Acta Montanistica Slovaca Volume **23** (2018), number **1**, 62-71

Development of GPS and GIS-Based Monitoring System for the Quality of Excavated Coal

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Because of the advancement of geospatial technologies such as GIS and GPS integration, many mining companies have started to use the technology for mine planning, analysis and management. In this context, this study focuses on real-time monitoring of the excavated coal quality using GIS and GPS integration. For this purpose, firstly, digital maps and tabular quality data were created by analysing the drill holes data, and then they were combined under the GIS environment by writing a MapBasic computer application using Visual Basic. The application consists of three sections. A GPS section that awaits the coordinate information that will be received over the GPS and that makes coordinate transformations; a map analysis section that functions in order to view digital maps and track shovel or trucks on the screen and the point-block-quality query section allows flexible data extraction, based on the structured query. Finally, by mounting a GPS receiver on the bucket wheel excavators in exemplary opencast coal mining, the monitoring of the excavation point over the digital maps were enabled , and the monitoring of the stock accounts as a database for the quality data such as the amount, LCV, MC%, and AC%, simultaneously with the coal production were provided.

Key words: *GIS, GPS, Geostatistics, Afsin-Elbistan Coal Basin, Opencast Mining*

Introduction

The mining industry is changing as the industry is becoming increasingly competitive. To keep pricing low, mining companies have been turning to advanced automation technologies to keep up. In this context, beneficiations practices such as selective mining and blending-homogenization processes are increasingly gaining prominence, and this requires both effective production management and planning. As well as the increase in efficiency, companies are also looking to ensure that safety is at the top priority. For this reason, with the increasing popularity and functional development of geospatial technologies such as Geographical Information System (GIS) and Global Positioning System (GPS), many mining companies have started to use the technology as the preferred tool for mine planning, analysis, and management (Zhou et al., 2007; Wang et al., 2011; Craynon et al., 2016).

In general, GIS is a computer system capable of assembling, storing, manipulating, and displaying layers of geographically referenced information, i.e., data identified according to their locations (Carranza, 2008). The system replaced old map-analysis processes, traditional drawing tools, and drafting and database technologies. In GIS, each layer of spatial data is linked to corresponding tabular information (Harris and Barrie, 2006). Each object on the map layers has location-coordinate information in which the objects are defined and expressed on the map (Bonham-Carter, 1994). For the extraction of the location-coordinate information, or the need to access GIS data over the location, data producing devices are quite important and difficult to use. In this respect, the Global Positioning System (GPS) receivers, which can measure at a sensitivity of 1-2 cm, has been used as the most practical alternative to classical data extraction methods (Trimble, 1999; Misra and Enge, 2010). GPS is well known to work independently and provide real-time data for construction equipment (Behzadan et al., 2008). GPS devices are also affordable and easy to install. The data it provides can also be analysed with relatively little computational effort (Pradhananga and Teizer, 2013). The GPS positional accuracy enhances the functioning of GIS by improving the spatial quality of GIS data. The integration of GPS as a spatial data source for GIS makes it possible to successfully combine features accurate geographic coordinates and the corresponding attributes and values of that feature.

A number of GPS and GIS studies on the mining activities are available in the literature. Mainly, Gili et al. (2000) have discussed the applicability of the GPS to the monitoring of landslide surface displacements and achieved high-precision measurement results. Prakash et al. (2004) have designed and installed GIS based system for managing surface and underground fires in coal mining areas; Nieto and Dagdelen (2006) have developed a vehicle proximity warning-collision avoidance system to improve safety of trucks in open pit mines; Gu et al. (2008) have designed and developed an intelligent monitoring and dispatch system of trucks and shovels in an open pit mine; Salap et al. (2009) have developed a GIS-based monitoring and management system for underground mine safety in three levels as constructive safety, surveillance and maintenance, and emergency; Mancini et al. (2009) have monitored the ground subsidence by using GPS in a salt mine, and created a hazard map using the GIS techniques; Enji et al. (2010) have monitored the trucks on 3D maps to reduce mining

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accidents and indicated that 3D assisted driving system has the potential to increase reliability and reduce uncertainty in open pit mining operations by customizing the local 3D digital mining map; Qinghua et al. (2010) have designed and developed a dynamic management system of ore blending in an open pit mine by using GIS and GPS. Briefly, these studies carried out in particular on the subject of monitoring the trucks and shovels and/or increasing the safety in open pit mines. In this study, a system that was not previously in the literature to monitoring quality of the excavated mine was discussed. To this end, Afşin- Elbistan-Turkey opencast coal mine which is equipped with six bucket wheel excavators was selected as an exemplary mining area, and the system approach has been established to monitoring the qualities of the excavated coal.

The study consists of two sections. In the first stage, preparation of GIS database containing the quality data of the opencast coal mine; and in the second stage, development of a monitoring system for the coal qualities, have been discussed.

Preparation of GIS Database

In this section of the study, firstly, all geologic and sampling data such as *x*, *y*, *z* coordinates, dip and azimuth angles of drill holes, lithological definitions of samples taken from drill holes, lower calorific value (LCV), ash content (AC%), moisture content (% MC) on an as-received basis, core recovery area entered and maintained in an electronic database (Fig 1). Then, coal basin was divided into blocks sized 2.5 m x 100 m x 100 m, and average quality values of the blocks were estimated using 3D geostatistical analyses described graphically in Fig. 2. In these analyses, respectively, an appropriate theoretical variogram models were determined, cross-validation methods were performed to the variogram model, and representative estimates and their errors were generated for a volume by kriging interpolation techniques which were further discussed in detail in Mert (2010), Mert and Dag (2015, 2017), Singer and Menzie (2010) and Srivastava (2013).

