Musculoskeletal disorders and posture analysis of ethylene dichloride (EDC) production operator

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Abstract. The production process of Ethylene Dichloride (EDC) in most companies has been integrated with technological advances, but the role of the human as an operator is still vital. In this study, the operator’s work posture analysis, as well as an evaluation of three main production activities at the petrochemical company in Qatar, were conducted. The main objective is to assess the risks carried out by panel & field operators. This assessment is important to maintain the operator’s productivity within the industrial system context. A Nordic questionnaire was applied to collect information on Musculoskeletal Disorders (MSDs) symptoms from 34 operators, while Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) was utilized to analyze risks of work postures. How operators perceived their workload was also evaluated using NASA-TLX. About 79% of operators suffered from shoulder pain, 70% suffered a waist disorder as a symptom of MSDs, and it can cause disrupted productivity in the long run. The operators’ posture during performing their tasks was identified as a high level of risk and requires immediate action based on RULA and REBA scores. To reduce MSDs symptoms and posture risk scores, a portable platform and handle wheel chain was proposed. Based on NASA-TLX result the operators perceived that workload as somewhat high to high with score 49-60 on average (scale 1-100). Addition outsourced personnel was suggested to decrease the workload level in a certain operation.

Keywords: Ethylene Dichloride, musculoskeletal disorders, Nasa-TLX, RULA, REBA, Nordic questionnaire

1. Introduction
Ethylene dichloride (EDC) is used primarily for the production of vinyl chloride monomer (VCM). It is used mainly in the polymerization manufacture of polyvinyl chloride (PVC) which is used in pipes, fittings, profiles, tubes, windows, doors, and others including construction and infrastructure, agriculture, electrical and healthcare products. EDC is also used as an intermediate in the manufacture of chlorinated solvents and ethylene amines, and as a solvent in the textile, metal cleaning, and adhesive industries. The production process of EDC is one of the complex petrochemical manufacturing industries, which includes a large part of the processes in the oil and gas and petrochemical industries from both the equipment and the technology. At present many companies have been integrated with technological advances, but the role of humans is still important especially for activities that need some physical efforts [1]. The operation of some equipment can be done
automatically and operated remotely, but there will be times when the equipment is damaged and does not work. In this such condition, the operation should be taken over by humans to reducing further the downtime (loss) of production. Not only that, for safety reasons, some activities cannot be done automatically and should operate and control by human which related to judgment and alertness. During the operating of industrial equipment, several complaints were found about the inconvenience and pain felt by most operators after carrying out operational activities. There are at least 595 cases that related to musculoskeletal disorder in Malaysia, and the operators who operate a valve has experienced pain in the hand muscles and the waist [2]. These symptoms were also reported unofficially by ethylene dichloride production operators at one company in Qatar.

Activities such as re-boiler activation, pump replacement, controlling valve during pump standby mode had to be finished manually and those activities need a physical effort and close attention of the operators to complete the operation. While finishing the tasks, the operators felt some discomfort and pain caused by valve-hand wheel height and pulling directing or force exertion [3, 4]. Not only a physical effort, but the physical environment can also influence the discomfort level such as temperature and humidity level. In Qatar, those natural conditions are often at a high-risk level. In June to September for example, the temperature and humidity usually are very high and causing the increasing heat stress index (over 31 points) (supreme council of heat) [5]. When it happened, the operators tend to "want to finish their work immediately" which results in losing concentration especially in positioning the body when operating the equipment.

This research addresses the MSDs problem experienced by ethylene dichloride (EDC) production operator and the effect of working conditions on employee productivity. The objective is to propose any improvement for valve operation operator to reduce the risks which focus on improving the operator’s posture.

2. Subject and Methods
To gather the data, a workload assessment was conducted using NASA-Tlx [6]. About 34 operators agreed to involve in this research. A translated Nordic Musculoskeletal Questionnaire was used to snapshot the physical pain and discomfort at certain body parts such as shoulder, wrist, hand, etc. [7]. A posture risks that were experienced by the operators was assessed using Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) method [8][9][10]. Figure 1 showed the methodology for this study.

![Research flowchart](image)

3. Data Collection and Analysis
Participants of this study are including 34 respondents (operators) from Indonesia (62%), Indian (18%) and the Philippines (20%) ranging in age from 25 - 52 years old, working experience 1 - 18 years with
169 cm height in average. The operation of this production process requires 24-hour supervision for 7 days which requires the number of production operators between 8-10 operators per shift.

