Abstract
Occupational fatigue is a serious problem since it may cause several issues, including deteriorating human performance. Some major accidents in the oil and gas industries were associated with the lack of human performance due to occupational fatigue. This study aimed to analyze the impact of occupational fatigue on human performance among oil and gas workers in Indonesia. This study used a cross-sectional design using a self-administered validated questionnaire to gather information on demographic (gender and age), work characteristics (work rotation, work duration, shift work model, day/night shift, job position), sleep debt, sleep quality, occupational (acute and chronic) fatigue, and at-risk behavior as the indicator of human performance. In this study, a total of 1,650 workers from different fields (production, drilling, well service, construction, and administration/office) participated. This study showed that occupational fatigue (both chronic and acute) has potentially decreased level of human performance. This implied that managing occupational fatigue may prevent deteriorating human performance.

Keywords: at-risk behavior, business continuity, fatigue, human performance, oil and gas workers

Introduction
Fatigue is one of the contributors to human errors and results in slower reactions. It reduces the ability to process information, memory lapses, absent-mindedness, decreased awareness, lack of attention, underestimation of risk, and reduced coordination. Fatigue can lead to errors and accidents, moreover in workplaces. The Health and Safety Executive of the United Kingdom even stated that fatigue contributes to 20% of accidents on major roads and causes financial costs. Oil and gas industries are well known to be linked to very-high-risk operations. A small mistake (at-risk performance) may lead to a catastrophic incident resulting in multiple fatalities, environmental damage, loss of assets, and business disruption.

The British Petroleum Texas City Refinery accident on March 23, 2005, caused fifteen fatalities, 180 injuries, and financial losses of up to more than US$ 1.5. From the results of The U.S. Chemical Safety and Hazard Investigation Board (CSB) investigation, it was also found that the workers experienced sleep deprivation, some of them forced to work overtime due to a reduction in workers. The British Petroleum had to pay a total compensation cost of US$65B after the incident. The investigation revealed that some crewmen were working three weeks offshore and were thus perhaps suffering from fatigue. There was a similar incident at the Deepwater Horizon oil rig in the Gulf of Mexico on April 20, 2010. The drilling rig was preparing to temporarily abandon the Macondo Well when it, unfortunately, experienced a kick and ended with a disastrous oil spill in the Gulf of Mexico. The oil rig’s crew was also exposed to commercial pressure to speed up the temporary abandonment procedure, which was already six weeks behind schedule.

The British Petroleum Texas City and Deepwater Horizon incidents show that defective human performance can lead to major incidents or business disruption. In many industrial incidents, fatigue was observed to be the critical factor that influenced human performance. It was also explained that when workers experience excessive fatigue, they will be unable to make the right decisions or find it difficult to do so. Especially when there is an emergency situation or when excessively fatigued workers come to face a life-threatening condition, the probability of them making a wrong decision increases.
up to 99\%.\textsuperscript{8} Mostly, a wrong decision caused by fatigue can lead to impaired reasoning, decreased decision-making ability, reduced vigilance and focus/attention, reduced mental functioning. This decision is usually low reaction time, temporary loss of situational awareness, bypassing procedures, or shortcuts.\textsuperscript{9}

Occupational-fatigue risk factors as consisting of three main groups: individual factors, work factors, and non-work-related factors.\textsuperscript{10} The individual factors include age, health status, and adaptability. Work factors include roster pattern, work time, poor work scheduling, shift time, type of work done, continuous demanding work, and position level/decision latitude. Non-work-related factors include recovery time between shifts, long periods of awake time, inadequate rest breaks, a non-conducive environment, lack of sleep and rest, poor quality of sleep, other employment, and excessive travel time.\textsuperscript{10}

Acute fatigue is fatigue after a period of physical and mental stress, including strenuous muscle effort, immobility, heavy mental workload, intense emotional distress, monotony, and lack of sleep.\textsuperscript{11} If acute fatigue is experienced continuously over a long period and there is no adequate recovery, it will develop into chronic fatigue. Chronic fatigue brings with it a combination of physiological and psychological problems.\textsuperscript{11} Fatigue that workers experience has the potential to cause negligence and poor judgment.\textsuperscript{9}