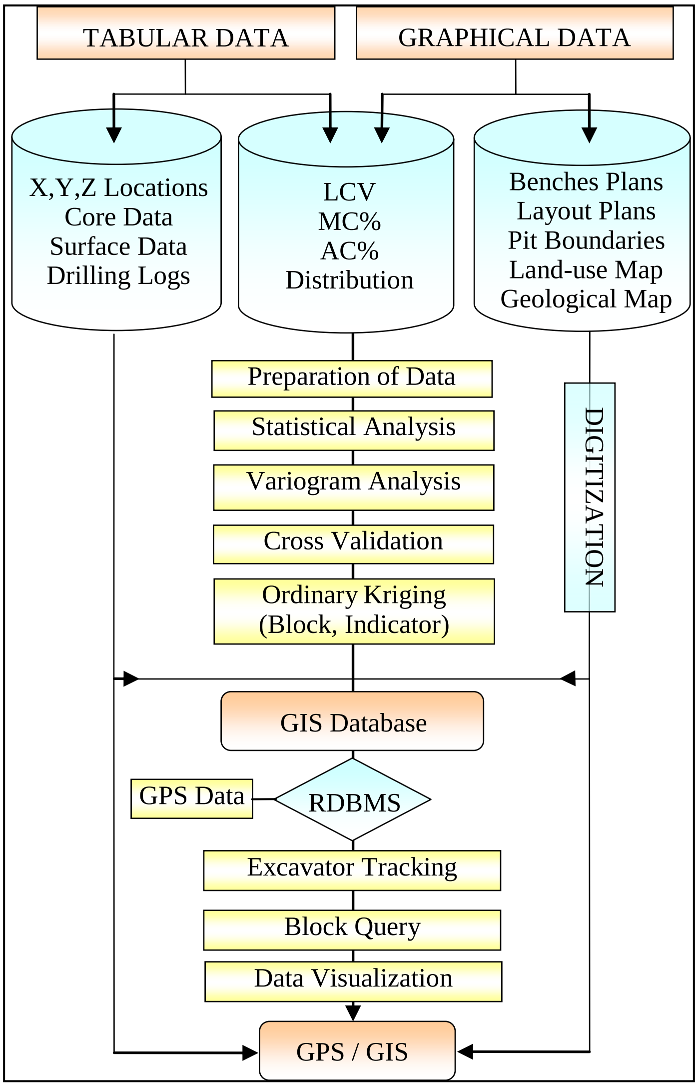


Fig. 1. General flow chart of the study.

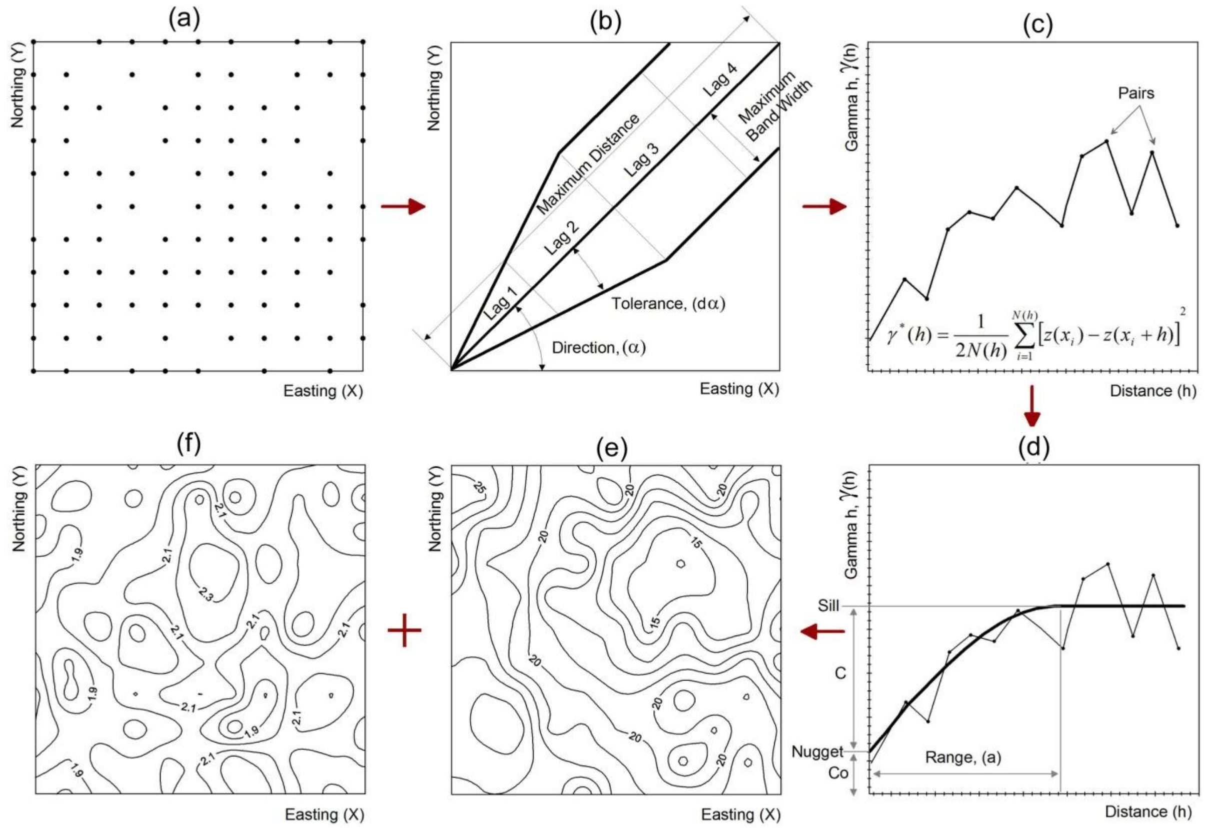


Fig. 2. Graphical representation of geostatistical analysis stages: a) post plot of sample data, b) tolerance angles and distance tolerances, c) experimental semivariogram, d) theoretical semivariogram, e) contouring of kriged values, f) kriging error map.

The final stage of the analyses, all of the kriging estimation results were combined as a spreadsheet format for the following applications in GIS/GPS querying. The created spreadsheet data includes 2.938.880 blocks value such as LCV, AC%, MC%, and geographical coordinates (Tab. 1).

