Redesign and development of railway track tools on ergonomics principles

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Abstract
The present study aims at evaluation of the existing track maintenance tools like beater, shovel, spanner, crowbar and the hand safety lamp, and their redesign and development from the view points of ergonomics and industrial design. The paper also describes in detail the experience of undertaking this unique project and the critical issues that the designers' had to deal with to arrive at final solutions. Questionnaire study, direct observation and detailed activity recording were carried out to identify different problem areas with special reference to their work. Merits and demerits of each tool were studied from the view points of functionality, grips and comfort, materials used and manufacturing aspects. Thermal data were also recorded to analyse the existing work environment. Study revealed that none of the tools are provided with proper hand grips. The space between handle and body of the lamp is very small and most of the time, users get burn injuries on their hands. While working with most of the tools, awkward bending postures resulted in severe back pain as well as pain in the leg muscles, shoulders, lower and upper arms. Gang men are also exposed to high solar and reflected thermal radiation mainly during the summer months. All these resulted in an early onset of fatigue among them and affect their health, work performance and productivity. A number of alternate design directions for each of the problems were worked out through mock-up wooden models. After initial testing, prototypes of alternate designs of each tool were fabricated and evaluated in the field through subjective and objective assessments. Based on the field trials, modifications were made to finalize the new designs. Recommendations have been made to improve occupational safety and health of the gang men.

Key Words: Design ergonomics, Hand tools, Indian railways, Occupational health, Safety

1. INTRODUCTION

The Indian Railways are one of the largest railways in the world today. To ensure smooth running of the trains, regular maintenance of the tracks is very essential. Track maintenance in India has traditionally been done manually. The tools and techniques used are more or less similar; however there are minor regional variations as expected in a big country. Most of these frequently used tools require considerable muscle forces and stressful working postures (1, 2 and 3). The musculoskeletal load on a person shoveling often may be high and may result, in the short term, in muscle fatigue and reduced capacity for work. In the long term, the consequences may be cumulative and result in musculoskeletal trauma disorders and chronic muscle pain (4). Studies by Kadefors et al. in 1993 (5) and Freivalds in 1996 (6) showed that handle features such as diameter, length, shape, and surface texture or the presence of contaminants, vibrations, and gloves may alter the hand/tool interface. Poor design of the grip of a tool leads to exertion of higher grip forces (7) and to extreme wrist deviations (8) and therefore to more fatigue. Shovel weight should be below 1.5 kg (9). They also observed that a blade size/weight ratio of 0.0676 m^2/kg is optimum; that is, for a 1.5 kg shovel the optimum blade size is 0.1 m^2 with a load of 4.4 kg.

Use of age-old tools, awkward posture and hazardous work environment lead to considerable reduction in the efficiency, performance and productivity of the gangs (10). So far little attention has been paid to solve some of the important problems inherent in the track tools presently used by the gangs. The present study aimed at design evaluation of the existing four track tools, i.e., beater, shovel, spanner and crowbar, and the hand safety (HS) lamp on ergonomics principles considering mainly the occupational health, safety and efficiency and productivity of the gang men and development of new designs.

2. METHODOLOGY

The study was divided into three phases – analysis of existing condition; development of concepts and fabrication of working prototypes; and field trials and finalization of designs. Following methodology was applied.

2.1 Selection of subjects

Subjective assessment through questionnaire studies was conducted on 39 gang men to find out their responses, reactions and feedback. All the selected gang men were interviewed separately so that they could express their opinions freely without interference or being influenced by the others. Objective assessment was carried out through the measurement of physical (Figure 1) and physiological (Figure 2) parameters on the 15 gang men. Physical characteristics such as height, weight, age, etc., of all the subjects were recorded.