NASA-TLX data was collected from all operators involved in operating the valve in the company (34 operators). The workload indicators including mental demand (MD), physical demand (PD), temporal demand (TD), performance (OP), effort (EF) and frustration (FR). NASA-TLX contained 15 indicator pairs which were chosen one in each box according to which they were more dominant. Participants also filled the rating in scale of 1 - 100 on each indicator that is adjusted to the conditions experienced by the respondent. The results of the questionnaire can be seen in the following Table 1 below:

| Participant | MD | PD | TD | OP | EF | FR | Total |
|-------------|----|----|----|----|----|----|-------|
| Opr 1       | 45 | 85 | 70 | 25 | 75 | 70 | 15    |
| Opr 2       | 60 | 85 | 85 | 25 | 80 | 60 | 15    |
| Opr 3       | 70 | 90 | 75 | 20 | 70 | 95 | 15    |
| Opr 4       | 60 | 95 | 80 | 25 | 65 | 70 | 15    |
| Opr 5       | 75 | 90 | 85 | 20 | 70 | 80 | 15    |
| Opr 6       | 75 | 95 | 85 | 20 | 85 | 70 | 15    |
| Opr 7       | 55 | 90 | 70 | 10 | 75 | 90 |       |
| Opr 8       | 50 | 85 | 75 | 10 | 55 | 85 |       |
| Opr 9       | 50 | 90 | 80 | 15 | 55 | 80 |       |
| Opr 10      | 40 | 90 | 80 | 10 | 65 | 85 |       |
| Opr 11      | 50 | 90 | 70 | 10 | 80 | 70 |       |
| Opr 12      | 70 | 95 | 80 | 5  | 85 | 70 |       |
| Opr 13      | 70 | 95 | 85 | 10 | 80 | 75 |       |
| Opr 14      | 65 | 95 | 80 | 10 | 75 | 85 |       |
| Opr 15      | 60 | 95 | 80 | 5  | 60 | 85 |       |
| Opr 16      | 50 | 95 | 70 | 10 | 65 | 85 |       |
| Opr 17      | 45 | 95 | 80 | 10 | 85 | 85 |       |
| Opr 18      | 45 | 95 | 75 | 10 | 85 | 90 |       |
| Opr 19      | 40 | 90 | 80 | 15 | 60 | 95 |       |
| Opr 20      | 45 | 95 | 85 | 10 | 65 | 90 |       |
| Opr 21      | 50 | 85 | 85 | 15 | 75 | 80 |       |
| Opr 22      | 60 | 75 | 75 | 15 | 75 | 75 |       |
| Opr 23      | 65 | 70 | 80 | 15 | 80 | 80 |       |
| Opr 24      | 50 | 90 | 75 | 15 | 70 | 90 |       |
| Opr 25      | 55 | 90 | 75 | 15 | 65 | 90 |       |
| Opr 26      | 50 | 90 | 70 | 15 | 55 | 80 |       |
| Opr 27      | 55 | 90 | 70 | 15 | 60 | 90 |       |
| Opr 28      | 65 | 80 | 75 | 10 | 75 | 80 |       |
| Opr 29      | 55 | 85 | 75 | 15 | 70 | 85 |       |
| Opr 30      | 65 | 85 | 75 | 10 | 65 | 80 |       |
| Opr 31      | 60 | 80 | 80 | 10 | 75 | 90 |       |
| Opr 32      | 60 | 85 | 85 | 10 | 75 | 85 |       |
| Opr 33      | 65 | 80 | 70 | 10 | 80 | 85 |       |
| Opr 34      | 55 | 85 | 80 | 10 | 80 | 85 |       |

After the NASA-TLX questionnaire filled and the result was obtained, the next step is to calculate the product and Weight Work Load value (WWL). The value of this product was determined by multiplying each indicator in the weighting table data (factor weight) with each indicator in the rating in Table 1. While the WWL value is the number of indicators for each respondent. The average WWL score is the WWL value divided by the total weight (Table 2).
Table 2. NASA-TLX result (2): WWL value and Workload level

