Postural discomfort analysis of EOT crane operators

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Abstract. Ergonomics aims at ensuring good fit between the worker and the work station. It is an important field of research in the development process to increase safety, comfort and performance. A comfortable work station can help employees to work more efficiently and effectively by reducing the probability for Musculoskeletal Disorders (MSDs). This study has been carried out to evaluate the postural discomfort of Electric Overhead Travelling (EOT) crane operators in tubular products shop of a boiler manufacturing company located in southern India. The modified Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) is used to interact with 67 crane operators, working with 24 EOT cranes of three different models in alternative shifts. The study revealed that 48(71.6%) employees suffered with some kind of MSDs. Most of them suffered with lower back pain followed by neck pain. The discomfort level is increased with age. Sixteen anthropometric dimensions are measured from all the operators. Statistical analysis is carried out using ANOVA. Frequent working postures are analysed by RULA, using Egrofellow-3 software. The obtained RULA score is 6. Suitable ergonomic chair provided for comfortable sitting and front side cabin guard height 100mm reduced to increase the visibility. After 3 months of trail run again questionnaire survey is conducted which clearly indicates that discomfort level drastically reduced and RULA score also reduced to 3.

1. Introduction

EOT cranes are mechanical equipment used for moving materials within the plant. Cranes are located between two parallel and longitudinal rails which are fixed at top of the plant. A cabin is fixed at one side of crane. The crane cabin is used to operate and control the crane. The cabin contains operator seat, control units for longitudinal and cross travelling and control unit for hoisting. The material movement using crane is carried out at the ground level but the operator is in the cabin, which is located at higher level. So the operator needs to bend forward and tilt his head down to see the movement of material and his hands are away from its natural position to operate the control levers. Figure 1 shows the typical EOT crane.
Therefore crane operators are exposed to the risk factors such as bending, over reaching and activating control levers with uncomfortable body position. Repeatedly doing same work for long period of time, affects their muscles and skeletal system also leads to musculoskeletal disorders. MSDs affect the muscles, skeleton, tendons, ligaments, blood vessels and nerves. MSDs are the main factor for loss of working hours and these are the major constituent of all recorded and compensated work related disease of western countries [1]. The factors for musculoskeletal disorders are physical mismatch between worker & work centre, heavy workloads and psychological reasons [2]. Muscular fatigue is the important factor for MSDs [3]. Ergonomics deals with the capacity of workers and their body measurement to make the workplace suitable to them. The ergonomic study plays major role in designing the workplace which provides pleasant interaction between worker, work and the environment in many industries like manufacturing, process industry, construction, agriculture, mining and textile etc. Improper location of control units and small cabin not creating pleasant workplace [4]. The control units and levers must be placed systematically so that the work can be divided by two hands equally [5]. Working with uncomfortable body position repeatedly for long period of time leads to Musculoskeletal Disorders [6]. Providing safe and comfort workplace is the responsibility of employers. The cost for physical overexertion and injury will be reduced in ergonomic work centres.

2. Ergonomic assessment

Even now, most of the crane cabins are made based on fifty years old design, therefore cabins must be developed to meet present needs [7]. The objective of this study is to investigate the current working condition of EOT crane operators relates to MSDs. Also to formulate and propose corrective actions to posture adoption and cabin design to reduce MSDs. This can be done by collecting data using discomfort questionnaire and analysing frequent working postures. Postural analysis helps to identify the severity of body movement in real time. Rapid Upper Limb Analysis (RULA) method is simple and accurate tool to evaluate working posture severity.