When workers experience or are exposed to fatigue, their performance will decrease. This decrease has the potential to cause human error. Gerald Matthews, \textit{et al.},\textsuperscript{12} showed that each individual has different susceptibility (Individual Differences IDs) to the fatigue they experience. The human performance decrease is mainly determined by the level of vulnerability (fatigue vulnerability) and resilience (fatigue resistance) of each worker IDs.\textsuperscript{12}

Therefore, managers need to know the relationship between worker fatigue and human performance, so they will be able to anticipate potential incidents by managing the factors contributing to worker fatigue in the organization by developing a fatigue risk management system (FRMS).\textsuperscript{13} This study aimed to analyze the association between work fatigue and human performance among Indonesian oil and gas workers. The results of this study can be considered to prevent and control worker fatigue in the workplace and maintain and improve human performance for business continuity management.

\textbf{Method}

This cross-sectional study used a self-administered validated questionnaire to measure occupational fatigue using a standard method, “Occupational Fatigue Exhaustion Recovery (OFER),” as the independent variable and nine at-risk behaviors to predict the change of human performance as the dependent variable. In order to have represented the sample, this study used random sampling method. The sample calculation refers to Roscoe (1975) quoted by Sakaran U,\textsuperscript{14} the minimum sample required is 10 times the number of variables. In this study the number of variables was 25 variables. Thus, the minimum sample required was 10 x 25 = 250 sample. The sample inclusion criteria in this study were all employees of oil and gas at Perusahaan Migas X. Meanwhile, the exclusion criteria in this study were employees who were sick, on leave, and workers who were not willing to fill out questionnaires. This study was deployed to all entities in the organization, such as the Production & Maintenance Department, onshore & offshore fields workers, drilling rigs & well servicing, construction, and administration/office. There were 1,573 data out of 1,650 total respondents included in this study analysis, and 77 were excluded (50 data were used for questionnaire validity test, and the other 27 data were incomplete and thus considered invalid).

The OFER standard questionnaire developed by Windwood, \textit{et al.},\textsuperscript{15} consisted of 15 questions, including three sub-scales; acute fatigue five questions, chronic fatigue five questions, and inter-shift recovery five questions. All subscales were scored using 7-point Likert Scale and scored 0-100.\textsuperscript{15} Overall, the results of the acute and chronic fatigue calculation were grouped into four quartiles of 0-100 (e.g., scores 0-25 was categorized as a mild acute or chronic fatigue level; 26-50, moderate acute or chronic fatigue level; 51-75, high acute or chronic fatigue level; and 76-100, very high acute or chronic fatigue level).

At-risk performance was measured using a self-administered questionnaire which adopted from the U.S. Department of Energy (DOE),\textsuperscript{9} and had been tested for the reliability and validity. The results of the validity test showed all the questions in the questionnaire were valid that showed by the significant value (2-tailed) was 0.000 (p value<0.05). The reliability test, used the Cronbach Alpha test, showed an alpha value of 0.883 where the value into the category of high reliability. The at-risk performance questionnaire consist nine at-risk behaviors when the respondents worked in a fatigued state in the last 12 months before the survey (Table 1). These nine at-risk behaviors are shown below.

\textbf{At-risk 1 – Working while tired/sleepy}
\textbf{At-risk 2 – Short memory loss}
\textbf{At-risk 3 – Mis-prediction/anticipation}
\textbf{At-risk 4 – Wrong/poor decision}
\textbf{At-risk 5 – Slow body movement/reflex}
\textbf{At-risk 6 – Taking a shortcut/skipping or bypassing a task in the task sequence}
\textbf{At-risk 7 – Lack of focus/attention}
At-risk 8 – Working in a hurry
At-risk 9 – Lack of verification (over-assumption)

The total at-risk behavior score is cumulative of nine individual answers: never = 0, once = 1, and more than one = 2. The total score for each respondent will vary from 0 to 18. The gathered data were analyzed using Stata for Windows version 12.1 for the univariate and multivariate analysis. Level of acute and chronic fatigue, a score of acute and chronic fatigue, and human performance respondents were variables explained by univariate analysis. Single linear regression linear analysis was used to determine the relationship between acute fatigue score and chronic fatigue score as independent variables and human performance score as the dependent variable. The significance of multivariate analysis was alpha 5%. If p-value<0.05, it means that acute fatigue and chronic fatigue significantly could predict human performance.

