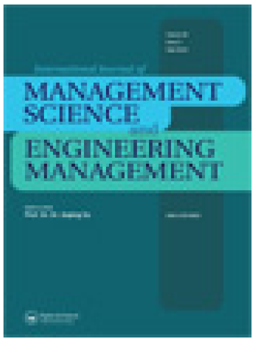

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Evaluating technology management factors for fly-ash utilization in the road sector using an ISM approach

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ABSTRACT

The generation of fly ash is supported by much effort to utilize it to the greatest extent possible. Present usage of around 58% of fly ash generated every year demands more effort. Around 6% of fly ash utilized is being used in road applications. More fly ash can be utilized in road sector because of its having huge potential mainly in embankments. Fifteen factors have been identified, studied, analysed, classified and presented as a model that suggests their significance towards accomplishing the objective of more fly-ash utilization in the road sector. Interpretive structural modelling (ISM) is applied to these factors to obtain their relative relationships. The key factor is local specific strategic planning, which is identified and recommended for implementation in the present scenario along with maintaining focus on all factors for successful implementation towards the desired objective.

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1. Introduction

The government of India started making concerted efforts from 1994 to utilize fly ash. As a result, the utilization of fly ash been increased from one million tonnes during 1993–94 to 108 million tonnes during the year 2015–16 (Central Electricity Authority, 2016). A number of technologies were developed and demonstrated in the field along with user agencies. Standards and specifications were prepared/updated and statutory measures were also taken during the last decade.

Coal has a prominent share of the means of electricity generation in India and will probably continue to hold its prominence against other modes of power generation. The use of coal in thermal power stations results in the production of fly ash. Engineers are facing greater challenges in containing the degradation of land and atmospheric pollution caused by ever mounting deposits of fly ash at power plants. The solution to this problem lies in the gainful utilization of fly ash. The construction of roads and embankments provides an avenue for bulk utilization of fly ash.

Table 1 shows the generation and utilization of fly ash by various countries. A study by Caldas-Vieira & Feuerborn (2012) stated that in Europe (EU 15) in 2009, the total fly ash utilized was 15 million tonnes, of which 23.1% was used in road construction. In the USA in 2007 (American Coal Ash Association, 2013) fly-ash production was 71.7 million tonnes, and 8.07 million tonnes (11.26%) was used in structural fills and road base with a total usage of 31.63 million tonnes. Yao et al. (2015) stated it to be 12.83% in 2012 against 39.03 million tonnes of usage. They also stated that, in China in 2011, only 5% of the fly ash utilized was utilized by the road sector against 367 million tonnes of overall usage.

2. Fly-ash utilization in India

The Central Electricity Authority (CEA) of the Ministry of Power, Government of India (Central Electricity Authority, 2014a) , compiles the figures for fly-ash generation and utilization in India. Figure 1 shows the trend since 1996–97 (Central Electricity Authority, 2016). Figure 2 shows the fly-ash generation and utilization trends in last six years along with their utilization in the road sector (Central Electricity Authority, 2011, 2014b, 2014c, 2015, 2016).

The data has been compiled from CEA data for total fly ash generated in the last six years, viz. 2010–11 until 2015–16. Fly-ash generation has increased from 131.08 to 176.74 million tonnes (Central Electricity Authority, 2011, 2014b, 2014c, 2015, 2016) with a maximum of 184.14 during 2014–15. During that period, the utilization of fly ash increased from 73.19 to 107.77 million tonnes. In terms of a percentage of fly-ash generation, fly-ash utilization has been in the range 55 to 61% with an overall percentage of 58.38% in these six years. This demands that all possible action should be taken to utilize the fly ash generated fully. It also demonstrates that there is a huge potential for finding ways and means to utilize the fly ash.

During this period of 6 years, around 974 million tonnes of fly ash was generated, but only about 569 million tonnes could be utilized. The volume of fly-ash that remains to be gainfully utilized is around 405 million tonnes during these six years. This means that around 67 million tonnes of fly ash is accumulated every year. Such a volume covering a depth of 3 m would need an area of around 18 km^2 every year, an area that is more than the half the area of Lakshadweep Island. Therefore, there is a need for a timely roadmap so that concerted efforts can be made in earnest (Saurikhia, Ahmed, Haleem, & Gangopadhyay, 2014).

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Table 1. Generation and utilization of fly ash in different countries (American Coal Ash Association, 2013; Basu, Pande, Bhadoria, & Mahapatra, 2009; Caldas-Vieira & Feuerborn, 2012; Dhadse, Kumari, & Bhagia, 2008; Yao et al., 2015).

Country	Fly-ash production (millions of tonnes per year)	Fly-ash utilization (%)	Fly-ash utilization in road sector as percentage of total usage (%)
India	112	38	7
China	100	45	5
USA	75	65	11.26
Europe[a]	64	78	23.1
Australia	10	85	
Canada	6	75	

[a]Europe above represents cumulative values for UK, Germany, France, Denmark, Italy and The Netherlands.

