previous question was 'stand' is it mainly because it is difficult to perform these operations efficiently while sitting?:
   (a) because seats are badly designed : 4·5%
   (b) because one is more alert while standing : 45·6
   (c) both of these : 50·0
   (d) neither of these : 0

Though drivers stand for a large portion of the time, the seats provided are (a) quite comfortable, (b) *cannot be adjusted* for individual requirements.

Although drivers insisted that they could reach all controls and see all displays while seated, this was observed to be patently difficult, if not impossible. Furthermore, once the driver or his assistant is seated, it is not possible for the other to cross over to the opposite side of the cabin. An important reason why drivers stand may be that it is much easier to monitor vibration characteristics while standing, and these provide information about the condition and load and speed bearing capacity of the track.

Noise levels

Powell and Cartwright (1977) reported that most British Rail electric locomotive cabins have noise levels below 85 dB A (8 h exposure), a limit self-imposed by the organisation. Heino *et al* (1978), however, have found that 45% of their measurements exceed 85 dBA, with momentary noise levels from horns being 98–105 dBA.

In the present preliminary study, only subjective estimates on the basis of speech interference (Sen, 1967; McCormick, 1967) could be made. These estimates (by the authors) indicated levels of 80-85 dBA in stationary locomotives and 90-100 dBA running with horns blowing. When drivers were asked to give their views, they replied as follows:

The noise level in the cabin (while running) is:

		with doors to engine compartment	
		closed	open
(a)	acceptable	73·1%	0%
(b)	disturbing	23·1	34·6
(c)	excessive	3·8	65·4
(d)	intolerable	0	0

Does the noise (doors closed) prevent verbal communication between driver and assistant?

(a)	yes	:	0%
(b)	no	:	77·0
(c)	sometimes	:	23·1

All drivers questioned felt that the noise levels in the driving cabin (with doors to the engine room closed) are not excessive, and do not hamper verbal communication with co-drivers. However, they admitted that there are fatigue effects (34·6%) and some masking of the horns of distant trains (7·7%). Drivers indicated that some noise provides auditory clues about the smooth functioning of the motors (53·8%, mainly the senior drivers).

Thermal environment

Drivers were questioned about their cabin temperature by a direct question concerning feelings of cold or warmth in both summer and winter.

How do you feel		In summer (day)	In winter (nights)
(a)	very cold	0%	88·5%
(b)	cold	0	7·7
(c)	cool	0	0
(d)	comfortable	0	3·8
(e)	warm	0	0
(f)	hot	19·2	0
(g)	very hot	80·7	0

Maximum discomfort is experienced by the drivers due to heat and cold stresses. During summer, there are intense thermal radiations from the hot metal walls, and the cabin appears like a furnace to the drivers. The fans provided are usually kept switched off, as otherwise they only aggravate the situation by circulating hot air. However, the drivers are more uncomfortable during the winter months. With the passage of time, the insulation of the door-frames wears out and the heavy-duty blowers in the engine compartment produce draughts of very cold air. The two cab heaters are ineffective in keeping the cabin warm under these conditions, and bundling up in warm clothes and blankets restricts the movements of the drivers.

Ladders

The steps by which the drivers climb into or out of the cabin are vertical, narrow, and mostly worn smooth. Some dimensions are described in Table 6.

The ladder should be a collapsible one, with lower first step and broader, deeper steps. A collapsible ladder would permit the extended ladder to be at an angle (of 45°–60°) to the horizontal, and the first step could be lower to the ground, with the collapsed ladder stored compactly where the present ladder is located.

Anthropometry

Apart from the study of Andrew and Manoy (1972), there appears to be a dearth of data on the anthropometry of railway locomotive drivers. Robinson *et al* (1976) (p 141) used the data on the US adult male population, and recommended that a suitable data base be created. In view of the differences in the body dimensions of Indians, the loco driver population should be studied for any significant departures from the Indian adult male population.

Monotony and drowsiness

Polygraphic recordings in 1972 in Japan (Endo and Kogi, 1975) showed that drivers sometimes drowse for short durations intermittently, accompanied by temporary drops in heart rate, absence of controller action, and increase in detection errors. In the present study, all drivers admitted monotony and drowsiness effects, particularly between the hours of 0100 and 0400. Most of them attempt to prevent these effects by drinking tea, smoking, standing (according to habits), and talking with the assistant. The

Table 6: Dimensions of the cabin ladder, and some anthropometric measurements of Indians (Sen, 1964)

		Mean	± SD (cms)
Height of the first step from ground:	:	51·9	± 0·67
Height between steps	:	32·0	
Breadth of each step	:	36·0	
Depth of each step	:	13·0	
Trochanteric height	:	87·32	± 4·07
Patellar height	:	51·18	± 2·41
Foot length	:	24·73	± 1·16
Foot breadth	:	10·24	± 0·43

