A CART technique to adjust production from longwall coal operations under ventilation constraints

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ABSTRACT

Methane emissions in longwall coal mines can arise from a variety of geologic and production factors, where ventilation and degasification are primary control measures to prevent excessive methane levels. However, poor ventilation practices or inadequate ventilation may result in accumulation of dangerous methane–air mixtures. The need exists for a set of rules and a model to be used as guidelines to adjust coal production according to expected methane emissions and current ventilation conditions.

In this paper, hierarchical classification and regression tree (CART) analyses are performed as nonparametric modeling efforts to predict methane emissions that can arise during extraction of a longwall panel. These emissions are predicted for a range of coal productivities while considering specific operational, panel design and geologic parameters such as gas content, proximate composition of coal, seam height, panel width, cut height, cut depth, and panel size. Analyses are conducted for longwall mines with and without degasification of the longwall panel. These models define a range of coal productivities that can be achieved without exceeding specified emissions rates under given operating and geological conditions.

Finally, the technique was applied to longwall mines that operate with and without degasification system to demonstrate its use and predictive capability. The predicted results proved to be close to the actual measurements to estimate ventilation requirements. Thus, the CART-based model that is given in this paper can be used to predict methane emission rates and to adjust operation parameters under ventilation constrains in longwall mining.

1. Introduction

Methane emissions during longwall mining can adversely affect the safety of underground coal miners. The combination of methane emitted from the coal transported out of the mine by the conveyer belts and methane emissions from the face and ribs is directly discharged into the mine ventilation air. The methane emitted from fractured strata, if not controlled by existing degasification methods, can migrate to the caved zone and finally to the ventilation system. Therefore, the ventilation system must be appropriately designed based on the existence of any existing degasification system and must have sufficient capacity to maintain methane levels within statutory limits.

The ability to predict methane emissions is important to provide adequate ventilation air to dilute and render harmless high gas levels that threaten mine safety. However, accurate prediction of methane inflows into the ventilation system is complex due to the large number of variables that impact these potential emission sources. These variables include, but are not limited to, lithology and stratigraphy of the mining horizon, depth of the mined coalbed, seam thickness, coalbed reservoir properties, gas content coal seam, coal rank, longwall panel dimensions, face advance rates, existence of any methane drainage, conveyor speed, and time-dependent changes in these parameters.

Due to the complexity and number of parameters that can influence the magnitude of methane emissions, it is not easy to model these emissions in a longwall environment. Lunarzewski (1998) suggested an empirical model and linked methane emissions to different stages in the life of a coal mine and to coal production, which were regressed to measured emissions using two empirical constants. This approach summarized methane emissions as a function of coal production and life of the mine only and combined other important variables into empirical constants. Although simple to use, this approach was site-specific due to the empirical constants and required a long period of data collection before a correlation could be established for predictions.

Numerical modeling efforts, either based on boundary element (Lunarzewski, 1998), finite element (Tomita et al., 2003), or finite-difference reservoir models (Karacan et al., 2005, 2007) have

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improved the prediction of methane emissions. In addition to the efforts in predicting in-mine emissions, several studies have also investigated performance of vertical and horizontal boreholes in reducing gas content of coal seams for controlling methane gas in underground coal mines (e.g. Keim et al., 2011; Packham et al., 2011; Sang et al., 2010). An extensive review of coal mine methane, its control and prediction techniques and their importance for coal mine safety and greenhouse gas production is given in Karacan et al. (2011).

However, numerical models require expertise and, in most cases, specialized and expensive software packages In order to address that challenge, Karacan (2008, 2009) developed an artificial neural network (ANN) and principle component analysis (PCA) based approach to model and predict ventilation methane emissions from US longwall mines, to diagnose the need for degasification, and to suggest the best degasification combination for an operation. These models have been published as methane control and prediction software (MCP), which can be downloaded at the following site: http://www.cdc.gov/niosh/mining/products/product180.htm (Karacan, 2010). These modeling techniques predict methane emissions and perform sensitivity analyses to adjust ventilation or coal production quantities. However, they are mostly implicit in that the functional relationships between various parameters and outcomes are either too complex or not defined in a simple way for visual recognition by the user. Hence, this paper employs a nonparametric modeling approach, CART (classification and regression tree) analyses, to define the relationships between methane emissions levels and their causative factors so that production can be adjusted to not overwhelm the existing ventilation.

2. Data set used in CART modeling of longwall methane emissions

Classification and regression tree (CART) analysis is a nonparametric modeling technique that produces “trees” that are formed by a collection of rules based on the values of certain variables in the modeling data set. The data set used in this work is similar to the data set used in Karacan (2008, 2009) and was compiled from the same sources described in those references. That work also gives a detailed discussion of these variables and how they may impact both the emissions of methane into the ventilation system and the selection of an appropriate degasification system.

An effective degasification system, although of secondary importance to ventilation for controlling methane emissions, can greatly affect an operation’s productivity. Therefore, the data set used in this work was first searched for the existence of a degasification system in the operations that were included in the database. Based on this information, the database was categorized into two groups for separate CART analyses: (1) cases where no degasification system was employed and (2) cases where at least one or a combination of gob gas ventholes, horizontal borehole (either in-mine or surface), and vertical degasification borehole was used. The number of cases included 126 longwall mines without degasification and 354 longwall mines with degasification.

Tables 1 and 2 give the parameters and their ranges used in the current CART modeling work for mines without degasification and with degasification, respectively. To eliminate the site dependency of the current work, variables dealing with geographical locations were excluded from the data set and other variables were included to improve data variability and predictive capability. These new variables were ash content of coal, sulfur content, heat value, overburden depth, panel length, cut depth, lost and desorbed gas content, and residual gas content. Ash and sulfur contents are complementary information to gas content (higher ash and sulfur usually indicates lower gas contents). Overburden depth and heat value are indicative of caving pattern (together with panel width) and rank (high heat value indicates higher rank), respectively. Cut depth affects production rate while panel length affects methane reservoir size.

Simple analyses between the mean values of parameters in Tables 1 and 2 show how these values differ with and without the presence of a degasification system (Fig. 1). Mean methane emissions when using a degasification system are 172% higher than mines without a degasification system. Although this sounds paradoxical, it can be interpreted that mines operating at greater depths, in higher rank coals, and in gassier seams usually have higher emissions and, consequently, use degasification to supplement their main ventilation system. The larger average differences between degasification (D) and no degasification (ND) for overburden (OB, 69.3%), coal height (HC, 7.7%), total gas content (T-GAS, 115.3%), and lost and desorbed gas content (LD-GAS, 155.3%) prove this comment. Moreover, mines with a degasification system and with higher emissions have higher coal production (23.4%) and operate in thicker seams (SH, 14.9%) with increased cut depths (CD, 7.6%) and with faster face conveyors (SLS, 10.6%; FCS, 5.5%). One exception is that average sulfur content is 15% lower for operations using degasification because higher rank coals are usually associated with lower sulfur contents.

Table 1
Variables used for CART analyses for longwall mines without degasification. The table gives basic statistics conducted on 126 samples.