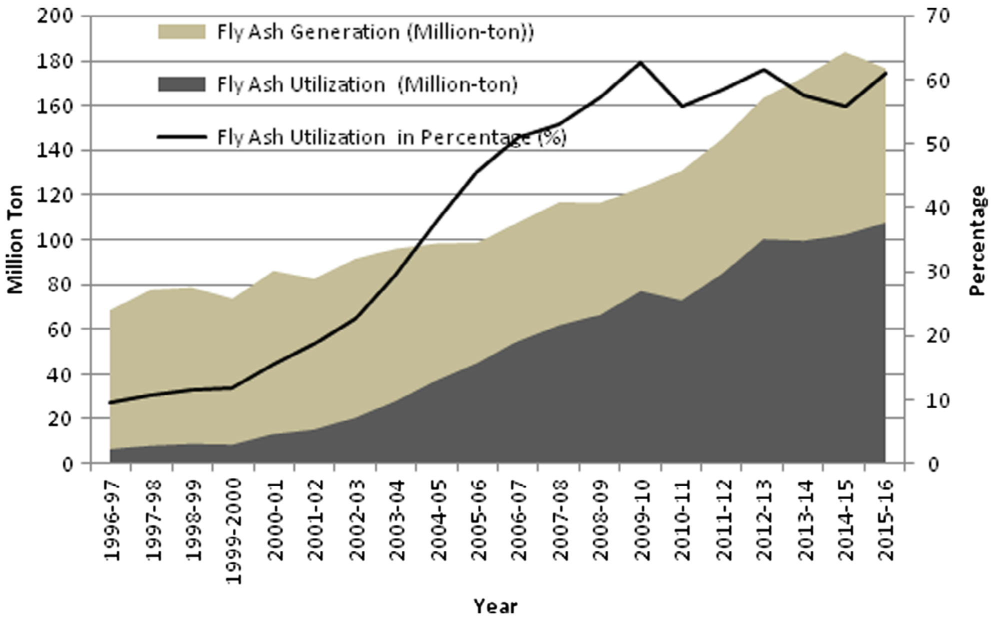

Figure 1. Fly-ash generation and utilization in India.

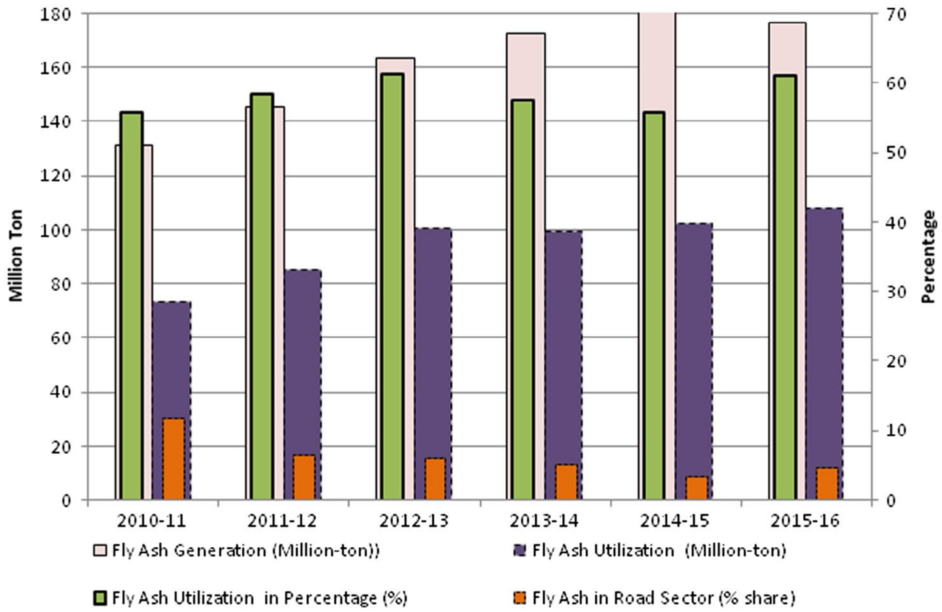

Figure 2. Fly-ash utilisation with reference to road sector.

3. Need fo the study

The fly-ash utilization pattern both in overall terms and also for the road sector suggests the need to take steps to increase the figures. It demands that action be taken so that 100% utilization of fly ash is made. The road sector has good potential to consume fly ash in embankments, sub-bases, and cement replacement, using several techniques, since the volume of fly ash that is consumed in significant in the road sector. Thus there is a need for a study to identify the factors that are either enablers or barriers to fly-ash utilization in the road sector.

4. Research objective of the paper

Considering the need for the study as discussed under Section 3 above, the following are the major research objectives set out for this paper:

- to identify various factors that can enhance fly-ash utilization in the road sector;
- to study the contextual relationships between these factors;
- to develop a hierarchical structural model indicating the relationships;
- to analyse the model for its practical significance.

The above-mentioned objectives of the research are accomplished by the methodology of interpretive structural modelling (ISM). ISM was developed for theory building and grounded theory research in complex situations (Warfield, 1974). The methodology and the results are discussed in the following sections.