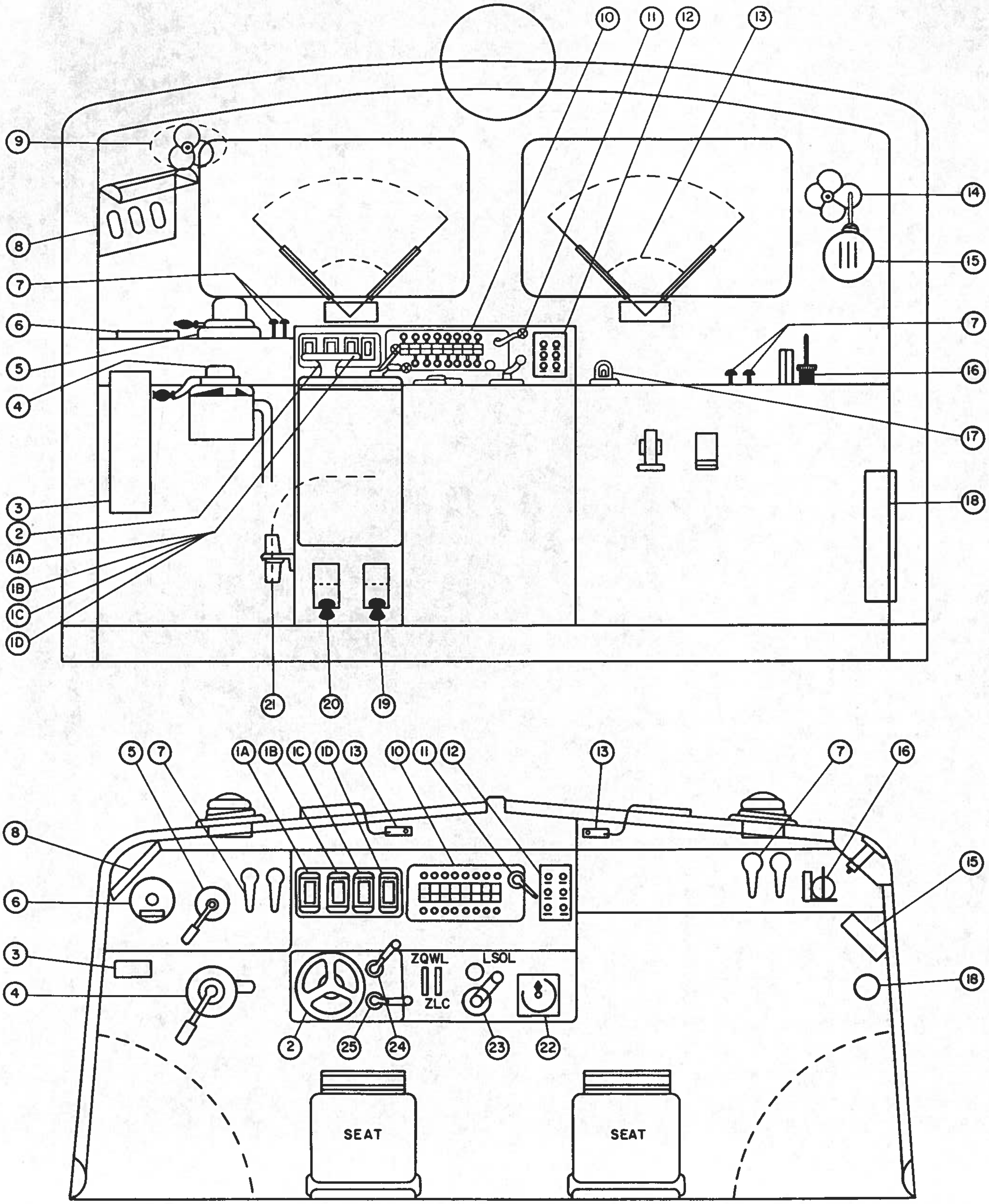

Fig. 1 Indian Railways 5 ft 6 in (1·68 m) gauge AC electric locomotives $\frac{WAM}{4}$ 20515. Arrangement of apparatus in driving cab

1A Traction motor ammeter (DC)
1B Traction motor ammeter (DC)
1C Voltmeter
1D Voltmeter (AC) (Both catenary and motor)
2. Master controller
3. Cab heater
4. Vacuum brake valve
5. Air brake valve
6. Speedometer
7. Horn (1—MT, 1—LT)
8. Pressure gauges (L to R): (1) Train pipe and equaliser reservoir. (2) Main reservoir. (3) Loco brake
9. Blower for cab
10. Switch box
11. Locking lever for switch box
12. Indicating lamp panel
13. Windshield wiper
14. Cab blower (Asst side)
15. Sonny
16. Emergency brake (Asst)
17. Auxiliary driver lamp
18. Extinguisher
19. PVEF-brake isolator pedal
20. Sanding pedal
21. Socket for master controller Canon plug
22. Indicator for tap changer
23. Operating switch for pantograph
24. Shunting contactor
25. Reverser

existing rule of repeating signals and orders with the assistant helps them to keep awake to some extent. When asked for their suggestions, some drivers suggested radio communication with the controlling station and/or the guard. Others who had presumably heard details of automatic warning systems/ cab signalling outlined similar systems.

