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Optimal Location of a Copper Smelter in Saudi Arabia for Polymetallic Deposits Using a Computerized Numerical Approach

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ABSTRACT. The objective of this research work is to locate an optimal site for a copper smelter in Saudi Arabia to utilize the polymetallic ore deposits in the Arabian Shield. The research is concerned with investigating the potential ore deposits including their reserve sizes and ore grades. The study includes determining the deposits' locations with reference to industrial facilities, business centers, and shipping yards along with its location with reference to national highway network. The research includes a survey of seven applicable smelter sites that include two districts of the metalliferous ore deposits, four seaports, and the central region of the Kingdom. The survey includes determining the involved potential local ore deposits, possible imports of copper ore concentrates, and available industrial facilities. A computer program was constructed using Lotus spreadsheet to manipulate the relevant data to rank the candidate smelter sites. A macro function programming allows the reflection of any relevant information to update the ranking result. The analytical technique has ranked the candidate smelter sites. The seaport of Yanbu was ranked first to host the smelter plant. The district of Jabal Sayid in the Northern belt of mineral prospects ranked second amongst all candidate smelter sites.

1. Introduction

This research is concerned with locating an optimal site for a copper smelter in Saudi Arabia, to serve the metalliferous copper ore deposits in the Arabian Shield. The Shield contains more than 800 sites of copper occurrences[1]. It investigates the metalliferous ore deposits in the Arabian Shield that contain significant grades of copper. The study covers the deposits' reserve sizes in tonnage and ore grades.

The paper includes an investigation of applicable smelter sites. These sites include the two locations of the metalliferous ore deposits districts both in the North and in the South of the Arabian Shield, i.e., Jabal Sayid and Al Masane. Additional sites include the major seaports in the Kingdom, Jeddah, Jubail, Yanbu, and Jazan. Riyadh is also added as a possible site for the smelter, since it lies midway along the eastern edge of the Arabian Shield and the ore belt of Samra. These locations should cover the entire Arabian Shield zone excluding insignificant areas.

The survey includes determining sizes of copper concentrates supplied to these candidate sites from potential ore deposits, and possible copper ore concentrates from abroad. The investigation includes available industrial facilities at these sites, such as power, fuel, treated water, maintenance, and machine shops, availability of skilled labor, and housing accommodations. Community acceptance of the smelter construction and the smelter contributions to regional prosperity are also considered in locating the optimal site of the smelter.

Twenty factors are identified and quantified in order to characterize the properties pertaining to the nominated smelter sites. A computer spreadsheet program is constructed to manipulate relevant data, such as ore reserves, ore grades, expected ore depletion time, mill concentrate grades, mill metal recoveries, and distances to the potential smelter sites. The spreadsheet program determines the mine output and the annual concentration rates. Macro programming is executed to determine and display the equivalent ranking of the candidate sites for the proposed smelter plant.

2. Smelter Purposes and Needs

The first stage of ore upgrading is performed at mine site to concentrate the ore that contains a few percentage of copper into a product that grades over 20% copper. Smelting is the process of upgrading such copper concentrate to over 90% in anode forms, when the product is ready to be further refined in an electro-winning process to generate over 99% metal cathodes, bars, or other forms[2].

Smelting is a costly process that requires both a high capital investment and a continuous and efficient maintenance. It is also a major source of air pollution in the mining process. Cost of an average size modern smelter could surpass the combined costs of mine and mill for an average size of ore deposits such as those of the Arabian Shield. Therefore, it is uneconomic for mining companies to establish a smelter for each mine plant. However, a lack of a nearby smelter would render a mining project unviable, even if all other parameters are economically favorable.

2.1 *Smelting Process and Products*

The conventional process of smelting involves a reverberatory furnace to oxidize the ore and to extract the metals. The pressure caused by industry competition to reduce cost, along with the environmental regulations to curb pollution, have contributed to develop new methods in order to both improve productivity and control the generated sulphur dioxide. Most of the gas that goes to the acid plant originates in the converters when around 30% of the total sulphur in the concentrate feed is eliminated in the converters. Therefore gas cleaning and sulphur capture currently constitutes almost 35% of the capital cost of a new smelter[3].

2.2 *Existing Smelters and New Smelting Development*

The increasing air quality regulations in developed countries have placed many copper producers at a competitive disadvantage compared to smelters in countries lacking similar restrictions. Due to high capital requirement of establishing a modern smelter, mines in countries less concerned with environment still operate on old type highly polluting and inefficient small-scale smelters. However, flash-furnace smelters have replaced older reverberatory smelters in developed countries. The major manufacturer of these modern furnaces is the Outokumpu Company of Finland. This company has installed more than thirty smelters in all five continents and four in Australia in the past decade [4].

Japan, though not a major copper ore producer, accommodates seven modern efficient smelters, and is considered a major copper exporter. Its huge smelting industry can both control and affect the metal prices [5].

3. Preview of Applied Procedure

In order to locate an optimal site for a copper smelter serving numerous mines of potential ore deposits in the Arabian Shield as shown in Fig. 1, a procedure consists of the following stages is carried out:

a) Surveying the promising polymetallic ore deposits in the Arabian Shield, identifying the potential ore deposits, and investigating their reserve sizes, copper grades, and proximity to city business centers as well as the travel road conditions and distances needed to reach the proposed smelter sites through the national highway network. Contributions of these deposits to feed copper concentrates to the proposed smelter are also investigated.

b) Determining the required upgrade of ore deposits includes the following:
   1) Mill Concentration of Ore
   2) Concentrate Size

c) Surveying applicable smelter sites for their characteristics to be qualified to host the proposed smelter plant. These include seven locations including industrial zones, major seaports and center of mineralization districts next to major copper ore deposits. These locations should cover the entire Kingdom, excluding no essential areas, and they are listed from North to South, as follows, (and as shown in Fig. 1): Jubail, Riyadh, Yanbu, Jabal Sayid, Jeddah, Al Masane, and Jazan.

