

Total Interpretive Structural Modeling (TISM) of the Enablers of a Flexible Control System for Industry

B. Jayalakshmi · V. R. Pramod

Received: 3 March 2014 / Accepted: 21 September 2014 / Published online: 25 October 2014
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Abstract *The incumbent trend in process industry is to deploy information and communication technology (ICT), enabled wired process control systems. Distributed control system, supervisory control and data acquisition systems with wireless open loop control systems are commonly used to facilitate the same. However, wireless closed loop control system is a flexible system, which is not yet been introduced in the process industry. The major theme of this research work is to model the enablers of implementing ICT enabled control system in the process industry based on their interrelationships, with the help of industrialists in an oil refinery in central Kerala. The relationships of enablers have been established effectively by interpretive structural modeling (ISM). However, the interpretation of links is comparatively weak in ISM. Qualitative criteria are often accompanied by obscurities and vagueness. To compensate for this, ISM is further modified by total ISM (TISM). TISM is a novel qualitative modeling technique that has been used by researchers in diverse fields of investigation. For this study, TISM is used to develop the performance model for the enablers of a flexible control system for industry. The structural model developed using this methodology helps to understand the interaction between the various elements of*

enablers. After the model is developed, it is further subjected to assessment by a different group of domain experts so as to enhance its validity.

Keywords Enablers · Flexible control system · ICT · Interpretive logic-knowledge base · Interaction matrix · TISM

Introduction

Current researchers and practitioners are extremely fascinated by the adoption of information and communication technology (ICT) as it will be highly beneficial (Hollenstein 2004) to all fields of business. Analysis of composite project management can be efficiently done with the help of project management services (Stoshikj et al. 2014). Existing IT service quality measurement framework is refined for the IT service industry (Lepmets et al. 2014). In continuation of this, the field of education is significantly improved due to the adoption of ICT. Recent trend in education is to implement different types of educational programs using ICT (Bidarian and Davoudi 2011). While peeping into the world of literature, a plethora of research can be witnessed in internet based control systems accessing data wirelessly from a remotely located process. Monitoring and controlling of such systems are done by using wireless and internet communications technologies (Thompson 2004). The rising reliance of businesses over information and information usage with ICT tools and mediums, have formed an inevitable requirement of information security in organizations (Singh et al. 2013). Some multiplicity aspects together with geographic remoteness and cultural differences impact the success of ICT projects (Bohm 2013).

B. Jayalakshmi
Mechanical Engineering Department, Karpagam University,
Coimbatore, Tamil Nadu, India

B. Jayalakshmi (✉)
I C E Dept, NSS College of Engineering, Palakkad, Kerala, India
e-mail: b_jayahari@yahoo.com

V. R. Pramod
Mechanical Department, NSS College of Engineering, Palakkad,
Kerala, India
e-mail: pramodram68@yahoo.com



A wireless communication system is a flexible system and has a number of advantages; besides the mobility of the devices within the environment. Adding a communication device to the system or removing one from it without any disruption to the remainder of the system is cakewalk. Keeping apart the initial outlay on setting up the cell sites, the cost of running and maintaining a radio based communication system is minimal. These coupled with other factors prove the demand for a radio communication system in the office environment. Being a public frequency network, wireless interface is extremely risky for official private information. As the number of users utilizing the same frequency increase, the rapidity and the feasibility of the wireless signals decline. The shortcomings of the aforesaid wireless network can be overcome to a great extent by using high speed point-to-point wireless networking and wireless backhaul. Point-to-point wireless networking uses series topology instead of mesh, which increases the radial distance coverage and removes geographical barriers. This network, being an invisible one is not easily hindered and an alternate solution helps to restore the connectivity in the event of any interruption. Wireless backhaul is an economic connection, which can handle a huge amount of data uploading, and downloading in a blink of an eye (<http://freewimaxinfo.com/point-to-point-wireless-networks.html>, 15th January 2014).

Only a few researches have been reported in emerging systematic design methods using this technology or in designing ICT enabled process control systems. Several open loop wireless control systems such as wireless transmitter and ICT enabled control valves are available in the process industry. Nevertheless, owing to security issues, industrialists have not dared to implement these innovative methods for a closed loop system till date even on a trial basis. This provides the motivation for this study.

