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AN INTERPRETIVE STRUCTURAL MODEL OF ENVIRONMENTAL IMPACTS OF A COAL FIELD

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ABSTRACT

Interpretive structural modeling is a technique which helps in structuring large complex systems. This article presents a case study of identification and structuring the activities and impacts of a coal field in India. A checklist method is used to identify the variables of the system and a paired comparison method is used to develop a binary matrix representing interrelationships. The variables are analyzed to identify a hierarchy of relationships and obtain an interpretive structural model. The model helps in developing a causal loop diagram which can then be used in a comprehensive environmental impact analysis.

Coal is an essential source of energy in India and may remain a prime source for at least thirty to forty years. Coal mining in India is nearly 100 years old. Until 1973, the industry was in the hands of private industrialists who made no efforts to reduce environmental damage in the coal field areas. Though the industry was nationalized in 1973, much work has yet to be done regarding the environment—though it is very clear now that there is greater awareness of environmental deterioration in coal fields [1-3]. There is also a demand to conduct an environmental impact assessment of every coal field [1]. The Government of India, through the Department of Environment, has asked every coal field to prepare an "environmental management plan" [4]. At present, these plans are mostly restricted to land restoration, social forestry, and

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combating spontaneous fires in the coal field [5]. But overall impact assessment does not form a part of this plan [6]. In fact, there is hardly any attempt to minimize environmental pollution due to coal mining even after fifteen years of the nationalization of coal mining—the main priority of the mines being the level of production. Though wages increased considerably after nationalization, there is little change in the quality of life of mine workers: poor housing, polluted environment, low or no education, and drinking (liquor) habits, etc., are responsible factors for their poor quality of life, and few noteworthy efforts have been made for improvement. There is a great need for a comprehensive environmental impact assessment of coal fields in India, which assessment should include bio-geo-physical impacts as well as social impacts.

This article attempts to identify the impacts using an eclectic approach, developing an "Interpretive Structural Model," leading to the construction of a causal loop diagram which can then be used for a comprehensive environmental impact analysis.

LOCALE OF THE STUDY

This study was conducted in an area which includes a semi-urban town, and its surroundings where there are nine collieries within a 5 km radius. There are four open-cast mines and twenty underground pits. The total coal production is approximately 2000 tons per annum. There are no coke ovens or washeries within this area. The population of the two is about 50,000.

IDENTIFICATION OF IMPACTS

It is a primary and important task to identify the relevant impacts of coal mining, both bio-geo-physical and socio-economic and there is no foolproof method of this identification. It is proposed here that as in many other fields such as forecasting, one should resort to an *eclectic* approach in reducing uncertainty in identification of the impacts. An eclectic approach does not restrict itself to a particular method but uses various methods and synthesizes the information so collected. In order to make the identification more certain, the following methods were used to identify the impacts.

Expert Opinion

Expert opinion on any issue can be mainly sought in two forms, either by compiling, analyzing, and reporting the existing expert opinion expressed in various forums or reports, or by meeting with the experts and summarizing their opinions. This also can be done with survey or Delphi methods.

For the purpose of this article, personal discussions were held with several colliery managers, and environmental scientists who were working on the coal mine environment. Their opinions were noted and compiled.

Content Analysis

In the content analysis method, an extensive search of the related literature is made in order to list the activities and impacts of the project under consideration. There are a number of studies on environmental pollution and impacts of coal mining [7-28]. Some of these studies do not go beyond giving a description of the impacts [8, 11]. Many of them (for example, [17, 18, 20, 21]) are full of statistical data on pollution levels, measured over a period of time, meteorological data, correlations between meteorological data and pollution levels, and descriptions of remedial measures. There are very few studies that deal with some form of social problems arising from coal fields [29, 30]. A thorough search of the literature was made in order to compile the activities and impacts of coal mining for this study.

Strategic Impact Assumptions—Identification Method (SIAM)

This systematic method is used for identifying the "stakeholders" affected by activities and impacts in terms of inputs and outputs and the assumptions underlying the input/output-stakeholder linkage. This helps in explicitly identifying the groups to be involved in an environmental impact analysis (EIA), and in obtaining "multiple perspectives," i.e., the opinions of various groups. SIAM identifies the key issues of the project by ranking every assumption in terms of certainty and importance.

The coal mining inputs and outputs are listed and stakeholders are identified with the help of mining engineers working in the local collieries. They have also generated the assumptions underlying the input/output-stakeholder linkages and rated their certainty and importance. The key issues and the stakeholder groups were identified from this exercise.