Control, display and sub-system analysis

Arrangement and description of controls and displays

The general arrangement of controls and display is shown in Fig. 1. A description of the main controls and displays, along with the preliminary remarks regarding design, layout, etc, is given in Tables 7 and 8.

Table 7: Controls in driver's cabin

Name	Fig. 1 reference	Function	Range	Type	Associated display	Remarks
Air brake	5	Locomotive braking	Moves in horizontal arc from left to right	Large lever	Brake cylinder pressure	1) Both brakes are left hand operated and hence cannot be released simultaneously.
Vacuum brake	4	Train braking	ditto	ditto	Brake pipe pressure	2) Direction of motion of levers is not conducive to maximum speed of movement. 3) Should be closer to central area.
Horn	7		Press to sound	10 cm lever (palm depression)	–	Should be closer to central area.
Master controller	2	Regulates power to traction motor	From '++' (forward) at 10 o'clock to '++' (reverse) at 2 o'clock, through '0' at 6 o'clock	Horizontal hand wheel (25 cm dia) detent type	Notch indicator LSGR lamp	Should be redesigned as a lever so that shoulder movements can be used.
Reverser	25	Sets	Moves forwards and backwards through 45° with neutral position at centre	3-position lever (10 cm); horizontal movement	LSB lamp	Secondary control occupying primary space.
Shunting contactor	24	Weakens motor field	Moves in horizontal arc	5-position lever (10 cm)		Arc of movement awkward
Pantograph control	23	Raising/ lowering rear or leading pantograph	Moves in 120° arc from '0' at 12 o'clock to '2' at 8 o'clock	4 position horizontal lever (10 cm) 0 = both down 1 = rear up 1 + 2 = both up 2 = leading up	LSCHBA lamp should go off	Should be 4-position rotary selector switch in secondary location.
Emergency brake	16	Emergency braking by assistant	Pull vertical handle to release brake	Vertical handle	Pressure gauges	Crude design
Sanding pedal	20	Manual release of sand	Press to operate	10 cm pedal	LSP lamp	Pedal should be redesigned
Loco-brake isolator	19	Isolates loco-brake when vacuum brake operated (to prevent piling)	ditto	ditto	Pressure gauges	ditto
Electrical switches	Cabinet behind driver	To isolate various motors and relays	Arcs of 30° to 180° (in vertical plane)	2 to 5 position levers (6–10 cm long)		

Table 8: Displays in driver's cabin

Name	Fig. 1 reference	Function	Units and range	Type	Associated control	Remarks
Train pipe pressure	8	Monitors pressure in train pipe	0–70 cm Hg (2 cm divisions, marked every 10 cm)	Moving pointers (10 cm dia dial)	Vacuum brake	1) Only qualitative readings needed 2) TP and ER should be replaced by 'vertical tape' displays to conserve space and help comparison of pointer positions
Equaliser reservoir pressure	8	Monitor pressure in ER	0–76 cm Hg (2 cm divisions, marked every 10 cm)	ditto	ditto	ditto
Main reservoir pressure	8	Monitors pressure in main reservoir	0–10 kg/cm² (0·2 unit divisions, marked every 1·0 unit)	ditto	Compressor switches	Normally automatic operation, so qualitative readings should be made possible
Loco brake cylinder pressure	8	Monitors loco brake pressure	ditto	ditto	Air brake	White and red marks provided for 'operating' and 'danger' levels, but still too quantitative
Speedometer (with clock and odometer)	6	Monitors time, speed and distance	0–120 km/h (10 km/h divisions)	Moving pointer (15 cm dia dial)	Master controller, brakes	1) Difficult to see if sitting 2) Too far from central area 3) Maximum and operating speeds should be marked 4) Clock and odometer extremely difficult to read
Notch indicator	22	Indicates position of transformer tapping	0–32; '0' at 12 o'clock increasing in clock-wise steps of 1 unit to '32' at 10 o'clock	Moving pointer (dial 10 cm square)	Master controller	Pointer and scale good, but start and end of scale should be repositioned for proper motion stereotype. There should be marks to indicate points where blowers must be switched on, etc
SONNY	15	Signal for excess current	–	Auditory	–	Missing in some locomotives
Ammeters	1A, 1B	Traction motor current	–1 to 1·15 (0·01 unit divisions)	Vertical scale, moving pointer	–	1) All prominent orange pointers which are horizontally aligned when operating normally
Voltmeter	1C	Traction motor volts DC	0–800 V	ditto	–	2) All have colour-coded zones
						3) Less emphasis should be placed on quantitative readings (only required for fault finding)
Voltmeter	1D	Catenary and motor voltage	0–600 (V×2) and 0–35 kV	ditto		4) Lighting is bad
LSRSI lamp	12	Unbalanced current in recitifers	Off-flicker -glow	Visual	–	
LSB lamp	12	Throwing of reverser	On-off	ditto	Reverser	
LSP lamp	12	Wheel-slip (auto sanding not working)	Off-dim-on	ditto	Sanding pedal	Due to cracking of surface paint, all lamps look the same at a glance
LSDJ lamp	12	Tripping of circuit-breaker (loco not energised)	On-off	ditto	Current breaker re-set switch	
LSCHBA lamp	12	Battery charge	ditto (off = loco energised)	ditto	ditto	
LSGR lamp	12	Notch indicator	On-off (off = notch taken)	ditto	Master controller	