The objectives of the study are

- To identify the elements of the enablers of wireless control system for oil refinery.
- To develop total interpretive structural model for the enablers of wireless control system for the case organization.

Interpretive Structural Modeling (ISM) and Total ISM (TISM) Methodologies

The interrelationships among the various elements and their degree of association can be effectively assessed by ISM. ISM is used to translate vague and inadequately articulated rational models of systems into visible, well-defined models (Sushil 2012). It is used to determine the most prominent knowledge sharing barriers that deserve

serious consideration (Sharma et al. 2012). Based on correlation, an overall configuration is hauling out from the complex set of variables (Mandal and Deshmukh 1994; Thakkar et al. 2007; Warfield 1974a, b; Faizal et al. 2006). ISM is effectively used to determine the critical success factors of R&D performance in Indian manufacturing firms (Tripathy et al. 2013). In an ISM, the interpretation of the digraph is done at two levels, i.e., at the nodes and at the links. Though an ISM interprets the nodes by defining the elements representing it, the interpretation of links provided is comparatively weak. The links simply indicate the contextual relationship between the elements in terms of the direction of relationship in a paired comparison. The causal thinking behind the directed link in terms of how it operates remains implicit as it is neither captured nor represented in the ISM.

In the ISM of enablers of wireless control system, the contextual relationship between the elements is clarified. However, the interpretation and logic behind the interrelationship between the elements of enablers are not elucidated. Most important enablers can be selected only by knowing the exact meaning of the relationship between elements. An ISM interprets the association in terms of the contextual relationship between each pair of elements, and the direction of their relationship. There is a requirement to interpret the relationship further in terms of causal thinking behind the associations which can be accomplished with the help of TISM. In TISM technique, the limitation of ISM is tackled by using the tool of interpretive matrix (Sushil 2005a) where the causal thinking is captured at the time of collecting data from the experts and is made explicit in the matrix. The model case study reported in the present work details the application of TISM model for the enablers in the implementation of a flexible control of plant using ICT. After the model is developed, it is further subjected to assessment by a different group of domain experts so as to enhance its validity.

For the development of TISM model, brainstorming sessions were conducted with the top and senior level managers of an oil refinery where the case study was conducted and these suggestions were analyzed to identify the elements of enablers. The TISM (Sushil 2012) is a pioneering extension of ISM that is used to develop a hierarchical structure of the set of variables of interest. The TISM developed a directed graph for the complex system amongst the set of variables, which helps transform poorly articulated mental models into a systematic form that can be used for many interpretations. This is an innovative qualitative modeling technique that has been used by researchers in various fields of investigation (Nasim 2011; Prasad and Suri 2011; Wasuja et al. 2012; Srivastava and Sushil 2013; Dubey and Ali 2014).

As in the case of ISM, reachability matrix and its partitions are adopted to develop the TISM model. The steps of the basic process of TISM are briefly outlined as follows.

Step I *Identify and define elements.* The first step in TISM modeling is to identify and define the elements whose relationships are to be modeled. The elements for modeling in the study are enablers related to the implementation of wireless control in industry and are identified through interviews with experts in an oil refinery.

Step II *Define contextual relationship.* To develop the configuration, it is essential to define the contextual relationship between the variables of interest. Here, the contextual relationship identified between the elements of enablers is “enabler A will influence or enhance enabler B”. An example may be “enhanced efficiency will influence or enhance ease of maintenance”.

Step III *Interpretation of relationship.* Traditional ISM seeks an interpretation of the relationship between the variables of interest, but remains almost silent to interpret how that relationship really works. However, in TISM, clarification of the interpretation is also available. In the context of this study, the interpretation will be “In what way enabler A will influence or enhance enabler B?” (Table 1). It will help achieve in-depth knowledge.

Step IV *Interpretive logic of pair-wise comparison.* An “Interpretive Logic - Knowledge Base” can be created for pair-wise comparison of the elements of enablers. In this, the i th element is compared independently to all the elements from $(i - 1)$ th to the n th element. If there are n elements, there will be all $n(n - 1)/2$ paired comparisons. Since each pair of elements (i, j) may have two possible directional links $(i - j)$ or $(j - i)$, there will be in all $n(n - 1)$ rows in the knowledge base. For each $(i - j)$ link the entry code could be “Yes”(Y) or “No”(N) and if it is “Yes”, then further interpretation is necessary. The interpretive logic-knowledge base for enablers is illustrated in Appendix I (Table 6). The total number of pair-wise comparisons is $11 * 10/2 = 55$ and total number of rows is $11 * 10 = 110$ for the knowledge base (Sandbhor and Botre 2014).