3. Materials and methods

3.1. Crane details

24 EOT cranes of three different models (Aacess, Unicon and Cranex) are available in this shop floor. Aacess cranes are having two hoists of 20Tonne and 10Tonne capacity, other cranes having single hoist of 10Tonne capacity. The details of all cranes are given Table 1.
Table 1. EOT crane details and dimensions.

| Crane   | Quantity | Cabin size (mm) | No. of operators |
|---------|----------|-----------------|------------------|
|         |          | Length | Width | Height |          |
| Aaccess | 10       | 1345   | 1085  | 1900   | 25       |
| Unicon  | 10       | 1500   | 1245  | 1930   | 34       |
| Cranex  | 4        | 1840   | 1245  | 2000   | 8        |

3.2. Operators’ characteristics

69 employees are operating all these cranes in alternative shifts, 67 of them agreed for this survey, all are male and aged between 28 to 51 and having experience of 3 to 8 years. All the operators were informed about the study and prior consent is obtained, no one reported health issues which may affect this study. Table 2 shows the characteristics of the crane operators.

Table 2. Characteristics of crane operators.

| AGE | EXPERIENCE | HEIGHT | WEIGHT | BMI |
|-----|------------|--------|--------|-----|
| MINIMUM | 28 | 3 | 154 | 50 | 16.9 |
| MAXIMUM | 51 | 8 | 182 | 93 | 34.2 |
| MEAN | 33.75 | 6.88 | 166 | 65.7 | 23.9 |
| STANDARD DEVIATION | 5.04 | 0.98 | 6.7 | 2.41 |

3.3. Questionnaire Survey

The Questionnaire survey method is the famous and fundamental method for gathering data from the participants [8]. Getting self reports from the respondents are better and cheap method to use and sufficient for gathering information from huge participants [9]. Questionnaires are more transparent tool for gathering required data [10]. A questionnaire is developed similar to Cornell Musculoskeletal Discomfort Questionnaire [11]. All the crane operators are interviewed with this questionnaire and their responses are recorded. The questionnaire (Figure 2) contains a body diagram and questions about the prevalence of pain or discomfort in 19 regions of body, it inquire about frequency of pain, discomfort level and interference of work due to pain. The discomfort score is calculated as given in Table 3.

Figure 2. Questionnaire.
Table 3. Discomfort score calculation method.

| Frequency score | Severity score                      | Interference score |
|-----------------|-------------------------------------|--------------------|
| Never - 0       | Slightly uncomfortable - 1          | Not at all - 1     |
| 1 or 2 times/week - 1.5 |                        |                    |
| 3 or 4 times/week - 3.5 |Moderately Uncomfortable - 2       | Slightly interfered - 2 |
| Every day - 5    |                                     |                    |
| Several times per day - 10 | Very uncomfortable - 3            | Substantially interfered - 3 |

Discomfort score = Frequency score * Severity score * Interference score

3.4. Anthropometric study of crane operators
Designing of ergonomic work centre is not possible without knowing human anthropometry and nature of body movements. Anthropometric study is carried out for all the 67 crane operators. Figure 3 shows measuring stature of crane operator. 16 body dimensions are measured out of which 15 are static and 1 is dynamic dimensions. After that mean, standard deviation, Range, 5th, 50th and 95th percentiles of all dimensions are calculated and given in Table 4.

Table 4. Anthropometric details of crane operators.

| DETAILS                  | MINIMUM  | MAXIMUM | MEAN   | STD DEVIATION | 5th PERCENTILE | 50th PERCENTILE | 95th PERCENTILE | 50th PERCENTILE Indian |
|--------------------------|----------|---------|--------|---------------|----------------|-----------------|-------------------|------------------------|
| STATURE                  | 1564     | 1850    | 1690   | 56.4374       | 1609           | 1680            | 1798             | 1648                   |
| STANDING EYE HEIGHT      | 1440     | 1721    | 1574.119 | 54.1945       | 1495           | 1563            | 1669             | 1529                   |
| STANDING ELBOW HEIGHT    | 993      | 1197    | 1074.104 | 43.5163       | 1002           | 1072            | 1141             | 1039                   |
| KNUCLE HEIGHT            | 718      | 784     | 761.5 97 | 15.4538       | 725            | 765             | 780              | 703                    |
| SITTING HEIGHT           | 810      | 921     | 877.8 507 | 22.6964       | 845            | 876             | 910              | 837                    |
| SITTING EYE HEIGHT       | 706      | 806     | 763.3 881 | 23.1352       | 722            | 764             | 796              | 738                    |
| SITTING ELBOW HEIGHT     | 213      | 288     | 256.3 881 | 17.2327       | 230            | 254             | 284              | 213                    |
| POPLITEAL HEIGHT         | 406      | 524     | 472.1 045 | 30.6683       | 420            | 477             | 520              | 425                    |
With the help of ANOVA, 50th percentile of study population is compared with Indian anthropometric data, which are complied and developed by Dr. Chakrabarti [12]. The obtained p-value is 0.918, therefore no significant different between these two groups. Table 5 illustrates the summary of ANOVA.