5. Factors responsible for fly-ash usage in the road sector

The fly-ash usage pattern is less than 58% of the volume generated in a year, and around 64 million tonnes (during 2013–14) is accumulated every year. A brainstorming session of area experts was carried out in the month of March 2014 to identify factors that could drive fly-ash utilization in the road sector. Factors from the overall management perspective (Sushil, 1990) were consolidated that are considered to have an impact on fly-ash utilization in the road sector. Critical factors for the successful usage of fly ash were also studied (Haleem et al., 2016), which were categorized under two areas, viz. roads and bridges, and embankments. The difference in the selection of factors with the present study may be due to the experts' overall perspective in which the workshop or session was carried out. A study by Kanungo and Bhatnagar (2002) suggests that it is good to use multiple research approaches for and among different stakeholders to ensure the quality of service.

The factors discussed in the following subsections were identified in consideration of the issues considered to be enablers or barriers towards ensuring more fly-ash utilization in the road sector.

5.1. Focus on known technologies

Use of fly ash in the road sector is mainly in the construction of embankments, soil or waste stabilization, bituminous pavements, roller compacted concrete, high-performance concrete, mixed with waste like copper slag as a base material, the construction of bridges and structures, plastic coated fly ash, and other such areas. It is opined that if a focus on these known technologies is made, then the road fraternity will enhance the usage of fly ash in the road sector.

5.2. Confidence building on new known technologies through field demonstration, scale-up, and hands-on training

Even when a new technology is known in terms of its advantages and limitations, the road sector is reluctant to use it because of lack of confidence. Measures like field demonstration, hands-on training, etc. are required to inculcate confidence in the implementation teams. Alhough such measures are the inherent requirement of implementing a new technology, the gestation period of new technology adoption in the road sector in India appears to be on the high side. Therefore, measures need to be taken at the level of various stakeholders or at regional level.

5.3. Development of new technologies

The development of new technologies is always required. Similarly, new technologies for more fly-ash utilization in economical, faster, and safer modes are required to be developed taking field requirements into account. New technologies have a life cycle time from development to implementation, and need an appropriate supporting framework.

5.4. Standards, specifications, and guidelines

Standards, specifications, and guidelines are required to be in place so that users are able to implement a new technology coherently and consistently. Their absence or non-availability can be a source of confusion or lack of reliability. The road sector has relevant standards/guidelines in place for the use of fly ash. The Indian Roads Congress (IRC) has relevant publications, viz. IRC SP 058: Guidelines for Use of Fly Ash in Road Embankments; IRC 088: Recommended Practice for Lime Fly Ash Stabilised Soil Base/Sub-Base in Pavement Construction, etc.

5.5. Statutory notifications and fiscal incentives (government policies)

Government policies such as statutory notifications, fiscal, incentives, etc. are important for institutionalizing a concept or procedure for effective, consistent, and mandated implementation. Fly ash has the advantage of having judicial as well as governmental notification of its use within 100 km of the radius of any thermal power plant, alongwith a planning to extend it to 500 km. Targets for fly-ash utilization for thermal power plants have also been fixed. Such notifications have great bearing on utilizing fly ash.

5.6. Location-specific strategic plan

A few factors always play a significant role at regional or location-specific level. Towards fly-ash utilization, some of the important factors may be stated as follows.

- Availability of fly ash in terms of quality and quantity.
- Economic feasibility of using fly ash particularly due to handling and transportation costs.
- Interest and managerial potential of concerned teams.
- Awareness about various technology options and policy framework.
- Availability of appropriate ecosystem for adopting or implementing each technology options for utilizing fly ash.

A location-specific strategic plan is a requirement to drive all key stakeholders towards a common cause. Fly-ash utilization at state level or in a specific location needs to be framed to ensure and enhance its utilization.

5.7. Dissemination and sharing of information through workshops, seminars, training programs, etc

Human resource management is a regular phenomenon, whether it is for recently-graduated employees or senior level executives. It is more important if it is for creating awareness about new technologies or sharing information for official use. Dissemination and sharing of information through workshops, seminars, training programs, etc. is very pertinent for ensuring fly-ash utilization. The process is required to spread awareness at a very basic level about the details. Once sufficient information is available, stakeholders may need confidence building measures to implement or utilize such information.

5.8. Handholding with all stakeholder agencies

For any activity to succeed, all stakeholders are required to be on a common platform for which handholding is required. Alhough it appears to be an easy exercise, it is very hard to implement in reality. Fly-ash utilization also needs handholding of various stakeholders such as thermal power plants, policy makers, road agencies, contractors, researchers, academicians, logistics managers, technology managers, etc. along with the public at large through their associations.

5.9. Establishing a complete ecosystem for technology utilization

One of the factors that needs to be worked upon is establishing a complete ecosystem for technology utilization. Implementing different aspects or components for effective technology implementation in parts may leads to confusion or ineffective results. A well-designed ecosystem involving all stakeholders is the existential need for large-scale fly-ash utilization.

