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Article

SmartISM: Implementation and Assessment of Interpretive Structural Modeling

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Abstract: Interpretive Structural Modeling (ISM) is a technique to establish the interrelationships between elements of interest in a specific domain through experts' knowledge of the context of the elements. This technique has been applied in numerous domains and the list continues to grow due to its simplistic concept, while sustainability has taken the lead. The partially automated or manual application of this technique has been prone to errors as witnessed in the literature due to a series of mathematical steps of higher-order computing complexity. Therefore, this work proposes to develop an end-to-end graphical software, SmartISM, to implement ISM technique and MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (cross-impact matrix multiplication applied to classification)), generally applied along with ISM to classify variables. Further, a scoping review has been conducted to study the applications of ISM in the previous studies using Denyer and Tranfield's (2009) framework and newly developed SmartISM. For the development of SmartISM, Microsoft Excel software has been used, and relevant algorithms and VBA (Visual Basic for Applications) functions have been illustrated. For the transitivity calculation the Warshall algorithm has been used and a new algorithm reduced conical matrix has been introduced to remove edges while retaining the reachability of variables and structure of digraph in the final model. The scoping review results demonstrate 21 different domains such as sustainability, supply chain and logistics, information technology, energy, human resource, marketing, and operations among others; numerous types of constructs such as enablers, barriers, critical success factors, strategies, practices, among others, and their numbers varied from 5 to 32; number of decision makers ranged between 2 to 120 with a median value of 11, and belong to academia, industry, and/or government; and usage of multiple techniques of discourse and survey for decision making and data collection. Furthermore, the SmartISM reproduced results show that only 29 out of 77 studies selected have a correct application of ISM after discounting the generalized transitivity incorporation. The outcome of this work will help in more informed applications of this technique in newer domains and utilization of SmartISM to efficiently model the interrelationships among variables.

Keywords: interpretive structural modeling (ISM); MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (cross-impact matrix multiplication applied to classification)); Microsoft Excel; SmartISM; VBA (Visual Basic for Applications); reduced conical matrix

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1. Introduction

Every discipline is expanding its frontier and multiple disciplinary approaches have become essential to solve complex problems. This leads to the study of a large number of constructs of interests simultaneously. These constructs may have been identified in theory or practice. Warfield [1–4] in the 1970's developed a technique to establish an interrelationship model between variables known as interpretive structural modeling (ISM). The holistic picture of important constructs in the structured form derived from ISM technique helps the practitioners to solve the problem effectively. This technique is widely used due to its simplistic procedure and profound value addition in problem solving in different domains.

ISM helps in representing partial, fragmented, and distributed knowledge into integrated, interactive, and actionable knowledge. This technique is therefore particularly useful for the areas that are inherently multidisciplinary, such as sustainability. The discipline of sustainability ensures the performance in three areas: economic, social, and environmental, termed as triple bottom line (TBL) [5], while the world undergoes development. Additionally, the literature shows the maximum number of applications of this technique in the area of sustainability.

The search with the quoted keywords of “interpretive structural modeling” on the single database of Scopus yielded 5184 documents. There is an exponential growth in the usage of this technique from 2007 onward; prior to this year articles are around 10 each year starting from 1974. For the year 2007, 46 documents are listed and the numbers are exponentially increasing each successive year to 1200 documents in the year of 2020. With around 36% contribution in articles, India is leading the application of ISM, followed by China, USA, UK, and Iran. Together these five countries contribute around 71% of total articles. This technique is being used in many disciplines in decreasing order, namely business, engineering, computer science, decision science, environmental science, social science, and others.

ISM helps in modeling the variables and brings out the existing interrelationship structure among them. It helps a group of people or decision makers to debate and share their knowledge and achieve consensus on the relationships among the variables. The participants can share their views without any knowledge of mathematical complexity involved in the underlying steps. A computerized program may automate all the graphical and algebraic computation and convert their inputs into a pictorial model consisting of variables along with the relationships among them. The ISM process does not add any information [6] but brings in structural value [7].

In the same time period of the 1970’s, another technique known as MICMAC (Matrice d’Impacts Croisés Multiplication Appliquée á un Classement (cross-impact matrix multiplication applied to classification)) was developed by J. C. Duperrin and M. Godet [8]. MICMAC helps in classification of the variables into one of the four categories, namely dependent, independent, linkage, and autonomous variables. ISM coupled with MICMAC becomes a strong tool to visualize the structure of variables along with the interrelationships between them. ISM is also used in several multi criteria decision making (MCDM) techniques such as analytical hierarchy process (AHP) [9], analytic network process (ANP) [10–12], technique for order of preference by similarity to ideal solution (TOPSIS) [13,14], decision-making trial, evaluation laboratory (DEMATEL) [15,16], and others.

Implementation of this technique and conduction of brainstorming sessions with experts in previous studies [17,18] led to identification of some key challenges such as variables’ identification, selection of decision makers and method of decision making, and unavailability of end-to-end software for ISM and MICMAC. Furthermore, the literature shows erroneous applications of steps of ISM such as wrong reachability matrix [19–22], wrong transitivity calculations [9,13,16,23–37], incorrect level partitioning and wrong structure of the model [31,38–42], and incorrect addition [11,14,43–48] or reduction [49–52] of edges affecting the reachability of variables. An error in an earlier step generally leads to an error in subsequent steps. Similarly, the wrong calculation of transitivity leads to wrong MICMAC diagrams. Therefore, there exists some important issues in implementation of this technique, namely identification of variables, decision makers, expertise and experience of decision makers, method of decision making, and computerization of the steps of ISM. Previous ISM reviews [53–55] don’t critically analyze the steps of ISM applications in the articles. Similarly, although some automation of the ISM technique has been provided earlier [56,57], there does not exist any end-to-end graphical software that may help in applying this technique and allow the decision makers to focus on sharing knowledge and iterate the ISM technique until a high-confidence consensus model is arrived at. These challenges set the objectives of this research as follows:

- Development of SmartISM, a software tool for ISM and MICMAC using Microsoft Excel and VBA.
- Scoping review of applications of ISM on existing studies to identify application domains, types and numbers of variables studied, composition of decision makers, decision making and data collection techniques, and accuracy of ISM application using SmartISM.

The remainder of the paper is organized into the following sections: literature review, research methodology, development of SmartISM using Microsoft Excel, results, discussion, and conclusion.

2. Literature Review

There are numerous studies in the literature that illustrate the ISM technique. They can be summarized into the seven steps approach with an additional eighth step for MICMAC analysis, as given in the following subsection. The next subsection illustrates the existing available automation of the ISM. The last subsection presents some studies that have reviewed the implementations of ISM.

2.1. ISM and MICMAC Techniques

The interpretive structural modelling (ISM) can be defined as constructs' directional structuring technique based on contextual interrelationships defined by domain experts, utilizing computerized conversion of relations into a pictorial model using matrix algebra and graph theory. It may be explained in the series of steps as follows, which will assist in automating all the processes of the ISM technique.

2.1.1. Elements or Constructs or Variables

Identification of elements or constructs of the subject being studied is the most important of all activities. Similarly, the establishment of their definition along with the theoretical boundaries or scope is very critical. Elements must be explained with the details of their definition, objectives, and possible indications or measurements. These elements are generally identified by literature review, expert opinions, and/or surveys. Some of the unique approaches have been use of thematic analysis [58], upper echelon theory [11], contingency theory [59], content analysis [52], strengths, weaknesses, opportunities, and threats (SWOT) analysis [30], idea engineering workshop [40,60], and Delphi technique [37,61]. One study [42] has defined the source, understanding, and interpretation for each variable.

2.1.2. Decision Makers (DMs)

DMs play a very significant role in ISM as the whole process and outcome are dependent upon their input. There are three important aspects for the selection of a group of DMs such as size, expertise, and diversity. The group of DMs should be representative of all of the stakeholders in the domain of the problem. They should have sound experience of domain and expert level knowledge of variables being studied. The literature shows the number of DMs ranging between 2 [62,63] to 120 [64] with a median value of 11, and very few studies [16,30,41,65] have taken DMs from academia, industry, and government together.

2.1.3. Structural Self-Interaction Matrix (SSIM)

Elements or constructs are interrelated with one of the four relations such as x influences y, y influences x, x and y mutually influence each other, or x and y are unrelated. These relations are almost universally represented by 'V', 'A', 'X', and 'O' characters respectively in the SSIM. These relationships are assigned by DMs based on contextual relationships during pairwise comparison on variables. The number of comparisons is nC2 (mathematical combination), where n is the number of variables in the domain of study. Finally, an n by n matrix is formed with nC2 cells filled with A, V, X, and O symbols and the remaining cells are blank. Most studies have used these standard symbols except few such as [35]. As this is the basic matrix and required for all other steps therefore has been documented in most of the studies except few such as [15,66].

2.1.4. Reachability Matrix (RM) and Final Reachability Matrix (FRM)

RM is the representation of SSIM in binary form. V, A, X, and O symbols of SSIM are replaced with 1, 0, 1, and 0, digits respectively. At their transposed positions by row with column and column with row, 0, 1, 1, and 0 digits are placed, respectively. The constructs are assumed to influence self, so ones are placed at the diagonal positions. The resultant RM is checked for transitive relations. Transitivity is the basic assumption in the ISM such as if variable x influences y and y influences z then x will influence z transitively. This is second-order or two-hop transitivity whereas generalized transitivity means x is related to z through one or more variables. The transitive relations hence identified are represented in the RM with 1*s to distinguish from original 1s and the resulting matrix is known as FRM. FRM also consists of driving and dependence powers of each variable by counting 1s and 1*s in rows and columns respectively. Very few studies mention usage of some software for transitivity calculations such as [56,57]. However, one of the most frequent reasons for incorrect ISM calculations have been wrong transitivity calculations, such as in studies [9,13,16,23–37]. Therefore, this study proposes the use of an established Warshall algorithm [67] for transitivity calculations.