Opinion Survey

This survey is mainly intended to obtain multiple perspectives on environmental and socio-economic impacts in a coal field from the stakeholder groups identified from the SIAM exercise. There are several techniques in this category, the most popular being questionnaire administration. The stakeholder groups who are identified using SIAM are the following:

1. Farmers;
2. Mine managers;
3. Other employees of coal mines;
4. Local business community;
5. Dealers and contractors;
6. Local doctors; and
7. The general public of the area.

In addition, environmental scientists working on the coal mine environment and officers of the government organizations, i.e., Directorate of Mine Safety and the Pollution Control Board, were included as respondents to the opinion survey.

An opinion survey of all the groups of people or stakeholders was made using a structured 5-point scale questionnaire.

Administering the questionnaires, even personally, was not feasible with the farmers. The explanation may lie in their low level of

- Awareness;
- Education;
- Understanding of the issues;
- Understanding of the questions of the questionnaire; and
- Estimating and predicting capacity.

Therefore, a different approach has to be adopted to collect their opinions. This article proposes the use of a delphi-like approach, called here a "Survey Delphi," to collect opinions in such an environment.

Survey Delphi

A structured questionnaire was prepared methodically. The questions were administered to a group of (say) ten people in their own mother tongue with the help of a translator. Each question was explained; a discussion was initiated to obtain a consensus of their responses. For example, for the question, "What percentage of people in this village are employed in coal mines?," the earlier responses were varying from 10 percent to 80 percent. Substitute questions like "How many households are there in the village?," "How many houses have at least one person employed in coal mines?," helped them to fully understand the question, and the ultimate consensus answer was 60 percent. The questionnaire was administered to four such groups of ten members each.

Though more than one round, with feedback, is suggested as an additional step of the survey delphi, no further round of questionnaire was administered as the responses of all the groups for this study were converging.

The responses of the farmers from survey delphi and those from opinion surveys were statistically analyzed for their mean values, median, interquartile range and standard deviation. A final, comprehensive list of activities and impacts was prepared as a result of this eclectic study. They are categorized into six groups, namely, technological factors, environmental factors, impacts on physical environment, impacts on human health and cattle health, socio-economic factors, and pollution abatement factors. (See Table 1.)

Checklist Method

The possible or probable impacts are listed using the checklist method in the case at hand. The factors listed in Table 1 are thoroughly examined, and where possible, aggregated for 1) a better understanding and 2) to reduce redundancy.

Table 1. Expanded List of Activities and Impacts of Coal Fields

Technological Factors	
1. Face drilling	7. Loading of overburden
2. Blasting	8. Unloading of overburden
3. Loading of coal	9. Transportation of overburden
4. Unloading of coal	10. Coking of coal in ovens
5. Coal combustion	11. Coal preparation (washeries)
6. Removal of overburden	12. Local transport
Environmental Factors	
13. Dust fall	18. Sulphur dioxide
14. Suspended particulate matter	19. Sulphate rate
15. Carbon monoxide	20. Trace elements
16. Carbon dioxide	21. Mine drainage
17. Nitrogen oxides	
Impacts on Physical Environment	
22. Water availability	27. Land restoration
23. Water quality	28. Land irrigation
24. Land loss	29. Land subsidence
25. Land yield	30. Damage to building structures
26. Forest loss	
Impacts on Human and Cattle Health	
31. Bronchitis	34. Tuberculosis
32. Pneumoconiosis	35. Visual impairment
33. Asthma	36. Cattle disease
Socio-economic Factors	
37. Employment	41. Crime rate
38. Business	42. Education
39. Immigration	43. Unemployment
40. Population	44. Social pressure
Pollution Abatement Factors	
45. Water treatment	47. Water spraying before blasting
46. Dust arrestor during drilling	48. Water spraying on roads

For example, the elements "loading of coal," "unloading of coal," "loading of overburden," "unloading of overburden," "transportation of overburden," and "local transport" are aggregated as "transportation of coal and overburden" because the impacts of all transport elements are comparatively the same. The environmental factors, except mine drainage, are dust or gaseous emissions and mainly emerge from "extraction of coal and overburden," and "transportation." They affect the air quality, water quality, and land yield. In fact, extraction and transportation are activities and air, water, and land quality are areas of potential impacts. Therefore, the intermediary emissions were found to be redundant elements and therefore eliminated. Also, as there are no coke ovens and washeries in this area, the elements "coking of coal in ovens," and "coal preparation in washeries" were not included.

The output of this exercise is a more appropriate list of factors to be considered for further analysis.

DESCRIPTION OF VARIABLES

The following terms and definitions are the factors listed in Table 2.