Tab. 1. View of the coal quality from the integrated database.

Block ID	East (X)	North (Y)	Elev (Z)	LCV	LCV Std.Err.	AC%	AC% Std.Err.	MC%	MC% Std.Err.
1	325150	4243650	968.75	1233.00	139.30	12.69	6.49	52.88	7.35
2	325250	4243650	968.75	1233.00	145.04	12.69	7.39	52.88	7.58
3	325350	4243650	968.75	1220.67	142.10	12.31	7.09	50.76	7.20
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
2938879	332950	4247450	1226.25	903.40	38.50	23.39	4.94	56.89	2.26
2938880	333050	4247450	1226.25	905.73	57.12	23.39	6.04	58.15	3.26

Development of Quality Monitoring System

This section deals with the development stages and qualities of the coal quality monitoring system which can perform location dependent analyses. The primary principle during the development stage of the system was to enable real-time tracking of the incidents and product movements in the opencast mine enterprises.

In the Afsin-Elbistan opencast mine, the overburden and coal excavated by the bucket wheel excavators are sent to dump sites through conveyors (Ural and Onur, 2001; Tutluoglu et al., 2011). According to the design of the thermal power plant, the lower calorific value (LCV) of the demanded coal should be 1050 kcal/kg on average, a minimum of 950 kcal/kg, and a maximum of 1600 kcal/kg; while the 30-day maximum average should be greater than 1000 kcal/kg (Gunalay, 1969). The ash content (AC%) should not exceed

250 g / 1000 kcal, and the moisture content (MC%) should not exceed 64 %. The coal blending and stocking site has a large design with an effective capacity of 660.000 tons and a maximum capacity of 1.000.000 tons. Thus, instant tracking of the quality and amount of coal that is conveyed to the stock area is important for processes such as blending. Based on the tabular data, we combined under the GIS, we had blocks at 112 different depth levels, and at 100x100x2.5 m dimensions, whose LCV, AC%, MC%, and coal boundaries and geographical coordinates were known (Fig. 3). Based on this information, we attempted to answer the following three questions were:

1. On which geographical coordinate does the excavator excavate?
2. Into which block in our tabular data does the coordinate, where the excavation is carried out, fall?
3. What are LCV, AC% and MC% quality values of the block in the coordinate where the excavation is made?

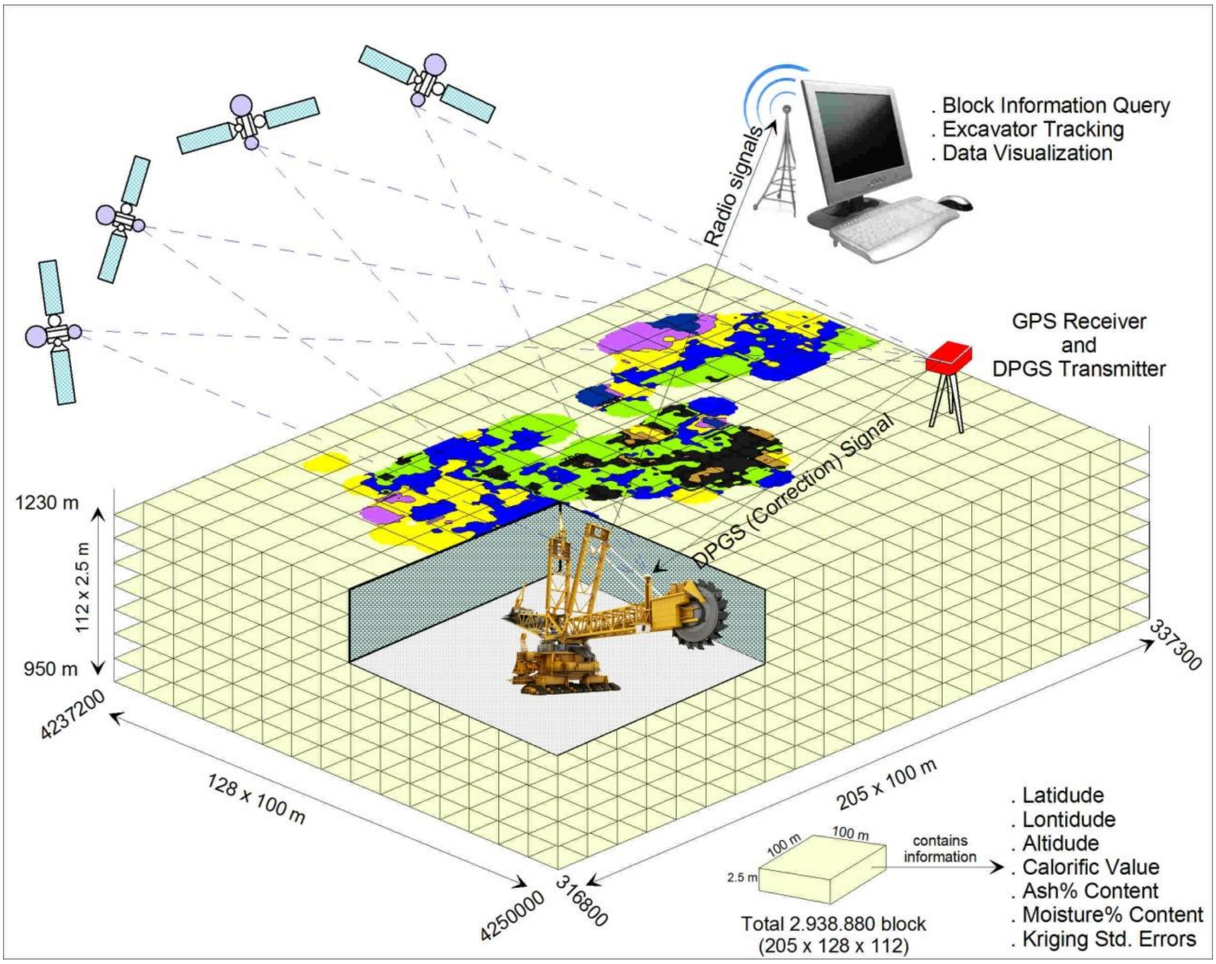


Fig. 3. Working principle of the system.