Variable and unit	Definition	Minimum	Maximum	Mean	Std. deviation
SH (in)	Seam height	39.0	96.0	72.3	14.7
CH (in)	Cut height	53.0	120.0	74.4	15.9
PW (ft)	Panel width	400.0	1100.0	799.8	151.0
PL (ft)	Panel length	3000.0	13000.0	7625.0	2470.7
OB (ft)	Overburden depth	300.0	1850.0	671.3	335.0
ENT	Number of gateroad entries	2	5	–	–
CD (in)	Cut depth	29.0	42.0	32.8	3.6
FCS (ft/min)	Face conveyor speed	215.0	357.0	267.8	34.6
SLS (ft/min)	Stage loader speed	247.0	517.0	329.4	44.9
T-GAS (scf/ton)	Total gas content of coal	9.6	249.6	123.2	58.7
SULP (%)	Sulfur content of coal	0.6	4.5	2.0	1.1
LD-GAS (scf/ton)	Lost and desorbed gas content	6.4	211.2	83.9	44.1
R-GAS (scf/ton)	Residual gas content	3.2	96.0	39.3	29.0
HC (BTU/lb)	Heat content of coal	10,300	13,300	12,200	720
ASH (%)	Ash content of coal	4.0	15.0	8.2	3.4
CP (M tons/day)	Daily coal production	0.3	20.0	7.7	4.3
Variable		Minimum	Maximum	Average	Std. deviation
Ventilation methane emission (MM scf/day)		0.1	10.3	2.5	2.3

Table 2

Variables used for CART analysis for longwall mines with degasification. The table gives basic statistics conducted on 354 samples.

Variable and unit	Definition	Minimum	Maximum	Mean	Std. deviation
SH (in)	Seam height	50.0	276.0	83.1	37.6
CH (in)	Cut height	43.0	156.0	79.3	19.2
PW (ft)	Panel width	465.0	1060.0	832.0	145.5
PL (ft)	Panel length	1400.0	13000.0	7682.7	2348.7
OB (ft)	Overburden depth	400.0	2700.0	1136.8	508.1
ENT	Number of gateroad entries	3	5	–	–
CD (in)	Cut depth	27.0	44.0	35.3	4.4
FCS (ft/min)	Face conveyor speed	187.0	450.0	282.4	42.9
SLS (ft/min)	Stage loader speed	220.0	600.0	364.3	67.6
T-GAS (scf/ton)	Total gas content of coal	70.4	585.9	265.3	136.8
SULP (%)	Sulfur content of coal	0.4	4.3	1.7	1.1
LD-GAS (scf/ton)	Lost and desorbed gas content	44.8	542.1	214.1	153.2
R-GAS (scf/ton)	Residual gas content	6.4	97.4	51.2	28.8
HC (BTU/lb)	Heat content of coal	9400	14,900	13,100	1025
ASH (%)	Ash content of coal	4.0	29.0	9.3	5.5
CP (M tons/day)	Daily coal production	0.5	28.2	9.5	5.8
Variable		Minimum	Maximum	Average	Std. deviation
Ventilation methane emission (MM scf/day)		0.1	19.2	6.8	4.2

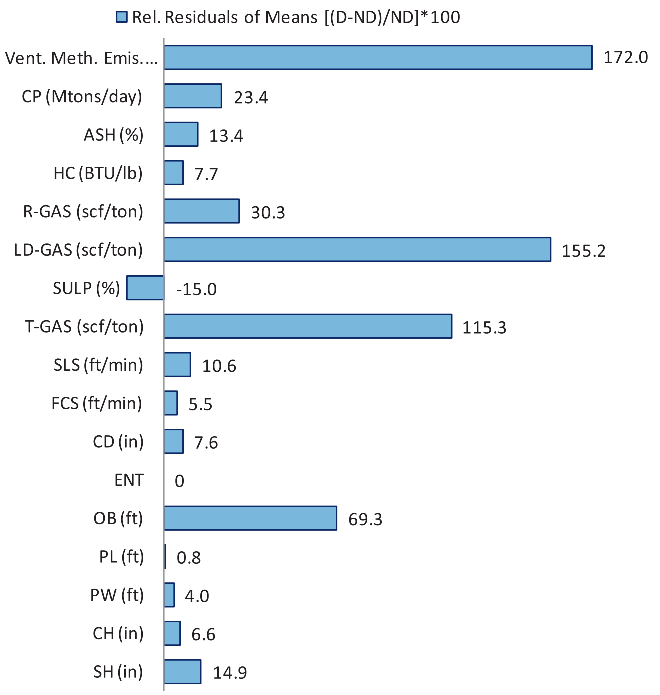

Fig. 1. Percentage differences between mean values of variables in mines operating with a degasification system (D) and without a degasification system (ND).

3. CART modeling technique

3.1. Brief description of CART

CART represents a computational–statistical algorithm that generates predictions in the form of a decision tree. The CART procedure can be defined as a method of partitioning data into terminal nodes (child nodes) by a sequence of binary splits starting at a parent node. Binary split means that each node has the potential of splitting into only two new nodes within a split level. CART repeats the partition for each child node, continuing recursively until the homogeneous level in the required generic node is obtained or a given stopping criterion is verified. Typically, the modeling algorithm will stop if either the maximum tree depth set by the user is reached or if no more splits can be made because there is no significant predictor variable left to split the node.

The CART splitting algorithm in each node is based on the concept that each child node must be more "pure" than the original parent. "Pure" is a concept linked to the values of a given variable which leads to zero variance between the splitting steps (Bevilacqua et al., 2003). The splitting procedure builds a tree structure based on a set of "if–then" rules that guide the decision maker. In starting the analyses and decision making, the variable choices and specifications should be causal and rational, just as with any traditional statistical methods.

The decisions using CART modeling are usually better than simple regressions because the variables are allowed to change based on hierarchical prioritization and are also allowed to interact and have different values under different conditions. CART modeling is used in materials science (Li, 2006), mechanics (Bevilacqua et al., 2003), clinical epidemiology (Li and Rapkin, 2009), intensive care medicine (Abu-Hanna and de Keizer, 2003), and modeling of environmental contaminants (Vega et al., 2009).

3.2. Application of CART in modeling methane emissions and validation methods

In this work, all of the variables listed in Tables 1 and 2 were used for CART modeling of emissions from longwall mines operating without (ND) and with (D) a degasification system, respectively. Methane emissions from the ventilation system were selected as the dependent variable and various maximum tree depths (level of branching) were implemented to find the optimum tree size. During these trials for both categories, tree depths ranging from 5 to 10 were employed. For interpretation of results and cross validation of the predictive capability of various tree models, predicted results were tested with Kolmogorov–Smirnov (KS) goodness-of-fit tests with a 5% significance level (α) and with regression analyses using a 95% confidence level.

Tables 3 and 4 give the results of regression analyses and KS tests for goodness-of-fit tests between the original data and the predicted values from model building and cross-validation. Tree depths of 8 and 10 were employed in Tables 3 and 4, respectively as these values were determined to be the best depths for CART modeling of methane emissions. The *d*- and *p*-values are indicative parameters of the KS test determining whether the null hypothesis, that the data follow a specified distribution with a significance level (α), should be accepted or rejected. The hypothesis regarding the proposed distribution is rejected if the d-value test statistic is greater than the critical p-value obtained for the corresponding significance level (α) and if the critical p-value is less than the

Table 3

Regression and Kolmogorov–Smirnov (KS) goodness-of-fit test statistics of predicted data with the original data in model building and cross-validation steps. MSE and RMSE stand for mean square error and relative mean square error, respectively. Tree-depth of 8 was selected to predict methane emissions from mines using a degasification system in their operation.

Two-sample Kolmogorov–Smirnov test	Model building results	Cross-validation results	Regression test	Model building results	Cross-validation results
d-Value	0.062	0.233	R^2	0.95	0.86
p-Value	0.450	0.384	MSE	1.728	3.040
Null hypothesis	Accept	Accept	RMSE	1.314	1.744

Table 4

Regression and KS goodness-of-fit test statistics of predicted data with the original data in model building and cross-validation steps. MSE and RMSE stand for mean square error and relative mean square error, respectively. Tree-depth of 10 was selected to predict methane emissions from mines operating without a degasification system installed.