Figures 1 & 2 Measurement of Physical and physiological parameters of the gang men

2.2 Questionnaire and interview techniques

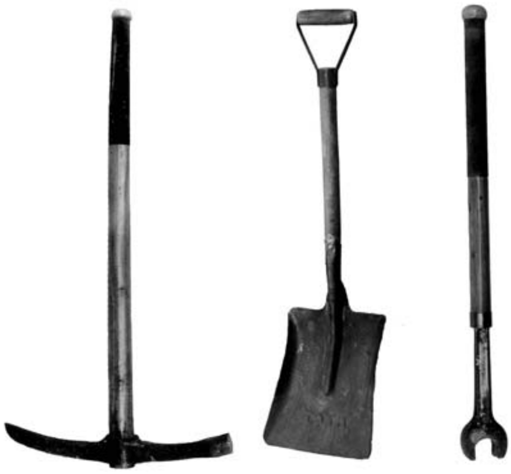
Questionnaire (11), direct observations (12) and interview techniques were carried out for enlisting and elaborating upon the different problems faced by the gang men and the gate men during their daily work with the existing track tools and the HS lamp. Their experiences on different hazardous situations, previous accidents and critical incidents (near accidents) along with their opinions and views on the relevant aspects of occupational health, safety and work performance were also recorded. Each of the new designs was validated by using a separate questionnaire.

2.3 Task analysis and study of existing designs

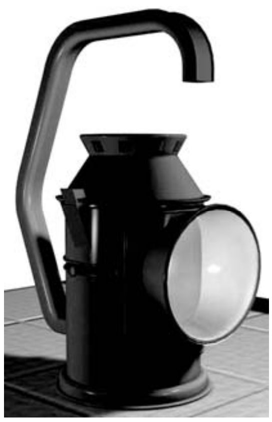
Daily activities and different task components of selected gang men were analysed giving stress on frequency and mode of using the tools. All the four existing track tools and the HS lamp were examined in detail to find out their merits and demerits from the view points of functionality, grips, comfort ability, uneasiness and materials used, weak points, manufacturing aspects, etc. Different postures adopted by the gang men while working with the existing track tools were studied in detail through photographs. Ergonomically good and bad working postures were identified.

2.4 Development of concepts and fabrication of prototypes

A number of alternate design directions for each of the problems were worked out through mock-up wooden models. The design I beater is provided with smooth wooden handle, length same as existing one and palm filling elliptical rubberized grip with a stopper at the end. In design II beater (Figure 3), length of the wooden handle is increased to reduce bending of the back. Length of the beating end is reduced and angle is increased so that it goes straight under the concrete sleeper without damaging it; digging end is shortened and the angle is increased. The new shovel is fitted with 'D' type grip (Figure 4), whereas in other concept, a second handle is attached to the long handle to reduce awkward bending. In new spanner, the jaw is only at one end and it is fitted with a long smooth and circular wooden handle with a stopper at the end. In second concept, the length of the spanner is increased (Figure 5) so that the gang men can exert maximum pressure comfortably in erect standing posture. A circular cross-section is maintained throughout the length of the new crow bar and the angle of the claw is increased for ease of operation.



Figures 3, 4 & 5 Newly developed prototypes of beater, shovel and spanner

Figures 6 & 7 Newly developed prototypes of HS lamp and 3-D rendering of concept 2.

In another concept the length of the crowbar is reduced to half for better use over the bridges. In hand safety lamp, a single long wooden handle, with two comfortable grips, replaces the existing two small handles (Figure 6). The window as well as the reflector is shifted upwards to provide better visibility and better reflection of light. In another concept, a long curved wooden handle (Figure 7) replaces the existing handles for a better grip at different angles. Based on the initial feedback received on mock-up models, 1:1 prototypes of alternate designs of each of the track tools and H S lamp were fabricated for field evaluation.

2.5 Evaluation of the tools

Experimental Design: Prototypes of all the newly developed track tools were given to the gang men for use (Figures 8 & 9) at least two weeks before the study. During work with the beater and the shovel, the gang men were asked to maintain a certain pace of work, i.e., 15-18 shoveling per minute and 20-25 strikes per minute for beater. Initially, the striking and shoveling rates were monitored with the help of a tally counter. Each subject was asked to take rest and then work for 45 minutes with each of the existing, Design I and Design II prototypes, with a gap of 15 minutes for rest in between. Environmental parameters, such as globe temperature and kata cooling time were measured. The ambient air temperature, dry and wet bulb temperatures and relative humidity were also recorded.