| opr | MD  | PD  | TD  | OP  | EF  | FR  | WWL Value | WWL Scores |
|-----|-----|-----|-----|-----|-----|-----|-----------|------------|
| opr 1 | 45  | 425 | 140 | 100 | 75  | 140 | 785       | 52.33 High |
| opr 2 | 0   | 425 | 170 | 100 | 160 | 120 | 855       | 57 High     |
| opr 3 | 70  | 360 | 150 | 60  | 70  | 380 | 710       | 47.33 Somewhat High |
| opr 4 | 60  | 380 | 240 | 125 | 0   | 140 | 805       | 53.67 High  |
| opr 5 | 75  | 475 | 240 | 50  | 70  | 240 | 910       | 60.67 High  |
| opr 6 | 75  | 475 | 255 | 60  | 85  | 150 | 950       | 63.33 High  |
| opr 7 | 55  | 450 | 210 | 20  | 75  | 270 | 810       | 54 High     |
| opr 8 | 0   | 425 | 225 | 30  | 55  | 240 | 735       | 49 Somewhat High |
| opr 9 | 60  | 450 | 240 | 45  | 0   | 240 | 795       | 53 High     |
| opr 10 | 40  | 360 | 240 | 40  | 65  | 170 | 745       | 49.67 Somewhat High |
| opr 11 | 0  | 450 | 140 | 40  | 240 | 70  | 870       | 58 High     |
| opr 12 | 140 | 475 | 160 | 15  | 85  | 160 | 875       | 58.33 High  |
| opr 13 | 70  | 475 | 255 | 30  | 80  | 150 | 910       | 60.67 High  |
| opr 14 | 130 | 475 | 320 | 20  | 0   | 170 | 945       | 63 High     |
| opr 15 | 0   | 475 | 160 | 20  | 60  | 255 | 715       | 47.67 Somewhat High |
| opr 16 | 0  | 475 | 140 | 40  | 65  | 255 | 720       | 48 Somewhat High |
| opr 17 | 0  | 475 | 80  | 40  | 170 | 255 | 765       | 51 High     |
| opr 18 | 0  | 475 | 150 | 40  | 85  | 270 | 750       | 50 High     |
| opr 19 | 0  | 360 | 160 | 60  | 60  | 380 | 640       | 42.67 Somewhat High |
| opr 20 | 45  | 475 | 170 | 30  | 65  | 270 | 785       | 52.33 High  |
| opr 21 | 50  | 340 | 255 | 60  | 75  | 160 | 780       | 52 High     |
| opr 22 | 120 | 300 | 150 | 45  | 150 | 150 | 765       | 51 High     |
| opr 23 | 65  | 280 | 160 | 45  | 160 | 240 | 710       | 47.33 Somewhat High |
| opr 24 | 50  | 450 | 75  | 60  | 140 | 180 | 775       | 51.67 High  |
| opr 25 | 0   | 360 | 150 | 45  | 130 | 360 | 685       | 45.67 Somewhat High |
| opr 26 | 0   | 450 | 210 | 15  | 55  | 400 | 730       | 48.67 Somewhat High |
| opr 27 | 55  | 450 | 140 | 30  | 60  | 360 | 735       | 49 Somewhat High |
| opr 28 | 0   | 320 | 225 | 20  | 150 | 320 | 715       | 47.67 Somewhat High |
| opr 29 | 55  | 425 | 150 | 30  | 70  | 340 | 730       | 48.67 Somewhat High |

It was found that the workload experienced by EDC operators can be categorized into moderate to high scores (perceived by 13 operators), and high workload (perceived by 21 operators). Risk assessment of operators’ posture, initiated by collecting information of discomfort and pain experienced by the operators (Table 3).
Table 3. Nordic Musculoskeletal Questionnaire

| Part of Body | Complaint (%) | Part of Body | Complaint (%) |
|--------------|---------------|--------------|---------------|
| Neck         | 47.06         | Lower Back   | 70.59         |
| Shoulder     | 79.41         | Hip/Thigh    | 0.00          |
| Elbows       | 55.88         | Knee         | 35.29         |
| Wrist/Hands  | 0.00          | Ankle/Feet   | 17.65         |
| Upper Back   | 41.18         |              |               |

As can be seen in Table 3, there were 79.41% of respondents experienced complaints on the shoulders, followed by 70.59% of others experienced complaints on the lower waist. The third complaint position was the elbow position which occupies 55.88% of the respondents. The complaints reported by operators were estimated to be caused by at least three operations which are pump change activity, Reboiler replacement operation, and flow rate regulation by bypass valve as seen in Figure 2 & Figure 3.

Figure 2. (a) Pump change over, (b) Reboiler change over
RULA and REBA was utilized to assess the posture risk for certain operation that described in Figure 3. The position of the operators can be seen as follows (Figure 4):