Step V *Reachability matrix and transitivity check.* The reachability matrix for the enterprise perspective is prepared and the entries 1 for Y and 0 for N from the interpretive logic-knowledge base. The matrix is checked for the transitivity rule (if A–B and B–C, then A–C). For each transitive link, the knowledge base is restructured as Y, and in the

interpretation column, ‘transitive’ is entered. If there is a significant interpretation available, it is written along with the ‘transitive’ entry.

Step VI *Level partition on reachability matrix.* The level partition is carried out, similar to ISM, to understand the placement of elements level-wise (Warfield 1974b; Saxena et al. 2006). The reachability, antecedent and intersection sets for all the elements are determined and arranged in a table. The elements in the top level of the hierarchy will not reach any elements above their own level. As a result, the reachability set for a top level element will consist of the element itself; and any other element within the same level which the element may reach whereas, the antecedent set consists of a group of enablers itself and other enablers, which may help achieving it. Therefore, intersection of the reachability set and the antecedent set will be the same as the reachability set if the element is at the top level. The top level elements satisfying the above condition should be removed from the element set and the same procedure is repeated iteratively till all the levels are determined. These levels are exploited for the formation of digraph and the TISM model.

Step VII *Developing digraph.* The elements are arranged graphically in levels and the directed links are drawn as per the relationships shown in the reachability matrix. Digraph or the directed graph, illustrates the relationship between the elements of enablers as per the numbers assigned to them. Relationship between elements j and i can be represented by an arrow which points from i to j . A simpler version of the initial digraph is obtained by eliminating the transitive relationships step-by-step by examining their interpretation from the knowledge base. Only those transitive relationships may be retained that have significant interpretation.

Step VIII *Interaction matrix.* The final digraph is translated into a binary interaction matrix form representing all the interactions by ‘1’ entry. The cells with ‘1’ entry are interpreted by selecting the pertinent interpretation from the knowledge base in the form of interpretive matrix.

Step IX *Total interpretive structural model.* The information obtained from the interaction matrix and digraph is used to derive the TISM. The nodes in the digraph are reinstated by the interpretation of elements placed in boxes. The interpretation in the cells of interpretive direct



interaction matrix is portrayed by the side of the respective links in the structural model. This leads to the formation of total interpretation of the structural model.

About the Refinery and Case Study

This study was done with the help of an oil refinery situated in, central Kerala, India. It was established in 1963. As the oil refinery is reluctant to reveal its identity, in this paper it is being referred as ABC refinery. It has a production capacity of 9.5 million metric tons per annum. The ABC refinery has presently embarking on the integrated refinery expansion project which would increase the refining capacity from 9.5 to 15.5 million metric tons. Founded as a public sector company owned by the Government of India in 1963, it was acquired by a leading private sector company in 2006, which presently owns and runs it. Fuel products of ABC refinery includes liquefied petroleum gas, naphtha, motor spirit, kerosene, aviation turbine fuel, high speed diesel, and fuel oils. The ABC refinery entered into the international petroleum business stream in January 2001. Since then, the refinery has earned the reputation as a reliable player in the international deal and the refineries fuel oil has been benchmarked in the various foreign countries fuel oil markets. The refinery has been blessed with fine scenery and the entire complex, scattering across over thousand acres has been so constructed as to merge naturally with it.

Wired systems are used for monitoring and controlling the process, thus consuming more space. The plant officials have an idea to innovate the plant to get enough space, better control and efficiency, greater flexibility and optimum plant operation. When the authors approached plant officials with their proposal, they instantly arranged for a model case study as a prerequisite for the implementation of the proposal. TISM model was used for the study. The study proposes a systematic approach that presents judgment on the best implementation strategy. To implement the project, data on user perspectives have to be generated.

Conventional control system used in the ABC oil refinery is as shown in the Fig. 1. Long cables are used for connecting controllers located in the control room and sensors placed in the field. Many wires are essential for this. Therefore, these types of control systems are limited

to a specified length of cable and are not flexible. The demerits of the wired systems can be eliminated by using a flexible wireless control system.