2.1.5. Level Partitioning

This is a very important step to develop the hierarchical directional structure among the variables. Reachability, antecedent, and intersection sets are derived for all the variables from the FRM. For a specific variable, a reachability set consists of itself and all the variables it influences, and an antecedent set consists of itself and all the variables influencing it. Thereafter, the intersection set of reachability and antecedent set is calculated. Variables having the same reachability and intersection sets are given the top rank and are removed for the next iteration and the process is repeated until all variables are ranked. Some studies such as [31,38–42] in the literature had incorrect leveling for variables.

2.1.6. Conical Matrix (CM) and Digraph

CM is row and column wise ordered FRM based on ranks or levels of variables identified in the level partitioning step. Further the levels of each variable are also recorded at the end of row and column in CM. This matrix helps in drawing the digraph to get the first visual output of the hierarchical directional structure of variables. Circular nodes are drawn with variable numbers. Further they are connected with directional edges based upon 1s or 1*s in the CM between pairs of variables. Fewer studies have mentioned CM and digraph [12,20,27,35,65,68–70], as the digraph resembles the final model with a lesser number of edges. The importance of the digraph further goes down in automatic calculation of transitivity.

2.1.7. Reduced Conical Matrix (RCM) and Final ISM Model

Digraph is converted into a final model by replacing the node numbers with names of the variables and representing nodes in the rectangular shapes. Moreover, efforts are made to remove maximum edges from digraph while maintaining the levels and structure of variables and reachability of variables. This is done to improve the readability of the final model. Several studies have committed mistakes at this step either by adding extra edges [11,14,43–48] or omitting edges [49–52] that have affected the reachability of the variables. Therefore, a new algorithm, reduced conical matrix (RCM), has been devised to remove maximum possible edges without affecting structure and reachability of variables, as explained in the fourth section. This RCM is used for making the final ISM model. The final model may further be subjected to validations by different means such as review by DMs, interviews from different sets of participants, or statistical validations.

2.1.8. MICMAC

MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (cross-impact matrix multiplication applied to classification)) in the simplest terms is a variable classification technique. Variables are mapped onto a two-dimensional grid based on their dependence and driving power values, represented on horizontal and vertical axes respectively. The range of these values is between 1 and total number of variables and the axes are bifurcated at mid-points, resulting in four quadrants numbered anti clockwise. These quadrants classify variables into autonomous, dependent, linkage, and independent categories. The autonomous variables are not connected with the remaining system of variables whereas linkage variables are sensitive and strongly connected with independent and dependent variables. The final hierarchical ISM model coupled with the MICMAC analysis greatly improves the understanding of variables. Therefore, most studies have carried out MICMAC analysis except few such as [19,39,47,71,72].

2.2. Implementation of ISM

As originally proposed by Warfield [1–4], the ISM requires its steps to be executed with the assistance of a computer [6]. Some of the more recent studies demonstrate specialized software or routines being developed for ISM. The article [56] mentions the development of the ISM software package in R software. This software package takes the SSIM input in the comma separated (.csv) excel file and provides two outputs in excel file format, namely, "ISM_Matrix" for FRM step to incorporate transitivity calculations and "ISM_Output" for partitioning step to identify the levels of the variables. Similarly, some studies such as [57] have used MATLAB software to calculate the FRM and partitioning steps. The previous studies have attempted to automate FRM and partitioning steps, leading to partial automation of ISM. As pointed out earlier in absence of automation, the final model may introduce errors in edges regardless of correct FRM and leveling, leading to wrong reachability of variables. Further, having all the steps being carried out automatically shows the prompt results to researchers and decision makers for further possible iterations. Therefore, there exists a need to develop an end-to-end graphical software to implement ISM and MICMAC and identify the required algorithms for it.

2.3. Assessment of ISM Applications

The ISM technique is being applied in a range of domains [53–55]. The review article [54] provides 10 different application domains for ISM. It further provides additional parameters such as integration with other MCDM approaches. Similarly the review article [55] identified ISM applications in 14 domains without industry or organizations, 20 industrial sectors, and 4 other areas. Furthermore, among other characteristics, it mentions integration with other MCDM approaches, and the presence of constructs for cost and/or quality. These reviews haven't focused on operationalization of ISM technique. Therefore, there exists a gap to identify the methodology of steps of applications of ISM in the existing articles such as nature and number of variables, compositions of DMs, decision making and data collection techniques, and accuracy of ISM results.

3. Research Methodology

This study addresses two objectives, firstly the development of SmartISM for the implementation of ISM, as explained in the following section. The second objective is the scoping review of literature to identify the scope of ISM and MICMAC applications and the assessment of applications of ISM using SmartISM tool. For the scoping review the five-step framework of Denyer and Tranfield (2009) [73] has been adopted as explained in the following paragraphs, Figure 1. The review process also generated the data necessary for the assessment of application of ISM using SmartISM.

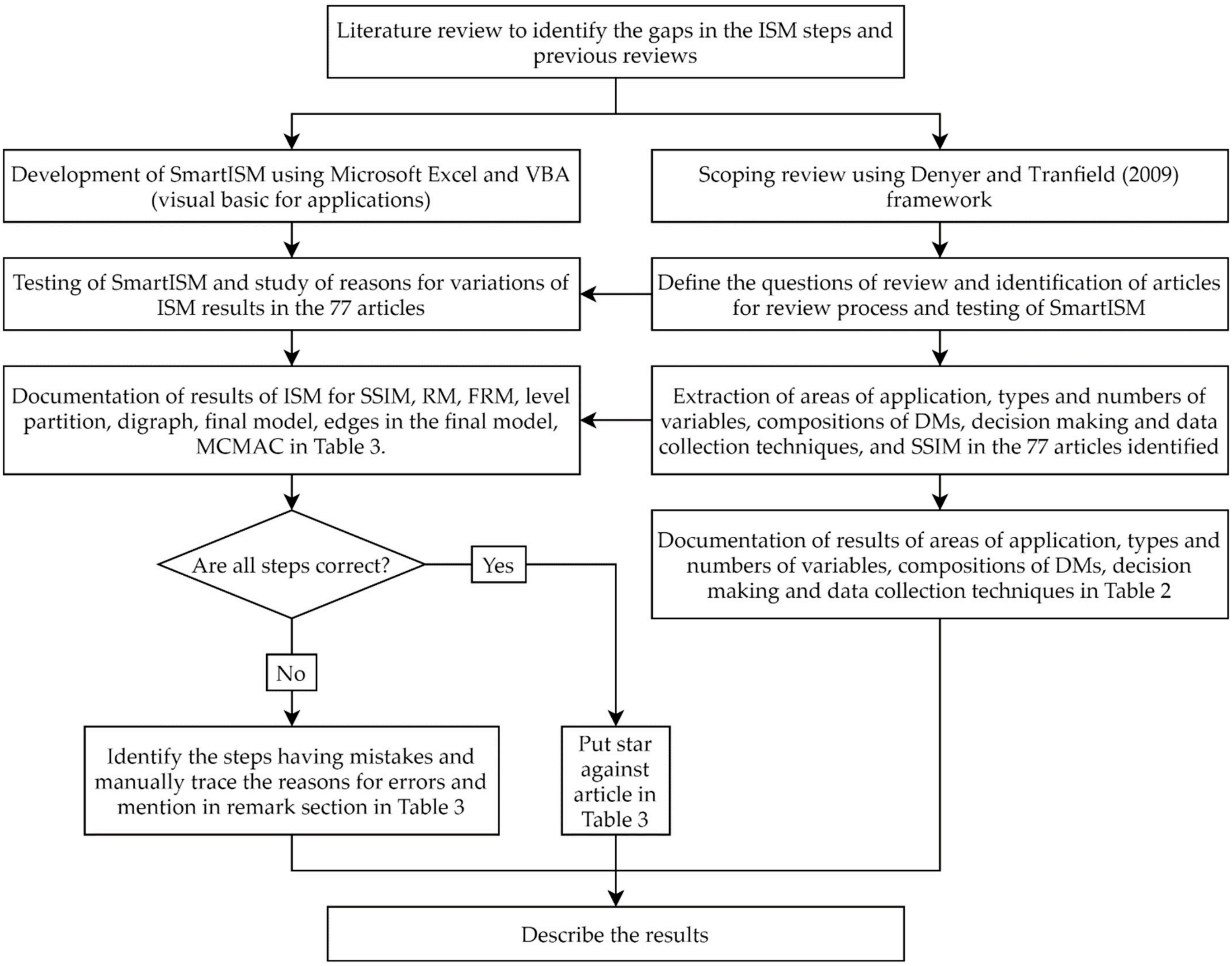

Figure 1. Research Methodology.

Step I: Question formulation: Formulating questions requires identification of context, interventions, mechanisms, and outcomes. In this study, context is considered to be domain, and decision makers; interventions are variables of interest in problem domain; mechanisms are techniques for data collection from DMs; and outcomes are the ISM outputs and MICMAC diagram. In essence there will be the following research questions that will help in addressing the second objective of this study.

- What are the different domains and sub-domains of ISM applications?
- What are the different types and numbers of variables being studied?
- What are the compositions of DMs in different studies?
- What are the different decision making and data collection techniques?
- How accurate has been the application of ISM technique, using SmartISM?

