NAMVS 2021 – Tukkaraja (Ed.)

Evaluating the effect of coal seam height and mine size on coal workers' pneumoconiosis prevalence in the United States coal mines, 1986-2018

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ABSTRACT: Coal has been a major source of energy in the U.S. since 1800s and is expected to remain essential for the foreseeable future. Dust exposure has several adverse effects on the health of mine workers. Several studies have shown the striking effect of contributing factors such as mining method, and geographic location in the prevalence of coal worker's pneumoconiosis (CWP). However, there has been limited investigation on the role of coal seam height and mine size. This study aims to investigate the effect of mine size and coal seam height on the CWP prevalence among coal miners, especially in underground mines. The data was drawn from the Mine Safety and Health Administration (MSHA) Employment and Accident/Injury databases. Statistical analysis including regression analysis performed on the data. A total of were included in our regression analysis. A Generalized Estimiation Equation (GEE) model was used to conduct a regression analysis on a total of 123,589 mine-year observations. The result of the statistical analysis reveals that coal workers in underground coal mines with lower coal seam height (less than 100 cm) and small mine sizes (less than 50 employees) are at a greater risk of CWP.

1 INTRODUCTION

As an inherent byproduct of mining, dust may impose various health and safety issues in mine operations. The term dust is used for solid particles in the air and is defined as airborne particles usually in a size range of 1 to 100 μm (WHO, 1999). Mineral clouds of dust generally occur when collisions, abrasions, cutting, crushing, and explosions break down rocks (Colinet et al., 2010). Such mechanical and chemical processes generate dust particles of various sizes, typically formed in irregular shapes (Sarver et al., 2019). Generally, the amount of dust generated during excavation is estimated to be approximately 3% of the total excavated material (Brondy and Tutak, 2018). The primary sources of respirable coal mine dust (RCMD) are found to be coal seam and surrounded rock strata, intake air, diesel exhaust, mining operations, and rock dusting (Schatzel et al., 2012; NAS, 2018; Sarver et al., 2019). The concentration of dust depends on several factors, including types of activity, the number of free surfaces in the cross-section walls, ventilation, and dust control practices.

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DOI: 10.1201/9781003188476-44

1.1 *Coal seam height*

Coal seam thickness is one of the potential contributing factor that could influence the prevalence of CWP among coal miners (Laney et al., 2010; Blackley et al., 2014). The coal seam height in coal mines varies based on the coal reserves' geographic location and geological properties. A total number of 532 underground mines in the U.S. produced around 330 million tons of coal in 2009 (MSHA, 2010). 28% of these mines were considered as low coal seam height (less than 100 cm). Suarthana (2012) reported that the average coal seam thickness for central Appalachia mines is lower than in other regions (i.e., 150 cm (ranging in between 65 and 350 cm) in central Appalachia vs. 200 cm (ranging in between 80 and 425 cm) in other regions). Further to this review, it was concluded that CWP and abnormal lung function prevalence were likely associated with the low seam height and small mine size in the U.S.

1.2 *Mine size*

Researchers such as Blackley et al. (2014) categorized the mine size based on the number of employees, and showed that mine size significantly affects the CWP prevalence and lung function abnormality. Previous studies indicated small mines were associated with the increased risk of CWP, but it was unknown if abnormal lung functions are linked to the mine size (Antao et al., 2006; Suarthana et al., 2012; Blackley et al., 2014). Their spirometry and radiographic analysis among 3770 coal miners showed that there is a higher risk of abnormal spirometry (18.5% vs. 13.8%, $p<0.01$), CWP (10.8% vs. 5.2%, $p<0.01$), and progressive massive fibrosis (2.4% vs. 1.1%, $p<0.01$) in miners working in small mine operations. Blackley (2014) concluded that coal workers in small mines in Kentucky, Virginia, or West Virginia are at a higher risk of CWP prevalences. Suarthana et al. (2012) found a negative correlation between mine size and prevalence of CWP and PMF among coal miners in the U.S. One possible explanation is that smaller mines may have fewer health and safety resources than larger operations. Moreover, another previous investigation indicated that the average concentration of RCMD for small mine size is higher than the large mine size (Antao et al., 2006).