- *Extraction of Coal and Overburden* – This variable, production of coal, includes the preparation, drilling, blasting, and winning of coal and also blasting and removal of overburden. It also involves the loading, transportation, and unloading of coal from mine to the surface.
- *Transportation of Coal and Overburden* – The transportation of coal from the surface of the mine to the coal yard, including loading and unloading operations, is considered next. This variable also includes the loading, transportation, and unloading operations of the overburden when it is transported from the surface of the open cast mine to the dumping field.
- *Coal Combustion* – Coal is used in this area mainly for domestic purposes and also for producing steam to operate steam winding machines for transport of coal from underground mine to the surface. Therefore, it includes coal burned for power as well as for domestic use.
- *Air Quality* – Air quality is generally assessed by measuring/estimating the fraction of suspended particulate matter, SO_2, NO_2, CO_2, and trace elements. Air quality decreases with increased presence of these substances.
- *Water Quality* – Water quality is assessed based on several characteristics, including pH value, amount of suspended solids, color and odor, biochemical oxygen demand, and chemical oxygen demand, etc. If these characteristics are not within tolerance limits, the water is declared of low quality.
- *Mine Drainage* – Large quantities of water have to be pumped out from mine pits while extracting coal, depending on the depth and geographical location of the pit. The pumped water is designated mine drainage.
- *Damage to Buildings* – Vibration and subsidence may damage buildings and structures, and produce cracks or collapse.
- *Water Availability* – This term refers to availability of water in the area for drinking, domestic use, industrial use, and agriculture.
- *Land for Agriculture* – When land available is being used specifically for agricultural purposes, this term applies. Purposes other than land for agriculture could be land required for mining, for urban use, for forest, etc.
- *Forest Loss* – As land is occupied for mining activities, loss of forest occurs leading to damage to ecology.

Table 2. Concise List of Impacts of Coal Fields

1. Extraction of coal and overburden	13. Land irrigation
2. Transportation of coal and overburden	14. Human health
3. Coal combustion	15. Business
4. Air Quality	16. Employment
5. Water Quality	17. Cattle Health
6. Mine Drainage	18. Education
7. Damage to Buildings	19. Per capita income
8. Water Availability	20. Crime rate
9. Land for Agriculture	21. Population
10. Forest Loss	22. Social pressure
11. Land Yield Rate	23. Pollution control
12. Land restored	24. Quality of Life

- *Land Yield Rate* – Land yield rate refers to the yield rate of grains, vegetables, etc., per unit area of land.
- *Land Restored* – Land is reclaimed after mining is completed and returned (or converted) to agricultural, forest, or home construction uses.
- *Land Irrigation* – Cultivation of land using continuous water during the crop season is called land irrigation.
- *Human Health* – Human health is defined as deteriorating if the inhabitants of the area are affected with diseases, such as pneumoconiosis, TB, asthma, etc., which are known to be caused by the mine emissions.
- *Cattle Health* – Cattle health deteriorates if the animals are affected with diseases, such as gastro-enteritis, caused by the mine emissions.
- *Employment* – The inhabitants of the area generally obtain employment from mining, ancillary industries, and supporting businesses.
- *Business* – This includes the business of coal, general businesses in the area (provisions, cloth, household goods, medical items, etc.). It also includes the wholesale business, i.e., contracts in mines and other industries, the building trade, etc.
- *Education* – This refers to the literacy rate in the area and also to the facilities for education.
- *Per Capita Income* – This refers to the income per capita in the area of study.
- *Crime Rate* – This includes the thefts, hooliganism, murder rate, theft rate, and number of clashes, etc., in the area under study.
- *Population* – This reference to population alludes not only to the population but also to the growth rate of the study areas.
- *Social Pressure* – This refers to the pressure brought by people in terms of protests, dharnas (a method of trying to get justice by sitting at the door

of one's debtor or wrongdoer and fasting until death or until satisfaction is given), newspaper statements and articles, memoranda, publicity, etc.

- *Pollution Control* – The activities undertaken by the mine authorities in order to control the pollution of air, water, and land utilizing appropriate control measures are considered herein.
- *Quality of Life* – "Quality of life" amolgamates many considerations, including material benefits like employment, wage rate, per capita income, goods available, and also such damaging factors as health hazards, crime rate, unrest in the area, and social conflicts.

THE PROBLEM STRUCTURE

Structuring the problem is more complex where large numbers of variables are involved as in this case. The number of interactions multiplies with the number of variables and makes it cumbersome to perceive the interrelations. It is also a difficult task to develop a digraph or causal loop diagram for these variables. Interpretive structural modeling is used for simplification.