Step II: Locating Studies: As the ISM based studies are huge, only quality sources were considered, rather than an exhaustive search. As per the objectives, articles that had significant discussion and documentation on ISM application as mentioned in Step I were needed. As defined earlier, the steps of ISM are structural self-interaction matrix, initial and final reachability matrix, level partitioning, conical matrix, digraph, and final model. It was observed that an article going into the details of level partitioning had sufficient demonstration of ISM. Therefore, “Interpretive Structural Modeling” + partitioning keywords were used on ScienceDirect database and it resulted in 300 articles up to the year of 2021, of which 291 belonged to review and research articles.

Step III: Study selection and evaluation: These articles were further perused for the relevance to present study and classified into different groups such as definition only, other techniques, no partitioning, non-related, incomplete outputs, and desired study. As the articles were growing nonlinearly each year, therefore, after the year of 2017, a random selection of five articles was preferred to keep the dataset manageable. It resulted in 77 articles in the desired study group that were considered further in this study.

Step IV: Analysis and Synthesis: This step has two components: first the analysis of articles for context, interventions, and mechanisms was performed, as explained in step one, by extracting relevant information as shown in Table 2. Second was the extraction of SSIM from the 77 selected articles to reimplement the ISM technique using SmartISM. The results from the SmartISM were compared with the outcomes illustrated in the article for SSIM, RM, FRM, LP, CM, digraph, final model and edges in the final model, and MICMAC and the variations are summarized in Table 3.

Step V: Reporting and using the results: Results of analysis and synthesis are reported in results and discussion section. They have been provided in a fashion that will assist in informed-adoption and application of ISM and MICMAC, and utilization of SmartISM for academicians, practitioners, and policy makers alike.

Articles' Details

Articles' publication years range from 2005 to 2021. As the articles are increasing non-linearly, therefore 2017 onwards only five articles were randomly chosen for each year. The publication sources having two or more articles have been shown in Table 1. Journals in the area of sustainability have the maximum number of articles. Journal of cleaner production had published 18 articles out of 77 selected articles.

Table 1. Publication sources for two or more articles.

Publication Title	2005	2007	2008	2009	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Journal of Cleaner Production							2	2		5	3	1	3	1	1	18
Renewable & Sustainable Energy Reviews							1	1		1	2					5
Resources, Conservation and Recycling				1	1		1	1		1						5
Resources Policy									3	1						4
Procedia Social and Behavioral Sciences									3	1						4
Procedia Engineering								1			1					2
Journal of Environmental Management											1	1				2
Computers & Industrial Engineering											1			1		2
Telematics and Informatics											1	1				2
International Journal of Production Economics						1		1								2
Sustainable production and consumption											1	1				2
Technological Forecasting and Social Change	1										1					2
Miscellaneous Sources with 1 article		1	2		1		1	3	5	1	3	1	2	3	4	27
Total	1	1	2	1	2	1	5	9	11	10	14	5	5	5	5	77

4. Development of SmartISM Using Microsoft Excel

Microsoft Excel provides an excellent environment for graphical representation and modelling of virtually any conceptual framework of any discipline. It has some important features such as cellular addressable input sheets, interactive output, vector graphic objects, integral atomic access of data in multiple ways, many inbuilt data processing functions, backend VBA (Visual Basic for Applications) interface to code any logic or algorithm, mechanisms for development of event driven interfaces, ubiquitous tool and ease of use, and widespread ecosystem of support and training. Hence it makes a natural choice for practitioners, decision makers, and researchers to develop their problem-solving models in Microsoft Excel. Its applications in business statistics and decision making are widely documented. Following are some advanced applications of MS Excel in different domains such as Genetic Analysis [74], Finite Element Analysis in Engineering [75], and Pharmacokinetic Pharmacodynamic fields of Pharmacology [76]. On the flip side it has a drawback to support multiple real-time concurrent users. This section explains the functions and features of VBA to develop SmartISM, an end-to-end graphical software to automate processes of

ISM and MICMAC with the help of pseudo codes. Additionally, the demonstration video for SmartISM has been attached as a Supplementary Material, see Video S1.

Firstly, the SSIM matrix defined by DMs is entered in Excel, and serves as the basic input for other steps of ISM. For n variables, the size of SSIM will be n by n. DMs will compare n(n + 1)/2 or $^{n}C_2$ unique pairs of variables and assign one of the relationships using symbols V, A, X, or O, as explained earlier. Thereafter, eight VBA macros will derive matrices of RM, FRM, CM, and RCM; level partitioning; and draw diagrams of digraph, final model, and MICMAC. RM is a binary form of SSIM using conversion rules for V, A, X, and O as explained earlier and keeping 1s at the diagonal positions of the matrix, as described in the following pseudo code. RM also contains the driving and dependence powers for each variable.

```
Function RM
//copy the content of SSIM into RM
RM ← SSIM
//loops to replace V, A, X and O symbols with 1, 0, 1 and 0, digits; and putting 0,1, 1 //and 0
digits at their transposed positions; and keeping the diagonal elements as 1
For i = 1 To n     //n is the total number of elements
    For j = 1 To n
        If i = j
            RM[i][j] ← 1
        If RM[i][j] = 'V'
            RM[i][j] ← 1
            RM[j][i] ← 0
        If RM[i][j] = 'A'
            RM[i][j] ← 0
            RM[j][i] ← 1
        If RM[i][j] = 'X'
            RM[i][j] ← 1
            RM[j][i] ← 1
        If RM[i][j] = 'O'
            RM[i][j] ← 0
            RM[j][i] ← 0
//count non-zero elements in rows and columns and append to show the driving and
//dependence powers
For i = 1 To n
    RM[i][n + 1] ← Countif(RM[i][] != 0)
    RM[n + 1][i] ← Countif(RM[][i] != 0)
```

The second function FRM requires calculation of transitive relations among variables. For manual calculation, RM can be visualized as a digraph with variables representing nodes and 1s in the RM representing the directed edges. By tracing different paths, transitive relations can be identified. For a large number of variables the process would be tedious and leads to errors, whereas a simple Warshall algorithm [67] for transitive closure can be used to automate it. This algorithm results in generalized transitivity if applied in-place, otherwise it will give second-order or two-hop transitivity. Transitive relations are marked with 1* in FRM, see the pseudo code for main logic in the following paragraph. Moreover, the 1s and 1*s are counted in rows and columns to calculate the driving and dependence powers respectively for each variable.

Function FRM
```
//copy the content of RM into FRM
FRM ← RM
//block for generalized transitivity (all levels) Warshall algorithm in-place
//start three level nested loop to parse through FRM
For k = 1 To n    //n is the total number of elements
    For i = 1 To n
        For j = 1 To n
            If FRM[i][k] = 1 And FRM[k][j] = 1
                FRM[i][j] ← 1
//putting 1* to differentiate between transitive links identified and links in RM
    For i = 1 To n
        For j = 1 To n
            If FRM[i][j] != RM[i][j]
                FRM [i][j] ← *1
//block for second-order transitivity (up to second level only) Warshall algorithm
//start three level nested loop to parse through FRM
For k = 1 To n
    For i = 1 To n
        For j = 1 To n
            If RM[i][k] = 1 And RM[k][j] = 1 And FRM[i][j] = 0
                FRM[i][j] ← 1*
//recount non-zero elements in rows and columns and append to show the driving and
//dependence powers
For i = 1 To n
    RM[i][n + 1] ← Countif(RM[i][] != 0)
    RM[n + 1][i] ← Countif(RM[][i] != 0)
```

The next step is to calculate the ranks of the variables through level partitioning. A new matrix LP is defined with five columns namely elements (Mi), reachability set R(Mi), antecedent set A(Mi), intersection set R(Mi)∩A(Mi) and level, and n rows. For a specific variable Mi in FRM, non-zero cells in the row comprise its reachability set and their corresponding identifiers are kept in the LP row of the same variable Mi. Similarly, non-zero cells in the column comprise its antecedent set and their corresponding identifiers are kept in the LP row of the same variable Mi. The intersection sets are calculated for all variables and variables having the same reachability and intersection sets are given first rank. In the next iteration, identifiers of all the ranked variables are removed from reachability, antecedent, and intersection sets. Again, variables having the same reachability and intersection sets are given the second rank and iteration continues until all the variables are ranked. The iteration results may be copied in one Microsoft Excel Sheet.

Function LP
```
//initiate a matrix LP of size n by 5 to keep element number, reachability set, antecedent //set,
intersection set and levels for each of the n elements; levels will remain empty
For i = 1 To n
    LP[i][1] ← i
    //reachability set R for ith element
    For j = 1 To n
        If FRM[i][j] != 0
            Append jth element to R
    LP[i][2] ← R
  //antecedent set A for ith element
    For j = 1 To n
        If FRM[j][i] != 0
            Append jth element to A
    LP[i][3] ← A
    LP[i][4] ← R∩A
```

```
//iteration for level calculations, where levels j can go up to n
For j = 1 To n
    //remove elements that have levels
    For i = 1 To n
        If LP[i][5] != Null
            For k = 1 To n
                Remove ith element from LP[k][2], LP[k][3], LP[k][4]
    //assign jth level to elements that have equal reachability and intersection sets
    For i = 1 To n
        If LP[i][2] = LP[i][4] And LP[i][5] = Null
            LP[i][5] ← j
    //print the jth iteration results
    Print LP
```