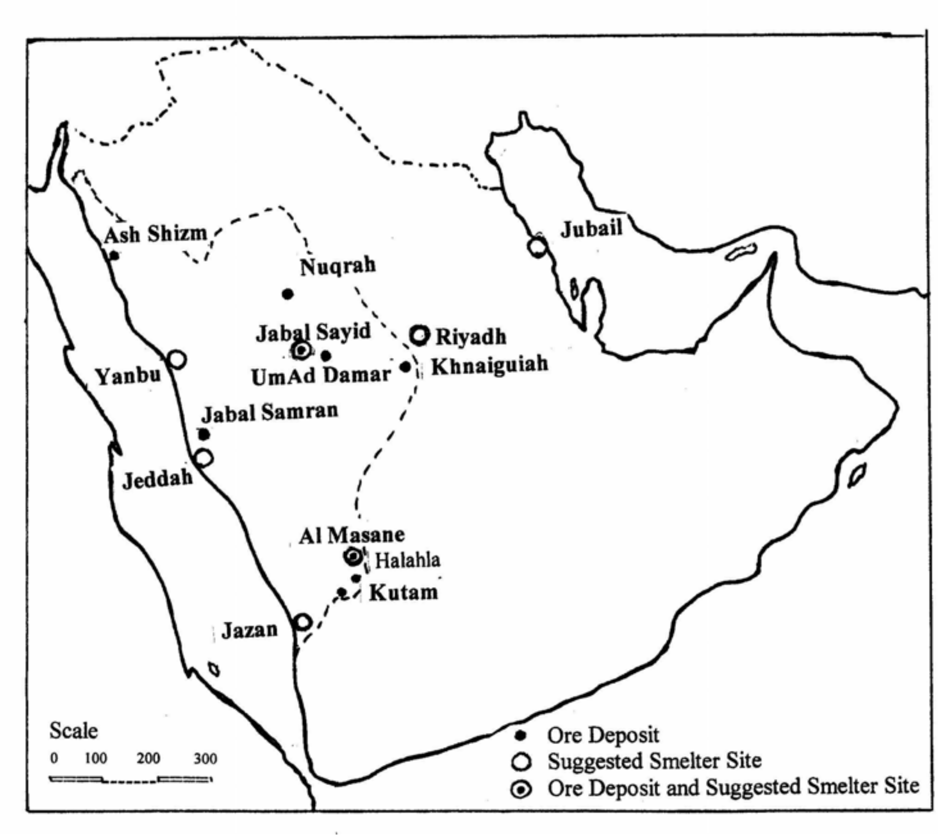

FIG. 1 Principal Copper Ore Deposits: and Candidate Smelter Sites in the Kingdom (Arabian Peninsula)

d) The analytical technique to rank candidate sites for smelter site selection process:
   1) Defining factors characterizing smelter sites
   2) Determining relative values of the characteristic factors
   3) Assigning degrees to and points within each factor
   4) Valuing each smelter site relevant to each factor
   5) Determining weighted average distance from each site to ore deposits

e) Programming the ranking technique:
   1) Constructing the computer spreadsheet
   2) Compiling Data
   3) Execution of the program
   4) Obtaining Results and Analysis
      i) Program Output
      ii) Analysis of Results
      iii) Data Modifications
   5) Conclusions and Recommendations

3.1 ***Survey of the Potential Ore Deposits (ore reserves and grades)***

The Arabian Shield, the geologic area of Western part of Saudi Arabia, hosts numerous polymetallic ore deposits that include hundreds of copper occurrences[6]. Ancient copper mining and present exploration activities are relatively concentrated around two districts characterized by high-grade ore of marginally commercial sizes. One district is in the northern Arabian Shield encompassing Jabal Sayid and Nuqrah deposits. The other district is located in the Southern Arabian Shield that encompasses the promising Kutam and Al-Masane areas. Another ore district in the Shield is Samra Belt where Khanaigiah is located. Other copper deposits are of lower grades and sizes and are quite scattered in the Arabian Shield [7].

A reverse relationship is normally established between ore grades and ore reserve in the metalliferous ore deposits. A local case is presented in Table 1 and Fig. 2. While the ore reserve is controlled by the cut-off grade which in turn is determined by the prevailing prices of the metal concerned, it is displayed in Fig. 3 that as metal prices decrease, the cut-off grade must be increased to limit the size of ore that can be economically mined. However, a new technology in improving ore production, i.e., decreasing cost of processing, would definitely lead to a decrease in the cut-off grade, allowing for more ore to be excavated at a profit. The principal copper ore deposits are displayed in Fig. 1. The ore reserves and ore grades of these potential deposits are summarized in Table 2.

TABLE 1. Demonstrated resources, Kutam copper-zinc deposit

Copper Grade %	Ore Reserve (million tons)
3.49	1.6
2.13	3.8
2.11	4.5
1.01	9.4
0.95	10.0

Source of data: DMMR Reports 1990-1999.