Two-sample Kolmogorov–Smirnov test	Model building results	Cross-validation results	Regression test	Model building results	Cross-validation results
d-Value	0.059	0.433	R^2	0.96	0.84
p-Value	0.515	0.515	MSE	0.401	0.676
Null hypothesis	Accept	Accept	RMSE	0.633	0.822

significance level. If the null hypothesis is accepted, the value of "p" is the risk of rejecting that hypothesis. In this work, the null hypothesis states that the distribution of CART-predicted emission values is close to that of the distribution of actual values. Tables 3 and 4 indicate acceptance of the null hypothesis meaning that the data predicted by CART analyses adequately represent the distribution of methane emission data used for modeling and cross-validation.

The CART-predicted data and the actual methane emissions data were compared using linear regression. These analyses were conducted for both model building and cross-validation phases. The purpose of this approach was to find the regression coefficient (R^2) between actual and predicted values, which under ideal conditions should be 1, mean square error (MSE), and relative mean square error (RMSE). The right-hand sections of Tables 3 and 4 show the results of regression tests which indicate high regression coefficients (>0.8) between predicted and actual values as well as low MSE and RMSE. These tree depths produced accurate predictions of methane emissions, but at the expense of generating unnecessarily large trees with many splits (rules).

Figs. 2 and 3 show the results given in Tables 2 and 3 for regression between actual and predicted values in CART building and KS-test, respectively. In each of these figures, (A) plots are for the methane emissions from mines that utilize degasification system and (B) figures are for the ones that do not use degasification at all in support to ventilation. These figures and Tables 3 and 4, show that the actual and predicted values and their cumulative relative frequency distributions are close to each other.

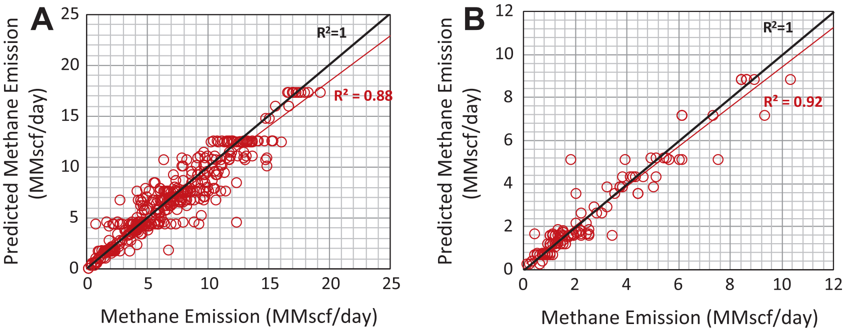

Fig. 2. Comparison of actual and CART-predicted methane emissions for mines operating with (A) and without (B) degasification. The regression coefficients are based on both model building and cross-validation analyses.

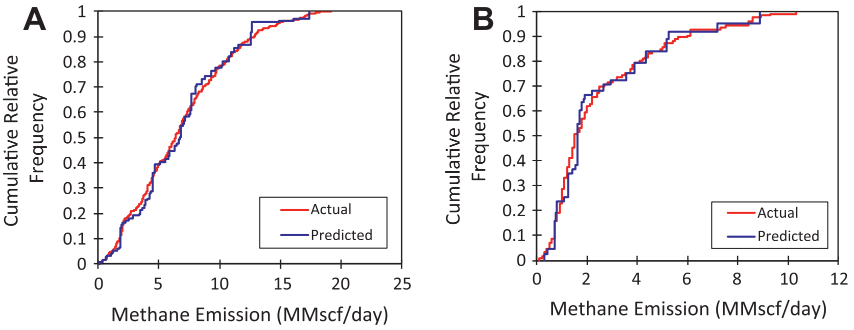

Fig. 3. Comparison of cumulative relative frequency distributions of actual and predicted methane emission data in two-sample KS goodness-of-fit test for mines operating with (A) and without (B) degasification.

Table 5
The rules extracted from the terminal nodes of the 8-level CART procedure for predicting methane emissions from longwall mines using a degasification system (D).

Rule	Ventilation methane emission (MM scf/day)	SH (in)	CH (in)	PW (ft)	PL (ft)	OB (ft)	ENT	CD (in)	FCS (ft/min)	SLS (ft/min)	T-GAS (scf/ton)	SULP (%)	LD-GAS (scf/ton)	R-GAS (scf/ton)	HC (BTU/lb)	ASH (%)	CP (M tons/day)
1	0.105		117–132									0.4–0.9	44.8–145.6		9400–12,800		0.822–8.904
2	0.400				2850–5785							2.9–4.25	44.8–145.6		9400–12,800		0.822–8.904
3	0.625		96–117	730–820								0.4–0.9	44.8–145.6		9400–12,800		0.822–8.904
4	0.750		69–72		5785–10,000		4.0					2.9–4.25	44.8–145.6		9400–12,800		0.822–8.904
5	1.033											1.3–1.5	44.8–145.6		12,800–14,040		0.822–6.164
6	1.100		96–117	610–730								0.4–0.9	44.8–145.6		9400–12,800		0.822–8.904
7	1.200			923.5–947								0.9–2.9	44.8–75.134		9400–12,800		0.822–8.904
8	1.600											1.3–1.5	44.8–145.6		12,800–14,040		6.164–8.904
9	1.700		64–69		5785–10,000		4.0					2.9–4.25	44.8–145.6		9400–12,800		0.822–8.904
10	1.800		58–76	630–730						280–382			44.8–145.6		9400–12,800		8.904–28.219
11	1.800				5350–10,000							1.5–3	44.8–145.6		12,800–14,040		0.822–4.11
12	1.809			568–923.5								0.9–2.9	44.8–75.134		9400–12,800		0.822–8.904
13	1.857				5785–10,000		4.0					2.9–4.25	44.8–145.6		9400–12,800		0.822–8.904
14	1.900			625–750					220–233			0.9–2.9	75.134–145.6		9400–12,800		0.822–8.904
15	2.033		76–80	630–730						280–382			44.8–145.6		9400–12,800		8.904–28.219
16	2.233				3300–5625			37.5–44					198.4–542.12				3.973–19.452
17	2.550		75–79.5				4.0	38.5–44		435–447.5		2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
18	2.860			730–1000	8000–9150					280–382			44.8–145.6		9400–12,800		8.904–12.603
19	3.350			585–625					220–233			0.9–2.9	75.134–145.6		9400–12,800		0.822–8.904
20	3.480			730–1000	9150–10,000					280–382			44.8–145.6		9400–12,800		8.904–12.603
21	3.667				4200–5350							1.5–3	44.8–145.6		12,800–14,040		0.822–4.11
22	3.825		75–79.5				4.0	38.5–44		447.5–460		2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
23	3.867								233–260			0.9–2.9	75.134–145.6		9400–12,800		0.822–8.904
24	3.867				7125–11,500			43–44					198.4–542.12				3.973–19.452
25	3.900					862.5–1025	3.0	38.5–44		509–550		2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
26	4.050					700–862.5	3.0	38.5–44		509–550		2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
27	4.257					400–1400							198.4–542.12				0.548–3.973
28	4.333			730–1000						280–382			44.8–145.6		9400–12,800		12.603–28.219
29	4.462											1.5–3	44.8–145.6		12,800–14,040		4.11–8.904
30	4.675					650–850		30–38.5	212–335				44.8–145.6		12,800–14,040		8.904–20.137
31	5.100		79.5–84				4.0	38.5–44				2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
32	5.540		72–76.5				3.0	38.5–44		280–509		2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
33	5.800		70.5–76				3.0	38.5–44				1.7–2.185	44.8–145.6		12,800–14,040		8.904–28.219
34	5.883		76.5–78					38.5–44		280–509		2.185–3	44.8–145.6		12,800–14,040		8.904–28.219
35	5.900			750–825		650–850		30–38.5	212–335				44.8–145.6		12,800–14,040		20.137–28.219
36	6.271									382–467			44.8–145.6		9400–12,800		8.904–28.219
37	6.500		66–70.5				3.0	38.5–44				1.7–2.185	44.8–145.6		12,800–14,040		8.904–28.219
38	6.620					850–1100		30–38.5	212–335	370–420			44.8–145.6		12,800–14,040		8.904–12.329
39	6.733				4250–4900			28–37.5	258.5–350				198.4–542.12				3.973–6.164
40	6.824					1400–2700							198.4–542.12				0.548–3.973
41	6.950				8000–9500	850–1100		30–38.5	212–335				44.8–145.6		12,800–14,040		12.329–28.219
42	7.075						4.0	38.5–44				1.7–2.185	44.8–145.6		12,800–14,040		8.904–28.219
43	7.143			825–1000		650–850		30–38.5	212–335				44.8–145.6		12,800–14,040		20.137–28.219
44	7.533		65–69					28–37.5	220–258.5				428.865–542.12				3.973–19.452
45	7.580		54–67.5		4900–7500			28–37.5	258.5–350				198.4–542.12				3.973–6.164
46	7.704				7125–11,500			37.5–43					198.4–542.12				3.973–19.452
47	7.970					850–1100		30–38.5	212–335	287–370			44.8–145.6		12,800–14,040		8.904–12.329
48	8.100		76–81	975–1050				30–38.5	335–400				44.8–145.6		12,800–14,040		8.904–28.219
49	8.529				4950–6750	575–1475		28–37.5	258.5–350				198.4–542.12				6.164–19.452
50	8.750				7100–11,300	1475–2050		28–37.5	258.5–350				198.4–542.12				6.164–19.452
51	9.313				9500–12,000	850–1100		30–38.5	212–335				44.8–145.6		12,800–14,040		12.329–28.219
52	9.650		67.5–72		4900–7500			28–37.5	258.5–350				198.4–542.12				3.973–6.164