The objective of this study is to determine the effect of mine size and coal seam thickness to the prevalence of CWP. To achieve this objective, a detailed statistical analysis of the relationship between the rate of CWP cases and the contributing factors was conducted.

2 MATERIALS AND METHOD

A comprehensive dataset was extracted from the MSHA accident/injury and MSHA employee/production databases. The number of CWP cases and mine ID[1] (as the unique key for this data) were obtained from the MSHA accident/injury. The number of employees (as an indicator for mine size), and coal seam thickness, mine ID were collected from MSHA employee/production file. The information was then merged based on the mine ID by utilizing SQL server data management. This process included clean the datasets, merge by mines I.D., define categories of interests, and provide a summary report to use in statistical analysis. Because of the panel nature of data, a linear regression model was utilized to analyze relationship between the rate of CWP and the independent variables. Considering a dependent variable of Y, and the independent variable of X, the following equation provides the relationship:

1 All mines are required to apply for an MSHA mine identification number. An MSHA ID is required for each mine site and must be issued before any operations may begin.

Table 1. Description of the variables used in the statistical analysis.

Variable	Type	Description
CWP rate	Dependent	The rate of CWP per total hours in each mine-year is used as an indicator for CWP prevalence in coal mines
RCMD	Dependent	Average concentration of RCMD per mine per year
Mine size	Independent	Small (a number of employees less than 50), medium (between 50 and 100 employees), and large (more than 100 employees)
Seam thickness	Independent	The average seam height as thin (less than 100 cm), medium (i.e., between 100 and 190 cm), and thick (more than 190 cm)

$$Yi, t = \beta Xi, t + ui + \varepsilon i, t \quad (1)$$

Where Y denotes dependent variable, ß is the coefficient, X is the independent variable, i stands for Mine-ID, t represents year, u is mine-specific unobserved heterogeneity (i.e., factors constant over time but unobserved to the econometrician), and ε is the error term (e.g., observation-specific error) (Shekarian et al., 2020). The Generalized Estimating Equation (GEE) model was used to conduct a statistical analysis of 12,537 (underground) and 9,050 (surface) observations for respirable dust concentrations between 1989 and 2018. As for the rate of CWP cases, a total of 123,589 mine-year observations was included in the regression analysis. The number of 29,707 observations were underground coal mine cases, 32,643 observations for surface coal mines, and 61,239 observations for other subunit. The dependent variable was the rate of CWP rate as reported by mines per total hours of employees in each year. Mine size and coal seam thickness were considered as the independent variables. The average number of employees was used as an indicator for mine size, classified in three categories as small, medium, and large with a number of employees less than 50, between 50 and 100, and more than 100, correspondingly. Furthermore, coal seams were categorized into three different groups based on the average seam height as thin (less than 100 cm [40 inches]), medium (i.e., between 100 and 190 cm [40 inches and 75 inches]), and thick (more than 190 cm [75 inches]). Table 1 summarizes the variables used in the statistical model.

3 RESULTS AND DISCUSSION

The observations show that the average RCMD concentrations in underground mines have been decreasing between 1991 and 2017. Also, the average RCMD concentrations in underground mines have been below the permissible exposure limit (PEL) (Figure 1.a).