5.10. Networking of laboratories and experts

The expertise of various technologies may not rest with a single organization. Even for a single technology, the skill or competency required for successful implementation may not be available to a particular team. Winning team should be strategically defined amongst the networked laboratories and experts with an aim to have successful and large scale implementation of technology. Such networking is needed for all potential technologies.

5.11. Agreements with stakeholders

Apart from the competency sets for a technology, concerned stakeholders need to come to an agreement. Without such agreements, the risk of project disruption due to non-availability of expertise at the appropriate time may be high. Such agreements should be framed to have a win–win situation for all parties to avoid any confrontation or no-action scenario at a later stage.

5.12. Transportation cost

It has observed that a few thermal power stations are selling fly ash while most of them are providing it free of charge. However, transportation costs have to be borne by the users, which is substantial most of the time. Logistics becomes a critical issue. Experts are of the opinion that fly ash should either be delivered or transported at the expense of the thermal power plant within a defined radius, or the transportation cost should be made part of the bill of quantities for road projects. The latter option is found to be more practical.

5.13. Transportation by rail

It is also observed that transportation costs make the project unviable if the site is at a significant distance and fly ash is to be used. Transportation by rail is suggested to be incorporated into project formulation or costing where the fly-ash volume that can be utilized is phenomenal.

5.14. Proper monitoring by regulating bodies for mandatory use of ash in road construction

With the judicial decision, adequate governmental notifications and standards in place, what is required is proper monitoring by regulating bodies for mandatory use of fly ash in road construction. Enforcement is important and plays a key role in effective delivery.

5.15. Compulsory use of fly ash should be incorporated in bid documents/concession agreements of agencies executing road construction

One of the reasons for poor utilization of fly ash in road works is that its use is not being mentioned in bid documents, owing to which contracting agencies are not bound to use fly ash in place of other materials. They will use it only when it is beneficial for them in terms of cost saving. If the compulsory use of fly ash is incorporated in bid documents or concession agreements while awarding road work contracts, fly-ash usage will certainly increase.

6. Interpretive structural modelling methodology

In this research, factors critical for improving the usage of fly ash have been identified. The purpose of the study is to understand the hierarchy and relationships between those critical factors that are playing a positive role in the better utilization of fly ash in the road sector. Since a limited number of experts is available, the ISM technique seems to be the most appropriate tool for developing a model (Haleem et al., 2016). A structural and hierarchal model using ISM methodology has been developed and analysed using matrice d'impacts croisés multipication appliquée à un classment (MICMAC) analysis. The experience and involvement of experts is the critical success factor for the effectiveness of the model.

There are 15 factors that have been identified during the brainstorming session that are considered to drive fly-ash utilization in the road sector. Although all of them appear to have been acted upon, to have an effective action plan we need to understand the relationship between them. Interpretive structural modelling (Haleem, Sushil, Qadri, & Kumar, 2012; Khan, Khan, & Haleem, 2014; Lendaris, 1980; Raghuvanshi & Kumar, 1999) is an effective method of understanding complex situations and finding solutions to complex problems. It aims to identify the direction and order of complicated interactions between the variables of the system (Warfield, 1974). It is a method of creating a 'road-map' of complex situations where there are many issues or options to consider (Sorach Inc., 1999). The steps involved in carrying out ISM are as follows.

Table 2. Self-structural interaction matrix.

S. no.	Factors	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	Focus on known technologies	X	V	V	V	V	V	V	X	A	A	A	V	O	V	
2	Confidence building on new known technologies through field demonstration, scale-up, and hands-on training	A	V	X	X	X	X	V	A	A	A	A	X	V		
3	Development of new technologies	A	X	A	A	A	A	V	A	A	A	O	A			
4	Standards, specification, and guidelines	A	V	X	X	X	X	V	A	A	A	A				
5	Statutory notifications and fiscal incentives (government policies)	V	V	V	V	V	V	O	V	V	V					
6	Location-specific strategic plan	V	V	V	V	V	V	V	V	X						
7	Dissemination and sharing of information through workshops, seminars, training programmes, etc.	V	O	V	V	V	V	O	V							
8	Handholding with all stakeholder agencies	X	V	V	V	V	V	V								
9	Establishing a complete ecosystem for technology utilization	A	A	A	A	A	A									
10	Networking of laboratories and experts	A	V	X	X	X										
11	Agreements with stakeholders	A	V	X	X											
12	Transportation cost	A	V	X												
13	Transportation by rail	A	V													
14	Proper monitoring by regulating bodies for mandatory use of ash in road construction	O														
15	Compulsory use of ash should be incorporated in bid document/ concession agreement of agencies executing road construction															

Step 1 Identify factors that are associated with the issue through literature review, brainstorming sessions, etc.
Step 2 Establish contextual relationships between such factors.
Step 3 Develop a structural self-interaction matrix (SSIM) based on pairwise relationships between factors.
Step 4 Develop an initial reachability matrix (IRM) from the SSIM.
Step 5 Check for transitivity (if A is related to B and B is related to C, then A is also related to C) to develop the final reachability matrix (FRM).
Step 6 Level partition the FRM to form the ISM hierarchy.
Step 7 Draw a directed graph (digraph) from the FRM relationships and remove the transitivity links.
Step 8 Convert the digraph into an ISM-based hierarchical model by replacing the nodes with statements.
Step 9 Review the structural model for conceptual inconsistency and make the necessary modifications.