Results

The distribution of respondents age between 20 – 57 years old which age mean in 37 years old. Mostly respondents work in onshore field (46.4%) and the second one was swampy field (43.2%). Mostly respondents (75.5%) have 12 working hours. A total of 53.6% of respondents worked with a shift work system. Respondent positions vary, consisting of manager, superintendent/assistant manager, foremen/supervisor, operator/technical/crew of land/sea/air transportation, and assistant operator/helper. The most position of the respondents was operator/technical/crew of land/sea/air transportation (52.4%).

Table 2 shows the distribution of the respondents with acute and chronic fatigue levels based on their score assessments. On average, almost all workers were at a moderate level of fatigue (score 26-50). Table 3 shows that the average acute fatigue score of the respondents was 42.3 (95% confidence interval (CI) = 41.3–43.2), with a standard deviation of 19. Meanwhile, the average chronic fatigue score of the respondents was 31.9 (95% CI = 30.8–33), with a standard deviation of 22.62.

The study participants’ human performance was assessed using nine questions regarding the at-risk behaviors experienced by the worker respondents in the last...
In this study, most of the workers in
the background of shortcuts is a motivational
impact of occupational fatigue on human performance among oil and gas workers in Indonesia.
CI = Confidence Interval, Dependent variable = Overall performance

Poor judgment happens as a consequence of a
chronic fatigue. Chronic fatigue at high and very high levels of chronic fatigue and even very high levels of
causes health problems for workers, especially in the nervous system and immune system.
Mild chronic fatigue can develop into moderate, high, and very high chronic fatigue levels. Chronic fatigue can cause health problems for workers, especially in the nervous system and immune system. In addition, it is paramount to note that there are workers who experience high levels of chronic fatigue and even very high levels of chronic fatigue. Chronic fatigue at high and very high levels has the potential to cause an accident in the workplace.

The findings of this study also showed that acute and chronic fatigue significantly impacted the human performance of workers. Acute and chronic fatigue negatively correlated to human performance, which means the more workers experience acute and chronic fatigue, the greater the decrease in their work performance. The human performance score decreased by 0.511 to increase acute fatigue value (Table 4). In other words, for every increase in chronic fatigue, human performance will decrease by 0.491 (Table 5). This result was in line with the finding of the study by the US DOE that a higher level of fatigue is likely to degrade work performance (increase in the probability of human errors, lapses, slips, mistakes, errors, and violations; negligence (human error); and inadequate judgment). In addition, other previous studies showed that fatigue was one of the contributors to bad human performance, known as a human error which consists of lapses, slips, mistakes, and violations in the petrochemical, oil, and gas industry. Furthermore, Yeow, et al., found that 48.8% of human errors committed by the subjects in her study were caused by fatigue, stress, work repetition, and the work environment.

In this study, human performance was indicated by nine at-risk behaviors. They were working while tired/sleepy, temporary memory loss, misprediction/anticipation, work in hurry, and short cut/skip/bypass were the most at-risk behaviors reported. In addition, all at-risk behaviors were experienced more than once (several times) a year (Figure 1).

Tables 4 and 5 show the results of the single linear regression analysis of how the worker respondents' human performance was affected by their acute and chronic fatigue as independent variables. The associated correlation based on Table 4 can be interpreted using the formula: HP = 104.353 – 0.511 AF, where HP is Human Performance and AF is Acute Fatigue. The associated correlation based on Table 5 can be interpreted using the formula: HP = 98.183 – 0.491 CF, where HP is Human Performance and CF is Chronic Fatigue.

### Discussion

The results of the study showed that most of the workers experience moderate acute fatigue. However, there were several workers experiencing high acute fatigue and even very high acute fatigue. This result must be a concern because a barrier failure can cause an accident due to high or very high fatigue. When workers experience acute fatigue continuously over a long time with no adequate recovery, it will accumulate, resulting in chronic fatigue. In this study, most of the workers in Perusahaan Migas X experienced mild chronic fatigue. Mild chronic fatigue can develop into moderate, high, and very high chronic fatigue levels. Chronic fatigue can cause health problems for workers, especially in the nervous system and immune system. In addition, it is paramount to note that there are workers who experience high levels of chronic fatigue and even very high levels of chronic fatigue. Chronic fatigue at high and very high levels has the potential to cause an accident in the workplace.