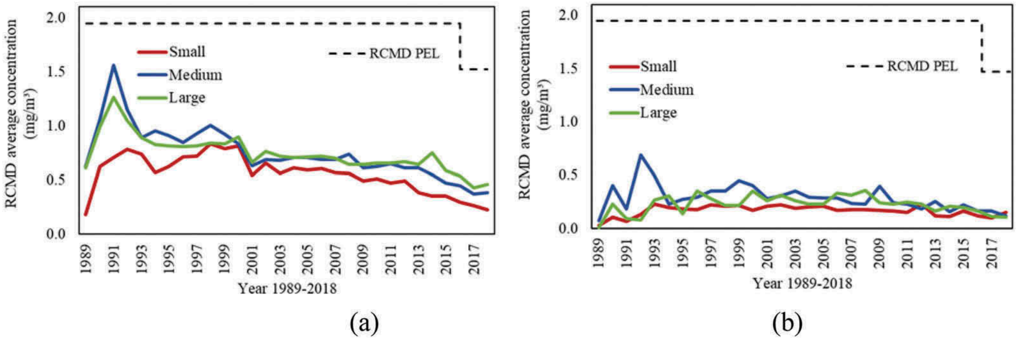

Figure 1. RCMD average concentrations in the U.S. underground (a) and surface (b) coal mines per category of mine size during 1989-2018.

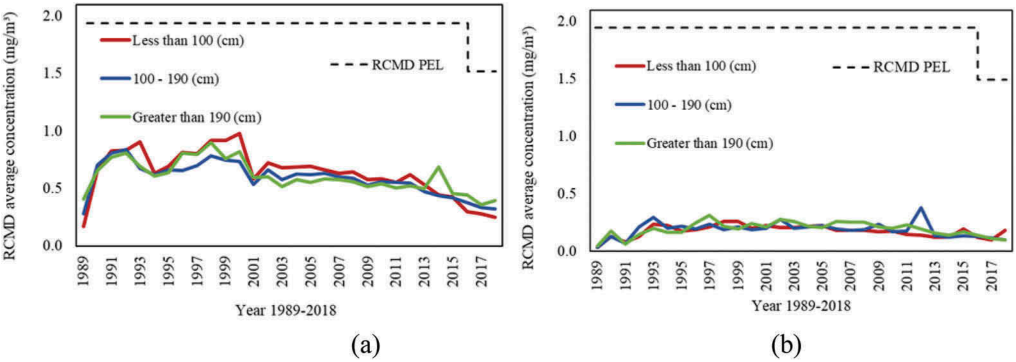

Figure 2. RCMD average concentrations in the U.S. underground (a) and surface (b) mines by coal seam height during 1989-2018.

Furthermore, small mines reported to have lower average dust concentrations compared to medium and large size mines. Likewise, the small mine category shows lower average RCMD concentrations in surface operations (Figure 1.b).

The average concentrations of RCMD have shown a descending trend at all coal seam height categories (Figure 2.a). Although the average RCMD concentrations are very close for all three seam-thicknesses, mines with seam height less than 100 cm have had slightly higher concentrations. The average RCMD concentrations in surface mines have been similar for all seam heights, although slightly higher in mines with a seam thickness greater than 190 cm (Figure 2.b) (Rahimi, 2020).

The distribution of surface and underground coal mines based on the seam thickness is shown in Figure 3. As shown, during 1986-2018, the total number of underground mines with an average of medium seam height (between 100 and 190 cm) is more than other classes. Furthermore, the majority of underground coal mines can be classified as small operations (i.e., less than 50 employees). As for surface mines, the majority of mines are in the thin seam thickness category, and most of the surface mines are small operations (Figures 4.a and 4.b) (Rahimi, 2020).

The distribution of the rate of CWP per coal seam height and mine size for both underground and surface coal mines was subsequently studied. The results showed that CWP is more prevalent in underground mines operating medium seams than that of mines operating thin and thick coal seams (Figure 5a). However, rate of CWP in surface mines indicated a higher percentage for thick seams than thin and medium seams (Figure 5b). Regardless of coal seam thickness, the majority of CWP cases in underground and surface mines was reported in the small mine size.

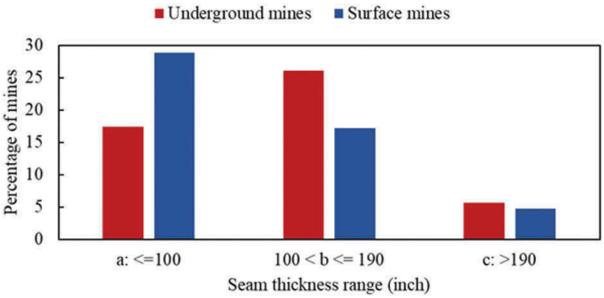

Figure 3. Distribution of underground and surface coal mines by coal seam thickness in the U.S. during 1986-2018.