The following points are of utmost importance for the optimal management of the field instrumentation:

- (i) Remote access to all the parameters of the installed devices,
- (ii) Remote calibration and test,
- (iii) Automatic recording of all test results as well as storage of all the configuration data.

Wireless devices can make all these functionalities available in control room, similarly to what plant operators are used to get with wired smart devices.

In the proposed wireless control model, controller and the plant to be connected via a two-way digital communication channel of limited bandwidth. As depicted in Fig. 2, sensors are monitoring the state of a process and occasionally forward the digital measurements (S_k) to a remote controller. Based on these measurements, the remote controller computes a control signal (U_k) and sends it to the actuator over the feedback channel. Upon recovering the control signal, the actuator applies a suitable action to adjust the plant state. Consistent communication occurs only if both measurement S_k and feedback control U_k are decoded within specified time limit defined by the controller.

Rationale Behind the Selection of Case Study

Conventional control systems are used in the ABC oil refinery. Many wires are essential for this and hence it requires so much space. Addition of instruments to the system necessitates excess length of cables and more space. With the introduction of a complete wireless control system, connecting cables between instruments can be eliminated. Any number of instruments can be added to or removed from the system. Flexibility and mobility of wireless control system are very high. Because of these advantages of wireless control systems, a case study is incorporated in the said oil refinery.

Development of the Total Interpretive Structural Model

As an initial step, the general awareness of the refinery was made available through interviews to the experts in the

Fig. 1 Cable based closed loop control (prior implementation of case study)

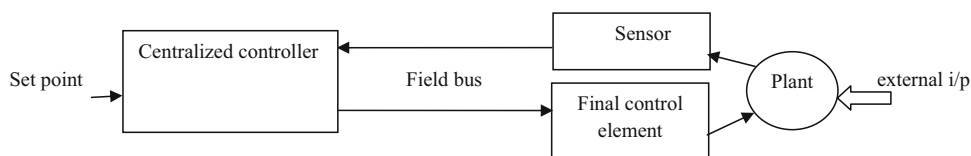
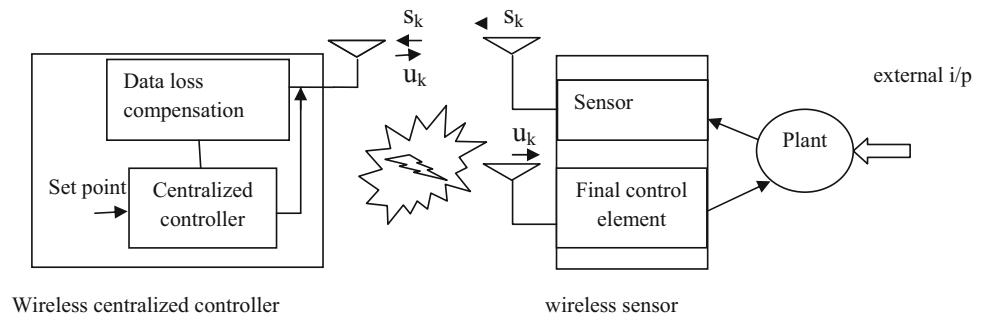


Fig. 2 Wireless closed loop control (post implementation of case study)



company. Later, data that is more relevant was collected through brainstorming in a small expert group from the industry. According to the experts in the refinery, while adopting ICT enabled wireless control system technology, many important factors also should be considered. This enabled to verbalize an initial draft of enablers for the proposed work. Five experts with rich experience and deep knowledge in the plant management were identified for the study. Enablers derived from the opinion of experts have been interrelated using TISM.

Enablers identified were as follows:

- (1) E1: free from the hassle of cables.
- (2) E2: work efficiency under harsh conditions.
- (3) E3: large scale deployment.
- (4) E4: ease of maintenance.
- (5) E5: low earth faults noise.
- (6) E6: user friendliness.
- (7) E7: fast installation and commissioning.
- (8) E8: flexibility.
- (9) E9: enhanced efficiency.
- (10) E10: suitable for areas where network is scarce.
- (11) E11: centralized monitoring.

Table 1 shows the elements, contextual relationship and interpretation for the elements of enablers of wireless control system in process industry.