According to GPS technology, it is possible to reach coordinate information with an error sensitivity of 2-5 cm (Nieto and Dagdelen 2006; Gu et al., 2008; Enji et al., 2010). Thus, it can be concluded that the coordinates where the excavations are carried out can be reached by mounting a GPS receiver onto the excavator and sensors on its boom. Thus, it would be possible to determine on which block the coordinate of the GPS receiver extracts falls, and determine the quality values of the block through the queries to be made in the tabular data. To this end, a computer application with GIS/GPS integration, which can make a point-block query in the tabular data, required needed. An algorithm was developed and written in Visual Basic 6.0 from MapInfo using MapBasic. The Visual Basic application consists of three sections. A GPS section that awaits the coordinate information that will be received over the GPS and that makes coordinate transformations; a map analysis section that functions in order to view digital maps and track heavy construction equipment on the screen and the point-block-quality query section (Fig. 4). In this section, the relational database management system (RDBMS) allows flexible data extraction, called a ‘query’, with a single criterion or multiple criteria, based on structured query language (SQL). The GPS section operates in the background. Every time it receives the coordinate information, it renews the display image in such a way to reflect its new status by sending this information to map the analysis section. In the point-block query section, a user can optionally make location-based quality queries over the database.

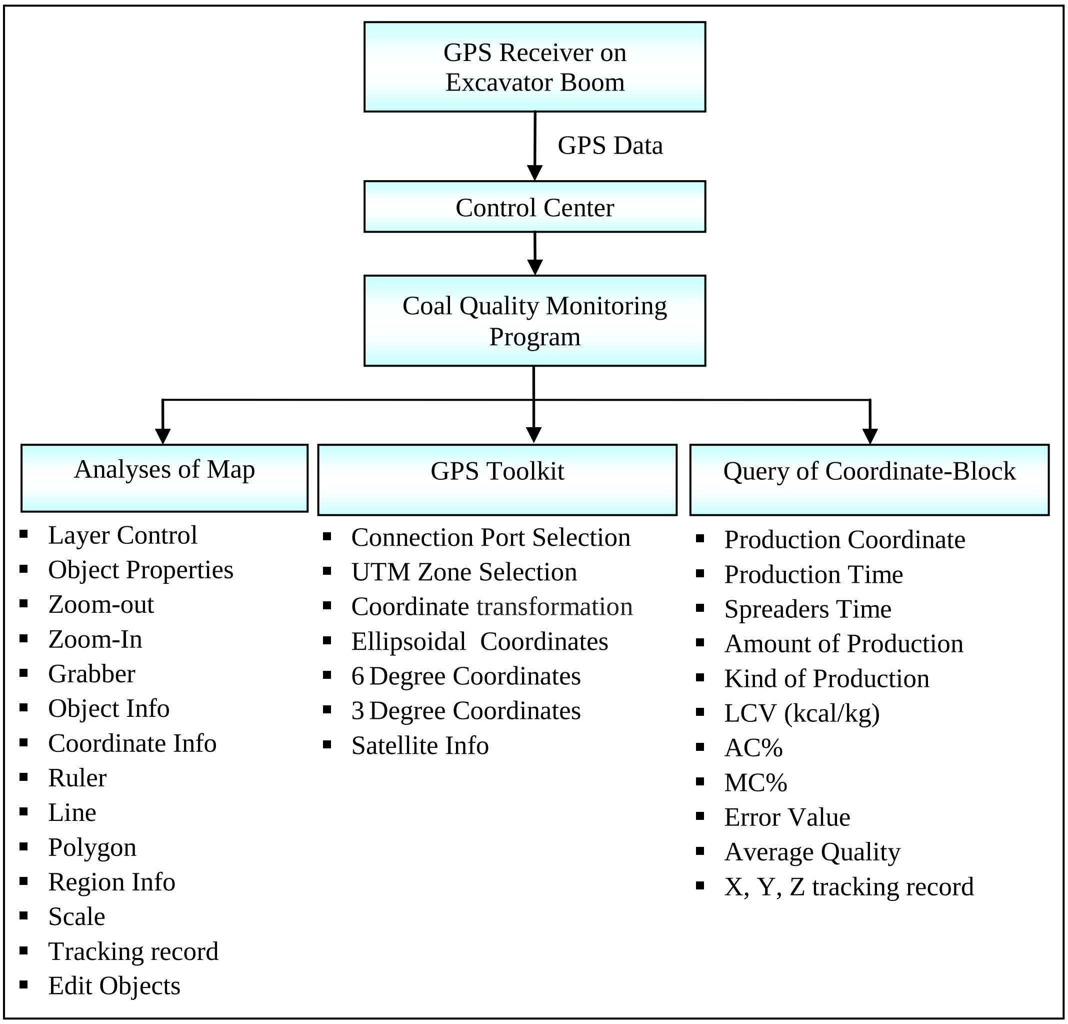


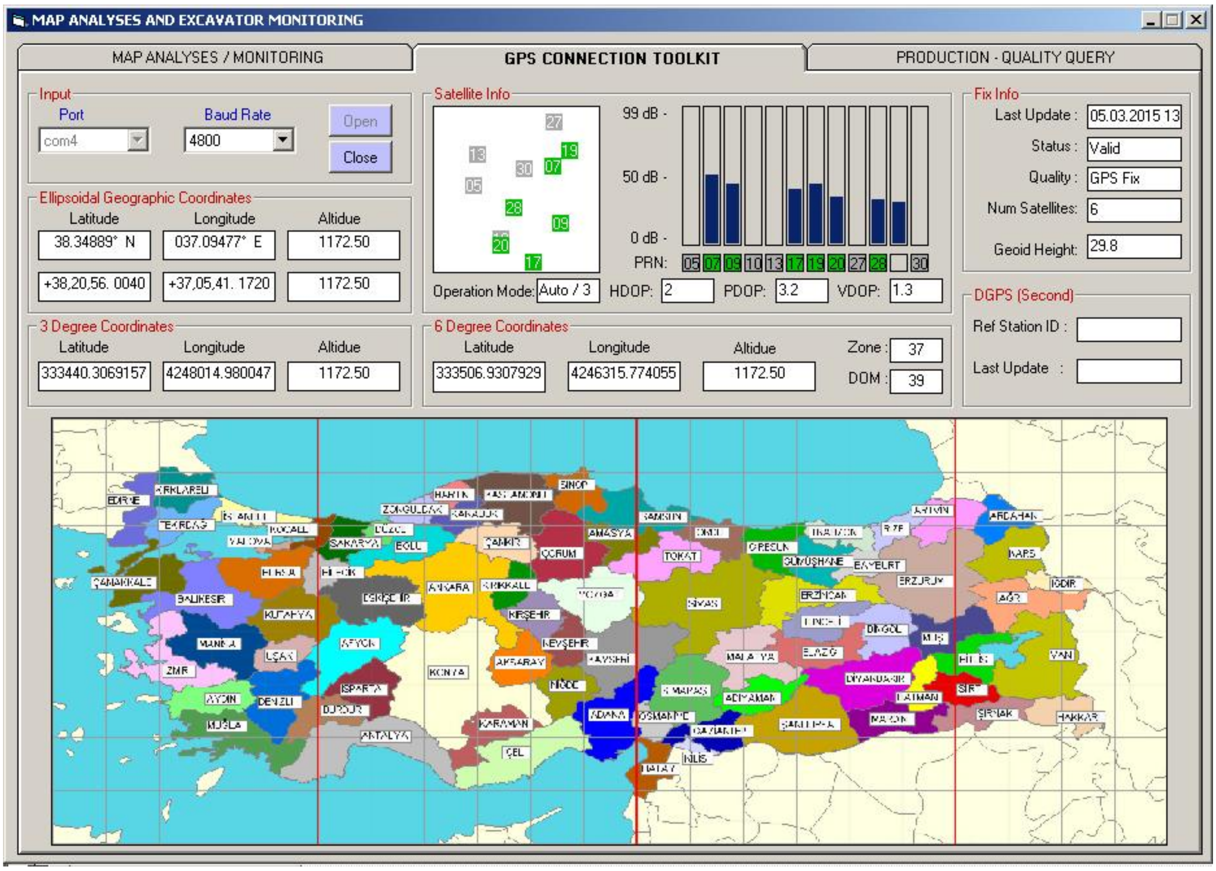
Fig. 4. The general working principle of the coal quality monitoring system.

GPS Section

The Garmin GPS III-Plus used in the applications is a versatile, portable receiver. A connection can be established between the GPS and the computer over the RS-232. When the GPS is connected from the serial communication port using the Visual Basic, the GPS transmits the location data to the computer in the form of NMEA sentences. GLL is the simplest sentence containing the location data. In a sample GLL sentence "$GPGLL, Latitude of position, North or South, Longitude of position, East or West, UTC of position, Status" such as "$GPGLL, 4916.2249, N, 12311.4500, W, 224509, A" the latitude is 49 degrees 16.2249 minutes north; the longitude is 123 degrees 11.45 minutes west, and fix taken at the time 22:45:09, data valid according to Greenwich.