Figures 8 & 9 Gang men are working with the newly developed prototypes of shovel and spanner

2.6 Measurement of physiological parameters

With the help of a portable electronic digital sphygmomanometer (OMRON, Japan), fitted on the left upper arm, systolic and diastolic blood pressure and instantaneous pulse rates of each subject were measured during rest as well as while working with existing and prototypes of newly developed beaters and shovels at regular intervals of 15 minutes. Every day the instrument was calibrated with the help of a mercury sphygmomanometer. The pulse rates were also checked manually by measuring the carotid pulse of the subjects.

3 RESULTS AND DISCUSSION

3.1 Problems while using the tools

i) None of the tools are provided with proper grip and due to the daily use of these existing tools, having very rough, uneven and sharp handles (Figure 10), their palms become very stiff and full of blisters (Figure 11). These not only reduce the sensory feedback but at the same time hinder easy maneuvering of the tools.


Figures 10 & 11 Due to the use of t-shaped grip of the shovel handle, their palms become very stiff and full of blisters

Striking with the beater leads to ulnar deviation of the wrists, even holding and carrying the tools resulted in ulnar deviation (Figure 12). Regular use results in severe pain and inflammation of the wrist joints. While striking the beater, the impact induces hand and arm vibrations. The existing beater damages the concrete sleepers. The packing end does not go inside the sleepers. While working with the tools like beater, shovel, spanner and crowbar, the awkward bending posture (Figure 13) results in severe pain in their backs, shoulders, knees, elbows and wrist joints and also in lower and upper arms and hands. This leads to decline in the quality of work performance as well as productivity.


Figures 12 & 13 Holding and carrying the tools lead to ulnar deviation of the wrist, where as awkward bending posture results in severe back pain

ii) In case of shovel, the T-shaped grip is not easy to grasp and operate. The sharp edges of the metal blade lead to a number of cut injuries. During the summer months or during winter, the spanners as well as the crowbar become too hot or too cold respectively, to use comfortably.

iii) In crowbar, the angle of the claw is too small to be used effectively. Most of the time it touches the rail and the gang men face difficulties while removing the dog's spike (Figure 14).

Figure 14 While using, crowbar touches the rail

iv) In HS lamp, both the metal handles become hot very quickly. Space between the handles and the body of the lamp is very small (Figure 15) increasing the chances of getting burn injuries on the right hand. The position of the window obstructs full visibility of the flame from a distance. The reflector is not placed at its proper position and the knobs, used to move the red and green coloured sheets, are not strong enough to take the load while operating.

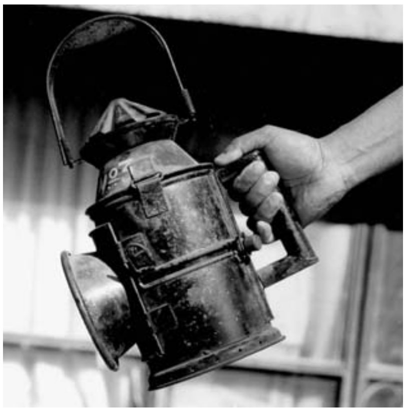


Figure 15 Small spaces between handle and the body lead to large number of burn injuries

v) Physical attributes of the subjects are presented in Table 1. During their daily work, gang men face problems relating to the impact of the highly hazardous work environment, especially the effects of high solar and reflected thermal radiation mainly during the summer months. Thermal environmental measurements were taken during winter. During the summer months all the temperatures would be very high.