TABLE 2. Locations of potential ore deposits, their ore reserve, and copper grades

Ore Deposit	Location	Reserve, Million tons	Cu Grade, %
Jabal Ash Shizm	26° 27' N., 37° 32'E	1.6	2.92
An Nuqrah	25° 36' N., 41° 30'E	0.9	1.15
Khnaiguiyah	24° 15' N., 45° 05'E	7.1	0.36
Jabal Sayid	23° 51' N., 40° 56'E	21.5	2.5
Umm Ad Damar	23° 39' N., 41° 03'E	1	2
Jabal Samran	22° 20' N., 39° 32'E	0.9	2
Al Masane	18° 08' N., 43° 51'E	7	1.44
Kutam	17° 36' N., 43° 35'E	4.5	2.11
Al Halahila	17° 29' N., 43° 55'E	1.04	0.44

Source of data: DMMR Reports 1990-1999.

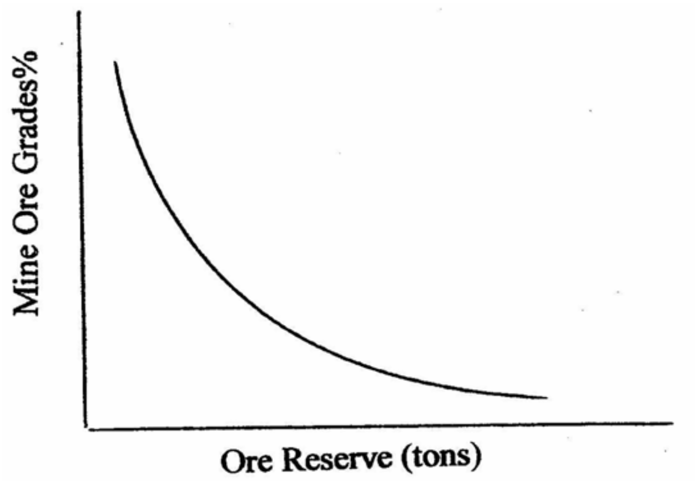

FIG 2. Ore grade and ore reserve relationship

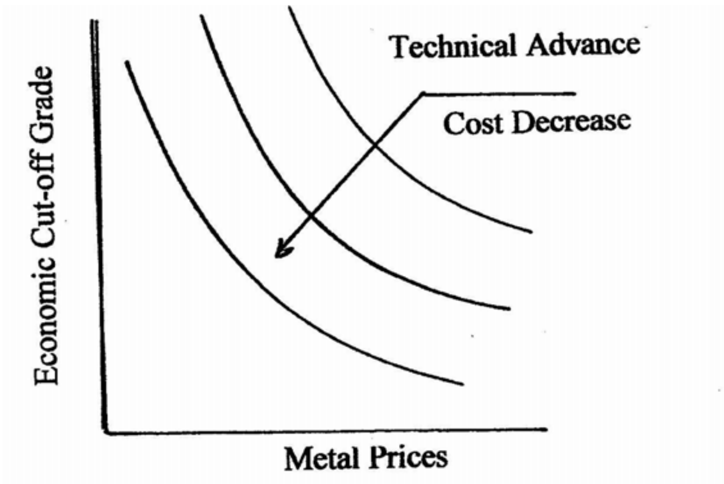

FIG 3. Cut-off grade vs. mineral prices

3.2 *Upgrading Excavated Ore*

3.2.1 *Concentration of the Ore*

The excavated ore from indigenous promising deposits contains around 2% copper and is not salable on site till the contained metals are converted to a real wealth. Therefore, a beneficiation plant is needed to eliminate the unwanted materials from ore while preserving the metal contents. Ore transportation to another destination for extraction is quite costly due to the high density and abraisivity of the ore. Therefore, mining companies situate a concentration plant at mine site. This ore concentrate product presents only 3 to 10% of the original weight of ore, but has a higher metal grade than that of the input run-of-mine. The resulted product is easier for transportation and subsequent smelting. The values of the above percentages are determined by the following factors[8]:

i) original metal grades of the mined ore,
ii) milling efficiency of recovering the metal contents, and
iii) metal grade of the concentrate, required by the smelter schedules.

3.2.2. ***Determining Concentrate Sizes from Potential Ore Deposits***

In order to economically justify a mine project, its ore reserve must last 5 to 20 years before depletion, depending on many factors, principally as follows:

a. ore reserve size, and the assayed ore grades,
b. shape of the orebody, its spatial position,
c. method of mining and corresponding ore dilution and ore recovery,
d. size of capital available,
e. availability of water and opening support materials,
f. availability of skilled staff and workers,
g. local minerals policy
h. production demand and market share,
i. efficiency of the mine operations.

Generally, mill copper concentrates contain 20-35% copper and the concentration process recovers 70-85% of the copper originally available in the mined ore [9]. Such grade and recovery percentages depend on the following factors:

a. Ore deposit grade
b. Complexity of ore
c. Mining selectivity and mining dilution which both depend on the applicable mining method
e. Size of plant and size of ore treated
f. Efficiency of operation during ore processing
g. Extent of transportation distance involved from mine plant to smelter site
h. Requirements of smelter schedules
i. Metal sales prices and production operation cost

There is normally an inverse relationship between mill concentrate grade and mill metal recovery as expressed in Fig. 4. This inverse relationship between these two parameters indicates that attempts to improve concentrate grade result in degraded metal recovery, unless an enhanced method or extra cost is allowed.