6.1. Structural self-interaction matrix

The SSIM is prepared in close discussion with experts in the area. The objective is to establish a pairwise relationship to recognize the direction of the relationships. In order to analyse the pair relationships, the following symbols are used to denote the direction of interaction between the factors (i and j).

V: Factor i will help to achieve factor j;
A: Factor i will be achieved by factor j;
X: Factors i and j will help to achieve each other;
O: Factors i and j are unrelated.

Table 2 shows the SSIM developed between the factors to enhance fly-ash utilization in the road sector.

6.2. Initial reachability matrix and final reachability matrix

The SSIM is converted into a binary IRM by substituting V, A, X, and O by 1 and 0 as per the following rules.

- If the (i, j) entry in the SSIM is V, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
- If the (i, j) entry in the SSIM is A, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
- If the (i, j) entry in the SSIM is X, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
- If the (i, j) entry in the SSIM is O, both the (i, j) entry and the (j, i) entry in the reachability matrix become 0.

Transitivity is checked to develop the FRM. Entries with an asterisk represent transitivity. Tables 3 and 4 show the IRM and FRM, respectively. The driving power and the dependence of each factor are shown in Table 4. The driving power for a factor is the total number of factors (including itself) that it may help to achieve or drive. The dependence power is the total number of factors (including itself) that may help it to achieve or drive. Thus the FRM depicts the driving power and the dependence power of each factor.

6.3. Level partitioning

Knowing the driving power and dependence power of each factor from the FRM, each factor is processed to indicate the overall position or level when they are structured in a hierarchy in terms of their significance (Lal & Haleem, 2009; Raghuvanshi & Kumar, 1999; Saxena, Sushil, & Vrat, 1992; Chandramowli,

Table 3. Initial reachability matrix (IRM).

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	1	0	0	0	1	1	1	1	1	1	1	1
2	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0
3	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
4	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0
5	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1
6	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	0	1	1	1	0	1	1	1	1	0	1
8	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
10	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0
11	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0
12	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0
13	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0
14	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0
15	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1

Table 4. Final reachability matrix (FRM).

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Driving power
1	1	1	1[a]	1	0	0	0	1	1	1	1	1	1	1	1	12
2	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0	9
3	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	3
4	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0	9
5	1	1	1[a]	1	1	1	1	1	1[a]	1	1	1	1	1	1	15
6	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
7	1	1	1	1	0	1	1	1	1[a]	1	1	1	1	1[a]	1	14
8	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	12
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
10	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0	9
11	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0	9
12	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0	9
13	0	1	1	1	0	0	0	0	1	1	1	1	1	1	0	9
14	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	3
15	1	1	1	1	0	0	0	1	1	1	1	1	1	1[a]	1	12
Dependence power	6	12	14	12	1	3	3	6	15	12	12	12	12	14	6	

[a]Entries with a supersript '*a*' represent transitivity.

Table 5. Level partitioning.

Factors	Reachability set	Antecedent set	Intersection	Level
1	1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 15	1, 5, 6, 7, 8, 15	1, 8, 15	4
2	2, 3, 4, 9, 10, 11, 12, 13, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	2, 4, 10, 11, 12, 13	3
3	3, 9, 14	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15	3, 14	2
4	2, 3, 4, 9, 10, 11, 12, 13, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	2, 4, 10, 11, 12, 13	3
5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	5	5	6
6	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	5, 6, 7	6, 7	5
7	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	5, 6, 7	6, 7	5
8	1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 15	1, 5, 6, 7, 8, 15	1, 8, 15	4
9	9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	9	1
10	2, 3, 4, 9, 10, 11, 12, 13, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	2, 4, 10, 11, 12, 13	3
11	2, 3, 4, 9, 10, 11, 12, 13, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	2, 4, 10, 11, 12, 13	3
12	2, 3, 4, 9, 10, 11, 12, 13, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	2, 4, 10, 11, 12, 13	3
13	2, 3, 4, 9, 10, 11, 12, 13, 14	1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15	2, 4, 10, 11, 12, 13	3
14	3, 9, 14	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15	3, 14	2
15	1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 15	1, 5, 6, 7, 8, 15	1, 8, 15	4

Morghan Transue, 2011; Singh & Kant, 2008). To carry out the level partitioning of various factors, the reachability and antecedent set for each factor are identified from the FRM. The reachability set consists of the factor itself and the other factors that it may help achieve, whereas the antecedent set consists of the factor itself and the other factors that may help in achieving it. The intersection of these sets is derived for all the factors (Subramanian, Chandrasekaran, & Govind, 2010). The top level is assigned to those factors for which the reachability and the intersection sets are the same. When the top-level factor is identified, it is separated out from the other factors, and the process is repeated until we get the level of each factor (Subramanian et al., 1980). Table 5 shows the level partitioning carried out for all factors.