Table 1 Subject attributes (N = 15)

Parameters	Values
Age (years)	43.0 $\pm$ 8.22 (26 – 56)
Experience (years)	18.5 $\pm$ 7.05 (5 – 29)
Height (cm)	160.3 $\pm$ 6.51 (150.5 – 173.4)
Weight (kg)	51.5 $\pm$ 10.25 (34.5 – 72.5)

Values: Mean $\pm$ SD (Minimum – Maximum)

Though the relative humidity is quite low, kata cooling time is very high. It means that the air speed is very low. Wet Bulb Globe Temperature (WBGT) is found to be within normal limits (Table 2). In most of the work places, the supply of drinking water is not sufficient. Sometimes, gang men carry water jugs with them, but these are not sufficient particularly during the summer months. In most places, the stores for keeping the track tools are quite far from the work sites. Everyday, gang men have to walk on average of 4 to 8 Km daily twice (early in the morning and late in the evening) carrying the tools weighing approximately 20 to 25 Kg. This results in an early onset of fatigue among the gang men.

Table 2 Thermal environmental data

Parameters	Mean $\pm$ SD (Minimum–Maximum)
Globe temperature (ºC)	33.8 $\pm$ 3.78 (29.0 – 40.5)
Dry bulb temperature (ºF)	85.5 $\pm$ 5.27 (76.0 – 94.0)
Wet bulb temperature (ºF)	64.7 $\pm$ 2.09 (61.0 – 68.0)
Relative humidity (%)	22.1 $\pm$ 6.27 (10.0 – 37.0)
Kata cooling time (seconds)	198.7 $\pm$ 49.23 (160 – 320)
WBGT (ºC)	23.02

3.2 Evaluation of tools

As the gang men are more familiar with the existing length of the handle, most of them preferred the handle of Design I, but at the same time they agreed that the long handle is very useful for working on the concrete sleepers and moreover it helps to reduce the bending of the back. Due to malleable casting, the digging end of the blade of all the prototypes was not sharp enough. That is why 53.85% of the gang men preferred the existing one (Table 3). But they recommended that if the digging ends are sharp enough they would accept Design I for the wooden sleepers and Design II for the concrete sleepers. Though work with the double-handed shovel reduces bending of the back, most of the gang men rejected it because they are not used to it. Most of the gang men preferred Design II spanner, which has

Table 3 Users' responses (%) to the improved design features implemented on track tools

Improved features	Existing	Design I	Design II
Beater			
Handle length	23.08	58.97	17.95
Grip	05.13	46.15	48.72
Blade	53.85	30.77	15.38
Weight	15.38	61.54	23.08
Working posture	20.51	28.21	51.28
Shovel			
Handle type	38.46	38.46	23.08
Grip	15.39	46.15	38.46
Working posture	30.77	25.64	43.59
Spanner			
Handle length	25.64	28.21	46.15
Grip	10.26	41.02	48.72
Working posture	17.95	17.95	64.10
Crowbar			
Length	41.03	35.89	23.08
Grip	30.77	41.02	28.21
Claw	23.08	38.46	38.46
Weight	30.77	43.59	25.64
Working posture	30.77	41.02	28.21
HS Lamp			
Handle	34.49	58.62	06.89
Grip	27.59	55.17	17.24
Visibility	24.14	51.72	24.14

a long handle, mainly because during work they can exert maximum pressure comfortably without bending the back and because of the rubber sheet fitted over the handle grip. More than 76% of the gang men prefer the existing length of the crowbar, but they agreed that the short one is very useful to operate over the bridge. According to 77% of the gang men, the new angle of the claw is very useful to operate. About 55% of the gang men prefer the grip of the handle of the Design I lamp particularly the moveable one, provided that the grip circumference were slightly increased.

The analysis of instantaneous pulse rates (Table 4) showed that the mean peak values while working with the Design I were less than that the values while working with the existing and Design II beaters. The present study shows that though the weight of the Design I beater is approximately 800 grams more than that of the existing one, the rise of pulse rates from resting or pre-working values is 16.4, 12.2 and 13.5 beats per minute after working for 45 minutes with each of the existing, Design I and Design II beaters, respectively. This change would have been more pronounced if the subject worked for several months instead of only two weeks. The rise of pulse pressure from pre-working level is 3.7 in the case of Design II, 5.7 in case of Design I and 7.9 in case of the existing beater (Table 5).