The contextual relationship identified was “Enabler A will influence or enhance Enabler B.” The interpretive logic-knowledge base was developed. As there were 11 enablers, the total number of rows in the knowledge base was $11 * 10 = 110$. The authors discussed the knowledge base with the same experts and hunted their help to fill in the knowledge base. These responses were further used to develop the reachability matrix. For any pair-wise comparison, if 60 % of the responses were Y, it was taken as Y otherwise as N. All the responses for Y were analyzed in terms of the interpretations given by the experts and a combined statement integrating all responses was developed. Appendix I (Table 6) shows the interpretive logic-knowledgebase of the study.

In the second sub-step, final reachability matrix is prepared. For this purpose, the concept of transitivity is introduced so that some of the cells of the initial reachability matrix are filled by inference. Transitivity can be explained with the following example: if element ‘i’ relates to element ‘j’ and element ‘j’ relates to element ‘k’, then

Table 1 Elements, contextual relationship and interpretation for the enablers of wireless control system in process industry

Element codes	Elements	Contextual relation	Interpretation
E1	Free from the hassle of cables	Enabler A will influence/ enhance enabler B	How or in what way an enabler A will influence/enhance enabler B?
E2	Work efficiently under hazardous conditions		
E3	Large scale deployment		
E4	Ease of maintenance		
E5	Low earth faults noise		
E6	User friendly		
E7	Fast installation and commissioning		
E8	Flexibility		
E9	Enhanced efficiency		
E10	Ideal for areas where network is scarce		
E11	Centralized monitoring		



Table 2 Reachability matrix

Elements	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
E1	1	1	1	1	1	1	1	1	1	0	0
E2	0	1	1	0	0	1	0	0	1	0	0
E3	0	0	1	0	0	0	0	0	0	0	0
E4	1	0	1	1	0	1	0	1	1	0	0
E5	0	0	0	0	1	1	0	0	1	0	0
E6	0	0	0	0	0	1	0	1	1	0	0
E7	0	0	1	0	0	1	1	1	1	0	0
E8	0	0	1	0	0	1	0	1	0	0	0
E9	0	0	1	0	0	1	0	0	1	0	0
E10	0	1	1	0	0	1	0	1	1	1	0
E11	0	0	1	0	0	1	1	1	1	1	1

Table 3 Final reachability matrix with transitivity

Elements	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
E1	1	1	1	1	1	1	1	1	1	1 ^a	0
E2	0	1	1	0	0	1	0	1 ^a	1	0	0
E3	0	0	1	0	0	0	0	0	0	0	0
E4	1	0	1	1	1 ^a	1	0	1	1	1 ^a	0
E5	0	0	1 ^a	0	1	1	0	1 ^a	1	0	0
E6	0	0	1 ^a	0	0	1	0	1	1	0	0
E7	0	0	1	0	0	1	1	1	1	0	0
E8	0	1 ^a	1	0	0	1	0	1	1 ^a	0	0
E9	0	0	1	0	0	1	0	1 ^a	1	0	0
E10	1 ^a	1	1	1 ^a	1 ^a	1	1 ^a	1	1	1	0
E11	1 ^a	0	1	0	1 ^a	1	1	1	1	1	1

^a Transitive relations

Table 4 Level matrix

Enabler codes	Enablers	Levels
E1	Free from the hassle of cables	IV
E2	Work efficiently under harsh conditions	III
E3	Large scale deployment	I
E4	Ease of maintenance	IV
E5	Low earth faults noise	III
E6	User friendly	II
E7	Fast installation and commissioning	III
E8	Flexibility	II
E9	Enhanced efficiency	II
E10	Ideal for areas where network is scarce	IV
E11	Centralized monitoring	V

transitivity implies element 'i' relates to element 'k'. Transitivity is the basic assumption in ISM and is always used in this modeling approach (Farris and Sage 1975;

Sushil 2005a, b). It also helps in maintaining the conceptual consistency. Reachability matrix and the final reachability matrix with transitive links are shown in Tables 2 and 3.

The final reachability matrix consists of some entries from the pair-wise comparisons and some inferred entries. Here, while framing the correlation between various enablers transitivity is also considered. The transitivity rule states that if a variable A leads to a variable B and if B leads to another variable C, then A leads to C (Pramod and Banwet 2010). From the final reachability matrix, the reachability and antecedents of each element of enablers are developed. Reachability set consists of a group of enablers itself and other enablers, which may help to realize, whereas, the antecedent set consists of a group of enablers itself and other enablers, which may help achieving it (Attri et al. 2013; Singh and Sushil 2013). The enablers that are common in reachability set and antecedent set are assigned at the intersection set. The elements

for which reachability and intersection sets are the same occupy the topmost level group (level I group). These top level elements are removed from the set for the formation of the next table. This process is repeated till all levels of each element are found. These levels are exploited for the formation of diagraph. These subsequent iterations are shown in Appendix II (Tables 7, 8, 9, 10 and 11).