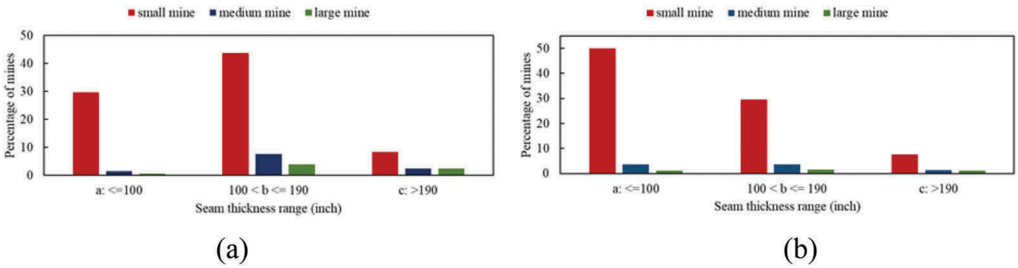

Figure 4. Distribution of coal mines by coal seam thickness (a), and percentage of underground (b) and surface (c) coal mines by coal seam thickness and mine size in the U.S. during 1986-2018.

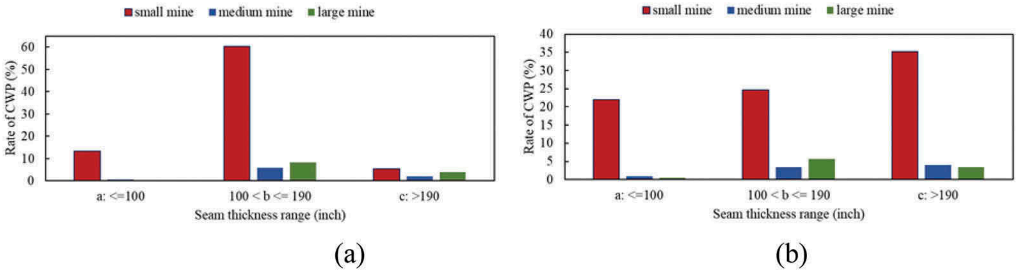

Figure 5. Percentage of CWP rate by seam thickness and mine size in the U.S. underground (a) and surface (b) mines during 1986-2018.

The results of the statistical analysis for the rate of CWP are shown in Table 2. The results of statistical analysis indicates that underground coal workers in small mines are at a higher risk of CWP in comparison with medium (column 1, β=-1.961, p<0.01) and large (column 1, β=-1.879, p<0.01) mines. Therefore, the hypothesis on contributing factor of mine size with CWP prevalences is supported for the underground mines. In surface mines, coal workers in small mines are at a higher risk of CWP in comparison with medium size mines (column 2, β=-1.277, p<0.1). We cannot make a conclusion for large operations. This may be due to the lower percentage of large surface mines compared to medium and small sizes. Therefore, this hypothesis is supported only for the medium vs. small surface coal mines (Shekarian, 2020).

The result of the coal seam thickness hypothesis demonstrates that coal workers in the underground area with thin-seam (column 1, β=1.416, p<0.05) and medium-seam (column 2, β=1.397, p<0.01) are at a higher risk of CWP prevalence in comparison with thick-coal seams. Therefore, this hypothesis on contributing factor of coal seam with CWP prevalences is supported for underground coal mines. The result of regression for surface mines shows that we cannot make a conclusion for thin-seamed mines. However, coal workers in the medium-seam thickness (column 2, β=-1.969, p<0.01) are at a lower risk of CWP prevalences in comparison with thick-seam mines. Therefore, the hypothesis of medium vs. thick-seam surface coal mines is rejected (Shekarian, 2020).