The most at-risk behavior experienced by workers in Perusahaan Migas X is working while tired/sleepy, either experienced once or several times in the last twelve months. While working in tiring conditions, workers have the potential for negligence, poor judgment, and decreased preparedness that potentially caused accidents. Poor judgment happens as a consequence of a decrease in mental function. Furthermore, taking a shortcut/skipping or bypassing task sequence was the second most at-risk behavior in this survey. They were taking a shortcut/skipping or bypassing a task in the task sequence, lack of focus/attention, work in a hurry, and lack of verification (over assumption). This study also showed a similar result with Enoka and Duchateau, that fatigue led the workers to experience impaired reasoning and decision making and decreased alertness/attention. Fatigue also slows down mental function and reaction time and leads to loss of situational awareness (forgetting for a moment) and shortcuts. Fatigue is considered an unsafe condition in the workplace as it is likely to increase the risk of accidents.

The most at-risk behavior experienced by workers in Perusahaan Migas X is working while tired/sleepy, either experienced once or several times in the last twelve months. While working in tiring conditions, workers have the potential for negligence, poor judgment, and decreased preparedness that potentially caused accidents. Poor judgment happens as a consequence of a decrease in mental function. Furthermore, taking a shortcut/skipping or bypassing task sequence was the second most at-risk behavior in this survey. They were taking a shortcut/skipping or bypassing a task in the task sequence, lack of focus/attention, work in a hurry, and lack of verification (over assumption). This study also showed a similar result with Enoka and Duchateau, that fatigue led the workers to experience impaired reasoning and decision making and decreased alertness/attention. Fatigue also slows down mental function and reaction time and leads to loss of situational awareness (forgetting for a moment) and shortcuts. Fatigue is considered an unsafe condition in the workplace as it is likely to increase the risk of accidents.

### Notes:

- Chronic fatigue
  - Constant
  - Independent Variable
    - Acute fatigue
    - R²
    - p-value
    - B (CI)
    - 95% CI (B)
  - Results: CI = Confidence Interval, Dependent variable = Overall performance

- Acute fatigue
  - Constant
  - Independent Variable
    - Chronic fatigue
    - R²
    - p-value
    - B (CI)
    - 95% CI (B)
  - Results: CI = Confidence Interval, Dependent variable = Overall performance
they consider some procedure steps trivial and do not fit their individual. Shortcuts increase the potential of an accident in the workplace because there were maybe the critical steps in the task sequence that workers bypassed.

In general, this study explained that most respondents reported having at-risk behaviors in various forms, implying negative human performance. Occupational fatigue may play a role, as shown that increasing occupational acute or chronic fatigue scores significantly increased at-risk behavior scores, which means more negative human performance. Occupational fatigue significantly impacted human performance by observing at-risk behavior among oil and gas workers. However, considering this study was conducted in the COVID-19 pandemic condition where several risk factors of fatigue could be different from normal. The authors suggest that the following study should be conducted in a normal situation.

Conclusion
During the last 12 months, the most-reported at-risk behaviors were working in tired/sleepiness, mis-prediction/anticipation, work in a hurry, and shortcut/skip/bypass. In addition, this study also found that occupational fatigue could cause a negatively impacts on human performance as it increases at-risk behavior among workers could lead to an incident, considering fatigue was one of many factors that could impacting to human performance. Therefore, understanding this condition is paramount to all managers to manage fatigue risk in the workplace in the Fatigue Risk Management System (FRMS) frame.

Abbreviations
CSB: Chemical Safety and Hazard Investigation Board; FRMS: Fatigue Risk Management System; OFER: Occupational Fatigue Exhaustion Recovery; DOE: Department of Energy; CI: Confidence Interval; AF: Acute Fatigue; CF: Chronic fatigue; HP: Human performance; SD: Standard deviation.