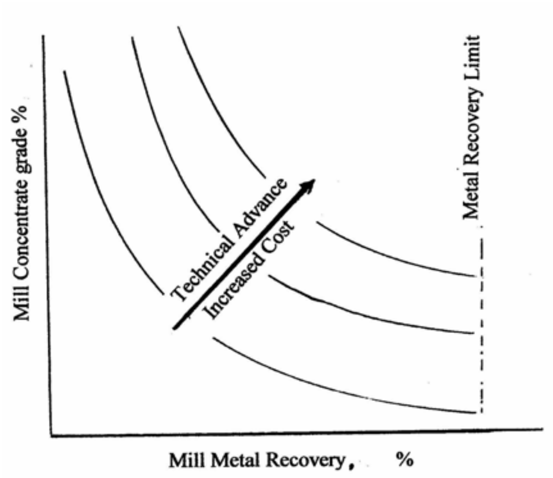

FIG. 4 Relationship of mill conc. Grade and mill metal recovery

3.3.3. *Review of Smelting Ore Concentrates*

The ore concentrate product may practically and economically be transported to another location for further refining. It is ready to be fed to smelter in order to integrally separate most of the metals from the attached unwanted gangue materials in a molten state.

But due to unavailability of a high capacity copper smelter in the region, let alone in the country, to accommodate the above ore concentrates, the cost of shipping ore concentrate overseas thousands of kilometers to Europe or to the Far East, would attach an extra expense to the total copper production costs, rendering these ore deposits "un-economical". Comparable foreign deposits are more competitive when a smelter is available nearby. In order to overcome this situation, and remove the burden of shipping cost, a copper smelter must be locally established to process the local copper ore concentrate, in order to turn those marginal ore deposits into profitable producing mines.

4. Present Work Procedure

4.1 *Anticipated Ore Concentrates*

Normally the copper ore concentrate represents 3 to 10% of the produced ore size, based on consideration of normal average concentrate grades and mill metal recoveries for local operations. The ore reserve of potential ore deposits, copper grades, life of the operation, yearly production, daily output, and yearly product of copper concentrates, in tons are summarized in Table 3. Concentrates from abroad are anticipated initially as 10% of capacity. The concentrates are shipped from overseas countries via major seaports of Yanbu, Jeddah and Jubail[10].

TABLE 3. Potential Ore Reserve, Ore Grades, Output and Concentrate

Ore Reserve	Reserve M. tons	Ore Grade, Cu %	Life, Years	Year Ore, M. tons	Day Tons	Yr Conc, Tons	Sea Port Code	Conc., DayTons
Jubail							JubPort	20.0
Ash Shizm	1.6	2.92	5	0.320	970	22400		67.9
Nuqrah	0.9	1.15	5	0.180	545	12600		38.2
Riyadh								0.0
Khnaiguiah	7.1	0.36	12	0.592	1793	41417		125.5
Yanbu							YanPort	40.0
Jabal Sayid	21.5	2.5	20	1.075	3258	75250		228.0
UmAd Damar	1	2	5	0.200	606	14000		42.4
Jabal Samran	0.9	2	5	0.180	545	12600		38.2
Jeddah							JedPort	10.0
Al Masane	7	1.44	12	0.583	1768	40833		123.7
Kutam	4.5	2.11	10	0.450	1364	31500		95.5
Al Halahlah	1.04	0.44	5	0.208	630	14560		44.1
Jazan							JizPort	10.0

4.2 ***Present Work: Need of Establishing a Local Smelter***

The capital cost of a mid-size modern smelter is around $400 millions[5]. This amount exceeds the capital costs of both mine and mill plants of most of the Saudi relatively small-size ore deposits. Presently world smelters operators compete to decrease processing costs by both using economics of scale to increase the size of the smelters and enhancing the efficiency of the operation. Therefore, it is uneconomic to establish a small smelter for each small ore deposit in the Arabian Shield. Preferably, one relatively large smelter must be established to serve more than one deposit. Such smelter must be well situated to effectively serve a group of potential ore deposits in the Kingdom. This research addresses this problem and surveys the applicable sites with regard to their characteristics and the corresponding locations of ore deposits that would feed such proposed smelter.

4.3 ***Investigation of the Appropriate Smelter Sites***

A proper location of the proposed smelter must be adjacent to groups of polymetallic deposits in Jabal Sayid district in the North, or in Al Masane district in the South. Industry-designated zones of Yanbu and Jubail can provide convenient infrastructure facilities. Jazan is another potential location that is close to Al Masane mining district, and is also a seaport. Jeddah is another logical location since it is a major seaport that can equally serve both the North and the South deposits districts. Riyadh region lies midway between North-South polymetallic deposits along their eastern edge. Its business center and facilities offer a potential location for a smelter. Therefore, seven potential sites for a smelter in Saudi Arabia are considered in the study, and are displayed in Fig. 1.

4.4 ***Analytical Techniques of the Site Selection Process:*** *Multiple Objectives*

There are many different factors to be considered in the smelter site selection decision, a technique for analytically considering many factors is the use of a method for decision making with multiple objectives[11]. The method is needed because so many factors such as suitable transportation facilities, weighted average distances to potential ore deposits, ease of securing concentrates from overseas, community attitude and local climate and so forth, cannot be readily quantified. Yet, they are important in the site location decision.

4.4.1 Defining Factors Characterizing the Smelter Sites

The first step is to make a list of all the important factors. It is important that the list contains all non-cost factors exerting an influence on the decision to insure that no significant items are omitted. Table 4 includes a list of twenty significant non-cost factors for the candidate sites for the proposed smelter plant.