Table 3 summarizes the results of the statistical analysis on the average RCMD concentrations. The hypothesis on the contribution of the mine size shows higher average RCMD concentrations in large mine sizes (only large vs. small mine sizes) in underground mines. Futhermore, the hyporthesis is supported for surface (only medium vs. small) coal mines. Therefore, the regression model supports this hypothesis for the data (Table 2) (Rahimi, 2020).

The regression analysis also showed that, in underground mines, the average dust concentrations is higher in thin coal seams height compared to thick seam mines (only seam height ≤100 cm vs. seam height >190 cm). In surface mines, the results of the statistical analysis show that mines with seam height between 100 and 190 cm have higher dust concentrations

Table 2. GEE estimation results for the CWP rate.

Category	Variables	Underground CWP rate (1)	Surface CWP rate (2)
Mine size	Small (reference)		
	Medium	-1.961*** (0.639)	-1.277* (0.756)
	Large	-1.879*** (0.563)	-0.429 (0.592)
Coal seam thickness	Seam height>190 cm (reference)		
	Seam height ≤100 cm	1.416* (0.791)	0.555 (0.741)
	100< seam height<190	1.397** (0.554)	-1.969 *** (0.496)
	Constant	-21.027*** (1.554)	-15.105*** (1.628)
	Observations	29,707	32,643
	Year	1986-2018	1986-2018
	Wald Chi-2	996.48***	1551.50***

Standard errors in parentheses:
*** p<0.01, ** p<0.05, * p<0.1

Table 3. GEE estimation results for the average RCMD concentrations.

Category	Variables	Underground	Surface
Mine size	Small (reference)		
	Medium	0.025 (0.033)	0.147** (0.071)
	Large	0.097*** (0.036)	0.023 (0.068)
Coal seam thickness	Seam height >190 cm (reference)		
	Seam height ≤ 100 cm	0.147*** (0.041)	0.024 (0.053)
	100 < seam height ≤ 190	0.040 (0.034)	0.100** (0.064)
	Constant	2.742*** (0.051)	0.574*** (0.297)
	Observations	6,428	6,109
	Year	1989-2018	1989-2018
	Wald Chi-2	1528.57***	2879.14***

Standard errors in parentheses:
*** p<0.01, ** p<0.05, * p<0.1

compared to mines with seam height greater than 190 cm (Table 2). As shown in this table, the regression coefficient for this statistical analysis is relatively small. Therefore, more data is required to better understand the relationships between the average RCMD concentrations and the mining parameters.

4 CONCLUSIONS

This study aimed to investigate the effects of mine size and coal seam thickness on the rate of CWP and RCMD concentrations. Statistical analysis performed by extracting reliable data from the available public sources. For underground and surface mine operations, hypotheses were developed to using Generalized Estimating Equation (GEE) to determine the relationships between the CWP rate and the average RCMD concentrations against independent variables. These analysis supported the hypotheses for underground and surface coal mines that mine size and coal seam thickness contribute to the prevalence of CWP among coal miners in the U.S. The results showed higher RCMD concentrations in large undergound mines compared to small mines and higher concentrations in medium size surface mines.

ACKNOWLEDGMENT

Expressed thanks to Mine Safety and Health Administration for providing the accident/injury/employee databases. Immeasurable appreciation for the National Institute for Occupational Safety and Health (NIOSH) funded this study [75D30119C06390].

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PROCEEDINGS OF THE 18TH NORTH AMERICAN MINE VENTILATION SYMPOSIUM (NAMVS 2021), JUNE 12-17, 2021, RAPID CITY, SOUTH DAKOTA, USA

Mine Ventilation

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by Integra Software Services Pvt. Ltd., Pondicherry, India

Library of Congress Cataloging-in-Publication Data

A catalog record has been requested for this book

Published by: CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: enquiries@taylorandfrancis.com
www.routledge.com – www.taylorandfrancis.com

ISBN: 978-1-032-03679-3 (Hbk)
ISBN: 978-1-032-03681-6 (Pbk)
ISBN: 978-1-003-18847-6 (eBook)
DOI: 10.1201/9781003188476