Table 4 Variations in pulse rates while working with existing, design I and design II beaters

Pulse rate	Existing beater	Design I beater	Design II beater
Pre-working	81.4±7.74 (72–97)	83.5±9.54 (68–97)	84.6±8.75 (72–97)
Working (after 15 minutes)	95.0±13.28 (76-114)	94.4±11.99 (72–115)	97.1±11.98 (79–113)
Working (after 30 minutes)	96.8±16.37 (75-114)	94.8±13.78 (72–124)	97.4±12.05 (77–115)
Working (after 45 minutes)	97.8±17.37 (69-119)	95.7±14.15 (72–114)	98.1±10.88 (81–115)

Values: Mean ± SD (Minimum – Maximum)

Table 5 Variations in pulse pressure (mm of Hg) while working with existing, design I and design II beaters

pulse pressure	Existing beater	Design I beater	Design II beater
Pre-working	46.5±9.61 (29–62)	46.6±9.42 (29–62)	46.5±10.43 (29–62)
Working (after 15 minutes)	54.3±11.22 (26–74)	53.3±11.43 (28–74)	51.7±11.19 (32–74)
Working (after 30 minutes)	53.7±13.39 (37–78)	55.8±10.16 (37–74)	51.5±12.47 (37–79)
Working (after 45 minutes)	54.4±13.29 (34–80)	52.3±10.51 (39–73)	50.2±9.15 (28–60)

Values: Mean ± SD (Minimum – Maximum)

Table 6 Variations in pulse rates while working with existing, design I and design II shovels

Pulse rate	Existing shovel	Design I shovel	Design II shovel
Pre-working	80.7±7.61 (72–97)	80.7±7.61 (72–97)	81.4±7.56 (71–97)
Working (after 15 minutes)	97.1±13.78 (66-115)	93.5±10.81 (76–116)	95.2±13.68 (72–115)
Working (after 30 minutes)	96.4±17. 7 (64-126)	93.5±11.56 (72–113)	97.6±12.89 (72–114)
Working (after 45 minutes)	97.1±16.11 (66-131)	95.9±13.67 (74–118)	97.4±14.37 (72–117)

Values: Mean ± SD (Minimum – Maximum)

It has been observed that the rise of pulse rate from resting or pre-working values are 16.4, 15.2 and 16.0

beats per minute (Table 6) after working for 45 minutes with each of the existing, Design I and Design II shovels, respectively. The rise of pulse pressure from the resting or pre-working level is 2.7 in the case of Design II, 2.8 in the case of Design I and 9.5 mm of Hg in the case of the existing shovel as shown in Table 7.

Table 7 Variations in pulse pressure (mm of Hg) while working with existing, design I and design II shovels

pulse pressure	Existing shovel	Design I shovel	Design II shovel
Pre-working	41.2±8.81 (29–57)	41.5±8.46 (29–57)	41.5±8.46 (29–57)
Working (after 15 minutes)	52.0±12.49 (30–68)	51.0±11.07 (36–74)	54.2±8.54 (40–65)
Working (after 30 minutes)	49.4±14.48 (17–69)	52.2±8.89 (37–69)	54.2±8.55 (35–65)
Working (after 45 minutes)	50.7±11.51 (30–66)	48.3±9.46 (35–64)	54.2±8.54 (34–64)

Values: Mean ± SD (Minimum – Maximum)

Table 8 Preference rating of the track tools and HS lamp

Items	Existing	Design I	Design II
Beater	15.38	53.85	30.77
Shovel	25.64	51.28	23.08
Spanner	17.95	38.46	43.59
Crowbar	30.77	48.72	20.51
HS lamp	37.93	55.17	06.90

4. CONCLUSION

Based on preference rating it can be concluded that for the beater, shovel, crowbar and H S lamp, Design I and for the spanner, Design II are well accepted by most of the gang men (Table 8). From objective assessment it is very clear that work with the Design I beater and Design I shovel resulted in an expenditure of comparatively less physiological costs than the other designs. Based on the results of the field trials modifications were made to finalize the designs.

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