TABLE 4. Significant Factors for Smelter Site Selection

	Significant Factors	Value Points
1	Availability of Concentrate Products and Anticipated Sizes	300
2	Weighted Average Distance to Potential Ore Deposits	250
3	Availability of Power and Other Utilities	100
4	Contributions to Regional Growth and Prosperity	90
5	Social Attitude and Community Acceptance	80
6	Securing Concentrate Supplies from Overseas.	70
7	Accessibility to Market Smelter Product	60
8	Availability of Industrial Water Supplies	55
9	Housing Availability to Accommodate Staff and Workers	40
10	Availability of Labor Supply	40
11	Proximity to Seaport And Airport	45
12	Building/ Construction Contracts and Costs	40
13	Availability of Recreation Facilities	35
14	Availability of Medical Facilities	35
15	Security and Civil Defense	30
16	Nearness to Business Center	30
17	Waste Disposal Facilities and Regulations	30
18	Regional Climate and Environment Pollution Concerns	30
19	Transportation Facilities and Roads Conditions	35
20	Site Characteristics and Public Facilities	20

4.4.2 *Determining Relative Values of the Characteristics Factors*

The second step in the analytical technique is to assign relative values for each of the factors for the smelter plant to be located with regard to potential mine deposits. The values vary according to characters of each candidate site as shown in Table 4, and can be updated and produced in the computer program.

4.4.3 *Assigning Degrees and Points within Each Factor*

The third step is to assign degrees and points within each factor. Six degrees are used with linear increments of points between these degrees in order to completely define this evaluation scheme. A method of assigning degrees to two different factors is displayed in Table 5 and Table 6.

TABLE 5. Availability of Industrial Water Supply /Power & Utilities

Degrees	Label	Point Assignment
0	Not Existing, Excluded	0
1	Not Available, Not applicable	45
2	Limited Access	90
3	Not readily available	135
4	Available	180
Maximum	Promoted, Subsidized,	225

TABLE 6. Social Attitude - Community Acceptance

Degrees	Label	Point Assignment
0	Rejection	0
1	Not cooperative	80
2	Passive	160
3	Unconcerned	240
4	Cooperative	320
Maximum	Supportive	400

4.4.4 *Valuing Each Smelter Site Relevant to Each Factor*

The fourth step is to assign degrees and corresponding points for each factor to each of the candidate site. Assigning degrees can vary extensively, but best judgment is used. Table 7 shows assigned degrees for all of the twenty factors. Table 7 is included in the computer program and thus can be produced there following any data update.

Table 7. Factors/ Parameters Value Points and Degree Weights

Parameter Number	Value Points	0 Min	1	2	3	4	5 Max
1--->	300	0	300	600	900	1200	1500
2--->	250	0	250	500	750	1000	1250
3--->	100	0	100	200	300	400	500
4--->	90	0	90	180	270	360	450
5--->	80	0	80	160	240	320	400
6--->	70	0	70	140	210	280	350
7--->	60	0	60	120	180	240	300
8--->	55	0	55	110	165	220	275
9--->	40	0	40	80	120	160	200
10--->	40	0	40	80	120	160	200
11--->	45	0	45	90	135	180	225
12--->	40	0	40	80	120	160	200
13--->	35	0	35	70	105	140	175
14--->	35	0	35	70	105	140	175
15--->	30	0	30	60	90	120	150
16--->	30	0	30	60	90	120	150
17--->	30	0	30	60	90	120	150
18--->	30	0	30	60	90	120	150
19--->	35	0	35	70	105	140	175
20--->	20	0	20	40	60	80	100

4.4.5 ***Determining Weighted Average Distance to Potential Ore Deposits***

This is a major factor that indicates the proximity of the ore deposits to the candidate site. It formulates the average distance from all potential deposits to each smelter site. Distance between remote sites cannot be accurately quoted since routes vary according to preference of motorists and current road conditions, and the extent of improving paved roads at the time of the smelter operation. A margin of 10% is included in the recorded distances. Table 8 tabulates the distance relationship between potential ore deposits and the candidate sites for the proposed smelter. Calculations of the weighted average distance from candidate smelter sites to potential ore deposits are mathematically performed and systematically programmed in the spreadsheet. The computer program initially ranks the candidate smelter sites according to corresponding weighted average distance to potential sites as shown in Table 9.

TABLE 8. Distances between Ore Deposits and Smelter Sites, in km.

Ore Deposits	Jubail		Yanbu		Jeddah		Jazan	Conc.
. Distances		Riyadh		J. Sayid		Al Masane		DayTons
Jubail	0	420	1400	1020	1450	1330	1700	20.0
Ash Shizm	1300	900	400	400	600	1200	1190	67.9
Nuqrah	1000	600	500	220	510	1100	1010	38.2
Riyadh	420	0	1100	620	1000	930	1250	0.0
Khnaiguiyah	600	200	720	500	700	900	880	125.5
Yanbu	1400	1100	0	400	330	900	970	40.0
Jabal Sayid	1020	700	370	0	350	800	870	228.0
Umm Damar	1040	720	400	20	308	770	770	42.4
Jabal Samran	1300	1040	300	250	110	700	710	38.2
Jeddah	1450	1000	330	350	0	610	730	10.0
Al Masane	1330	930	900	800	610	0	200	123.7
Kutam	1380	980	930	850	660	50	130	95.5
Al Halahila	1400	1000	980	870	680	70	160	44.1
Jazan	1700	1250	970	870	730	200	0	10.0

TABLE 9. Ranking of smelter sites according to weighted average distance from ore deposits.

Smelter Site	Avg. Distance	Ranking Order
Jubail	1102	7
Riyadh	755	6
Yanbu	593	3
Jabal Sayid	425	1
Jeddah	524	2
Al Masane	630	4
Jazan	693	5

4.5 *Programming Ranking Technique*

A numerical approach is performed to determine the optimal smelter location to serve multiple mine ore deposits. This procedure addresses an analytical method and uses the spreadsheet program for selecting and ranking smelter sites applicable to potential ore bodies and properties of candidate sites for the proposed smelter.