Through the analysis of the GLL sentences, the coordinate data can be digitally processed. In addition, the GPS Toolkit module, which is developed for Visual Basic programming language to reach the entire GPS functions, is available for use free of charge. A variety of data such as the number of satellites connected, the quality of the GPS signals, etc., can be accessed thanks to the module.

In the program, by selecting the port to which the GPS receiver is connected from the opened related boxes in the GPS screen, the user can connect to the GPS and see both the number of satellites connected and the connection qualities, visually on the screen (Fig. 5). Since the location information is presented in the form of ellipsoidal geographical coordinates, they were transformed into a 6° and 3° Turkish Coordinate System with the UTM Projection ED-50 datum using the equations given by Grafarend and Krumm (2006). However, the prepared graphical and tabular data was stored in the UTM Projection ED-50 datum coordinates, and these two should be compatible with the queries. For the datum and coordinate transformations, firstly, the central zone meridian of our mining area should be selected over the screen. After the selection of the zone central meridian, the transformed 3° and 6° coordinates and the connected GPS satellites are visually presented on the screen.



Input
Port: com4
Baud Rate: 4800

Ellipsoidal Geographic Coordinates
Latitude	Longitude	Altidue
38.34889° N	037.09477° E	1172.50
+38,20,56. 0040	+37,05,41. 1720	1172.50

3 Degree Coordinates
Latitude	Longitude	Altidue
333440.3069157	4248014.980047	1172.50

Satellite Info
PRN: 05 07 09 10 13 17 19 20 27 28 30
Operation Mode: Auto / 3 HDOP: 2 PDOP: 3.2 VDOP: 1.3

6 Degree Coordinates
Latitude	Longitude	Altidue
333506.9307929	4246315.774055	1172.50

Zone : 37
DOM : 39

Fix Info
Last Update : 05.03.2015 13
Status : Valid
Quality : GPS Fix
Num Satellites: 6
Geoid Height: 29.8