Once the variables are ranked, a digraph can be developed easily by positioning the variables as per their ranks with the help of CM. CM is row and column wise sorted FRM as per variables' ranks or levels. Directed edges can be drawn between variables as per non-zero cells in the CM. Two shape objects Oval and Connector are needed to automate the drawing of digraph. Positing of ovals needs to be carefully assigned, as there can be multiple ovals in one level. The simplest way to identify the needed objects in drawing is to auto record a macro and draw a sample. Afterwards, the macro can be manually edited and static names of the objects can be made dynamic for easy handling in the loop structures of VBA. The pseudo codes for the functions for CM and digraph is as follows.

```
Function CM
//copy the content of FRM into CM
CM ← FRM
//add levels from LP to CM for each element at the end of rows and columns
For i = 1 To n    //n is the total number of elements
    CM[i][n+2] ← LP[i][5]
    CM[n+2][i] ← LP[i][5]
CM.Sort key1: = Range(LP[n + 2][])
CM.Sort key1: = Range(LP[][n + 2]), Orientation: = xlLeftToRight
Function Digraph
//create ovals of size s to represent numbered nodes for each element
For i = 1 To n    //n is the total number of elements
    Ovals[i] ← Shapes.AddShape(msoShapeOval, 0, 0, s, s)
    Ovals[i].TextFrame.Characters.Text ← i
    //define and calculate the position arrays v and h of each rectangle based on
    //drawing canvas size, required interspacing between elements as per number of
    //elements, elements in each level and any offset needed
    Ovals[i].Top ← v[i]
    Ovals[i].Left ← h[i]
//add directed arrows between elements based on edges in CM
For i = 1 To n
    For j = 1 To n
        If CM[i][j] != 0 And i != j
            Shapes.Range(Ovals[i], Ovals[j]).Select
            Shapes.AddConnector(msoConnectorStraight, 0, 0, 0, 0).Select
            Selection.ShapeRange.Line.EndArrowheadStyle ← msoArrowheadOpen
            Selection.ShapeRange.ConnectorFormat.BeginConnect Ovals[i], 1
            Selection.ShapeRange.ConnectorFormat.EndConnect Ovals[j], 5
```

The final model represents variable names in the rectangular boxes in place of their identifiers in ovals and tries to remove maximum possible transitive links from the digraph. Transitive reduction is a technique to reduce the number of transitive links. Transitive reduction is complicated, specifically for the directed cyclic graphs, and the algorithm may even distort the structure of the digraph. Therefore, an algorithm was designed to develop a reduced conical matrix (RCM) that removes maximum links without changing the structure of digraph and reachability of elements. The main logic is to remove incoming links from second lower-level variables from the CM and results in RCM, see the pseudo code for the main logic in the following paragraph. RCM was used to draw automated final ISM model using Rectangle and Connector shape objects, as in the following pseudo code.

```
Function RCM
//copy the content of CM into RCM
RCM ← CM
//start loop to parse through columns
For i = 1 To n    //n is the total number of elements
    //start loop to parse through row of specific column for lower triangular matrix
    For j = i To n
    //search for first non-zero row cell whose level is greater than the level of that
    //column element
        If (RCM[j + 1][i] = 1 Or RCM[j + 1][i] = "1*") And RCM[j + 1][n +2] > RCM[i][n + 2]
            //set the L one higher than the level identified
            L ← RCM[j + 1] [n + 2] + 1
            Break For
    //identify the row that has level equal to L
    For j = i To n
        If RCM[j][n + 2] = L
            Break For
    //set all the rows starting from identified row in preceding step and below up to n
    //as 0
    For j = j To n
        RCM [j][i] ← 0
Function FinalModel
//create rectangles of size s to represent each element with variable text kept in names //array
For i = 1 To n    //n is the total number of elements
    Rects[i] ← Shapes.AddShape(msoShapeRectangle, 0, 0, s, s)
    Rects[i].TextFrame.Characters.Text ← names[i]
    //define and calculate the position arrays v and h of each rectangle based on
    //drawing canvas size, required interspacing between elements as per number of
    //elements, elements in each level and any offset needed
    Rects [i].Top ← v[i]
    Rects [i].Left ← h[i]
//add directed arrows between elements based on edges in RCM
For i = 1 To n
    For j = 1 To n
        If RCM[i][j] != 0 And i != j
            Shapes.Range(Rects [i], Rects [j]).Select
            Shapes.AddConnector(msoConnectorStraight, 0, 0, 0, 0).Select
            Selection.ShapeRange.Line.EndArrowheadStyle ← msoArrowheadOpen
            Selection.ShapeRange.ConnectorFormat.BeginConnect Rects [i], 1
            Selection.ShapeRange.ConnectorFormat.EndConnect Rects [j], 3
```

Lastly, a macro was written to draw a MICMAC diagram. The basic input for this diagram was the dependence and driving powers of variables from FRM. This was the longest macro as it required many shape objects such as Line, Connector, Rectangle, Oval, and Textbox. However, it didn't require any special algorithm to be used. Nevertheless, logic to initiate, aggregate, and draw different objects based on number of variables, and dependence and driving powers in a specified space, required careful arrangement.

```
Function MICMAC
//draw n + 1 horizontal and vertical lines where n is total number of elements spaced at
//s as per canvas size and number of elements, offset has been skipped for simplification
//and add numbered labels for each line
For i = 1 To n + 1
    Shapes.AddLine(0, i*s, n*s, i*s).Line //horizontal lines
    Shapes.AddLine(i*s, 0, i*s, n*s).Line //vertical lines
    With Shapes.AddTextbox(msoTextOrientationHorizontal, i*s, n*s, 30, 20)
        .TextFrame.Characters.Text ← i-1
    With Shapes.AddTextbox(msoTextOrientationHorizontal, 0, i*s, 30, 20)
        .TextFrame.Characters.Text ← i-1
//draw middle horizontal and vertical lines that may be of higher weight
With Shapes.AddLine(0, n*s/2, n*s, n*s).Line //horizontal
    .Weight ← 3
With Shapes.AddLine(n*s/2, 0, n*s/2, n*s).Line //vertical
    .Weight ← 3
//draw horizontal and vertical arrows to demarcate dependence and driving powers
Shapes.AddConnector(msoConnectorStraight, 0, n*s, n*s, n*s).Select
Selection.ShapeRange.Line.EndArrowheadStyle ← msoArrowheadOpen
With Shapes.AddTextbox(msoTextOrientationHorizontal, n*s/2, n*s, 110, 20)
    .TextFrame.Characters.Text ← "Dependence Power"
Shapes.AddConnector(msoConnectorStraight, 0, n*s, 0, s).Select
Selection.ShapeRange.Line.EndArrowheadStyle ← msoArrowheadOpen
With Shapes.AddTextbox(msoTextOrientationUpward, 0, n*s/2, 20, 80)
    .TextFrame.Characters.Text ← "Driving Power"
//write labels for each quadrant such as autonomous (I), dependent (II), linkage (III),
//and independent (IV) variables
With Shapes.AddTextbox(msoTextOrientationHorizontal, 0, s*n, 130, 40)
    .TextFrame.Characters.Text←"I-Autonomous Variables III-Linkage Variables"
With Shapes.AddTextbox(msoTextOrientationHorizontal, s*n, s*n, 135, 40)
    .TextFrame.Characters.Text←"II-Dependent Variables IV-Independent Variables"
//place the I to IV (Roman[]) in quadrants in appropriate positions x[] and y[]
For i = 1 To 4
    With Shapes.AddTextbox(msoTextOrientationHorizontal, x[i], y[i], 20, 20)
        .TextFrame.Characters.Text ← Roman[i]
//set dependence and driving in 2-dimensional arrays x and y
For i = 1 To n
    x[i][1] ← FRM[i][n + 1]
For i = 1 To n
    y[1][i] ← FRM[n + 1][i]
//aggregate elements with same dependence and driving powers in a 2-dimensional
//array E
For i = 1 To n
    If x[1][i], y[i][1] = x[1][i], y[i][1]
        Append i^th element at E[x[1][i]][y[i][1]]
//place ovals of size o and elements on the grid, offsets have been ignored
For i = 1 To nVar
    For j = 1 To nVar
        If E[i][j] != Null
            Shapes.AddShape(msoShapeOval, i*s, j*s, o, o)
            With Shapes.AddShape(msoShapeRectangle, i*s, j*s, 0, 15)
                .TextFrame.Characters.Text = E[i][j]
```

The SmartISM software was extensively tested on studies available in the literature. For any discrepancy between the reported results in the study and the SmartISM, steps were manually verified to validate the results of SmartISM, as shown in Table 3. The sample results of SmartISM for one of the previous studies [77] that had no discrepancy are shown in Figures 2–5.

All Steps	LA(1)	LETM(2)	LFFD(3)	LPE(4)	LRTP(5)	LPP(6)	IDI(7)	RIR(8)	OVIG(9)	IIF(10)	LSP(11)	LAPT(12)	LIS(13)	Driving Power
LA(1)	1	1*	1	1	1	1	1	1	1	1	1	1	1	13
LETM(2)	0	1	0	0	0	0	0	0	0	0	0	1	0	2
LFFD(3)	0	1	1	0	1	1	1	1	1	1*	0	1	1	10
LPE(4)	0	1	1	1	1	1	1	1	1	1	0	1	1	11
LRTP(5)	0	1	0	0	1	1	1	1	1	1	0	1	0	8
LPP(6)	0	1*	0	0	0	1	0	0	0	1	0	1*	0	4
IDI(7)	0	1	0	0	1	1	1	1	1	1	0	1	0	8
RIR(8)	0	1	0	0	0	0	0	1	0	1	0	1	0	4
OVIG(9)	0	1*	0	0	0	0	0	0	1	1	0	1*	0	4
IIF(10)	0	1	0	0	0	0	0	0	0	1	0	1	0	3
LSP(11)	0	1	1	1	1	1	1	1	1	1	1	1	1	12
LAPT(12)	0	1	0	0	0	0	0	0	0	0	0	1	0	2
LIS(13)	0	1	0	0	0	1	0	1	1	1	0	1	1	7
Dependence Power	1	13	4	3	6	8	6	8	8	11	2	13	5	

Figure 2. Final Reachability Matrix (FRM).