4.5.1 *Construction of the Computer program*

A multiple objective method and a Nicholas numerical approach were formulated and a spreadsheet was constructed to apply these techniques [12, 13]. The program can be run on an IBM-PC compatible, using spreadsheet software with a macro capability. The selected program software is Lotus 1-2-3. Version of Lotus Suite 97 as well as Microsoft Excel should run such application[14]. The program provides a user-friendly menu to enter the necessary data, modify it and execute it. Output from the computer program ranks the candidate smelter sites. The required input data are the characteristics of potential mine orebodies such as ore reserve, ore grades, ore production, and the distance involved in shipping the ore concentrate to feed the proposed smelter plant at the candidate site. The ranking data for the smelter site selections include all of the twenty factors considered in the selection process.

The program is menu-driven and is composed of a main program menu and several sub-routines menus [15, 16].

4.5.2 *Compiling Data*

From the main menu, a transaction must be selected to enter the needed data, in submenu, to display it, to modify it, and to run the program and view and analyze the results. The main menu is displayed in Fig. 5. The user gains access to any data collection sub-menu, subroutine by browsing, highlighting and selecting the sub-menu.

4.5.3 *Execution of the Program*

Subroutines prompt and direct the user to a series of necessary input data that will be needed for the ranking process. The user can gain access from the main menu to any of the data-collection subroutines in Fig. 5.

Main Menu (containing seven subroutines)

1. Ore Deposits
   - a. ore reserve,
   - b. ore grade,
   - c. Returning to main menu

2. Years, Days, & Concentrate Ratio to Ore
   - a. Life of mine operation
   - b. Working days per year
   - c. Ratio of ore concentrates to run-of-mine ore
   - d. Returning to main menu

3. Sea Port anticipated imports of overseas concentrates
   - a. Jubail, b. Yanbu,
   - c. Jeddah, d. Jazan,
   - e. Returning to main menu

4. Distance from potential ore deposits to smelter locations
   - a. Table marking for update
   - b. Returning to main menu

5. Non-cost factors characterizing the smelter locations
   - a. Table marking for updating
   - b. Returning to main menu

6. Results:
   - a. Displaying graphs,
   - b. Printing summary tables,
   - c. Returning to main menu

7. Printing
   - a. Printing Factors values
   - b. Printing
   - c. Printing Summary view
   - d. Printing Site value points
     1. Jubail
     2. Yanbu,
     3. Riyadh,
     4. Jabal Sayid,
     5. Jeddah,
     6. Al Masane,
     7. Jazan,
   - e. Returning to main menu

FIG. 5. Flow chart of the computer program main and sub-menus

5. Results and Analysis

5.1 *Computer Program Output*

Running the program and obtaining the results is accessed by the main menu, sub menu and selecting the highlighted "RESULTS". Output from the program can be in a form of tables and bar graphs. The current output ranks the candidate sites of the proposed smelter plant as displayed in Table 10.

Fig. 6 combines average distances and ranking order of the candidate seven sites. Other computer output tables can be produced upon executing the program.

Output of the program represents ranking candidate smelter sites. Each site is given ranking value points, which indicate its competency extent degree and priority of this site to serve the potential ore deposits according to given input data. The candidate smelter sites are orderly ranked in the last column in the table according to their competency points.

TABLE 10. Computer output of Ranking Candidate Smelter Sites

North to South	Candidate Smelter Site	Ranking Points	Ranking Order
1	Jubail	18.2	4
2	Riyadh	15.1	7
3	Yanbu	23.6	1
4	Jabal Sayid	21.1	2
5	Jeddah	19.8	3
6	Al Masane	18.1	5
7	Jazan	16.6	6

The analytical technique has remarkably ranked the candidate sites for establishing the smelter in the order displayed in Table 10, where Yanbu site is ranked first amongst all candidate sites for smelter. This conclusion reflects Yanbu's strategic location and attached available industrial facilities.

The Most Favorable Factors for the First Selection are as follows:

1. Weighted Average Distance to Potential Ore Deposits
2. Availability of Power and Utilities
3. Social Attitude and Community Acceptance
4. Securing Concentrate Supplies from Overseas
5. Waste Disposal Facilities and Regulations

