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Review of the spatial interpolation techniques used for estimating economic coal properties

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Abstract

Coal resource estimation relies on the spatial interpolation of coal quality properties, such as ash content and density. There are many available spatial interpolation techniques, and over the past decade geostatistical methods such as kriging have been recommended over simpler, historically popular techniques such as inverse distance. Despite this recommendation, it is shown in this study that inverse distance remains the most popular method for interpolating coal quality properties. This study analyses publicly available resource estimation reports from companies which are listed on the Australian Stock Exchange (ASX) from a period spanning 2013 through to 2019. A semi-automated approach to compiling resource estimation reports is undertaken and 53 documents from 30 of the largest companies (by market capitalisation) are compiled. From the analysis of these documents it is shown that inverse distance is used for interpolating coal quality properties in all but one document. The only other reported method was an alternative non-geostatistical method. Further, despite clear ASX rules mandating the report of quantitative reasons for the usage of an interpolation technique, reasons were totally absent or qualitative in all but one resource estimation report.

Keywords: Spatial interpolation, inverse distance weighting, geostatistics, coal resource, JORC

Introduction

Coal resources are reliant on the spatial interpolation of key economic properties of coal such as coal ash, density and volatile matter (Srivastava 2013). In the context of coal resource estimation, spatial interpolation is the process of estimating coal properties at regularly spaced intervals using a specific method (Srivastava 2013). Usually the method relies on existing coal analysis and auxiliary information which has been acquired from drill-core samples (Jeuken, Xu et al. 2017). To conduct spatial interpolation, there are many available methods including deterministic methods (e.g. inverse distance weighting), geostatistical methods (e.g. ordinary kriging, cokriging, kriging with external drift), spatial statistical methods (e.g. generalized least squares), machine learning methods (e.g. random forest, support vector machine) and hybrid methods (e.g. random forest regressing kriging) (Li, Heap et al. 2011, Li and Heap 2014). Of these methods, historically, inverse distance (ID) was the most popular method for interpolating coal properties (Casley, Bertoli et al. 2009). However, over the past decade, geostatistical methods such as kriging and hybrid kriging methods have been recommended as a preferred method over ID for spatially interpolating coal properties (Casley, Bertoli et al. 2009, Ertunç, Tercan et al. 2013, Saikia and Sarkar 2013, Srivastava 2013, Tercan and Sohrabian 2013, Jeuken, Xu et al. 2017, Jeuken, Xu et al. 2020). This study aims to determine if these geostatistical methods have been adopted by the coal industry at large.

To investigate the adoption of geostatistical methods, coal resource reports which are reported in accordance with Australian stock exchange (ASX) listing rules and with the 2012 Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') are compiled and reviewed. This study uses a semi-automated approach to compiling coal resource reports of the top 45 (by market capitalisation) mining companies. The report range spans from 2013 through to 2019. For each report, the spatial interpolation method and settings, and the software used for the interpolation methods are compiled and analysed.

ASX and the JORC code

Mining Companies which are listed on the Australian stock exchange (ASX) are required to report coal resources in accordance with both Chapter 5 of the ASX Listing Rules (Australian Stock Exchange 2019) and ASX Guidance Note 31 (Australian Stock Exchange 2013). Under these rules, companies must report various details for material mining projects[1]. Specifically, the rules mandate that the details about how a coal resource was determined must be prepared in accordance to relevant sections in Table 1 of Appendix 5A of the JORC Code (JORC 2012). Section 3 of Table 1 of the JORC code requires that the "nature and appropriateness of the (spatial interpolation) estimation technique" is described when reporting resources. Further, the 2014 Black coal guidelines (Guidelines Review Committee 2014), which are provided to assist with reporting of resource estimates, advise that the spatial interpolation parameters (the modelling parameters), and the quantitative suitability of the estimation technique are described. Therefore, it can be assumed that companies adhering to ASX listing rules, the JORC code and Black coal guidelines will fully describe the spatial interpolation technique used for estimating coal properties.