53	10.233	70–76	975–1050			30–38.5	335–400	44.8–145.6	12,800–14,040	8.904–28.219
54	10.786	96.5–111	582.5–950			28–37.5	220–258.5	198.4–542.12		3.973–19.452
55	10.967			6750–8000	575–1475	28–37.5	258.5–350	198.4–542.12		6.164–19.452
56	11.150			5625–7125		37.5–44		198.4–542.12		3.973–19.452
57	11.525		930–975			30–38.5	335–400	44.8–145.6	12,800–14,040	8.904–28.219
58	12.529			4000–7100	1475–2050	28–37.5	258.5–350	198.4–542.12		6.164–19.452
58	12.575	65–69				28–37.5	220–258.5	198.4–428.865		3.973–19.452
60	12.636	69–96.5	582.5–950			28–37.5	220–258.5	198.4–542.12		3.973–19.452
61	16.050	69–111	560–582.5			28–37.5	220–258.5	198.4–542.12		3.973–19.452

4. Rule-based results from CART modeling and discussions

CART models with tree depths of 8 and 10 were selected for mines with degasification (D) and without degasification (ND), respectively. These models resulted in 127 rules for D and 57 rules for ND, where these rules are the total number of rules for both internal nodes and for terminal nodes. As stated earlier in Section 3.1, the decisions in the CART technique depend on the internal- and terminal-node concept, and the final rules are based on how terminal nodes evolve from internal ones. At each level of split, the internal nodes produce two child nodes as a result of a binary split. During a binary split, the variance in the data is minimized in such a way that the child nodes of the previous level become parents in the next level until the level of variance in the data cannot support another split. This is the level that establishes a "terminal node" and is the level of least variance in the data.

4.1. Rules and results for predicting emissions for mines using a degasification system (D)

As mentioned before, the terminal nodes contain the most homogeneous data and are the "purest" in the CART. Out of 127 nodes and associated rules that describe the conditions under which certain methane emission levels could be expected, only the terminal nodes (61 nodes) were selected for rule-based decision making and interpretation. Each terminal node is associated with a set of "rules" that record a sequence of splitting criteria that lead to the formation of that specific node. These rules can predict methane emissions into a ventilation system while the interactions of different predictors can be analyzed and interpreted.

Table 5 gives all 61 rules with parameter intervals resulting in various predicted methane emissions levels from a longwall mine using a degasification system for different coal productivities. This table is formatted so that the rules are given in rows in the direction of increasing methane emission. Also, the empty cells in the table indicate that those parameters are not included in the corresponding rules as "rule-making" variables during the CART procedure. Qualitatively, this table shows that the coal quality parameters related to gas content, coal rank, and coal production are included in almost all rules; whereas cut depth and conveyor speed become more prevalent at methane emissions exceeding 1.9 MM scf/day. The other parameters and their determining intervals are included in the rules based on the level of emissions and the values of other parameters. In these 61 rules, SH, R-Gas, T-Gas, and ASH are not included in the rules at all, indicating their insignificant influence on the determination of methane emissions.

These rules can be used to define a specific emissions level for a range of coal production. As an example, Table 6 contains sets of rules for generating daily coal productions between 8.904 M tons/day and 28.219 M tons/day with seam degasification. This shows that methane emissions can vary from 1.800 MM scf/day to 11.525 MM scf/day. In this case, the coal's lost and desorbed gas content (LD-Gas) does not change and the higher methane emissions originate from the magnitudes of other parameters contained in the rules. The rules given in Table 6 are shown graphically in Fig. 4. In a similar fashion, the rules can be gathered to analyze the conditions that lead to other values of daily coal productions.

4.2. Rules and results for predicting emissions for mines operating without degasification (ND)

A CART with a tree depth of 10 created 53 nodes leading to predicted methane emissions at longwall mines that do not use a degasification system in their operation. A node-selection criterion similar to the "D" case in Section 4.1 was applied in this situation,

Table 6

Rules for achieving coal production between 8.904 M tons/day and 28.219 M tons/day and predicted methane emissions levels from 1.800 to 11.525 MM scf/day (with degasification).

Predicted methane emission (MM scf/day)	Rules to obtain a daily coal production from 8.904 and 28.219 M tons/day
1.800	CH [58,76]; PW [630,730]; SLS [280,382]; HC [9400,12,800]; LD-GAS [44.8,145.6]
2.033	CH [76,80]; PW [630,730]; SLS [280,382]; HC [9400,12,800]; LD-GAS [44.8,145.6]
2.550	SLS [435,447.5]; CH [75,79.5]; ENT [4]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
3.825	SLS [447.5,460]; CH [75,79.5]; ENT [4]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
3.900	OB [862.5,1025]; SLS [509,550]; ENT [3]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
4.050	OB [700,862.5]; SLS [509,550]; ENT [3]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
5.100	CH [79.5,84]; ENT [4]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
5.540	CH [72,76.5]; SLS [280,509]; ENT [3]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
5.800	CH [70.5,76]; ENT [3]; SULP [1.7,2.185]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
5.883	CH [76.5,78]; SLS [280,509]; ENT [3]; SULP [2.185,3]; CD [38.5,44]; HC [12,800,14,040] LD-GAS [44.8,145.6]
6.271	SLS [382,467]; HC [9400,12,800]; LD-GAS [44.8,145.6]
6.500	CH [66,70.5]; ENT [3]; SULP [1.7,2.185]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
7.075	ENT [4]; SULP [1.7,2.185]; CD [38.5,44]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
8.100	CH [76,81]; PW [975,1050]; FCS [335,400]; CD [30,38.5]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
10.233	CH [70,76]; PW [975,1050]; FCS [335,400]; CD [30,38.5]; HC [12,800,14,040]; LD-GAS [44.8,145.6]
11.525	PW [930,975]; FCS [335,400]; CD [30,38.5]; HC [12,800,14,040]; LD-GAS [44.8,145.6]