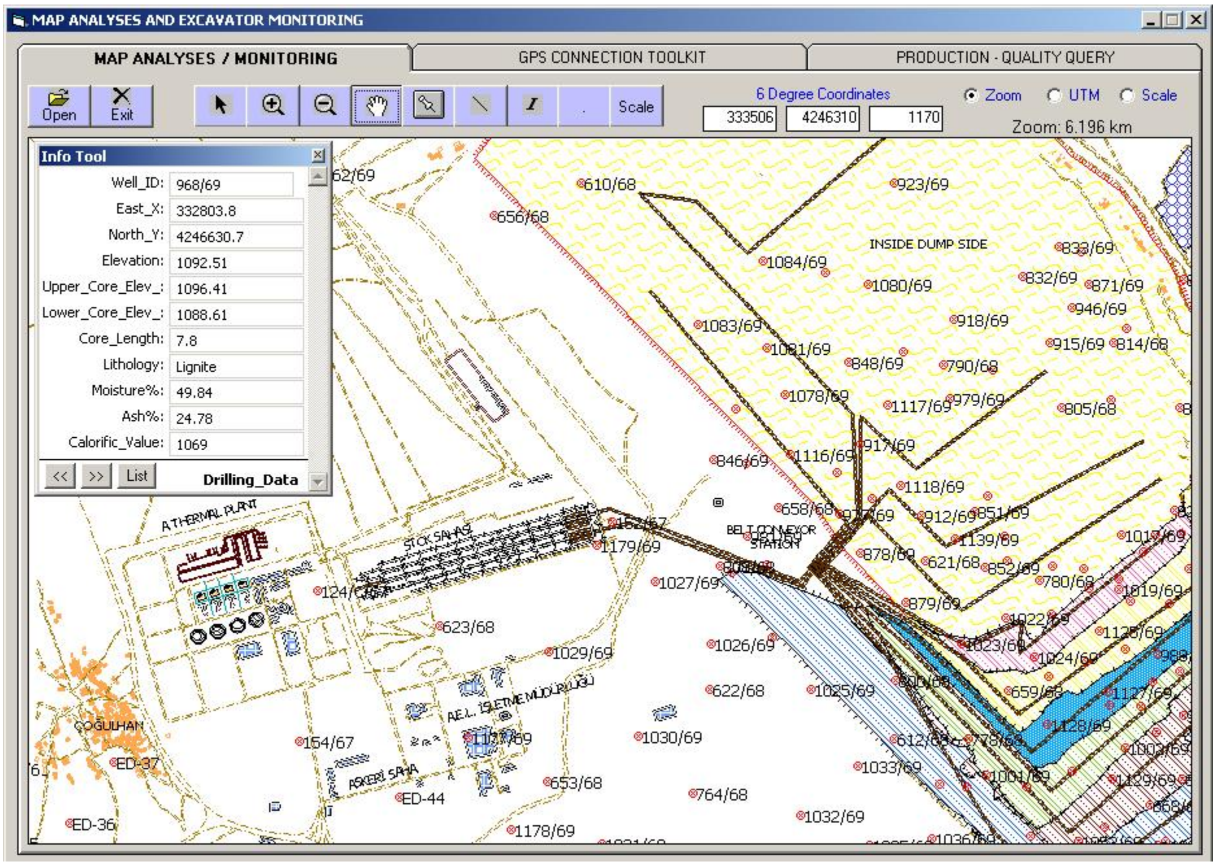
DGPS (Second)
Ref Station ID :
Last Update :

Fig. 5. An image from the GPS connection screen.

Map Analysis Section

The graphical data that is created on this screen of the section can be viewed as digital maps. The viewing of these maps requires various operations in terms of computer programming. First, the layers that constitute the map and geographical objects that form each layer are stored in the memory by processing the files that constitute the map to be imaged. The viewing takes place by drawing each graphical layer processed from the file over each other in the specified order. The coordinates of the geographical objects forming the drawn layer should be recalculated according to the coordinate systems of the screen during the drawing process. An important aspect in the viewing of digital maps is that the screen and the map have different coordinate systems and units. The origin is located in the upper left-hand corner of the screen coordinate system. The X-axis is towards the right, while the Y-axis is downwards. The unit of the coordinate system of the screen is a pixel. In this case, unexpectedly, the viewed part of the map is upside down, and these types of problems can be eliminated by a series of software techniques. Another issue is that the coordinate system is re-scaled according to the required magnification level, and the map should be able to be scrolled down in order to view different parts. All the coordinates that define the geographical objects that are needed to be viewed on the screen should be transformed into the new coordinate system before the viewing operation. This operation requires the application of a series of mathematical operations to all the coordinates. Considering that map operations are continuously performed, such a solution slows software viewing operating down. While performing operations such as viewing maps, updating the images, and answering user requests, by awaiting the location information to be received, incoming coordinates should be transformed into a suitable projection format. Since awaiting location information requires the constant operation of codes, it interrupts the operation of other parts of the software and makes it impossible to respond to user requests. This problem could be overcome by applying certain software techniques.

In this context, using the OLE support of the Visual Basic programming language in the map viewing section, applications integrated with powerful GIS abilities of the MapInfo were developed, and thus the map viewing operations were accelerated. In this section, a user can upload a map in*.dxf, *.dwg, *.mif, *.mid, *.dgn, *.e00, *.shp vector formats onto the screen by converting them to a MapInfo *.tab format and can view it at the requested magnification levels. The magnification level refers to the horizontal distance of the area viewed in the map in units of the distance unit of the map. The magnification level determines the number of details to be viewed on the map; the smaller the levels, the more detail one can see on the map (Fig. 6).



6 Degree Coordinates: 333506 4246310 1170

● Zoom ○ UTM ○ Scale

Zoom: 6.196 km

Well_ID: 968/69
East_X: 332803.8
North_Y: 4246630.7
Elevation: 1092.51
Upper_Core_Elev_: 1096.41
Lower_Core_Elev_: 1088.61
Core_Length: 7.8
Lithology: Lignite
Moisture%: 49.84
Ash%: 24.78
Calorific_Value: 1069

Drilling_Data

Fig. 6. Digital map analyses and excavator tracking screen.

Furthermore, the user can also view different sections of the map. This operation takes place by scrolling the map down to the desired amount to different directions. The user can reach the digital value of a point if they wish. For example, they can access the log data of a drill hole over a drill hole point.