6.4. Model development and its description

After determining the level of each factor, a hierarchical structural model is prepared as shown in Figure 3. It becomes evident from the model that 'Statutory notifications and fiscal

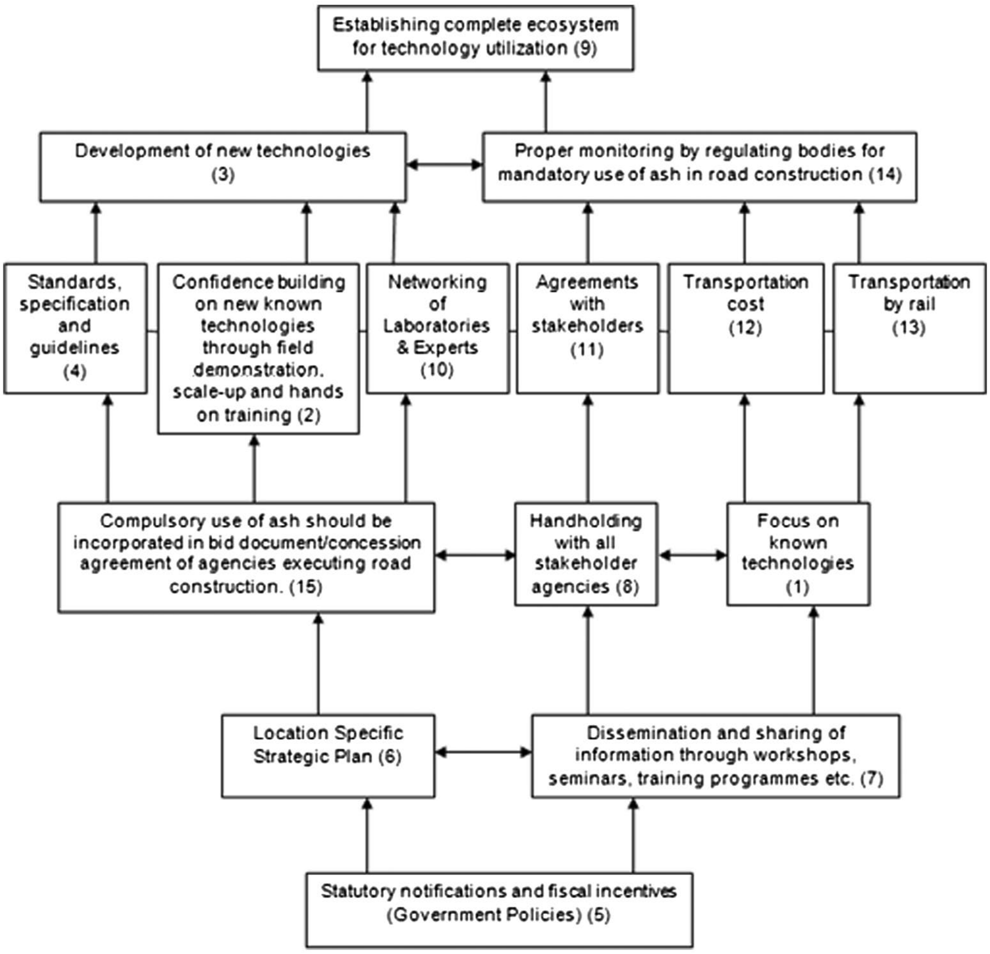

Figure 3. Hierarchical structural model.

incentives (government policies)' is the biggest driver for effective utilization of fly ash in the road sector. This will accomplish 'Establishing a complete ecosystem for technology utilization'. 'Statutory notifications and fiscal incentives (government policies)' leads to the dissemination and sharing of information, and the requirement for, and preparation of, location-specific strategic plans. These factors will lead to focusing on known technologies, handholding with all stakeholder agencies, and the incorporation of compulsory use of fly ash in bid documents, etc. These factors will either result in, or create a demand for, factors like standards to be in place, confidence building measures, networking of laboratories and experts, entering into agreements with stakeholders, incorporating transportation costs, and tracing the possibility of transportation by rail. The resolution of, or action on, these factors will create a demand for the development of new technologies and proper monitoring by regulating bodies. It will help in establishing a complete ecosystem for technology utilization for fly-ash utilization.

7. MICMAC analysis

MICMAC analysis is used to categorize given factors so as to identify those factors that drive the system (Dubey, Gunasekaran, Papadopoulos, & Childe, 2015). The driving power determined from the relationships is used to determine the hierarchy of variables and identify the key variable of the system (Kaushik, Kumar, Luthra, & Haleem, 2014; Saxena et al., 1992). All factors can be classified depending upon their driving power and dependence power as measured through the FRM into four regions as shown in Figure 4 (Kumar, Luthra, Govindan, Kumar, & Haleem, 2016; Singh, Gupta, & Ojha, 2014).