Interpretive Structural Model

A system with a large number of interdependent variables tends to become very complex. Warfield developed Interpretive Structural Modeling (ISM) to structure such complex systems [31]. He states that as the number of elements increases, the consideration of all possible connections becomes very tedious. By assuming transitivity of interconnections and using computers, a "reachability matrix" can be constructed. A multilevel hierarchical form can be obtained from the reachability matrix. The interpretive structural modeling process helps transform unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes [32, p. 92]. Interpretive structural modeling is an emerging methodology which is very useful as an aid to individuals and small groups in developing an understanding of complex situations [33, p. 397]. Wood and Christakis used ISM to structure the goals for the foresting of the North Piedmont area [34].

Figure 1 explains the role of interpretive structural modeling in policy analysis. Hornbach and Fitz show in Figure 1, a closed loop of improving decision making starting from mental model, and proceeding through a series of models, prose models, matrix models, structural models, and dynamic models [35, p. 212]. While this series is not characterized here, it is to be noted that it is a difficult and tedious process to develop structural models thorugh prose and matrix models. ISM simplifies this procedure and makes it easy to form a structural model from mental model as indicated by the dotted lines. While there is a loop connection between matrix models and structural models, ISM processes between them plays a significant role in developing a well formed, clear structural model. ISM is intended for analyzing a complex system, so that a qualitative model of the structure of the system can be composed.

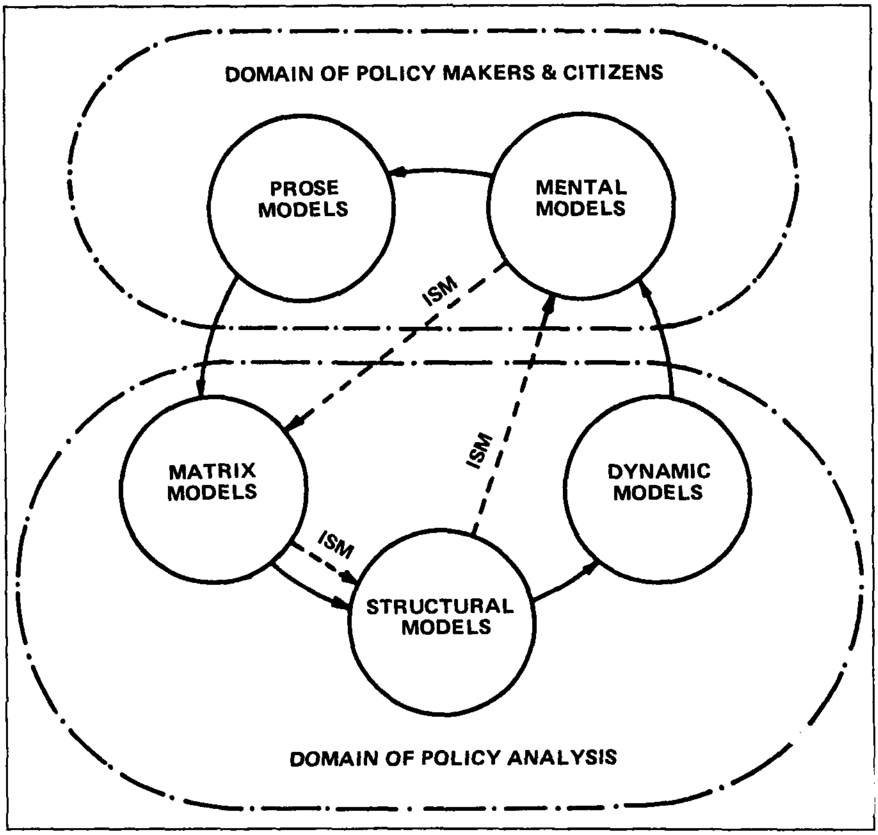

Figure 1. Models and domains of policy planning.

Watson compares the advantages and disadvantages of ISM [36]. He says that the process is systematic, encourages issue analysis, and produces a structured model or graphical representation of the original problem situation that can be communicated more effectively to others. He further says that it cannot adequately handle feedback, and that the process and product are sensitive to the ordering of elements in the element set. Austin and Burns regard any digraph produced by ISM as a starting point from which alternative structural models can be obtained [37]. However, they add that "as for any model, an ISM is never perfect, however, there must be an adequate level of collective satisfaction in it."

Nevertheless, interpretive structural modeling helps to analyze the interrelationships among the factors identified with a given problem. It develops a hierarchy of these factors based on their relationships. The hierarchy makes it possible to develop a structural model or diagram more comfortably—this is otherwise a painstaking and tedious process. Burns and Marcy content that an interaction matrix helps to avoid errors of omission whereas a causal loop diagram eliminates errors of commission [38]. In fact, ISM can address both types of error by developing a binary matrix and a structural model. This also leads to better understanding of the complex relations, particularly where the factors or variables are large in number. It is especially useful for decision makers, allowing them to gain an understanding of the complexity of issues with which they are forced to deal [35].