Table 5. Results of 50th Percentile comparison using ANOVA.

| Groups                  | Count | Sum        | Average | Variance |
|-------------------------|-------|------------|---------|----------|
| 50th PERCENTILE COMPANY | 16    | 10734      | 670.875 | 207052.3 |
| 50th PERCENTILE INDIAN  | 16    | 10469      | 654.3125| 202010.8 |

| Source of Variation | SS    | df  | MS              | F          | P-value | F crit |
|---------------------|-------|-----|-----------------|------------|---------|--------|
| Between Groups      | 2194.531 | 1   | 2194.531        | 0.01073    | 0.918189 | 4.170877 |
| Within Groups       | 6135945 | 30  | 204531.5        |            |         |        |

3.5. Study of workstation

The examination of EOT crane cabin shows that the seats provided for operators are not comfortable to sit for long time. Its height is 420mm and there is no provision for seat height adjustment. Arm rest, foot rest and back supports are also not provided. The control lever positions are not user friendly. Figure 4 shows the existing cabin and operator’s seat.
3.6. Posture analysis
Frequent working postures of crane operators are observed in real time and images are captured (Figure 5) and analysed with RULA using Ergofellow-3 software. RULA is the simple and good tool used to analyse the loads on the musculoskeletal system of workers due to their working postures and forces exert by muscles [13].

4. Results

4.1. Questionnaire survey results
Survey result shows that 48(71.6%) operators have affected by MSD. 19(28.3%) of them have consulted with doctor for their MSD and 9(13.3%) of them have taken leave because of their MSD during last one year. 26(38.8%) employees feel energetic during their full day of working but 23(34.3%) employees feel tired at second half of the shift and 18(26.8%) employees feel tired if there is more work on that day. Only 11(16.4%) employees feel that existing crane cabin is comfortable but 56(83.5%) employees feel that existing crane cabin is not comfortable for working. It is observed that the operators are affected by pain in various body parts, lower back(64%), neck(54%), upper back(37%), knee(33%), and shoulder(31%). Figure 6 indicates body parts vs. number of persons affected. Lower back is the most affected area and has highest discomfort score compare to other regions. Figure 7 indicates the discomfort scores of all body parts.
Figure 6. Number of persons affected on each body part.

Figure 7. Cumulative Discomfort scores of body parts.

Crane wise mean discomfort scores are compounded and indicated in Figure 8, which shows that Unicon crane has highest mean discomfort score compare to other type of cranes. Figure 9 shows the age wise mean discomfort score of crane operators which clearly illustrates the discomfort level is increased with age.
4.2. Postural analysis results

The observed postures are analysed with RULA using Ergofellow-3 software. Modern technology makes easy to evaluate the work station. Also it is used to identify the factors that create health
problems and diagnose the level of comfort of operators during their working postures [14]. The obtained RULA score is 6 (Figure 11), therefore investigation and changes are required soon.

Figure 11. Results of RULA.

5. Discussion
Operating of EOT Crane is a complicated and repetitive work. The operator needs to operate the control levers and watch the object movement and he should make an alarm to alert the employees those are on the path of the crane. Also he has to watch rigger for further instructions. Therefore operation of EOT Crane needs both mental and physical work at same time. Like others the crane operators cannot move easily out of their work centre because of the cabin constraints, height and isolation. During the study of work station, we have observed that the chairs provided are not suitable for sitting long duration. The chair is not having sufficient back support. Elbow rest and foot rest also not provided. The height of seat is only 420mm and it has no height adjustment system, so it is only suitable for 5th percentile of our study population.