7.1. Autonomous region

Factors that neither drive nor depend on other factors are categorized in the autonomous region. They are relatively isolated from the system and do not have much bearing on the overall performance of the system. In the present case there is no factor that falls into this region.

7.2. Dependent region

Factors that have high dependence power and weak driving power fall into this region. In the present study, establishing an ecosystem, the development of new technologies, and proper monitoring fall into this region.

7.3. Linkage region

Having both high driving power and high dependence power are the characteristics of factors that belong to this region. Various factors such as standards to be in place, confidence building measures, networking of laboratories and experts, entering into agreements with stakeholders, incorporating transportation costs, and tracing the possibility of transportation by rail are in the linkage region.

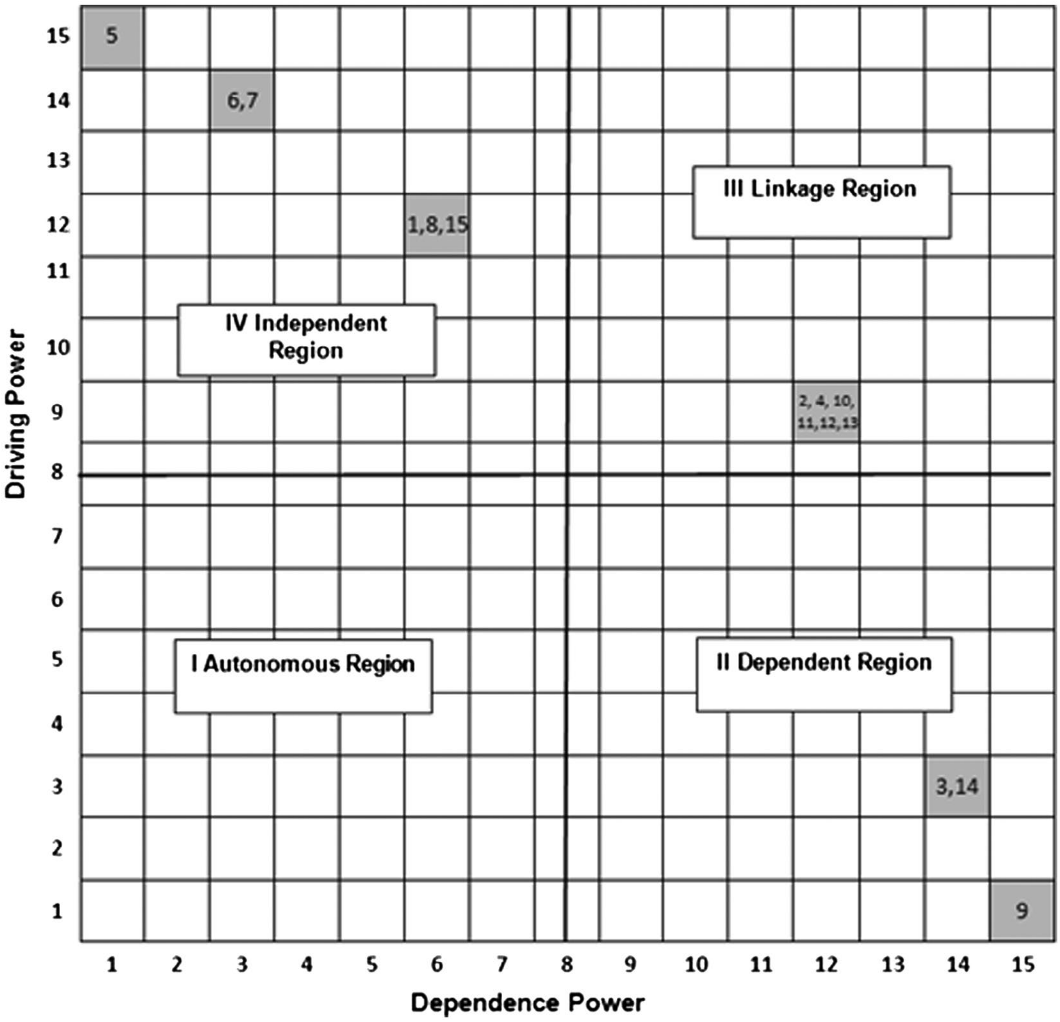

Figure 4. Driving and dependence power graph.

7.4. Independent region

Factors that drive the system fall into this region. They have high driving power such as: statutory notifications and fiscal incentives (government policies); dissemination and sharing of information; requirement for, and preparation of, location-specific strategic plans; focusing on known technologies; handholding with all stakeholder agencies; and incorporation of compulsory use of fly ash in bid documents. These factors come at the bottom of the hierarchical model (Haleem et al., 2016).