Interpretive structural modeling process involves:

1. *Developing a binary "adjacency matrix"* – A binary matrix represent relationships among variables. Here, each variable is compared with every other variable, i.e., a pair-wise comparison of all variables is made in order to identify whether there exists a relationship for each pair. Whenever there is a relationship between two variables, the corresponding element in the matrix is given a value "1" and if there is no relationship, the element value is taken as "0." The resulting matrix is called the adjacency matrix (of the corresponding digraph).

   Table 3 shows the adjacency matrix for the variables listed on pp. 72-75. For example, "extraction of coal and overburden" affects "transportation of coal and overburden." Therefore, the element (1,2) of the matrix is "1." Whereas, since the extraction has no affect on land restoration (i.e., restoration of land does not depend on the extraction of coal), the element (1,14) of the matrix is "0," (etc.).
2. *Obtaining reachability matrix from adjacency matrix* – Element a_i is reachable from a_j if a path can be traced from a_j to a_i. Here it is assumed that the transitivity relationship exists among variables. That is, if a_i is related to a_j and a_j is related to a_k, then it is assumed that a_i is related to a_k. The number of lines in the path is called the length of the path. The adjacency matrix "A" defines reachability having path length 1 and unit matrix "I" defines reachability with path length "0" because in a unit matrix every variable is a self-affecting variable and does not affect any other variable. Therefore, (A+I) defines reachability of all a_j to a_i having path lengths of 0 and 1. The reachability matrix "P" is complete when the relationships through all paths are identified with "1." This can be achieved when $P(n) = P(n+1)$ or $(A+I)^n = (A+I)^{n+1}$. Therefore, the reachability matrix "P" is defined as

   $$P = (A + I)^n \tag{1}$$

   Table 4 is the reachability matrix P obtained through a computer program in Fortran 77 developed for this purpose.
3. *Partition the reachability matrix to obtain hierarchical matrix* – A series of partitions is made on the reachability matrix. These partitions are made to determine the hierarchy of the elements. For every element p_i in the reachability matrix, there may be some elements reachable from it; these

Table 3. Adjacent Matrix "A"

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	1	0	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
21	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
23	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

elements constitute the reachability set $R(p_i)$. Similarly, there may be some elements constituting the antecedent set $A(p_j)$ of the element p_j which can reach the element p_j. Therefore, the reachability set $R(p_i)$ of the element p_i is the set of elements defined in the columns that contain 1 in row p_i. Similarly, the antecedent set $A(p_j)$ of the element p_j is the set of elements defined in the rows which contain 1 in the column p_j.

Table 4. Reachability Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	1	1	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1
3	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
4	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
5	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
6	0	0	1	1	1	1	0	1	0	0	1	0	1	1	1	0	0	0	0	0	1	1	1	1
7	0	0	1	1	1	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
8	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
14	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
15	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
16	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	1	0	1	1	0	1	1	1	1
17	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1
18	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	1	1	1	1
19	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	1	1	0	1	1	1	1
20	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	1	1	1	1	1
21	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
22	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
23	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
24	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1

For example, in the reachability matrix (Table 4), for row element 1 there is 1 in all the columns except 12. It means that element 1 can reach all the elements except 12. Therefore, the reachability set of P_1 is given by

$R(p_1)$ = 1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18,19,20,21,22, 23, and 24.

Similarly, for column 1, there is 1 only in row 1. It means that the element can be reached by only itself and no other elements can reach it. Therefore, the antecedent set of element 1 is given by $A(p_1) = 1$.

The intersection of the reachability set and the antecedent set, i.e., the common elements in both the sets results in $RA(p_i)$ which is $R(p_i) \cap A(p_i)$. That is, $RA(p_i) = 1$.

Table 5 presents the Reachability set, Antecedent set, and Intersection set for all the elements. The elements for which the reachability set and the intersection set are the same, are taken out to represent the hierarchy or partition and in this case, the first hierarchy or partition. From Table 5, the elements 9,10, and 11 have the same reachability set and intersection set, and, therefore, form the first hierarchy.

Hierarchy here means that no link is going out of this element, except a mutual link. However, one or more links may come to this element from other elements. In other words, it identifies a hierarchy similar to that of a vertical network in reverse order. Elements which will be at the bottom of a network are identified as the first level hierarchy in ISM. Unlike the networks, the links exist from lower level to higher level and also between the elements at the same level.

Now, the rows and columns of these elements, i.e., 9, 10, and 11, are struck out and only the remaining matrix is considered to determine the elements for the second level. Table 6 shows the matrix with elements 9, 10, and 11 eliminated. The reachability set, the antecedent set, and the intersection set for this matrix are shown in Table 7.