Method

Due to the large number of publicly available resource reports across all commodities, and to reduce any author bias in document search, a semi-automated approach to compiling and sorting reports was conducted. All data processing and automated scripting was conducted in the R programming language (R Core Team 2017). This semi-automated approach is described in the following section.

A list of the top 45 (by market capitalization) ASX listed mining companies which have coal assets was obtained (Capitalistic Man 2019, Capitalistic Man 2019). For each of these companies, the title of all ASX announcements spanning from 2013 to 2019 was searched on several keywords including "*Resource*", "*Reserve*", and "*JORC*". For any announcement which contained one of these key words, and which had a document attachment, the full announcement was downloaded to local computer disk. Subsequently, a full text search of each of these documents was undertaken searching for keyword phrases including "*Estimation and Reporting of Mineral Resources*" and "*Estimation and modelling techniques*". These phrases are specific to section 3 of table 1 of the 2012 JORC code. The reports which did not contain these key phrases were assumed not to contain JORC code Table 1 or extractable text and were archived. The remaining documents were manually inspected, and several details were tabulated including the company name, announcement date, web address of the announcement, competent person/s, software and settings used for modelling coal properties and the reasoning for the suitability of the reported modelling method. Finally, if no JORC code Table 1 information was retrieved for a company, a manual search of the company website was conducted.

Results

After the semi-automated search and sorting, 53 documents were compiled. Of these 53 documents, JORC Table 1 information was found for 30 of the companies. This search also revealed that several companies reported multiple resource estimates over the period, while other companies did not report any resource estimates. Companies which reported multiple resource estimates usually reported the

[1] *A 'material mining project' is one in which has an economic interest which is likely to be material in the context of the overall business operations or financial results of the company (entity) Australian Stock Exchange (2013). Guidance note 31 Reporting on Mining Activites, Australian Stock Exchange.* ***31:*** *18.*

exact or near same details such as the software and estimation technique. Where these details differed, the details of the most recent resource report were used. The complete (unconsolidated) details of all 53 documents are provided in Appendix 1. The complete details of the 30 consolidated documents are provided in Appendix 2.

For modelling coal quality properties, 21 of the 30 resource reports documented the use of inverse distance while 8 did not document the method at all (Table 1). One report documented the use of alternative (non-geostatistical) methods. There were no resource reports which described the use of geostatistical methods. Of the resource reports which documented the coal quality modelling method, 16 (76%) also reported the method settings (Appendix 2). Of all 30 resource reports, 23 (76%) did not provide any reason for the ‘appropriateness of the technique’. Of the 7 resource reports which did provide a reason for the ‘appropriateness of the technique’, only one was deemed ‘quantitative’ (Appendix 2). All other reasons were qualitative, generally citing the historic use of the method (Appendix 2).

Table 1: The spatial interpolation method used for interpolating coal quality variables and number of times it was reported in resource estimation reports.

Coal quality Modelling	
Method	Count
Inverse Distance (ID)	21
Not Recorded (NR)	8
Finite Element Method (FEM)	1
Total	30

The most popular method for modelling coal surfaces was finite element method (FEM) which is a proprietary, deterministic method utilised by MineScape software (Datamine 2019). Its usage was reported in 11 of the 30 resource reports (Table 2). Alternative reported methods included triangulation (8 records), inverse distance (2 records) and ‘Growth’ (2 records) (Table 2). Growth technique is a proprietary deterministic technique provided by Minex software (Dassault Systèmes 2019). The coal surface model method was not described in 7 of the 30 JORC reports.

Table 2: The spatial interpolation method used for interpolating coal surfaces and number of times it was reported in resource estimation reports.

Coal surface Modelling	
Method	Count
Finite Element Method (FEM)	11
Triangulation	8
Not Recorded (NR)	7
Inverse Distance (ID)	2
Growth	2
Total	30

In all cases, the same modelling package used to derive the coal quality and coal surfaces was the same. The most popular modelling package was MineScape (Datamine 2019) followed by Vulcan (Maptek 2019) (Table 3). MineScape is the only software which provides the FEM method. In 2 of the 30 resource reports, the modelling software which was used was not reported.