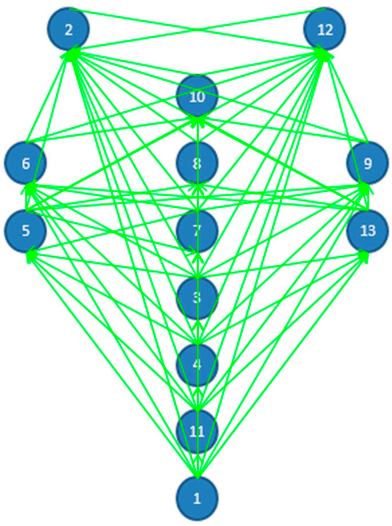

Figure 3. Digraph.

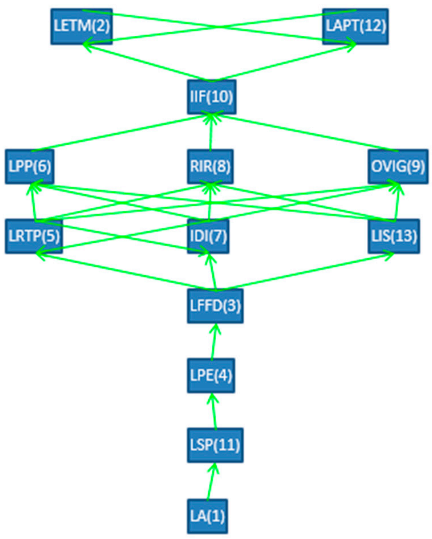

Figure 4. Final ISM Model.

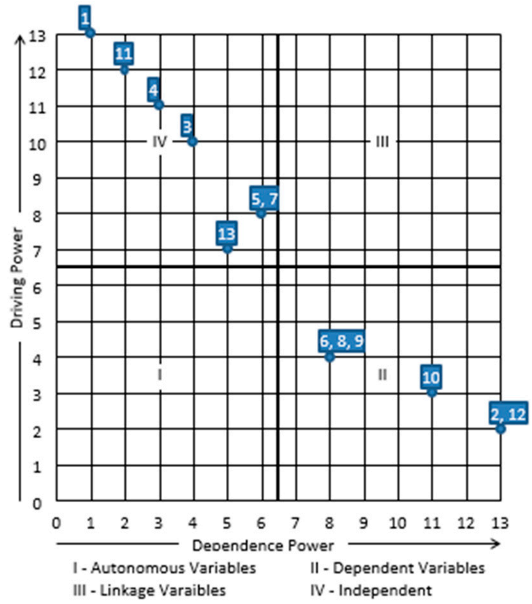

Figure 5. MICMAC Diagram.

5. Results

This section presents the scoping review answers to the questions described in the research methodology section with respect to domain of ISM applications, variables of study, composition of decision makers, decision making, and data collection techniques, as summarized in Table 2. Furthermore, the results of the assessment of ISM technique using SmartISM on the selected 77 papers are summarized in Table 3.

Table 2. Articles' domain, variables, decision makers and techniques, and ISM and other MCDM approaches.

S. No.	Reference	Domain (Sub-Domain)	Variables Description	Method of Decision Making	Number of Decision Makers	Techniques
1	[43]	Sustainability (Eco-Design)	6 barriers	workshops, seminars, telephonic enquiries, and individual and consensus questionnaire	4 excluding authors	ISM and MCDM
2	[15]	Sustainability (Manufacturing)	10 barriers and 10 enablers	two-phase questionnaire survey and online survey	10 (5 academic and 5 industry)	DEMATEL-MMDE-SEM-ISM Separate analysis for academic and industry
3	[49]	Sustainability (GSCM)	11 drivers	decision team	Including experts from the industry	ISM
4	[78]	Sustainability (GSCM)	26 CFS	personal interview, Likert scale questionnaire, decision team	10 (9 industry and 1 government)	ISM
5	[16]	Sustainability (E-Waste recycling)	10 barriers	brainstorming, and interviews	10 (6 industry, 1 NGO, 2 government and 1 academic)	DEMATEL-ISM
6	[13]	Sustainability (Healthcare-Waste)	8 factors	group decision making	industry, academic and government, 9 for AHP	ISM, fuzzy AHP and fuzzy TOPSIS.
7	[14]	Logistics (Reverse logistics Provider)	7 factors	expert opinion	5 for TOPSIS	ISM and fuzzy TOPSIS
8	[60]	Energy (Smart grid technologies)	12 barriers	idea engineering workshop	Industry and academia	ISM and MICMAC
9	[38]	Sustainability (GSCM)	18 factors	face to face interview using questionnaire	15, (OEM 3, tier-1 5, tier-2 4, tier-3 3)	ÌPA, ISM, MICMAC
10	[31]	Sustainability (Landfill Community)	12 barriers	expert opinions, interviews and group discussions	information not available	ISM MICMAC
11	[79]	Energy (Solar Power)	13 barriers	workshop	6 (4 industry and 2 academic)	ISM MICMAC

Table 2. *Cont.*

S. No.	Reference	Domain (Sub-Domain)	Variables Description	Method of Decision Making	Number of Decision Makers	Techniques
12	[32]	SCM (Food-Waste)	9 challenges	consultation	5 (industry and 2 academic)	Exploratory Factor Analysis, ISM MICMAC
13	[80]	SCM (Humanitarian SC)	12 CSF	consultation	7 (3 industry and 4 academic)	ISM MICMAC
14	[81]	Sustainability (SSCM)	13 enablers	one day workshop	15 or 25 industry	ISM MICMAC
15	[82]	Business (Offshoring)	9 elements	consultation and approval of interviewed experts	30 (6 each for 5 cases' development)	ISM MICMAC
16	[62]	Logistics (Reverse logistics)	11 barriers	consultation	2 (1 industry and 1 academic)	ISM MICMAC
17	[77]	Energy	13 barriers	questionnaire and communication	4 for questionnaire and 3 for agreement through communication (mix)	ISM MICMAC
18	[83]	HR (OSH)	8 factors	discussion for 72 h	5 industry	ranking order clustering ROC, ISM
19	[63]	Sustainability (GSCM)	26 barriers identification by more than 5 experts	questionnaire and discussion	2 (1 industry and 1 academic)	ISM MICMAC
20	[33]	Sustainability (GSCM)	20 barriers	brainstorming	5 (3 industry and 2 academic)	ISM MICMAC
21	[84]	Logistics (3rd party Reverse logistics provider)	7 attributes	consultation	information not available	ISM MICMAC
22	[66]	Tourism (Tour Value)	12 enablers	brainstorming	7 (4 industry and 3 academic)	ISM MICMAC
23	[39]	Marketing (Motivation)	17 motivations	laddering interview	52 respondents through content analysis of interviews	Content analysis ISM
24	[44]	Supplier Selection (Corporate social responsibility)	9 CSR issues	direct meetings, telephonic inquiries, and email, and questionnaire	150 firework industrial managers from SMEs and relevant field experts for variable identification	ISM MICMAC
25	[85]	Sustainability (SSCM)	25 SSCM practices	questionnaire and judgement group	45 or more survey response, consolidation judgement group of 15	ISM MICMAC
26	[10]	Sustainability (Production)	20 barriers	workshop	23 experts	ISM ANP
27	[58]	Sustainability (Green Business Model in Construction)	5 barriers	thematic analysis, semi-structured interviews	19	ISM MICMAC
28	[34]	Marketing (Retail Brand)	10 factors	brainstorming sessions	9 (4 industry and 5 academic)	ISM MICMAC
29	[86]	Sustainability (Neighborhoods)	19 barriers	interview	15 (10 industry and 5 academic) Divided into 2 nominal groups for validation	ISM MICMAC
30	[40]	Sustainability (Construction)	8 CSFs for roads and bridges, and 10 CSFs for embarkment	idea engineering workshop	3 (2 industry, 1 academia)	ISM MICMAC
31	[19]	IT (E-Commerce Security)	10 factors	13 semi structured interview	13 industry	Content analysis, ISM
32	[35]	Operations (Maintenance)	8 Maintenance tools and techniques	consultation	5	ÍSM MICMAC
33	[36]	Operations (Maintenance)	24 factors	discussion	information not available	ISM MICMAC
34	[45]	IT (ERP)	16 CSFs	face to face communication, questionnaire surveys since difficult to gather them	14 industry	ISM MICMA Fuzzy cognitive maps