The second level partition elements obtained by examining Table 6 are the elements 3, 4, 5, 12, 13, 14, 15, 21, 22, 23, and 24. The procedure is repeated until all elements are exhausted. Tables 8 through 13 show the third through eighth levels, respectively. The complete hierarchies/ partitions are given in Table 14.

4. *Developing the structural model using the partitions* – Partitions or hierarchies help us to develop a structural model in terms of a digraph. Elements are placed in a hierarchy as in the case of a network and the links are drawn, the arrow showing the impact. The model thus drawn is depicted in Figure 2. Here, several linkages at the same level exist along side linkages from lower level to higher level, making a more complex entity than a simple unidirectional network. Therefore, some manipulations and rearrangements may be necessary to develop the structural model.

Table 5. Reachability and Antecedent Sets for First Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2,3,4,5,6,7,8,9,10,11, 13,14,15,16,17,18,19,20, 21,22,23,24	1	1
2	2,3,4,5,9,10,11,14,15,16, 17,18,19,20,21,22,23,24	1,2	2
3	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
4	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
5	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
6	3,4,5,6,8,11,13,14,15,21, 22,23,24	1,6	6
7	3,4,5,7,11,14,15,21,22,23,24	1,7	7
8	8,11,13	1,6,8	8
9	9	1,2,9,12	9
10	10	1,2,10	10
11	11	1,2,3,4,5,6,7,8,11,13,14, 15,16,17,18,19,20,21,22, 23,24	11
12	9,12	12	12
13	11,13	1,6,8,13	13
14	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
15	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
16	3,4,5,11,14,15,16,18,19,21, 22,23,24	1,2,16,17	16
17	3,4,5,11,14,15,16,17,18,19, 20,21,22,23,24	1,2,17	17
18	3,4,5,11,14,15,18,21,22,23,24	1,2,16,17,18,19	18
19	3,4,5,11,14,15,18,19,21,22, 23,24	1,2,16,17,19	19
20	3,4,5,11,14,15,20,21,22,23,24	1,2,17,20	20
21	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
22	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
23	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
24	3,4,5,11,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24

Table 6. Reachability Matrix after First Iteration

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	1	1	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1
3	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
4	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
5	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
6	0	0	1	1	1	1	0	1	0	0	1	0	1	1	1	0	0	0	0	0	1	1	1	1
7	0	0	1	1	1	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
8	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
14	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
15	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
16	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	1	0	1	1	0	1	1	1	1
17	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1
18	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	1	1	1	1
19	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	1	1	0	1	1	1	1
20	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	1	1	1	1	1
21	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
22	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
23	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1
24	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	1	1	1	1

Table 7. Reachability and Antecedent Sets for Second Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2,3,4,5,6,7,8,13,14,15,16, 17,18,19,20,21,22,23,24	1	1
2	2,3,4,5,14,15,16,17,18,19, 20,21,22,23,24	1,2	2
3	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
4	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
5	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
6	3,4,5,6,8,13,14,15,21,22,23,24	1,6	6
7	3,4,5,7,14,15,21,22,23,24	1,7	7
8	8,13	1,6,8	8
12	12	12	12
13	13	1,6,8,13	13
14	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
15	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
16	3,4,5,14,15,16,18,19,21,22, 23,24	1,2,16,17	16
17	3,4,5,14,15,16,17,18,19,20, 21,22,23,24	1,2,17	17
18	3,4,5,14,15,18,21,22,23,24	1,2,16,17,18,19	18
19	3,4,5,14,15,18,19,21,22,23,24	1,2,16,17,19	19
20	3,4,5,14,15,20,21,22,23,24	1,2,17,20	20
21	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
22	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
23	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24
24	3,4,5,14,15,21,22,23,24	1,2,3,4,5,6,7,14,15,16, 17,18,19,20,21,22,23,24	3,4,5,14,15, 21,22,23,24

5. *Developing interpretive structural model* – Figure 2 shows the structural model wherein the elements are identified with the same numbers as in adjacency matrix. Figure 3 depicts the interpretive structural model, after rearrangement, wherein the numbers are replaced with the description of the elements. This improves the understanding of relationships among the elements.