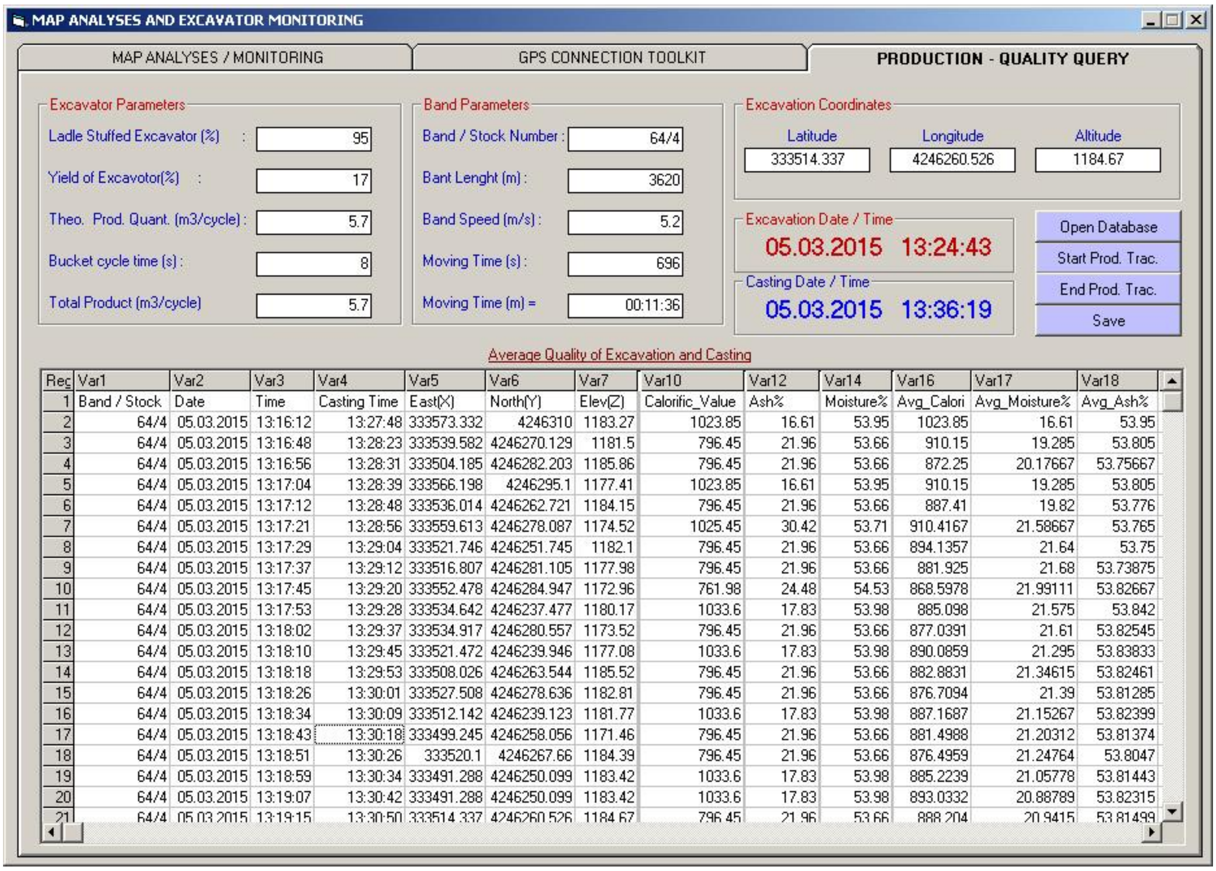
It is the duty of the MapInfo OLE inspection to perform all these requests for the user (MapInfo, 2004). In case of such a request, the MapInfo readjusts coordinate system of the screen transforms geographical objects according to this new screen coordinate system and renews the image. Moreover, the developed GPS section of the program awaits location information that will appear by operating in the background. The map analysis section renews the display image by processing the new location information it has obtained on the map that is being viewed. Thus, any mobile vehicle such as an excavator or truck bearing a GPS is tracked in real-time over the digital maps on the computer screen.

Production - Quality Querying Section

In this section, location data and GIS database are matched to determine excavated blocks and quality values in real time. In the matching process, the approach where the coordinate acquired by the GPS receiver falls into the nearest block among in our GIS database was adopted.

In the point-block query, the approach where the coordinate extracted by the GPS receiver falls into the nearest block among those with the known coordinates in our database was adopted. As block-distance calculations would be time-consuming at each received coordinate, the distances between all the blocks were calculated once only, and the nearest twenty blocks were taken to the buffer memory as a separate database. As the relocation was larger than the radius of the sphere covered by the twenty blocks we had, query operations were accelerated by taking the second twenty blocks to the buffer storage with the same variable identifications.

The quality values such as LCV, AC%, and the MC% of the block in the coordinate where the excavation is made are kept on the same line as the block number in our tabular data. The identification number, which is known as "ID" is the same in all the features for the identified block (Fig. 7). The quality values of the block where the excavation is made such as the number, the coordinate, the LCV, the LCV estimation error, the AC% estimation, the AC% estimation error, the MC% estimation, and the MC% estimation error, were determined and included in the database that was presented as output.



MAP ANALYSES AND EXCAVATOR MONITORING

Excavator Parameters

Ladle Stuffed Excavator (%) : 95
Yield of Excavotor(%) : 17
Theo. Prod. Quant. (m3/cycle) : 5.7
Bucket cycle time (s) : 8
Total Product (m3/cycle) 5.7

Band Parameters

Band / Stock Number : 64/4
Bant Lenght (m) : 3620
Band Speed (m/s) : 5.2
Moving Time (s) : 696
Moving Time (m) = 00:11:36