Table 2. *Cont.*

S. No.	Reference	Domain (Sub-Domain)	Variables Description	Method of Decision Making	Number of Decision Makers	Techniques
35	[61]	Innovation (Manufacturing)	11 innovation enablers (competitiveness)	Delphi technique	industry and academia	ISM Fuzzy MICMAC
36	[37]	IT (Cloud)	16 CSFs	Delphi technique from 20 to 16	14 (11 industry and 3 academic)	ISM MICMAC
37	[87]	Sustainability (SSCM)	10 enablers	27 survey response followed by the telephonic interviews	27 industry survey based on Fawcett et al. (2014)	TISM MICMAC
38	[88]	HR (Team)	11 factors	expert opinions	14 (10 industry and 4 academic)	ISM
39	[89]	HR (OHSAS)	9 factors influencing safety	expert opinions	25 to 16 industry responded	ISM MICMAC
40	[90]	Sustainability (SSCM)	10 hurdles	decision team rated on 5-point Likert scale and brainstorming for SSIM	7 (4 industry, 3 academic)	ISM MICMAC
41	[91]	Energy (Solar)	16 barriers	LR and expert opinion	None	ISM Fuzzy MICMAC
42	[41]	National (National Infrastructure)	13 Indian Critical infrastructure sectors	LR, brainstorming, face to face interview	30 experts (7 academic, 13 industry, 10 gov.)	ISM MICMAC
43	[68]	Energy (Biodiesel)	5 risk factors for ISM	expert opinions through group discussions	research group of senior university professors	ISM Bayesian network
44	[92]	Sustainability (Emission trading system)	15 factors	semi structured interviews, factors selected on 4 to 3 votes, same rule of majority gives way to minority for relationship	58 to 10 to 7 experts	ISM MICMAC
45	[71]	Sustainability (Remanufacturing)	14 obstacles	consultation	industry and academia	ISM
46	[23]	SCM (SCM)	15 factors	2 brainstorming sessions and verification by recirculation of model, 179 survey response to develop correlation matrix	5 industry	ISM MICMAC
47	[46]	Manufacturing	15 factors	340 to 480 self-administered questionnaires	experts from industry and academic	questionnaire-based survey; ISM MICMAC approach; EFA; CFA and GTMA
48	[24]	SCM (Food SCM)	14 Critical causal factors	Input from experts	13 Indian academics in phase 1, 12 industry	ISM MICMAC
49	[64]	Sustainability (Production)	21 criteria	linguistic preferences and that concurrently applies perception judgment-pretesting of survey-purposive sampling method-120 replies	10 researchers then 5 researchers for pre-testing, For ISM 120 responses	fuzzy set theory and ISM
50	[25]	SCM (Food SCM)	16 causes of food wastages	Semi structured interview Brainstorming	6 (4 industry 2 academic)	TISM fuzzy MICMAC
51	[11]	Sustainability (Green IT/IS)	13 psychological drivers of motivation	Upper Echelon Theory (UET) Focus group discussions Survey for ANP	10 (2 industry 8 academic)	Hybrid ISM -ANP
52	[93]	IT (Building Information Modelling)	15 capability factors for BIM adoption	the semi-structured interviews and focus groups were conducted and LR	7 industry	ISM MICMAC
53	[69]	Sustainability (Reverse logistics)	7 grouped barriers	Phone consultation and face to face structured interview	4 (2 industry 2 academic)	ISM MICMAC

Table 2. *Cont.*

S. No.	Reference	Domain (Sub-Domain)	Variables Description	Method of Decision Making	Number of Decision Makers	Techniques
54	[65]	Sustainability (GSCM)	12 behavioral factors	Opinion of experts	15 (10 industry, 3 academic, 2 government)	ISM MICMAC
55	[70]	Sustainability (GHRM)	7 factors	Ability Motivation Opportunity theoretical lens Questionnaire and personal interview Pilot study from 97 respondents to 7 factors ISM on 7 factors SEM to validate model	11 experts listed 42 variables EFA 42 to 32 variables to 7 factors CFA 32 to 24 variables Same 11 experts for ISM	LR, expert opinion to EFA to CFA to ISM MICMAC to ISEM
56	[12]	Operations (Lean Manufacturing)	9 antecedents and critical success factors	Group discussion for ANP and pairwise comparisons, Also, for identifying 9 factors and ISM	7 industry	ANP -horizontal integration of human ISM- vertical integration of human
57	[94]	IT (SCM)	11 technological capabilities	Brainstorming	3 industry	TISM
58	[9]	Supplier relationship management (SRM)	10 factors	library survey method-questionnaire-research method in this survey is descriptive and analytical	managers and the production heads	leveling the factors using ISM model MICMAC, fuzzy TOPSIS-AHP- ranking suppliers
59	[72]	SCM (E-Procurement)	14 barriers and 15 benefits	Five-point scale survey followed by brainstorming session	8 industry for variable reduction + 4 academic for ISM	ISM SEM
60	[20]	Sustainability (SSCM)	32 CSFs of motivation and encouragement	32 CSFs were identified from LR and opinions of academicians and industry practitioners	consultation with industry experts and academic	ISM MICMAC
61	[95]	IT (Social networking sites (SNS))	12 Factors of abandoning usage of SNS	survey on 60 PG students who have abandoned the SNS at least once and validation by LR	60 students as experts	ISM MICMAC
62	[59]	Sustainability (GSCM)	19 influential factors on the implementation	LR, and invoking the contingency theory perspective to get 19 factors group discussion for ISM (4 sessions)	13 Industry	ISM MICMAC
63	[47]	Sustainability (recycling 3D printing waste)	22 barriers	Interview for identification of barriers and 3 experts consulted for relationships between barriers	13 (12 industry and 1 academic)	ISM
64	[26]	Sustainability (Green Lean Six Sigma)	12 enablers	LR, survey and expert opinion for identification of enablers	Not mentioned	ISM MICMAC
65	[21]	IT (Building Information Modelling)	12 barriers	LR and survey for identification of enablers and semi-structured interview for relationships between barriers	5 industry	ISM MICMAC
66	[22]	Sustainability (Oil and gas SSCM)	7 determinants	LR and expert opinion for identification of determinants, individual expert opinion for relationships among determinants	18 (13 industry 5 academic)	ISM MICMAC and SEM

Table 2. *Cont.*

S. No.	Reference	Domain (Sub-Domain)	Variables Description	Method of Decision Making	Number of Decision Makers	Techniques
67	[96]	IT (m-commerce)	10 barriers	LR and survey for identification of determinants, survey for relationships among determinants	Number of participants not mentioned	ISM MICMAC
68	[50]	Building energy performance	16 factors	LR and interview for identification of factors, and interview for relationships	12 industry	ISM MICMAC
69	[51]	Quality of Passenger interaction process	15 enablers	Report, passengers' opinion including authors and observations for identification of enablers, and also for relationships	Authors opinions	ISM MICMAC
70	[52]	IT (Cloud computing)	7 determinants	Content analysis on interview transcripts of 58 industry people for identification of determinants, Group discussion for relations	Not mentioned	ISM MICMAC, AHP and TOPSIS
71	[27]	SC (Lean Sis Sigma)	10 barriers	LR and 10 consultation sessions with 35 experts using brainstorming and focused group method to identify barriers and relationships	35 (industry and academic)	ISM MICMAC
72	[42]	Sustainability (CSR)	12 enablers	LR, survey and interviews for identification of enablers and experts' opinions for relationships	20 (industry and academic)	ISM MICMAC
73	[28]	Automobile (Electric Vehicle)	12 barriers	LR, expert opinion and best worst method to select barriers	10 (7 industry and 3 academic)	ISM MICMAC and Best worst method
74	[97]	Marketing (app-based retailing)	20 factors	LR and survey from expert for factors identification and relationships	33 (30 industry and 3 academic)	ISM MICMAC
75	[48]	SC (Food loss and waste)	8 factors	LR and consultation with experts for factors selection and relationships	11 (5 industry and 6 academic)	ISM MICMAC
76	[29]	New product development (time to market)	19 capabilities and 5 drivers	LR and expert interview for identification of capabilities and drivers and relationships	14 (8 industry and 6 academic)	ISM fuzzy MICMAC
77	[30]	Sustainability (Renewable energy)	13 strategies	LR and SWOT analysis for strategies identification and experts' opinion for relationships	5 (2 industry, 2 academic and 1 government)	SWOT ISM MICMAC

SC: Supply chain, SCM: SC management, SSCM: Sustainable SCM, GSCM: Green SCM, SRM: Supplier relationship management, OSH: Occupational safety and health, IT: Information technology, IS: Information Systems, ERP: Enterprise resource planning, HR: Human resources, GHRM: Green HR Management, OHSAS: Occupational health and safety assessment series, NGO: Non-governmental organization, SME: Small and medium scale enterprises, ISM: Interpretive structural modelling, SSIM: Structural self-interaction matrix, AHP: Analytical hierarchy process, ANP: Analytic network process, TOPSIS: Technique for order of preference by similarity to ideal solution, LR: Literature review, CSF: Critical success factors, SEM: Structural equation modeling, EFA: Exploratory factor analysis, CFA: Confirmatory factor analysis; CSR: Corporate social responsibility; SWOT: Strengths, weaknesses, opportunities, and threats.

Table 3. Assessment of application of ISM using Smart ISM.