Table 8. Reachability and Antecedent Sets for Third Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2,6,7,8,16,17,18,19,20	1	1
2	2,16,17,18,19,20	1,2	2
6	6,8	1,6	6
7	7	1,7	7
8	8	1,6,8	8
16	16,18,19	1,2,16,17	16
17	16,17,18,19,20	1,2,17	17
18	18	1,2,16,17,18,19	18
19	18,19	1,2,16,17,19	19
20	20	1,2,17,20	20

Table 9. Reachability and Antecedent Sets for Fourth Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2,6,16,17,19	1	1
2	2,16,17,19	1,2	2
6	6	1,6	6
16	16,19	1,2,16,17	16
17	16,17,19	1,2,17	17
19	18	1,2,16,17,19	19

Table 10. Reachability and Antecedent Sets for Fifth Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2,16,17	1	1
2	2,16,17	1,2	2
16	16	1,2,16,17	16
17	1,16,17	1,2,17	17

Table 11. Reachability and Antecedent Sets for Sixth Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2,17	1	1
2	2,17	1,2	2
17	17	1,2,17	17

Table 12. Reachability and Antecedent Sets for Seventh Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1,2	1	1
2	2	1,2	2

Table 13. Reachability and Antecedent Sets for Eighth Level

Element (p_i)	*Reachability Set* $R(p_i)$	*Antecedent Set* $A(p_i)$	*Intersection Set* $RA(p_i) = R(p_i) \cap A(p_i)$
1	1	1	1

Table 14. Heirarchy of Variables

Level	*Variable Numbers*
1	9, 10, 11
2	3, 4, 5, 12, 13, 14, 15, 21, 22, 23, 24
3	7, 8, 18, 20
4	6, 19
5	16
6	17
7	2
8	1

CONCLUSION

Environmental impact analysis of a coal field is very complex, as the number of variables is large (twenty-four in this example). Interpretive structural modeling helps simplify the structuring process. The digraph representing the complex interrelationships can be easily obtained using Interpretive structural modeling. ISM helps structure the problem straightforwardly, revealing hierarchical and other relationships holding among variables. We, therefore, recommend the use of ISM as one of the tools in comprehensive environmental impact analysis.