Table 3: The number of times a modelling package was reported in resource estimation reports

Software	Count
Minescape	12
Vulcan	8
Minex	5
No recorded	2
Surfer	2
Surpac	1
Total	30

Discussion

It is apparent from the results that the choice of method to model coal quality properties and coal surfaces is associated with geological modelling software. MineScape was the most popular software and when this software was used, FEM and ID were used for generating surfaces and coal properties respective. When Vulcan modelling software was reported as being used, triangulation and ID were used for generating surfaces and coal properties respective. Despite the correlation between estimation methods and modelling software, both MineScape and Vulcan have options to use geostatistical methods (for example kriging) for modelling coal properties. Therefore, the use of ID for modelling coal quality properties cannot be fully attributed to the modelling software workflow.

Fifteen of the 45 companies did not report any resource or reserve updates in the research period. There are several possible reasons for this. For the largest of companies, this is likely due to the materiality of the resource to the company. That is, changes to resource estimates do not markedly affect the overall financial results or viability of the company. It may also be possible that some resource estimates were not obtained due to key word search on the title. For example, if the full JORC resource report was announced to the ASX with the title named 'Appendix', or some other obfuscated title, these may have been missed. Finally, JORC reports which could not be successfully text searched (for example in the case of poorly scanned documents), may have also been missed.

Since clear reasons for the use of ID for modelling coal quality properties were absent in almost all reports, the continued reliance on ID may be based on several factors. These factors include:

- the simplicity, and speed of ID over geostatistical and other interpolation methods;
- the onerous or complex pre-processing steps required in geostatistical methods (for example variogram interpretation);
- reliance on historic workflows or results; and,
- lack of expertise or knowledge of geostatistical methods.

Despite these suggested factors, true reasons for the continued use of ID will remain unknown until they are more robustly reported in resource estimation reports.

Conclusion

The use of geostatistical methods (such as kriging) over inverse distance (ID) for modelling coal quality properties have been heavily recommended by academia over the past decade. This paper aimed to determine if geostatistical methods were being utilised for modelling coal quality properties in the coal mining industry, or if there was a continued reliance on ID. To do this, a semi-automated approach to compiling resource estimation reports (JORC reports) from coal mining companies listed on the Australian Stock Exchange (ASX) was undertaken. Companies listed on the ASX were used because there are clear requirements for these companies to report the method for modelling coal properties in resource reports. The search period for reports spanned from 2013 through to 2019. The paper also analysed additional details about the estimation technique, which were captured during the process. These included the method used to model coal surfaces, the appropriateness or the reason for the use of the method for modelling coal quality properties and the modelling software which was used.

In all, 53 resource reports from 30 individual companies were compiled and analysed. These 53 reports were consolidated into 30 records, one for each company. For modelling coal quality properties, all but one resource report described the use of ID. Additionally, only a single JORC report provided an appropriate, quantitative reason for the use of ID. All other resource reports simply stated the usage of ID or provided a qualitative reason such as its usage historically. The only other reported method was an alternative non-geostatistical method. The most popular method for modelling coal surfaces was finite element method (FEM) which is a proprietary, deterministic method utilised by MineScape software. This was used in over half of the reported cases. The most popular software used for modelling coal quality properties and surfaces was MineScape (12 instances), followed by Vulcan (8 instances).

It was clear from the results that ID remains the most popular method for modelling coal quality properties in resource estimation reports. Since robust, quantitative reason the continued use of ID is not provided, it is proposed the continued use of ID is due to its simplicity, speed, onerous or complex pre-processing steps required in geostatistical methods (for example variogram interpretation), reliance on historic results, and lack of expertise or knowledge of geostatistical methods.

Appendix

Copies of the appendix can be obtained by contacting the author.

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