Ranking

Sub-system ranking

Following the method outlined by Robinson *et al* (1976), a matrix was set up, with the 'level-2' functions (the jobs involved in train driving, such as 'start train', 'achieve speed'. 'negotiate gradients') on the axis, and each of the locomotive systems (such as brake, propulsion, etc) on the other. Considering each level-2 function in turn, an entry was made in the matrix corresponding to the sub-system activity required to carry out that function. (For example, to perform the level-2 function of 'start-train', the driver would have to operate the propulsion and the brake systems, and monitor the signals, the cabin instruments, and the caution orders). After all the level-2 functions were so analysed, the number of matrix entries for each sub-system was counted, and this count formed the basis of the rank order given in Table 9.

The rank order obtained is similar to that reported by Robinson *et al* (1976) (p = 0·8). In both cases, the train brake system had been found to be of primary importance while the engine and pneumatic systems are on the lowest rungs of the ladder. These matrix entry counts can also be utilised for weighting in priority allocations, and for inputs to linear-programming applications.

By counting the number of entries, the tasks were also ranked in a similar fashion. Communication with the assistant driver was seen to be the most frequent activity followed by those of controlling tractive effort, braking the locomotive, monitoring speed, wheel-slip, signals, and so on.

Control display ranking

The drivers were asked to rank (in order of importance) the controls and displays (separately). The rank order obtained is given in Table 10. All the drivers did not assign ranks to all the controls or displays (often stopping after the 5–7th rank), and many assigned the same rank to two displays.

Table 9: Rank order of locomotive sub-systems

Rank	Sub-system	Matrix entries
1.	Monitoring/communicating with external environment	84
2.	Train (vacuum) brake system	75
3.	Locomotive (air) brake system	54
4.	Internal signals/communications/information	44
5.5	Propulsion system	43
5.5	Drive system	43
7.	Lighting system	21
8.	Electrical system	20
9.	Miscellaneous auxiliary systems	12
10.	Pneumatic system	10
11.	Engine (traction motor) system	9

Table 10: Rank order of controls and displays

Controls	Total of assigned ranks	Rank order
Air brake	104	4
Vacuum brake	47	2
Horn	146	5
Master controller	31	1
Shunting contactor	150	6·5
Reverser	98	3
Sanding pedal	150	6·5
Loco-brake isolating pedal	182	8
Pantograph control	199	9
Displays		
Train pipe/equaliser reservoir pressure	30	1
Main reservoir pressure	100	3
Loco-brake pressure	163	8
Speedometer	110	7
Ammeters	109	5·5
Voltmeters	109	5·5
Indicator lamps	104	4
Notch repeater	45	2

Conclusion

In a situation where three out of every five accidents are thought to be due to human error, the deficiencies in the working conditions and environment outlined above assume greater significance. The lack of biomechanical and anthropometric considerations in the design of the work station, the irregularities of the 'link' system, improper cabin/instrument illumination, and the poor seats are particularly disturbing in this respect. The results indicate that the next part of the investigation should be devoted to the collection of anthropometric and psychophysiological data on the drivers, to be followed by the formulation of different design alternatives. The alternatives would be the bases of 1 : 1 mock-ups which would be evaluated using driver opinions. The 'link' system is thought to be material for a separate future study as it is not directly relevant to the primary objective of the present study – the design of the driver's cabin.

Glossary

Consist : The total assembly of locomotive, carriages, wagons, coaches and/or additional locomotives.

Aspect : The position, quality or status of signal.

EMU : Electrical Multiple Unit, operates as a rapid commuter transport system in some metropolitan cities.

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