Excavation Coordinates

Latitude 333514.337
Longitude 4246260.526
Altitude 1184.67

Excavation Date / Time
05.03.2015 13:24:43

Casting Date / Time
05.03.2015 13:36:19

Average Quality of Excavation and Casting

Reg	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var10	Var12	Var14	Var16	Var17	Var18
1	Band / Stock	Date	Time	Casting Time	East(X)	North(Y)	Elev(Z)	Calorific_Value	Ash%	Moisture%	Avg_Calori	Avg_Moisture%	Avg_Ash%
2	64/4	05.03.2015	13:16:12	13:27:48	333573.332	4246310	1183.27	1023.85	16.61	53.95	1023.85	16.61	53.95
3	64/4	05.03.2015	13:16:48	13:28:23	333539.582	4246270.129	1181.5	796.45	21.96	53.66	910.15	19.285	53.805
4	64/4	05.03.2015	13:16:56	13:28:31	333504.185	4246282.203	1185.86	796.45	21.96	53.66	872.25	20.17667	53.75667
5	64/4	05.03.2015	13:17:04	13:28:39	333566.198	4246295.1	1177.41	1023.85	16.61	53.95	910.15	19.285	53.805
6	64/4	05.03.2015	13:17:12	13:28:48	333536.014	4246262.721	1184.15	796.45	21.96	53.66	887.41	19.82	53.776
7	64/4	05.03.2015	13:17:21	13:28:56	333559.613	4246278.087	1174.52	1025.45	30.42	53.71	910.4167	21.58667	53.765
8	64/4	05.03.2015	13:17:29	13:29:04	333521.746	4246251.745	1182.1	796.45	21.96	53.66	894.1357	21.64	53.75
9	64/4	05.03.2015	13:17:37	13:29:12	333516.807	4246281.105	1177.98	796.45	21.96	53.66	881.925	21.68	53.73875
10	64/4	05.03.2015	13:17:45	13:29:20	333552.478	4246284.947	1172.96	761.98	24.48	54.53	868.5978	21.99111	53.82667
11	64/4	05.03.2015	13:17:53	13:29:28	333534.642	4246237.477	1180.17	1033.6	17.83	53.98	885.098	21.575	53.842
12	64/4	05.03.2015	13:18:02	13:29:37	333534.917	4246280.557	1173.52	796.45	21.96	53.66	877.0391	21.61	53.82545
13	64/4	05.03.2015	13:18:10	13:29:45	333521.472	4246239.946	1177.08	1033.6	17.83	53.98	890.0859	21.295	53.83833
14	64/4	05.03.2015	13:18:18	13:29:53	333508.026	4246263.544	1185.52	796.45	21.96	53.66	882.8831	21.34615	53.82461
15	64/4	05.03.2015	13:18:26	13:30:01	333527.508	4246278.636	1182.81	796.45	21.96	53.66	876.7094	21.39	53.81285
16	64/4	05.03.2015	13:18:34	13:30:09	333512.142	4246239.123	1181.77	1033.6	17.83	53.98	887.1687	21.15267	53.82399
17	64/4	05.03.2015	13:18:43	13:30:18	333499.245	4246258.056	1171.46	796.45	21.96	53.66	881.4988	21.20312	53.81374
18	64/4	05.03.2015	13:18:51	13:30:26	333520.1	4246267.66	1184.39	796.45	21.96	53.66	876.4959	21.24764	53.8047
19	64/4	05.03.2015	13:18:59	13:30:34	333491.288	4246250.099	1183.42	1033.6	17.83	53.98	885.2239	21.05778	53.81443
20	64/4	05.03.2015	13:19:07	13:30:42	333491.288	4246250.099	1183.42	1033.6	17.83	53.98	893.0332	20.88789	53.82315
21	64/4	05.03.2015	13:19:15	13:30:50	333514.337	4246260.526	1184.67	796.45	21.96	53.66	888.204	20.9415	53.81499

Fig. 7. On-screen monitoring of the quality of the excavated coal

The total production amount, depending on the theoretical production amount, performed within the cycle time determined by the user and the mean quality and error values calculated according to the total production are presented in the output. The stock records can also be viewed in the data by entering the stock number of the coal fed into the stocks, the band length, and the band speed data of the conveyor from the screen. Furthermore, all the defined features can be presented as output while preparing the tabular data such as the date, hour, etc., of the excavation.

Conclusions

The GPS was mounted on a joint on the bucket of a bucket wheel excavator by an application carried out in the Afsin-Elbistan coal opencast mine, and three different types of quality data were recorded with a relocation of almost twice the block sizes (100x100x2.5 m) in our data in measurements that took one and half hours. The analysis of the screen image on the tables in Fig. 7 shows that the production amounts were summed up on a continuous basis depending on the time and the total production amount, and the mean quality values were presented in the related digits. Thus, the engineer who is responsible for production can have information on temporal quality and the amount of coal that is conveyed to the stocks. Considering that the production quality is envisaged to be equal to the quality values of the core samples obtained from the nearest drill hole to the excavation point, there is no doubt that more accurate results can be achieved in digital decision making with an approach in which the production is estimated by various drill holes and functional relationships between them. As mining progress, the GIS database should be updated by importing new experimental results to the data set used in kriging estimates. In this view, the accuracy of kriging estimates will increase, and more realistic results will be obtained.

Considering other bucket wheel excavators, excavating coal at different levels and thus, different qualities in the opencast coal enterprise, knowing the average quality of the coal in the stocks will throw light on the blending process. Furthermore, the three-dimensional extractions of the coordinates where the excavations are made enable updating all the changes and measurements regarding the mine in a short time in the computer media, which enables the preparation of the production maps instantly or for a desired period. Further studies can be carried out on the preparation of excavation maps simultaneously with excavation using GPS/GIS techniques.

Acknowledgements: *The research reported in this paper was partially supported financially by the Scientific Research Project Unit of Cukurova University (MMF2007D5). The authors also gratefully acknowledge General Directorate of Mineral Research and Exploration of Turkey (MTA) for borehole logs and Turkish Electricity Transmission Company (EUAS) for providing logistical support during this project study.*

Abbreviations

The following abbreviations are used in this manuscript:
AC: Ash Content
MC: Moisture Content
LCV: Lower Calorific Value

Appendix A

The MapBasic computer application and source codes are available from: http://www.jeostat.com/MEC.zip

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