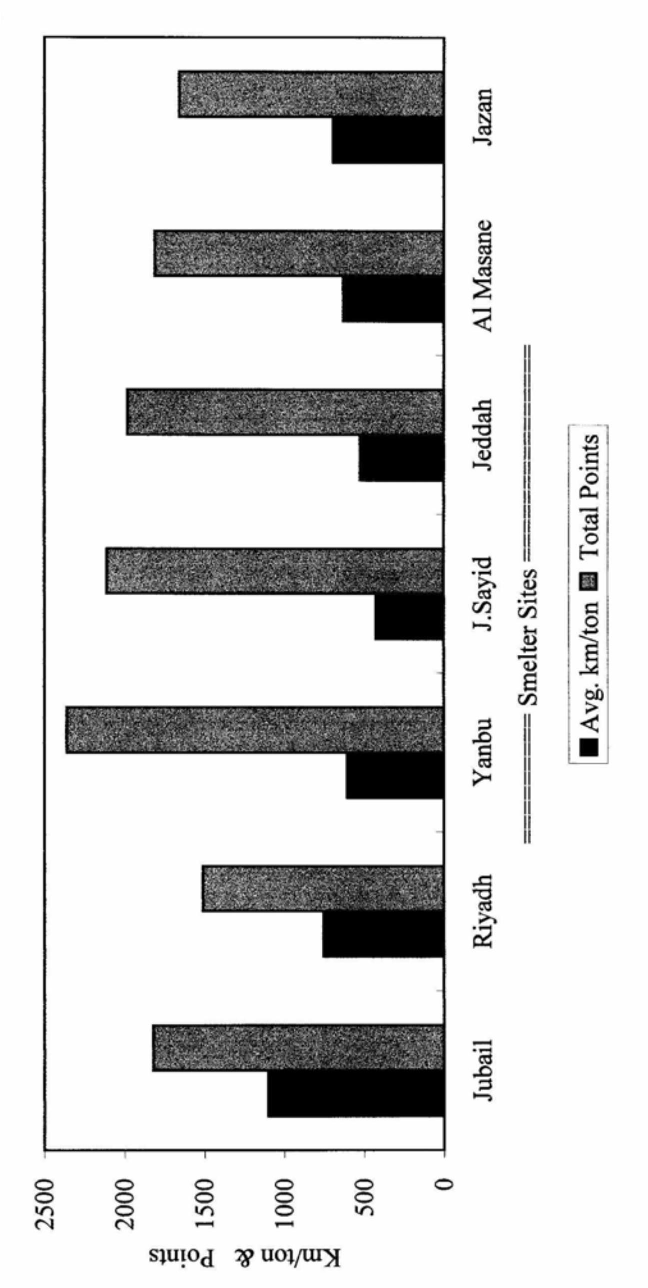

FIG. 6 Ranking of Candidate Smelter Sites (Avg. Km/ton and Total Points)

The second candidate smelter site of Jabal Sayid has the following favorable factors:

1. Availability of local concentrate products and possible sizes
2. Weighted average distance to potential ore deposits
3. Contributions to regional growth and prosperity

5.2 *Data Modifications*

It is allowed in the program to modify input data and obtain corresponding ranking results as reflected by the updated information. The program can be initiated by executing the macro functions. Any new entry or a change according to the program flow chart of Fig. 5 can be selected by pointing to any of the following areas for modifications:

1) Surveying of the Potential Ore Deposits
   - Table of Ore Deposits, Reserve Sizes and Copper Grades
2) Upgrading the Ore from these Deposits to Produce Concentrates
   - Milling Feed Capacity, Yearly and Daily Tons of Ore
   - Size of Produced Concentrates from Ore Deposits
3) Surveying of the Applicable Smelter Sites
   - Candidate Smelter Sites, and Distances Involved
4) Determining the Value Points of Factors of the Sites
   - Value Points of Factors Characterizing Candidate Sites
5) Programming Execution of the Ranking Technique
   - Modifying Procedure and Adding Subroutines

6. Conclusion and Recommendations

6.1 *Conclusion*

The ore reserves, ore grades, and copper concentrate outputs of the Arabian Shield polymetallic ore deposits have been defined. Meantime, seven applicable sites in the Kingdom to host the smelter plant were determined. A survey of the parameters of these sites with respect to availability of facilities was performed. The survey also included determination of distances from the candidate smelter sites to the potential ore deposits and their copper concentrate supplies.

A computer program was set up to apply an analytical technique of multiple objectives in order to rank the candidate smelter sites as a method of decision making. The process included quantifying the non-cost parameters for the candidate sites of the proposed smelter plant. The output of the program included tables and bar charts to rank the proposed sites.

Yanbu site was ranked first due to its industrial facilities and its strategic seaport location midway along the western edge of the Arabian Shield. Jabal Sayid site for a smelter was selected second since it constitutes the center of the northern district of the potential metalliferous ore deposits. Operating a mine and installing a smelter in Jabal Sayid would greatly contribute to the prosperity of this undeveloped area of the Kingdom.

Other candidate sites were ranked last due to either, lack of local copper concentrate supply, lack of industrial facilities, or lack of enthusiasm toward establishing a polluting plant in heavily populated regions.

6.2 *Recommendations*

The following recommendations are presented to concerned authority:

1. Extending railroad network to cover regions of potential ore deposits in order to minimize cost of shipment of ore concentrate. Railroad transportation is the least expensive for bulk land shipments and its capital cost is much less than that of highways. Priority of railroad extension includes the following:
   a. A short link of 100 km between Jubail and Dammam is needed to complete the connection of the center of the Kingdom at Riyadh by railroad directly to Jubail, the major industrial zone in the East.
   b. Future extension of railroad from the Northern district of ore deposits at Jabal Sayid to Yanbu is of great economic importance. It would transform numerous marginal ore deposits situated along this proposed railroad, into producing mines.
   c. Similarly, a railroad connection from the Northern areas of Turayf (phosphate ore) and Wadi Sawawin (iron ore), to Yanbu, will definitely motivate the exploitation of these important deposits.
   d. A railroad connection of Al Masane to Jazan will effectively enhance the prospect of mining the Southern ore deposits. The concentrate products of these deposits would then be shipped from Jazan by sea to any other seaport site selected for the smelter, e.g., Yanbu, Jeddah or Jubail.

2. Extending the national electricity grid-system to include regions of potential ore deposits such as Jabal Sayid in the North and Al Masane in the South, to minimize cost of generating own local power for the mine-smelter plants.