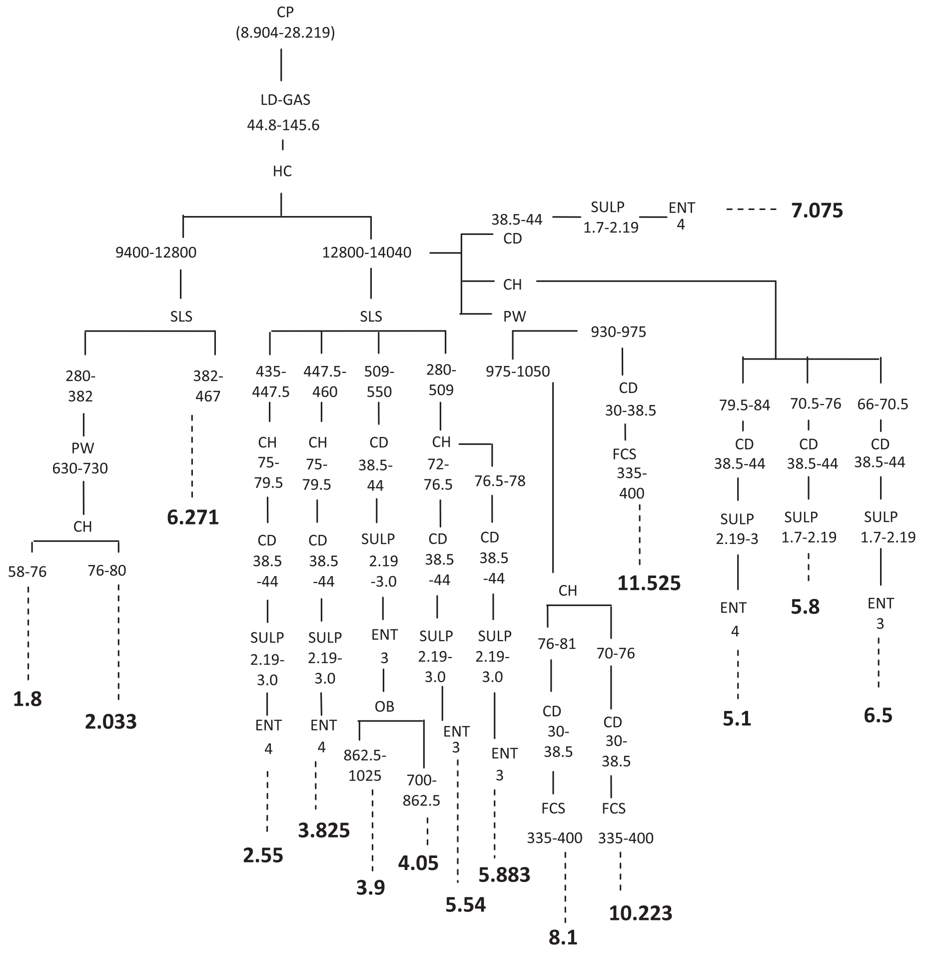

Fig. 4. A tree diagram for coal production between 8.904 and 28.219 M tons/day and the rules that produce various methane emission rates (in bold).

which populated 27 rules for obtaining various emissions levels. These 27 rules are given in Table 7.

Table 7 shows the rules that lead to predicted methane emissions rates between 0.300 and 8.867 MM scf/day into the ventilation system of a longwall mine without degasification. The table shows that coal production significantly impacts methane emissions into the mine's ventilation system and that production should be adjusted with ventilation constraints and with the values of other parameters related to coal, mine size and operation. Besides production, the ash content, gas content, cut depth, and stage loader speed seem to be indicative parameters that can be used to make this adjustment based on the values of other variables. However, the absence of cut height and the heat value of coal (rank indicator) in any of the rules suggest that these parameters do not significantly affect methane emissions.

Table 8 gives the rules for a daily coal production between 0.274 and 14.110 M tons/day without using a degasification system. This table shows that methane emissions between 0.3 MM scf/day and

Table 7

The rules extracted from the terminal nodes of the 10-level CART procedure for predicting methane emissions from longwall mines not using a degasification system (ND).

Rule	Ventilation methane emission (MM scf/day)	SH (in)	CH (in)	PW (ft)	PL (ft)	OB (ft)	ENT	CD (in)	FCS (ft/min)	SLS (ft/min)	T-GAS (scf/ton)	SULP (%)	LD-GAS (scf/ton)	R-GAS (scf/ton)	HC (BTU/lb)	ASH (%)	CP (M tons/day)
1	0.300					565–800		29–38.5		247–295		1.4–1.5	6.4–119.626			4–11.8	0.274–14.11
2	0.433					300–565		29–31		247–387.5			6.4–119.626			4–11.8	0.274–4.247
3	0.729					300–565		29–31		247–387.5			6.4–119.626			4–11.8	4.247–14.11
4	0.750					565–800		29–38.5		247–295		1.5–4.5	6.4–119.626	3.2–12.83		4–11.8	0.274–14.11
5	0.800				5240–8500	300–487.5		29–38.5		387.5–517							0.274–14.11
6	0.800					300–565	4.0	31–38.5		247–387.5			6.4–119.626			4–11.8	0.274–14.11
7	1.100			896–992				29–38.5		247–387.5			6.4–119.626			11.8–15	0.274–3.973
8	1.233					300–565	3.0	31–38.5		247–387.5			6.4–119.626			4–11.8	0.274–14.11
9	1.267					565–800		29–38.5		247–295		1.5–4.5	6.4–119.626	12.8–68.65		4–11.8	0.274–14.11
10	1.400			896–992				29–38.5		247–387.5			6.4–119.626			11.8–15	3.973–14.11
11	1.550	55–72.5						38.5–42									0.274–9.589
12	1.629					565–800		29–38.5		295–387.5			6.4–119.626			4–11.8	0.274–14.11
13	1.700					1150–1575		29–38.5		247–387.5	179.2–236.8		119.626–211.2				0.274–14.11
14	1.775			573–716				29–38.5		247–387.5			6.4–119.626			11.8–15	0.274–14.11
15	1.850	75–96			5240–8500	487.5–650		29–38.5		387.5–517							0.274–14.11
16	1.900					1575–1850		29–38.5		247–387.5	179.2–236.8		119.626–211.2				6.986–14.11
17	2.200			716–896	6000–7500			29–38.5		247–387.5			6.4–119.626			11.8–15	0.274–14.11
18	2.667			716–896	7500–9000			29–38.5		247–387.5			6.4–119.626			11.8–15	0.274–14.11
19	2.950	54–75			5240–8500	487.5–650		29–38.5		387.5–517							0.274–14.11
20	3.575					1575–1850		29–38.5		247–387.5	179.2–236.8		119.626–211.2				0.274–6.986
21	3.880							29–38.5		247–387.5	236.8–249.6		119.626–211.2				0.274–14.11
22	4.350	72.5–90						38.5–42									0.274–9.589
23	4.350				8500–10,688			29–38.5		387.5–517							0.274–9.863
24	5.150								291–325								14.11–20
25	5.225				8500–10,688			29–38.5		387.5–517							9.863–14.11
26	7.200							38.5–42									9.589–14.11
27	8.867								254–291								14.11–20

Table 8

Rules for achieving coal production between 0.274 M tons/day and 14.110 M tons/day and predicted methane emissions levels from 0.300 to 3.880 MM scf/day (without degasification).