S. No.	References	SSIM	RM	FRM	Partitioning	Transitivity	Digraph	Model	Edges	MICMAC	Remarks
1	[43]	Y	Y	Y	Y	2nd Level	N	Y	Varied	Y	Added extra edge from variable 4 to variable 5
2	[15]	N	N	N	N	N	N	N	N	N	No SSIM
3	[49]	Y	Y	Y	Y	2nd Level	N	Y	Varied	Y	Some edges are missed such as between variable 9 and variable 1
4 *	[78]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
5	[16]	Y	Y	N	N	N	N	N	N	Y	Wrong calculation for transitivity
6	[13]	Y	Y	N	N	No Level	N	N	N	Y	Transitivity not incorporated though mentioned in the methodology
7	[14]	Y	Y	Y	Y	2nd Level	N	Y	Varied	Y	Added extra edge from R to I
8 *	[60]	Y	Y	Y	Y	All Levels	N	Y	Y	Y	
9	[38]	Y	Y	Y	N	2nd Level	N	N	Y	Y	At 8th level one variable is wrong in model
10	[31]	Y	Y	N	N	No Level	N	N	N	N	Didn't incorporate transitivity though the concept is mentioned
11 *	[79]	Y	Y	Y	Y	All Levels	N	Y	Y	Y	
12	[32]	Y	Y	N	N	All Levels	N	N	N	N	Wrong calculation for transitivity, only two transitive links but shown more
13 *	[80]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	No transitive links
14 *	[81]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
15 *	[82]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	Retained some transitive links in the model
16 *	[62]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
17 *	[77]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
18 *	[83]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	Model upside down
19 *	[63]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
20	[33]	Y	Y	N	N	N	N	N	N	Y	Wrong calculation for transitivity and for generalized transitivity; all will be having same dependence and driving powers with max value
21 *	[84]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	MICMAC axis interchanged and for generalized transitivity all will be having same dependence and driving powers with max value
22	[66]	N	N	N	N	N	N	N	N	N	No SSIM and directly starts with RM
23	[39]	Y	Y	Y	N	All Levels	N	N	N	N	No MICMAC
24	[44]	Y	Y	Y	Y	2nd Level	N	Y	Varied	Y	Added extra edge from variable 6 to variable 9
25 *	[85]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
26 *	[10]	Y	Y	Y	Y	2nd Level	N	Y	Y	N	B2 element wrong on MICMAC
27 *	[58]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	
28	[34]	Y	Y	N	N	N	N	N	N	N	RM and FRM together, one transitive link skipped between elements EM and BN
29 *	[86]	Y	Y	Y	Y	All Levels	N	Y	Y	Y	
30	[40]	Y	Y	Y	N	2nd Level	N	N	N	N	Wrong leveling, one element missing on MICMAC
31	[19]	Y	N	N	N	2nd Level	N	N	N	N	No MICMAC, one extra wrong self-relation
32	[35]	Y	Y	N	N	No Level	Y	N	N	N	Transitivity not incorporated though mentioned in the methodology, non-standard relation symbols in SSIM such as F, R, FR, and X
33	[36]	Y	Y	N	N	2nd Level	N	N	N	N	Wrong transitivity calculation
34	[45]	Y	Y	Y	Y	All Levels	N	Y	Varied	Y	Added wrong edges for F12 and F15
35 *	[61]	Y	Y	Y	Y	2nd Level	N	Y	Y	Y	No transitivity relations found
36	[37]	Y	Y	N	N	2nd Level	Y	N	N	N	Wrong transitivity calculation
37 *	[87]	Y	Y	N	Y	2nd Level	N	Y	Y	N	Skipped one transitive relation between 8 and 9, same results for second-order and generalized transitivity
38 *	[88]	Y	Y	N	Y	No Level	N	Y	Y	Y	Transitivity mentioned but not included; rest of all the things correct
39	[89]	Y	N	N	N	2nd Level	N	N	N	N	Wrong transitivity calculation
40 *	[90]	Y	Y	Y	Y	All Levels	N	Y	Y	Y	Same results for second-order and generalized transitivity
41 *	[91]	Y	Y	Y	Y	All Levels	N	Y	Y	Y	
42	[41]	Y	Y	Y	N	2nd Level	N	N	N	Y	No transitive links
43 *	[68]	Y	Y	N	Y	2nd Level	Y	Y	Y	N	
44	[92]	N	N	N	N	N	N	N	N	N	Non-standard SSIM
45 *	[71]	Y	Y	N	Y	No Level	N	Y	Y	N	Transitivity not calculated and no MICMAC
46	[23]	Y	Y	N	N	2nd Level	N	N	N	N	

Table 3. *Cont.*

S. No.	References	SSIM	RM	FRM	Partitioning	Transitivity	Digraph	Model	Edges	MICMAC	Remarks
47	[46]	Y	Y	Y	Y	2nd Level	N	Y	Varied	Y	Extra edges added
48	[24]	Y	Y	N	N	2nd Level	N	N	N	N	
49	[64]	N	N	N	N	N	N	N	N	N	Non-standard SSIM, fuzzy ISM
50	[25]	Y	Y	N	N	2nd Level	N	N	N	N	TISM
51	[11]	Y	Y	Y	Y	2nd Level	N	Y	Varied	N	One extra edge, MICMAC calculation is correct but drawn wrong
52	[93]	Y	N	N	N	2nd Level	N	N	N	N	For self-relation X shown in SSIM whereas RM and FRM not given
53 *	[69]	Y	Y	Y	Y	2nd Level	Y	Y	Y	Y	
54 *	[65]	Y	Y	Y	Y	2nd Level	Y	Y	Y	Y	For self-relation X shown in SSIM
55 *	[70]	Y	Y	Y	Y	No Level	Y	Y	Y	Y	Transitivity not included
56 *	[12]	Y	Y	Y	Y	2nd Level	Y	Y	Y	Y	
57	[94]	N	N	N	N	N	N	N	N	N	Non-standard SSIM
58	[9]	Y	Y	N	N	2nd Level	N	N	N	N	Many mistakes in transitivity calculation
59	[72]	Y	Y	Y	Y	2nd Level	N	N	N	N	No MICMAC, extra edges
60	[20]	Y	N	N	N	2nd Level	N	N	N	N	RM onwards wrong calculations
61 *	[95]	Y	Y	Y	Y	All Levels	N	Y	Y	N	MICMAC explained in detail
62	[59]	Y	N	N	N	2nd Level	N	N	N	N	Partitioning in simulation didn't give levels, for self-relation X shown in SSIM
63	[47]	Y	Y	Y	Y	2nd Level	N	Y	Varied	N	Some extra edges drawn in final model, no MICMAC
64	[26]	Y	Y	N	N	N	N	N	N	N	Wrong transitivity calculations
65	[21]	Y	N	N	N	All Levels	N	N	N	N	Non-standard SSIM, wrong conversion for relationship between elements B10 and B08 in RM
66	[22]	Y	N	N	Y	All Levels	N	Y	Y	N	in SSIM for CGLC, self-influence is considered wrong and assigned 0
67 *	[96]	Y	Y	Y	Y	2nd Level	N	Y	N	Y	Digraph is not mentioned
68	[50]	N	N	Y	Y	All levels	N	Y	Varied	Y	Adjacency matrix to represent RM, one edge F6 to F1 from adjacency matrix is not drawn
69	[51]	Y	Y	Y	Y	All Levels	N	Y	Varied	Y	Some edges are missed such as between NWFOB and AEPE
70	[52]	Y	Y	N	Y	No Level	N	Y	Varied	Y	1 in SSIM for self-relation, transitivity not included although concept is discussed; some reachability edges missed such as C6 to C1
71	[27]	Y	Y	N	Y	2nd Level	Y	Y	Y	N	5 transitive links missing in 2nd level transitivity and 6 missing from all levels
72	[42]	Y	Y	Y	N	2nd Level	N	N	N	Y	First partitioning iteration is wrong and incorrectly assigns level 1 to E4
73	[28]	Y	Y	N	Y	All levels	N	Y	N	N	One transitive link between B1 and B12 is missed out; B1 is wrongly placed in MICMAC diagram
74 *	[97]	Y	Y	N	Y	No Level	N	Y	Y	N	All 3 transitive links missing, although the concept is mentioned; Wrong MICMAC
75	[48]	Y	Y	Y	Y	All levels	N	Y	Varied	Y	One extra edge between F1 and F4 that changes the reachability
76	[29]	Y	Y	N	N	2nd Level	N	N	N	N	X for self-relation in SSIM, missing transitive link between T14 and T19, self-interaction between for T17 missing, Wrong transitive link given between T19 and T6
77	[30]	Y	Y	N	N	All Levels	N	N	N	N	Many mistakes in transitivity calculations such as between S5 and S13

* All SmartISM reproduced results similar to articles' ISM process results with varied transitivity considerations. Y: SmartISM reproduced results similar to articles' ISM process results, N: SmartISM reproduced results not similar to articles' ISM process results, Varied: edges in the final model varied, although the hierarchical structure of variables may or may not be correct. ISM: Interpretive structural modelling, TISM: Total ISM, SSIM: Structural self-interaction matrix, RM: Reachability Matrix, FRM: Final RM, MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (cross-impact matrix multiplication applied to classification)). Some variables code such as B2, EM, and BN have been given in the table for their description, refer to the articles. Symbol X in SSIM means both variables mutually influence each other.

5.1. Domain of Study

ISM is being applied in numerous fields such as sustainability, social sciences, management, engineering, and information technology. The results show 21 different domains, with highest studies in sustainability (32), supply chain and logistics (13), information technology (9), energy (5), human resource (3), marketing (3), and operations (3) (Table 2). Within sustainability, the highest studies are in the area of green supply chain management (GSCM) and sustainable supply chain management (SSCM) with seven studies each followed by two studies in construction [40,58] and several other areas such as e-waste recycling [16], healthcare waste [13], recycling 3D printing waste [47], green IT/IS [11], among others. In the area of supply chain and logistics, studies have focused on supplier relationship [9] and selection [44], food SCM [24,25], e-procurement [72], and reverse logistics [14,62,84], among others. In the field of information technology studies are conducted in the areas of building information modeling [21,93], cloud computing [37,52], e-commerce security [19], m-commerce [96], enterprise resource planning [45], supply chain management [94], and social networking sites [95]. Energy domain studies were in the area of bio-diesel [68], smart grid technologies [60], and solar energy [79]. For the human resource domain, two studies were in the area of occupational health and safety [83,89] and one in team performance [88]. The studies in the marketing area focused on motivation [39], retail brand [39], and app-based retailing [97]. Furthermore, the articles in the area of operations focused on maintenance [35,36] and lean manufacturing [12]. Some of the innovative areas were landfill communities [31], emission trading system [92], tour value [66], and quality of passenger interaction process [51].