3. Promoting copper-based industry in anticipation of exploiting local copper ore deposits and a copper smelter plant establishment. Such initiated industry is in turn needed to economically justify establishing a smelter plant in the Kingdom. Fig. 7 indicates the inter-dependence of the three economic industrial activities, i.e., an indigenous copper ore mine production, a local copper concentrate smelter plant, and a national copper-based industry.

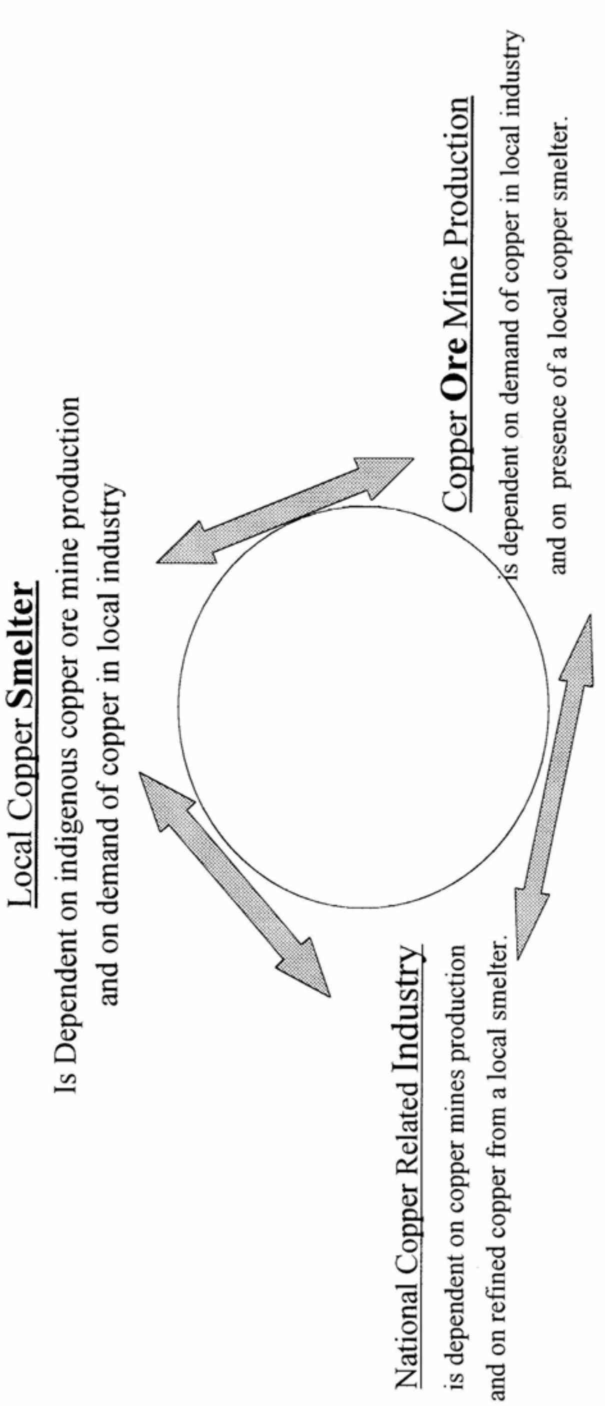

FIG. 7. Interdependence of Copper Ore-Smelter-Industry

4. Setting up an environment code and regulations pertaining to mining and smelting activities in order to avoid future conflicts with smelter operators.
5. Performing a detailed feasibility study to decide whether these ore deposits are amenable to commercial production.
6. Improving all transportation means, e.g., surface road conditions, rail-road extensions, and seaport facilities.
7. In order to minimize concentrate transportation costs and in order to avoid the risk of 100% accidental shutdown, a further study is recommended to assume two small size smelters to be situated in Jabal Sayid and in Al Masane area to serve the numerous ore deposits dispersed in the region of these two locations.

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تحديد الموقع الأمثل لمصهر نحاس للرواسب المعدنية متعددة الفلزات في الدرع العربي بالتقارب العددي المبرمج بالحاسب الآلي

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المستخلص. يهـدف هذا البحث إلى تحديد الموقع الأمثل لإقامة مصهر لمركزات الرواسب المعدنية المتعددة في المملكة، فنظراً لوجود مئات المواقع المتمعدنة بالمملكة والتي تحتوي على خامات نحاس منتشرة في الدرع العربي، يتم في البحث دراسة المواقع الواعدة منها والتي تحتوي على أحجام اقتصادية ذات درجات تركيز عالية من معدن النحاس، وتحديد مواقع الخامات الحيوية الممكن استخراج ومعالجة إنتاجها والتي تشكل نواة لمركزات الخام المعدني للنحاس كي تفي باحتياجات المصهر المرتقب حسب طاقته الاستيعابية. كذلك يتم تحديد مواقع تلك الخامات نسبة إلى شبكة الطرق الرئيسة وبُعدها عن المواقع الملائمة لإقامة مصهر لمركزات المعادن النحاسية، ويتم كذلك التعرف على المناطق الملائمة فنياً لمصهر النحاس وتأهلها لتكون الموقع الأمثل من ناحية قربها من المواقع الحيوية للخامات المعدنية ومن ناحية استقبال مركزات خام النحاس من خارج المملكة وتوفر الاحتياجات الصناعية والمرافق العامة، إضافةً إلى تحديد بعدها عن أقرب ميناء بحري وجوي، ويتم إعداد ذلك في برنامج الجداول الإلكترونية وعرض النتائج المستحدثة باستخدام برمجة (ماكرو Macro)، وقد تم إنجاز هذه الورقة العلمية عن بحث قامت بدعمه مدينة الملك عبدالعزيز للعلوم والتقنية بكل شكر وتقدير.