Eliminating physical and psychosocial hazards are important to reduce work related MSDs [15]. Operating EOT crane needs steady and static position to activate control levers by hand and it involves twisting of body frequently and extreme bending on sideways, these are the factors that cause lower back pain. Our study also indicates that majority of operators have affected by MSDs and most of them suffered by lower back pain followed by neck pain, which is inline with the similar studies of long duration sitting work of forklift operators. They also feel higher discomfort in lower back and neck [16].

The Mean discomfort scores were analysed with respect to age and experience. The discomfort level is increased with age, 28 - 32 years category operators having mean discomfort score of 38 and 33 - 37 years category operators having the score of 64. Age 38 years & above category operators having the score of 94 which is much higher than the younger employees. Aged employees quickly suffered by back and shoulder pain and they need more relaxation time to recover irrespective of their experience [17]. A nationwide study in Taiwan for the prevalence of MSDs in workers indicated that higher age group 55-64 suffered more 44% compared to lower age group 18-24 only 24.8% [18]. Older workers may quickly suffered by MSDs due to their natural ageing [19]. Whereas the study of discomfort while working in manufacturing industries showing that intermediate age group workers having higher discomfort level compared to younger and elder groups[20].

The years of exposure versus discomfort analyse illustrates that it is not direct proportional with experience. Least years of exposure operators(3-4years) have lesser mean discomfort score of 14 and moderate years of exposure operators have more mean discomfort score of 62 but it is decreased with higher years of exposure, 7-8 years category operators having discomfort level of 48. This is in line with the risk assessment of WMSD among TFT-LCD manufacturing operators, found that prevalence of WMSDs for 1 to 2 years of experience is 14.8% and 4 to 5 years of experience is 29.7% whereas over 6 years of experience workers affect 20.7% [21].

The position of control levers are not in accordance with operators reach, operators need to make awkward postures to activate the control levers and they have to maintain the same postures till
completion of movement and immediately start another movement. So they become tired and fatigue. Working in this method for a longer period of time leads them to musculoskeletal pain and disorders. Our analysis using RULA and Ergofellow-3 software indicates the score of 6.

The ergonomic chair selected from the market with the following facilities,

- Popliteal height adjustment system to accommodate 5th to 95th percentile (420 to 520mm)
- Adjustable arm rest (230 to 285mm)
- Wide seat width to accommodate 95th percentile (500mm)
- Sufficient back support

The chair fixed in the cabin (Figure 12) and cabin front side guard height is reduced for 100mm from existing level to improve visibility and reduce neck discomfort. After 3 months of trial, again the questionnaire survey is conducted to operators and results are compared with existing discomfort score, which is indicated that the discomfort level is drastically reduced (Figure 13). Particularly cumulative discomfort score of lower back is reduced to 404 from 1191 therefore 66% reduced from existing level. Postural analysis also conducted with new chair which gives the RULA score of 3.

**Figure 12.** New ergonomic chair attached and RULA analysis carried.

**Figure 13.** Comparison of Cumulative Discomfort scores of existing and new cabin.

### 6. Conclusion

Operators working in Unicon cranes have reported higher discomfort level. Many of the operators suffered on lower back, neck, upper back, knee and shoulder but lower back being the highest level of discomfort. Both discomfort survey and postural analysis indicated that working with existing crane cabin for longer period of time leads to the risk of getting musculoskeletal disorder to operators. Therefore cabin should be modified to fit with its working population by applying ergonomic principles. The control unit positions (LT, CT, HC) have to be located within the comfortable reach zone of operators with minimum bending and twisting of body parts as far as possible.
Provision of ergonomic chair and reduction of cabin front side guard height have drastically reduced the discomfort level of operators. In future joystick mechanism and VDU display may also be provided to increase the comfort level of operators.

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