Predicted methane emission (MM scf/day)	Rules to obtain a daily coal production from 0.274 to 14.110 M tons/day
0.300	SULP [1.4, 1.5]; SLS [247, 295]; OB [565, 800]; ASH [4, 11.8]; LD-GAS [6.4, 119.626]; CD [29, 38.5]
0.750	R-GAS [3.2, 12.8]; SULP [1.5, 4.5]; SLS [247, 295]; OB [565, 800]; ASH [4, 11.8]; LD-GAS [6.4, 119.626]; CD [29, 38.5]
0.800	OB [300, 487.5]; PL [5240, 8500]; SLS [387.5, 517]; CD [29, 38.5]
0.800	ENT [4]; CD [31, 38.5]; OB [300, 565]; ASH [4, 11.8]; LD-GAS [6.4, 119.626]; SLS [247, 387.5]
1.233	ENT [3]; CD [31, 38.5]; OB [300, 565]; ASH [4, 11.8]; LD-GAS [6.4, 119.626]; SLS [247, 387.5]
1.267	R-GAS [12.8, 68.65]; SULP [1.5, 4.5]; SLS [247, 295]; OB [565, 800]; ASH [4, 11.8]; LD-GAS [6.4, 119.626]; CD [29, 38.5]
1.629	SLS [295, 387.5]; OB [565, 800]; ASH [4, 11.8]; LD-GAS [6.4, 119.626]; CD [29, 38.5]
1.700	OB [1150, 1575]; T-GAS [179.2, 236.8]; LD-GAS [119.626, 211.2]; SLS [247, 387.5]; CD [29, 38.5]
1.775	PW [573, 716]; ASH [11.8, 15]; LD-GAS [6.4, 119.626]; SLS [247, 387.5]; CD [29, 38.5]
1.850	SH [75, 96]; OB [487.5, 650]; PL [5240, 8500]; SLS [387.5, 517]; CD [29, 38.5]
2.200	PL [6000, 7500]; PW [716, 896]; ASH [11.8, 15]; LD-GAS [6.4, 119.626]; SLS [247, 387.5]; CD [29, 38.5]
2.667	PL [7500, 9000]; PW [716, 896]; ASH [11.8, 15]; LD-GAS [6.4, 119.626]; SLS [247, 387.5]; CD [29, 38.5]
2.950	SH [54, 75]; OB [487.5, 650]; PL [5240, 8500]; SLS [387.5, 517]; CD [29, 38.5]
3.880	T-GAS [236.8, 249.6]; LD-GAS [119.626, 211.2]; SLS [247, 387.5]; CD [29, 38.5]

3.880 MM scf/day can be realized by mining a coal with a relatively low gas content, high ash content, in shallow overburden; properties that typify a low rank coal. Other parameters should be within the specified ranges to achieve the range of coal productions shown in this table. Similar tables can be constructed for other ranges of coal production and methane emissions.

Fig. 5 is a tree diagram that was generated using the rules given in Table 8 for coal production between 0.274 and 14.110 M tons/days for operations without degasification. This figure shows that the highest methane emission with coal production within this specified range is 3.880 MM scf/day and can originate with a cut depth (CD) between 29 and 38.5 inches, in a coalbed with loss and desorbed gas content in the range of 119.3–211.2 scf/ton, and with a total gas content in the range of 179.2–236.8 scf/ton. Also, stage loader speed should be between 247.0 and 387.5 ft/min. If the operational and coal seam characteristics are within these ranges for coal production up to 14.110 M tons/day and the mine is not using any degasification, then the ventilation air quantity should be based on predicted emissions of 3.88 MM scf/day. Similar analyses and interpretation can be performed for other emission rates.

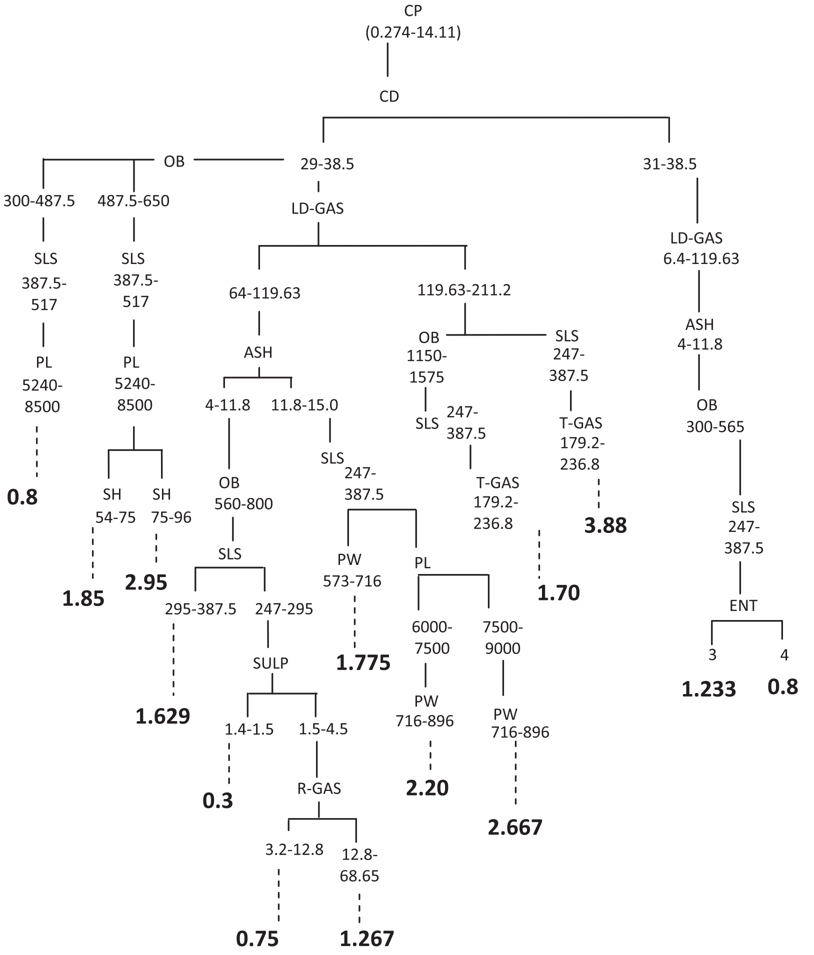

Fig. 5. A tree diagram for coal production between 0.274 and 14.110 M tons/day and the rules that produce various methane emission rates in MM scf/day (in bold).

5. Examples of the application of the technique

This section provides two examples and demonstrates the application of the CART technique and how the rules can be used to determine the methane emissions from the ventilation system of two mines and thus what the ventilation air requirements should be. This demonstration shows the 2006 operation of the selected mines.

5.1. Example from a mine utilizing degasification system (D)

5.1.1. The mine and its relevant data

The selected operation mines metallurgical coal of medium to low volatile rank from a longwall operation. As an aid to its ventilation system, the mine employs a coal gas degasification program that combines vertical, horizontal, and gob gas ventholes. Fig. 4 shows the daily average coal production, methane emissions from the mine's ventilation system and methane drained between 2002 and 2005. Fig. 6 shows that during this 5-year period, the mine averaged a daily coal production of 5–6 M tons/day and emitted daily average methane rates of approximately 7.5–11.0 MM scf/day from its ventilation system, while draining significant amounts of methane varying between 8 and 24 MM scf/day using its degasification system.

Thus, knowing that this particular mine produced 2.56 million tons of coal in 2006, which corresponds to an average coal production of 7.008 M tons of coal per day, our aim in this example application was to measure what the methane emission from the ventilation system would have been in 2006 and what the minimum average ventilation air quantity should have been to keep the mine's average methane level under 1%. In order to proceed with this example, the rules given in Table 5 are more appropriate because this mine uses a degasification system (D).

Average fundamental properties relevant to maturation, rank, composition, and heat value of the produced coal by this mine on an "as received" basis are given in Table 9. These values are determined in the laboratory by petrography as well as by elemental and proximate analyses. Although these values require non-mining related expertise to determine, they are known by almost all mine operators. In addition to the basic properties of the produced coal given Table 9, the 2006 longwall census reported that the particular mine operated with the conditions listed in Table 10.