**Figure 3.** Flow adjustment with Bypass valve activity

**Figure 4.** The operators during the operation of hand wheel
The operation of the valve in a pump replacement with a flow variation of 5 tons/hour to 3000 tons/hour requires operator assistance related to the pump operating characteristics. The operation of the valve cannot be replaced with a motorized model because it requires a smooth operation to obtain a fluid increase slowly. The valve in the reboiler replacement operation includes 3 main activities, which are: the operation of the valve for the steam line, liquid line and steam line which functions as a fluid heating media that will be vaporized. One of the activities is the operation of a steam valve with a size of 26 - 42 inches, to get steam flow up to 16 tons/hour. The operation of flow control with a bypass valve aims to get the flow that is suitable for the needs of the process and to bypass one of the equipment such as control valve, exchanger and reaction column when getting problems (trouble). For those activities that described above, the result of RULA and REBA was summarized in Table 4 below:

| Activity                | Assessment Method | Risk Score | Risk level                               |
|-------------------------|-------------------|------------|------------------------------------------|
| Pump Change Over        | RULA              | 7          | Further investigation and changes are required immediately |
|                         | REBA              | 8          | Very high risk, implement change now     |
| Reboiler Change Over    | RULA              | 7          | Further investigation and changes are required immediately |
|                         | REBA              | 8          | Very high risk, implement change now     |
| Adjustment with Bypass Valve | RULA              | 7          | Further investigation and changes are required immediately |
|                         | REBA              | 9          | Very high risk, implement change now     |

Based on RULA and REBA result, some tools was proposed to reduce the risks level (Figure 5 and Figure 6).

![Figure 5. Pump change over operator posture’s improvement](image)

The operation of the valve in a pump replacement with a flow variation of 5 tons/hour to 3000 tons/hour requires operator assistance related to the pump operating characteristics. In the operation
of pump replacement with a crouching position, the valve handle can be extended using a chain gearbox so that the trunk position which in the current position has an angle of 20-60 degrees, can be lowered to 0 degrees. The upper arm angle position can be lowered from scale 3 to 1. The addition of the extension of the valve handle, the operator's position in carrying out activities is expected to no longer sit crouching, correction of body position when operating the valve becomes standing (Figure 6).

The recommended valve height position limit is obtained between 108.73 cm and 145.09 cm. To reduce the value of the valve range and valve operating angle, it is recommended to use a portable platform that is expected that the valve operating angle at the upper arm can go down from scale 5 to scale 1 will greatly assist the operator in operating the valve comfortably. The material of portable platforms is expected to have good strength but quite light so that it does not burden the operator in moving this platform and the operator can adjust the operating angle properly. In the bypass valve operation, it is recommended that the valve position be changed perpendicular (vertical) and the valve handwheel is replaced with a handwheel equipped with chain extension (Figure 7).

In reducing RULA and REBA scores as proposed, anthropometric data were considered in the improved design. Anthropometric dimensions such as shoulder-grip length, the distance needed to determine the maximum size that must be set so that the majority of the population will be able to reach and operate work equipment (handle valve). The ideal posture is with the shoulder position not raised too high with a maximum limit of 200 to operate the valve. Based on anthropometry data, the average shoulder height is 145.09 cm with a 95% percentile. The lowest valve position is ideal when operating the body does not bend with the lower hand located at an angle of 200-1000, this position can be adjusted by measuring the height of the average elbow. Based on anthropometric data, elbow height is 108.73 cm with 95% percentile (Figure 7).
Table 5 summarized the proposed tool to reduced operator’s MSDs symptoms as follow:

| Activity             | Tool proposed               | Area of MSDs symptoms to be reduced |
|----------------------|-----------------------------|-------------------------------------|
| Pump change over     | Extended valve handle       | Knee, Upper Back, Lower Back, Shoulder, Wrist/hand |
| Reboiler change over | Foldable step               | Neck, Shoulder, Wrist/hand, Upper back |
| Bypass valve operation | Hand wheel with chain extension | Neck, Upper Back, Shoulder, Wrist/hand |

4. Conclusion
The results of the analysis of workload levels using NASA-TLX conducted on EDC companies, 61.8% of operators have high load scores, and the remaining 38.2% operators have moderate to high workload scores. While the results of the analysis of the NORDIC questionnaire showed that 79.41% of respondents had complaints on their shoulders, followed by 70.59% of others had complaints on the lower wrist. The third complaint position was the elbow position which occupies 55.88% of the respondents. REBA and RULA scores that have a scale above 7 with medium and high risk require investigation and implementation of changes in operating conditions. By providing the platform, the previous reach dimension angle at the upper arm > 90 degrees can be minimized to 0 - 20 degrees. Likewise for valve operation in a crouched sitting position, with the addition of an extension to the valve stem using a dual gearbox that will simplify operation and reduce REBA and RULA scores.
The workload measured using NASA-TLX showed that the operation of the valve in an uncomfortable position produced a high score, which means the workload carried out is considered heavy. The company should make changes and improvements by applying the method of scheduling operational activities of equipment by cooperating with involving the entire existing departments such as maintenance, inspection, reliability department, and production. In addition to this, the addition of outsourcing operator to help operate industrial equipment (valves) can also be done to reduce fatigue for the main operator in the production process.

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