5.2. Variables of Study

Most studies focus on enablers or drivers, challenges or barriers, critical success factors, and influencing or significant elements in the domain of research (Table 2). Other studies have tried to explore different sets of variables. For example, article [84] has studied seven attributes of third party reverse logistics; article [39] has studied 17 motivational factors in the marketing area; article [44] has used 9 corporate social responsibility factors in the area supplier selection; article [85] has studied 25 SSCM practices; article [35] interrelated maintenance tools and technique; article [11] explored 13 psychological drivers of motivation in the area of green IT/IS; article [95] studied the interrelationships between 12 factors for abandoning social networking sites; article [29] studied capabilities and drivers for new product development; and article [30] studied 13 strategies for renewable energy. The number of variables being studied ranged from 5 [58] to 32 [20]. Additionally, some studies explored two types of factors such as 10 barriers and 10 enablers [15] and 14 barriers and 15 benefits [72]. One study gave variables in two applications such as 8 CSFs for roads and bridges and 10 CSFs for embarkment [40]. These variables are identified mostly through literature review, experts' opinions, and/or survey. Some of the unique approaches used to identify variables are thematic analysis [58], upper echelon theory [11], contingency theory [59], content analysis [52], best worst method [28], SWOT (strength, weakness, opportunity, and threat) analysis [30], idea engineering workshop [40,60], and Delphi technique [37,61].

5.3. Domain Experts or Decision Makers

This is the most crucial step as it provides the input for further steps. There are two important aspects, namely, selection of decision makers (DM) and method of information gathering from them. There are three different sets of DMs in the sample studies participants from industry, academia, and government. Participants varied from 120 through survey [64] to 2 [62,63] through group discussion and consultation. The median value of the total number of participants was 10. Only four studies [16,30,41,65] had taken participants from all three sectors: industry, academia, and government. While 56 studies had DMs from industry including others and two studies [51,72] had only academic DMs, 17 studies didn't mention the number of DMs.

5.4. Decision Making and Data Collection Techniques

There are two approaches followed for decision making, namely, discourse and survey. For discourse many techniques have adopted such as idea engineering workshops [40,60], telephonic enquiries [43,44], group decision making [13,52], personal interview [70,78], brainstorming [16,33,34,66], laddering interview [39], direct meetings [44], semi-structured interview [21,58,93] and structured interview [69], Delphi technique [37,61], and focus group discussion [11,27]. Similarly, for surveys different techniques are as follows: individual and consensus questionnaire [43], Likert scale questionnaire [78,90], email questionnaire [44], library survey method [9], and self-administered questionnaire [46].

5.5. Assessment of Application of ISM Technique Using SmartISM

The SSIM matrices from all the 77 articles were entered into the developed SmartISM software and resulted in 77 excel files. Thereafter, for each article results were reproduced in the SmartISM software buy running the macros in 77 excel files. Variations between the reported results in the articles and corresponding SmartISM reproduced results were studied. Due to differences in transitivity incorporation FRM was checked for firstly non-incorporation of transitivity, followed by two-hop transitivity (second-order) and lastly generalized transitivity (all levels). In some cases, second order and generalized transitivity could be same. Furthermore, in case of inconsistency the digraph was manually built and transitivity was traced before reporting the results. Similarly, the complete process was analyzed to identify the reasons for the errors in any of the steps. As ISM technique is sequential, error in one step will cause subsequent steps to be erroneous specially if error exists in the steps of RM, FRM, and level partitioning.

The results of the assessments are summarized in Table 3 where 'Y' means the articles' calculations match with that of SmartISM and 'N' means different results. For each article SSIM, RM, FRM, level partitioning, digraph, final model, edges in the final model, and MICMAC diagrams are verified. Three studies [64,92,94] didn't report standard SSIM and two studies [15,66] had no SSIM, therefore results were not reproduced for them. Out of 72 remaining studies, 29 studies came out correct on all the parameters and their serial numbers (S. No.) are marked with stars '*'. Of these 29 studies, 25 had either second level (two-hop or second-order transitivity) or all levels (generalized transitivity), and four [70,71,88,97] had no transitivity calculations.

The remaining 43 studies with different results from the SmartISM outputs were further analyzed starting from first the step of SSIM and moving on until the variations were identified. One study [19] had one wrong self-relation in RM. Three studies [20–22] had incorrect RM and one article [93] did not provide RM and FRM. Two studies [59,89] didn't provide RM, and their FRM didn't match with the SmartISM output due to wrong transitivity calculations. Furthermore, eighteen studies [9,13,16,23–37] had incorrect transitivity calculations leading to variations in FRM. Five studies [38–42] had variations at the fourth step of level partitioning. One study [31] was checked for level partitioning without transitivity as it was not considered, and came out wrong in assigning levels to variables. Finally, 12 studies had accurate hierarchical structures of variables in the final ISM model but variations in the edges that distorted the reachability of variables. Of these 12 studies, eight studies [11,14,43–48] had some extra edges and four studies [49–52] had some missing edges in the final model.

In the documentation of application of ISM, only eight studies [12,20,27,35,65,68–70] reported digraph. MICMAC analysis has been used by all studies except five [19,39,47,71,72] to explain grouping of the variables. Five studies [27,29,59,65,93] have explicitly mentioned X and one study [52] has mentioned 1 in the SSIM for variables to represent mutual self-relation, although it is a basic assumption in ISM therefore, other studies have not mentioned it.

6. Discussion

The operationalization of the ISM is best to be conducted through software, as there are tedious calculations such as transitivity, level partitioning, and graphical displays of digraph, final ISM model, and MICMAC diagram. Moreover, these calculations and displays need to be iterated until the high confidence model is approved by the experts. Therefore, this study has explained the methodology to develop MS Excel and VBA based, end-to-end software, SmartISM for ISM and MICMAC with the help of pseudo codes. For incorporating transitivity in FRM, the Warshall algorithm has been used, and a new algorithm RCM has been introduced for removing edges from variables' second lower level onwards without affecting reachability and digraph structure. Further, the demonstration video of SmartISM has been added as a Supplementary Material, and this tool has been extensively tested on the existing studies and applied successfully in some of the studies [98–100].

Furthermore, the scoping review shows that the ISM and MICMAC techniques are being applied in different domains of social sciences, management, engineering, and technology such as sustainability, SCM, operations, manufacturing, human resource, information technology, and many other innovative areas. This technique is also employed in different multi criteria decision making techniques such as AHP, ANP, TOPSIS, DEMATEL, etc. There are four important issues that need to be addressed such as variables and their context, decision makers' experience and numbers, decision making and data collection techniques, and utilization of software tools. The nature of variables has been enablers or drivers, challenges or barriers, critical success factors, strategies, capabilities and drivers, and influencing or significant elements in the area of study. Their numbers have varied from 5 to 32 and they have been identified through domain specific literature review, experts' opinions, and/or survey. Furthermore, techniques such as thematic analysis, upper echelon theory, contingency theory, content analysis, best worst method, SWOT analysis, idea engineering workshop, and Delphi technique are used for variables' identification. Similarly, the variables have been explained well to establish the contextual meaning.

Another important aspect is the experts or decision makers, as the whole analysis is dependent upon their knowledge and experience. There should be representation from all stakeholders of the domain being studied. In the best-case, experts from academia, industry, government and regulatory bodies should be selected in the panel of DMs. There are very few studies such as four in the sample of articles that have had DMs from all the stakeholders. The number of DMs varied from 2 to 120, whereas in most of the studies they were 11. Two approaches have been utilized for extracting information from DMs namely discourse and surveys. The discourse techniques are idea engineering workshops, telephonic enquiries, group decision making, personal interview, brainstorming, laddering interview, direct meetings, semi-structured and structured interview, Delphi technique, and focus group discussion. Survey techniques have used individual and consensus questionnaires, Likert scale questionnaire, email questionnaire, library survey method, and self-administered questionnaire.

The SmartISM reproduced results, on the existing studies selected in scoping review, show that only 29 out of 77 studies had correct calculations with varied transitivity incorporation such as no transitivity, second order transitivity, or generalized transitivity. Wrong transitivity calculation has been the most frequent reason for incorrect ISM results followed by variations in drawing edges in the final model that affects the reachability of the variables.

Lastly, five studies didn't report standard SSIM, which is essential to reproduce the calculations. Therefore, as a standard practice some minimum outputs must be reported namely SSIM, FRM, level partitioning (final after all iterations), and final ISM model. Similarly, MICMAC analysis is also an important and indispensable part of ISM, as all studies except five have used it for classifying variables into one of the four groups, namely, dependent, independent, linkage, and autonomous.

7. Conclusions

Human decisions play a very important role in any social or technical system development. Domain experts have intricate knowledge on the system and can predict the contextual interrelationships between the variables of interest in the particular domain. The interpretive structural modelling technique can assemble their tacit knowledge into a tangible hierarchical model leading to an enhanced understanding of the subject. This study has developed a software tool such as SmartISM to implement ISM in an error-free, user-friendly, and graphical style. In addition to automation of existing routines of ISM, the Warshall algorithm is used for transitivity calculations and a new algorithm, reduced conical matrix, has been introduced to convert the digraph into a final model with lesser edges while retaining the digraph structure and reachability of variables. Furthermore, the scoping review of this research will guide practitioners, policy makers, and academicians in applying this technique in different disciplines in an informed way. It will help in managing ISM configuration settings such as variables' selection, composition of decision makers, decision making, and data collection techniques. The poor results of assessment of application of ISM technique in the previous studies necessitate the utilization of an end-to-end software, such as SmartISM, to produce a high confidence final model, explaining the interrelationships between important constructs in the applied domain. To limit the number of articles in the review process only the ScienceDirect database was used, and for the last four years articles were randomly selected; therefore, results should be interpreted accordingly. The future studies will focus on the development of software tools to apply ISM in conjunction with other MCDM techniques such as AHP, ANP, TOPSIS, and DEMATEL.

Supplementary Materials: The following is available online at https://www.mdpi.com/article/10.3390/su13168801/s1, Video S1: The SmartISM software demonstration.

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