8. Discussion and findings

The objective of the study is to trace the relationships between various factors that can enhance fly-ash utilization in the road sector. Understanding the relationships between various factors will help in charting a specific action plan for implementation so that the stated purpose of more fly-ash usage in the road sector is achieved. The depiction of relationships between the various factors through a hierarchical structural model as a digraph focuses on the factors in a structured flow.

The findings of the study suggest that the most important factor is 'Statutory notifications and fiscal incentives (government policies)' as it lies at the bottom of the digraph. For fly-ash utilization in the road sector, there are statutory notifications like compulsory use of fly ash in construction activities within 100 km radius of any thermal power plant, along with planning to extend this to 500 km. Targets for fly-ash utilization in thermal power plants have also been fixed. Although there are some basic advantages to using fly ash in road construction, such as environmental benefits, savings of natural soil, positive changes in the material properties of cement, bitumen, etc., the main driving force towards its use is the availability of statutory notifications, owing to which it will be under consideration from the outset. Thus, such notifications have become the reason for institutionalizing the concept of fly-ash utilization for effective, consistent, and mandated implementation. This is clearly spelt out by the model. Therefore, it is an independent, and the most important, factor that drives other factors.

With such notifications in place, it is imperative to disseminate and share information through workshops, training programs, etc. Another requirement that arises is to have location-specific strategic plans. This level in the hierarchical model is the need arising owing to the presence of statutory notifications. Dissemination activities happen as part of technology promotion for the sector within new technologies. More and concerted efforts are required particularly in the area of thermal power plants. According to the model, local specific strategic plans are required to drive all key stakeholders towards a common cause. The geographical spread of fly-ash utilization and residual potential reflect the need for such plans (Ahmed, Saurikhia, Haleem, & Gangopadhyay, 2016). Discussion with experts suggests that such plans are required because of the handling of regional issues such as the availability of material, motivation of manpower, awareness and political will, etc. Fly-ash utilization at state level or with location specificity needs to be framed to ensure and enhance its utilization.

Carrying out dissemination exercises and preparing strategic plans would then demand focusing on known technologies, handholding of all stakeholders, and ensuring provision for the compulsory use of fly ash in bid documents. If known technologies were focused upon, it would change the status quo, a change that is required to break the present pattern of technology usage. Handholding between stakeholders is important to implement new but known technologies since there are several competency requirements for new technological solutions. Different stakeholders will bring different sets of competencies. Provision for compulsory usage is also paramount in triggering fly-ash usage in the present ecosystem with the support of focusing and handholding factors.

The next level in the model includes standards to be in place, confidence building measures, networking of laboratories and experts, entering into agreements with stakeholders, incorporating transportation costs, and tracing the possibility of transportation by rail. Level 3 appears to be the precursor to level 4 as it sets the stage for the need for the factors at level 4. Level 4 factors are the execution side of the level 3 factors. The resolution or action on these factors will call for the development of new technologies and proper monitoring by regulating bodies. It will help in establishing a complete ecosystem for technology utilization for fly-ash utilization.

The model also satisfies all six technology transfer effectiveness criteria (Bozeman, 2000) in the given framework. The technology is transferred through dissemination, handholding, and agreements, ensuring 'out-the-door' criteria (that technology is transferred by one and received by another), changing economics (market impact), regional development through strategic plans (economic development), recognition of the efforts of all stakeholders and their involvement (political and opportunity cost), and capacity building in technical terms (scientific and technical).

9. Conclusion

With a usage pattern of less than 58% in a year, 6% of which being in the road sector, and with around 67 million tonnes accumulating every year, a focus or strategic approach is required to increase the percentage utilization of fly ash in the road sector. The road sector in itself could be one of the major sectors for fly-ash utilization because of the size of presently ongoing road development projects in the country. The hierarchical structural model developed using the ISM technique spells out the approach or action plan for enhancing fly-ash usage in the sector. Alhough the factors discussed have been acted upon individually by concerned agencies, the model developed suggests that the methodology, if adopted, would accelerate fly-ash utilization in the sector.

Since the factors that are at the heart of the model are the main drivers, location-specific strategic plans bear the major onus of criticality of the whole model from an execution point of view. Such plans being in place, the remaining factors would demand attention, and hence it is suggested that the whole model be implemented in unison in order to achieve the best results in terms of fly-ash utilization in the road sector. Successful adoption and execution of the model is expected to establish an effective ecosystem with a focus on technology utilization towards maximum usage of fly ash in the road sector.

There is a need to study the impact of actions taken on these factors. It may happen that when these factors are acted upon, new factors may emerge for attention. More studies are required considering factors from a technical perspective, or from overall fly-ash usage enhancement in different fields. There is also a need to study the impact of these factors in quantitative terms as usage in metric tonnes of fly ash.

This paper has accomplished its objectives as it has clearly identified various factors that can enhance fly-ash utilization in the road sector, and the contextual relationships between them have been studied in order to develop a hierarchical structural model. The model is analysed and found to be relevant in terms of field requirements and practical significance.

Disclosure statement

No potential conflict of interest was reported by the authors.

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