Gas content of the mined coal seam has a significant impact on emissions into the ventilation system in a longwall mine. Reducing the gas content of the coal is the main reason for degasification efforts prior to and during mining. Almost all the rules presented in Tables 5 and 7 for D and ND cases, respectively, contain lost and desorbed gas content data. In this example application, because the gas content of the coal was not available, NIOSH's MCP 2.0 (Karacan, 2010) was used to determine the total and desorbable gas content of the coal extracted by this operator. Using the rank, moisture, and ash average heat value given in Table 9, the total and desorbable gas contents were determined to be 519.5 scf/ton and 422.1 scf/ton, respectively. The difference between the two values corresponds to the combination of lost and residual gas content.

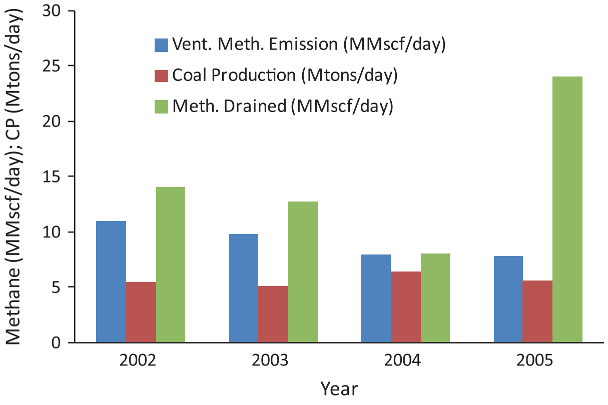

Fig. 6. Average daily coal production and methane emission values for the specific mine that utilized degasification system between 2002 and 2005.

Table 9
Average properties of the coals produced by the selected mines that are used in the examples.

Coal properties	Coal produced by the mine (D)	Coal produced by the mine (ND)
Average vitrinite reflectance (%Ro)	1.25	0.75
Heat value (BTU/lb)	13500.0–14300.0	13500.0–14000.0
Rank	Low-medium vol. bit.	High vol. bit.
Ash (%)	9.6	9.4
Moisture (%)	0.6	1.14
Sulfur (%)	0.6–0.8	0.9
Hydrogen (%)	4.7–4.9	5.03
Carbon (%)	76.8–81.1	78.6
Nitrogen (%)	1.6–1.7	1.1
Oxygen (%)	4.1–4.2	8.5

Table 10
Longwall size and operational parameters of the selected mines that are used in the examples.

Parameter	Description	Mine with (D)	Mine with (ND)
SH (in)	Seam height	50.0	48.0
CH (in)	Cut height	72.0	78.0
PW (ft)	Panel width	850.0	1000.0
PL (ft)	Panel length	12500.0	10000.0
OB (ft)	Overburden depth	1900.0	900.0
ENT	Number of gateroad entries	4	4
CD (in)	Cut depth	36.0	42
FCS (ft/min)	Face conveyor speed	305.0	347.0
SLS (ft/min)	Stage loader speed	390.0	450.0

5.1.2. Evaluation of the rules (D) with the data to predict methane emission potential into the ventilation system for the studied mine

Evaluation of the rules given in Table 5 starts with examining the goals to be achieved and the constraints at hand. The goal is to produce an optimum quantity of coal safely. The constraints can be operational conditions that can be adjusted, such as FCS, and those that cannot be changed, such as OB or PW, or physical and chemical properties of the coal. However, the ultimate constraint in terms of safety is the ventilation quantity, which is determined based on critical factors, such as methane emissions. The physical conditions of the mine and the power of main fans to provide that amount is another question of interest; however, once the methane emission is known, based on a set of goals and constraints, then either ventilation should be adjusted accordingly, or the adjustable constraints or goals should be changed to meet the requirements.

The mine in question produced an average of 7.008 M tons of coal per day in 2006. According to this productivity goal, rules 1–9, 12–14, 16, 19, 23–24, 29, 44, 46, 49–50, 54–56 and 58–61 can be applicable because this goal is within the ranges given as CP in these rules. However, some of these rules are not applicable for the constraints of this mine and cannot be changed. For instance, rule 12 and similar rules are applicable for the coals with lower rank (based on HC) or for those that have less LD-GAS. Similarly, some of these rules are applicable for OB depths less than

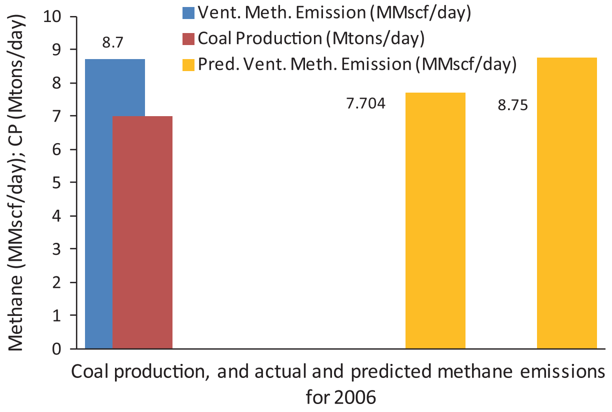

Fig. 7. A comparison of predicted and actual methane emissions into the study mine that uses degasification (D) for 2006 using Rule 46 and Rule 50.

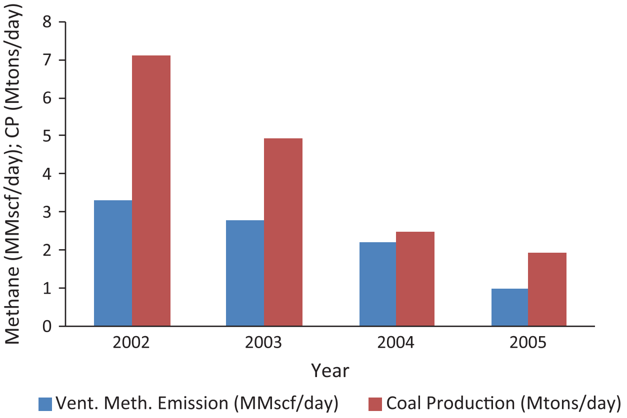

Fig. 8. Average daily coal production and methane emission values for the specific mine that did not utilize a degasification system (ND) in its operation between 2002 and 2005.

1900 ft. Therefore, the rules that do not include the HC (14000.0–14500.0 BTU/lb), OB (1900.0 ft) and LD-GAS (>422.1 scf/ton) should be eliminated. This examination reduces the applicable rules to 16, 24, 44, 46, 50, 54, 56 and 58–61.

Further examination on the remaining rules using other constraints given in Table 10, such as PL, CD, CH, and FCS reduces the applicable rules even further. For this examination, one should look for the rules that contain the range of values given in Table 10 for the operational parameters of this mine. For instance the CD, CH, and FCS used in this mine are 36 in, 72 in and 305 ft/min, respectively. Therefore, rule 44 and others that do not qualify for the operational constraints that survived in the previous step have been eliminated in this stage.

Elimination of rules as briefly described and applied to the study mine leaves only two rules that can most likely be applicable to the study mine: rules 46 and 50 which indicate that, under the given circumstances, the methane emissions into the ventilation system can be 7.704 MM scf/day and 8.750 MM scf/day, respectively. These can be considered as the low and high limits of the likely methane emissions under the given constraints and the values for which the ventilation amounts should be planned accordingly. These predictions, as well as the actual emissions measured from this mine, are given in Fig. 7. This figure shows that the predictions obtained, using the rule-based system introduced in this paper, actually encompass the measured methane emission rate of 8.7 MM scf/day in 2006. Therefore, a ventilation flow between 530,000 scfm and 610,000 scfm is required to keep the methane concentration at the 1% level.

The air rates predicted for this mine to keep its methane concentration at the 1% level were also compared with the actual ventilation rates documented in US EPA (2010) for 2008–2009 periods. This report is based on monthly and quarterly methane and ventilation air flow sampling studies conducted by MSHA at main fans of gassy underground coal mines in the United States. This report indicated that the example mine studied in this paper operated with an average ventilation air flow of 640,600 scfm to keep the methane levels at 1%. This comparison suggests that the ventilation air rates that were predicted under certain operation and productivity constraints are very close to the actual measurements.