Ethics Approval and Consent to Participate
The Ethics Review Board of Universitas Indonesia examined and approved this study with the number Ket-658/UN2.F10.011/PPM.00.02/2020.

Competing Interest
The author declares that there is no significant competing financial, professional, or personal interest that might have affected the performance or presentation of the work described in this manuscript.

Availability of Data and Materials
The raw data and output SPSS obtained from the study are available and kept by the corresponding author.

Authors’ Contribution
AD and BW conceptualized the theories related to fatigue, human performance, and major oil and gas incidents. AD and BW also prepared the administered survey questionnaire and analyzed the results using statistic computation software. Both authors drafted this full manuscript.

Acknowledgment
The authors declare that this paper has no sponsor.

References
1. Lerman SE, Eskin E, Flower DJ, George EC, Gerson B, Hartenbaum N, et al. Fatigue risk management in the workplace. J Occup Environ Med. 2012; 54 (2): 231–58.
2. Health and Safety Executive United Kingdom. Human factors: fatigue; 2020.
3. Murray SL, Thingan MS. Human fatigue risk management improving safety in the chemical processing industry. Geraghty F, editor. London: Joe Hayton; 2016.
4. United States Chemical Safety and Investigation Board. Investigation report refinery explosion and fire BP Texas city. Investigation Report; 2007.
5. Bousso R. BP Deepwater horizon costs balloon to $65 billion. Reuters; 2018.
6. Deepwater Horizon Study Group. Final report on the investigation of the Macondo Well Blowout. Deep Horiz Study Gr. 2011: 1–124.
7. Griffith CD, Mahadevan S. Inclusion of fatigue effects in human reliability analysis. Reliab Eng Syst Saf. 2011; 96 (11): 1437–47.
8. Gruhn P, Cheddie HL. Safety instrumetned system: design, analysis & justification. 2nd ed. United States of America: ISA; 2006.
9. Department of Energy. Human performance improvement handbook volume 1: concepts and principles. Washington DC: US DOE. 2009: 1: 1–175.
10. Schutte PC. Fatigue risk management: charting a path to a safer workplace. In: Journal of the Southern African Institute of Mining and Metallurgy. 2010 p. 53–5.
11. Federal Aviation Administration. Instrument flying handbook; 2001.
12. Matthews G, Desmond PA, Neubauer C, Hancock PA. The handbook of operator fatigue. The Handbook of Operator Fatigue. 2012 p. 1–310.
13. International Association of Oil and Gas Producers. Managing fatigue in the workplace. London; 2019.
14. Sekaran U. Metodologi Penelitian Untuk Bisnis Buku 1 Edisi 4. Jakarta: 2006.
15. Winwood PC, Winefield AH, Dawson D, Lushington K. Development and validation of a scale to measure work-related fatigue and recovery: the occupational fatigue exhaustion/recovery scale (OFER). J Occup Environ Med. 2005; 47 (6): 594–606.
16. Bobko N, Cherniuk V, Martynovska T, Gadayeva D, Sverjukova O. The role of sleep in the development of burnout, chronic fatigue and biological aging in the day and night workers. Sleep Med. 2019; 64: S42–3.
17. Health Navigator New Zealand. Chronic fatigue syndrome; 2019.
18. Mariana M, Sahroni TR, Gustiyana T. Fatigue and human errors analy-
sis in petrochemical and oil and gas plant’s operation. Proc Int Conf Ind Eng Oper Manag. 2018: 2611–9.
19. Yeow JA, Ng PK, Tan KS, Chin TS, Lim WY. Effects of Stress, repetition, fatigue and work environment on human error in manufacturing industries. J Appl Sci. 2014; 14 (24): 3464–71.
20. Enoka RM, Duchateau J. Translating fatigue to human performance. Med Sci Sport Exerc. 2016; 48 (11): 2228–38.
21. Rahmawati ND, Tualeka AR. Correlation between Individual characteristics, workload, and noise with work fatigue. Indones J Occup Saf Heal. 2019; 8 (2): 139.
22. Jones CEL, Phipps DL, Ashcroft DM. Understanding procedural violations using safety-i and safety-ii: the case of community pharmacies. Saf Sci. 2018; 105: 114–20.