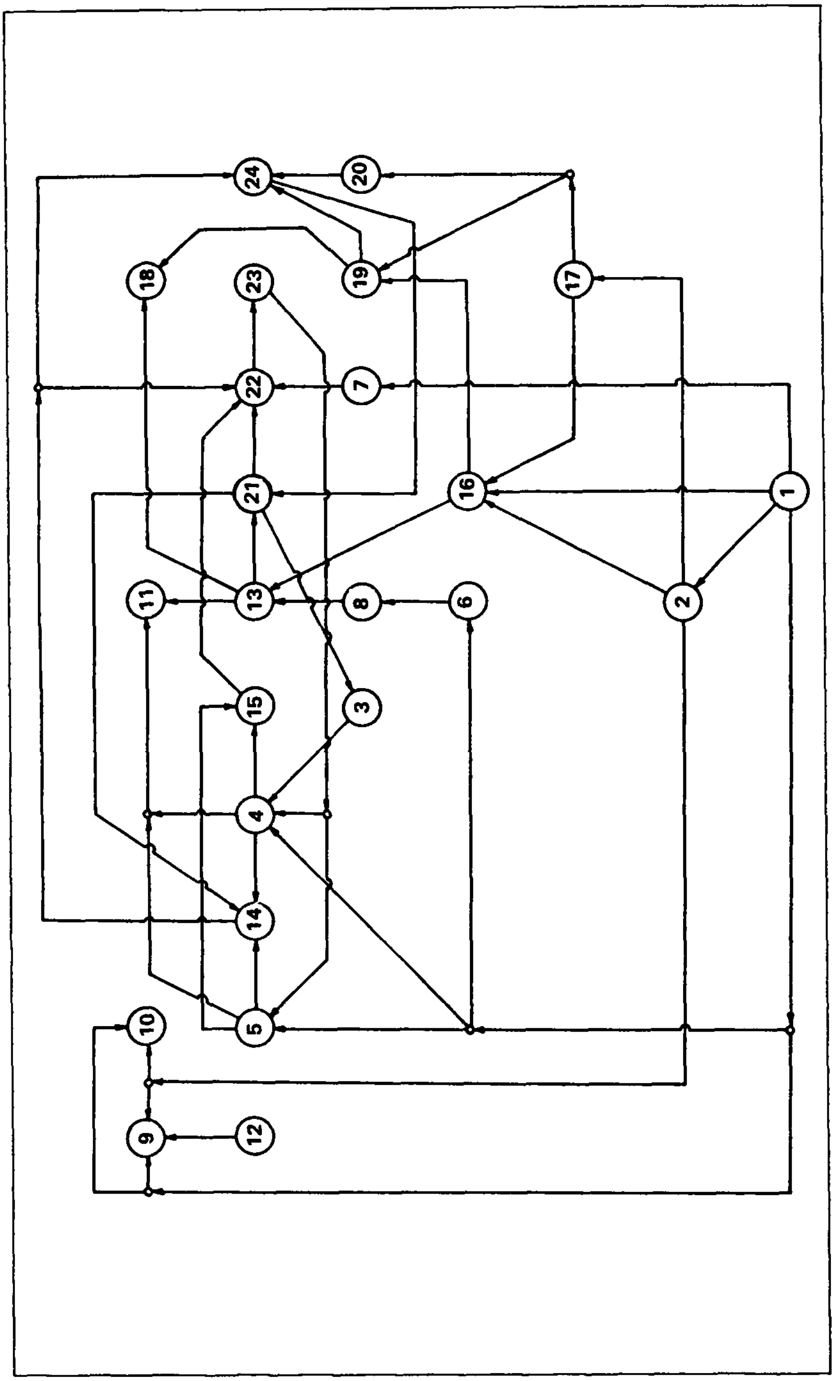

Figure 2. Structural model.

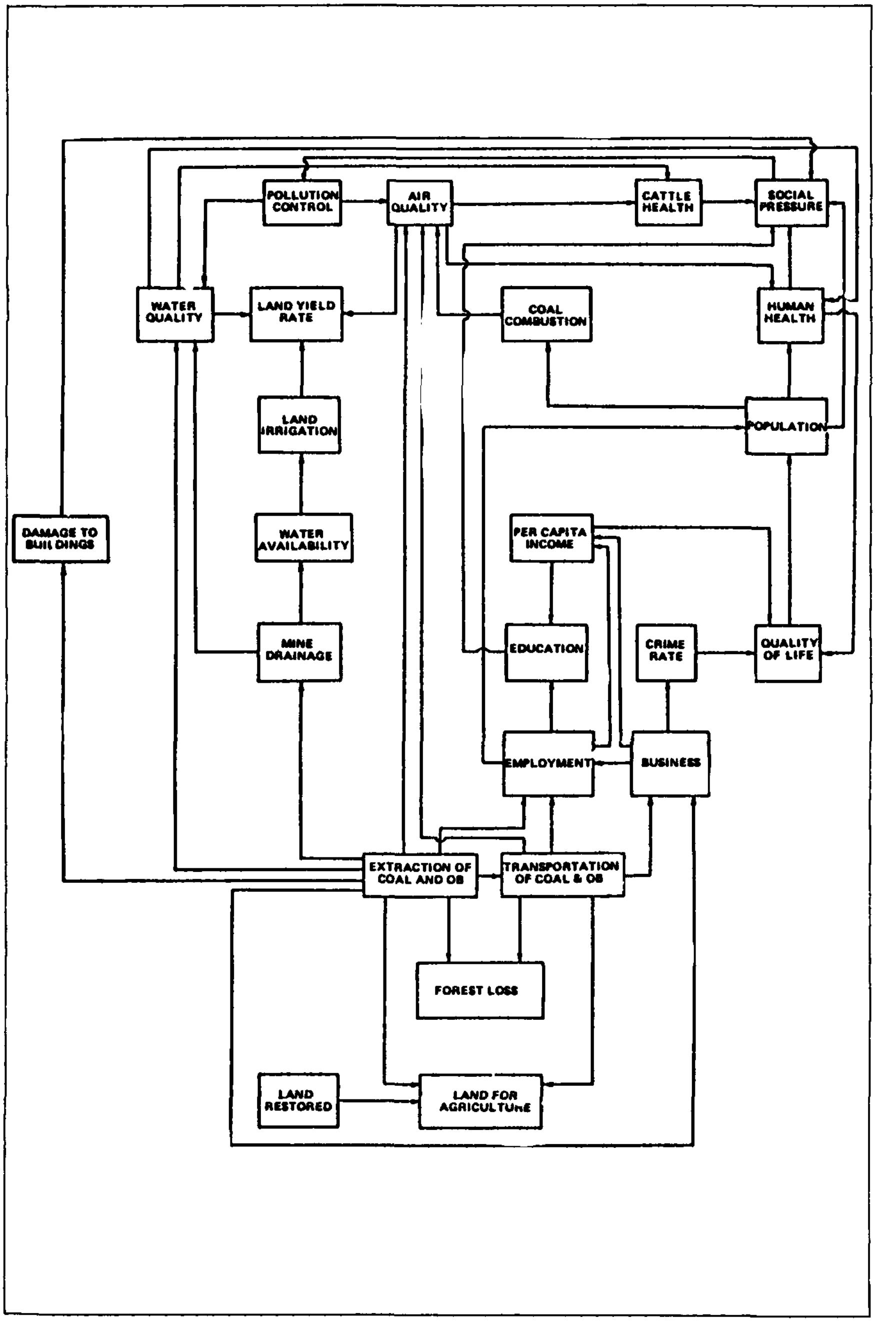

Figure 3. Interpretive structural model of a coal field.

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