5.2. Example from a mine that does not utilize degasification system (ND)

5.2.1. The selected mine and its relevant data

This mine produces coal for mainly steam production and metallurgical purposes and does not use any degasification system. Rank of the coal is high volatile bituminous. Fig. 8 shows the daily average coal production and methane emissions from the mine's ventilation system between 2002 and 2005. Fig. 8 shows that during this 5-year period, mine's daily coal production dropped from 7.1 M tons/day to 2.6 M tons/day. In accordance with this decrease in production, mine's methane emission from ventilation system has decreased from 3.3 MM scf/day to 1.0 MM scf/day too. Average coal production and methane emission during this period were 4.1 M tons/day and 2.32 MM scf/day, respectively.

This mine produced 933 thousand tons of coal in 2006, which corresponds to an average coal production of 2.55 M tons of coal per day. Methane emission from the ventilation system for 2006 and what the minimum average ventilation air quantity should be to keep the mine's average methane level under 1%, can be estimated using the same approach in the previous example. In order to proceed with this example, the rules given in Table 7 can be used since this mine does not use a degasification system (ND).

Average fundamental properties relevant to maturation, rank, composition, and heat value of the produced coal by this mine on an "as received" basis are given in Table 9, as well. In addition to the basic properties of the produced coal given Table 9, the 2006 longwall census reported that the particular mine operated with the conditions listed as (ND) in Table 10.

Gas contents of the coal produced by this mine were also predicted by using NIOSH's MCP 2.0 (Karacan, 2010). The total and desorbable gas contents of the coal were predicted as 157.2 scf/ton and 104.6 scf/ton, respectively by using the rank, moisture, ash and average heat value given in Table 9. The difference between total and desorbable gas contents is 52.6 scf/ton, which corresponds to the combination of lost and residual gas content.

5.2.2. Evaluation of the rules (ND) with the data to predict methane emission potential into the ventilation system

Evaluation of the rules given in Table 7 starts with examining the goals and the constraints, as it was in the previous example. The mine in this example produced an average of 2.55 M tons of coal per day in 2006. According to this productivity (CP) goal, rules 3, 10, 16, and 24–27 will be eliminated. In addition, of the remaining rules, some of them do not comply with the properties of the coal that is mined. For instance, when the ash content of the coal is considered, rules 7, 14, 17, 18 can be eliminated. Similarly, SULP and LD eliminates 1, 4, 9, 13, 20 and 21. This examination related to CP and coal properties reduces the applicable rules to 2, 5, 6, 8, 11, 12, 15, 19, 22, 23.

Further examination on the remaining rules using other constraints given in Tables 10, such as OB eliminates rules 2, 5, 6, 8, 15, 19 as these rules are for much shallower depths, and SH eliminates 22 and 11. Therefore, only rules 12 and 23 carry the closest

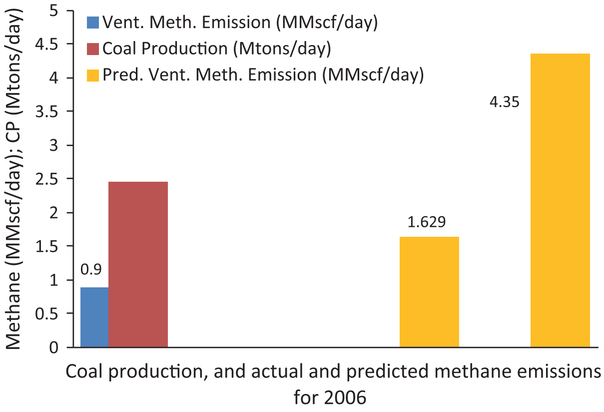

Fig. 9. A comparison of predicted and actual methane emissions into the study mine that operated without a degasification system (ND) for 2006 using Rules 12 and 23.

data that survive the elimination process. These rules show expected ventilation methane emission values of 1.629 MM scf/day (1131 scfm) and 4.350 MM scf/day (3021 scfm). These values can be considered as the lower and upper limits of possible methane emission under the given constraints and the values for which the ventilation amounts should be planned accordingly. These values, as well as the actual emission measured from this mine, are given in Fig. 9. This figure shows that reported methane emission from ventilation system for 2006 is 0.9 MM scf/day (625 scfm), which would require at least ~62,500 scfm of air for 1% methane in the ventilation system. On the other hand, predicted ventilation emissions for this mine would require ~115,000 scfm and ~300,000 scfm, for 1.629 MM scf/day and 4.350 MM scf/day methane emissions, respectively.

As in the previous example, the air rates predicted for this mine to keep its methane concentration at the 1% level were also compared with the actual ventilation rates documented in US EPA (2010). This report indicated that this mine operated with an average ventilation air flow of 345,000 scfm and measured methane concentrations were ~0.48%. For 1% methane concentration, the air requirement is ~166,000 scfm, which is almost the mid-value of the air rate predicted. Therefore, although the mine have not used methane drainage, the air quantity was enough to provide safe mining without overwhelming the ventilation system.

6. Conclusions

The magnitude of methane emitted into the working environment is dependent upon a number of geologic and operational parameters. Control of these emissions is critical to protect the safety of the underground workforce. This work used classification and regression tree analyses (CART) to predict methane emissions for longwall operations based on the levels of a number of parameters such as coal gas content, proximate coal analysis, seam and mining heights, cut depth, and panel size. The analyses were conducted for operations with and without the use of coal seam degasification.

CART analyses of operations using coal seam degasification identified 61 rules to predict methane emissions ranging from 0.105 to 16.050 MM scf/day for coal productions from 0.822 to 28.219 M tons/day. These analyses revealed that parameters related to coal quality were included in almost all rules, and operational parameters such as cut depth and face conveyor speed were prevalent when emissions levels exceeded 1.9 MM scf/day. The variables of seam height, residual gas, total gas, and ash content were not included in any of the rules, indicating their minimal impact on methane emissions. Similar assessments for those operations not employing coal seam degasification identified a total of 27 rules for predicting methane emissions ranging from 0.30 to 8.867 MM scf/day and coal productions from 0.274 to 20.000 M tons/day. Emissions between 0.30 MM scf/day and 3.88 MM scf/day can be realized by mining a coal with a relatively low gas content, high ash content, and shallow overburden, properties that typify a low rank coal. Emissions in excess of 3.88 MM scf/day were predicted when cut depth and panel length increased.

This method was applied to two large longwall mines operating with and without degasification to control methane emissions. For the mine utilizing degasification, comparison of operation and geologic conditions narrowed down the 61 rules for operations using degasification to only 2. The methane emissions rates of 7.704 MM scf/day and 8.750 MM scf/day predicted by rules 46 and 50, respectively, provided a lower and an upper bound on the actual emissions rate of 8.7 MM scf/day. These predicted emissions corresponded to ventilation rates of 530,000 scfm and 610,000 scfm, respectively, to maintain methane levels at 1%. The calculated ventilation rates were compared with the actual rates that the example mine exhausted from its ventilation system during its 2008–2009 operation. The comparison showed that this particular mine operated with an average ventilation rate of 640,600 scfm with an average methane concentration of 1%. On the other hand, for the mine operating without a degasification system, coal and operational parameters resulted in only 1 possible rule that can be applicable to estimate methane emissions and required ventilation amount. The rule-based decision process determined that the mine would likely have 1.629 MM scf/day. This amount would require an air flow rate of 115,000 scfm to keep methane at most 1% level. However, the mine was already providing ~345,000 scfm air to the mine and was able to keep methane at 0.48% level. It should be noted that cutting the air rate by half will bring the concentration ~1% and air rate to closer to the amount calculated for this concentration. These results suggest that this method is not only practical, but also accurate enough for predicting methane and ventilation rates.

Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Any commercial product mentioned in this paper is not endorsed by NIOSH.

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