Digraph is the synonym for directed graph, which illustrates the relationship between the elements of enablers as per the numbers assigned to them. Relationship between elements j and i , can be represented by an arrow which points from i to j . Digraph with significant transitive links is shown in Fig. 3.

The final diagraph is translated into a binary interaction matrix form Appendix III (Table 12). The information obtained from the interaction matrix and diagraph is used to derive the TISM (Fig. 4).

The hierarchical structure portrayed in Fig. 4 shows that the driving force related to the implementation of wireless

control system in industry is “centralized monitoring”. “Free from the hassle of cables” is the driver, “fast installation and low earth fault noise” is the driving force. The lagging enablers are “user friendliness, flexibility, enhanced efficiency and large scale deployment”. This TISM structure clearly depicts a hierarchy with the lagging elements of enablers at the top. It is very comprehensible that for “large scale deployment” of the wireless system, the system must develop action plans for easy maintenance, to be ideal even when the network is inadequate and to be free from the disturbances of cables.

Validation of TISM

Even though a TISM model is more meaningful than an ISM, it is much more demanding in terms of time required from the experts. Experts not only need to define the

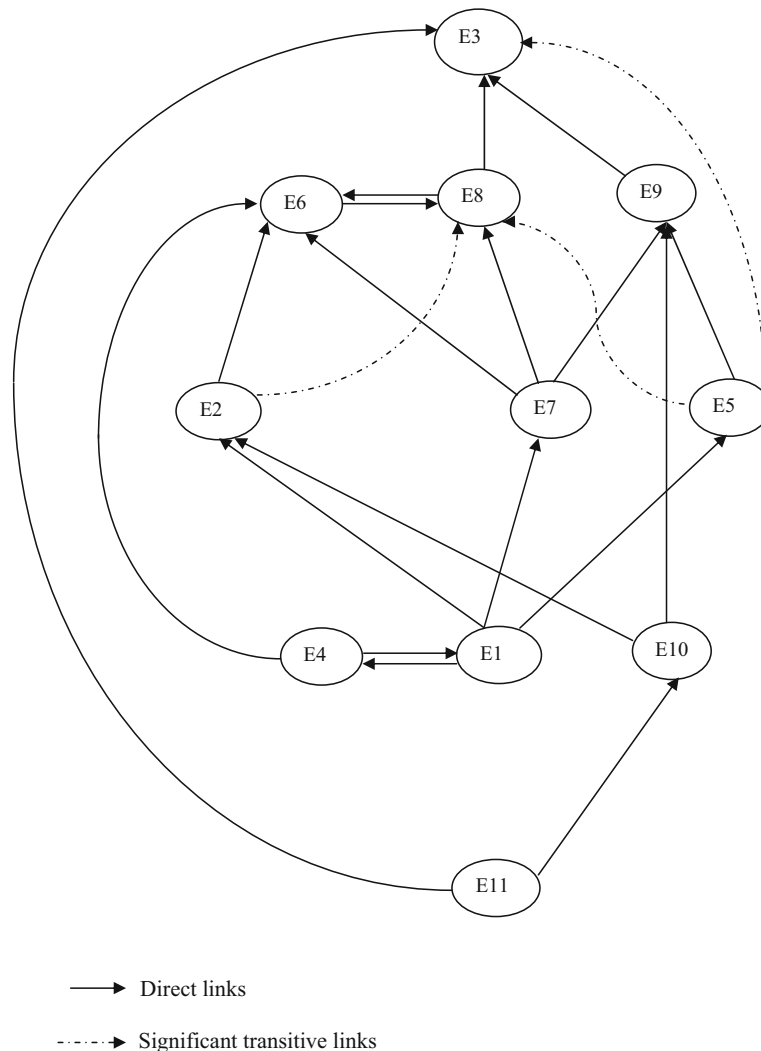


Fig. 3 Digraph with significant transitive links



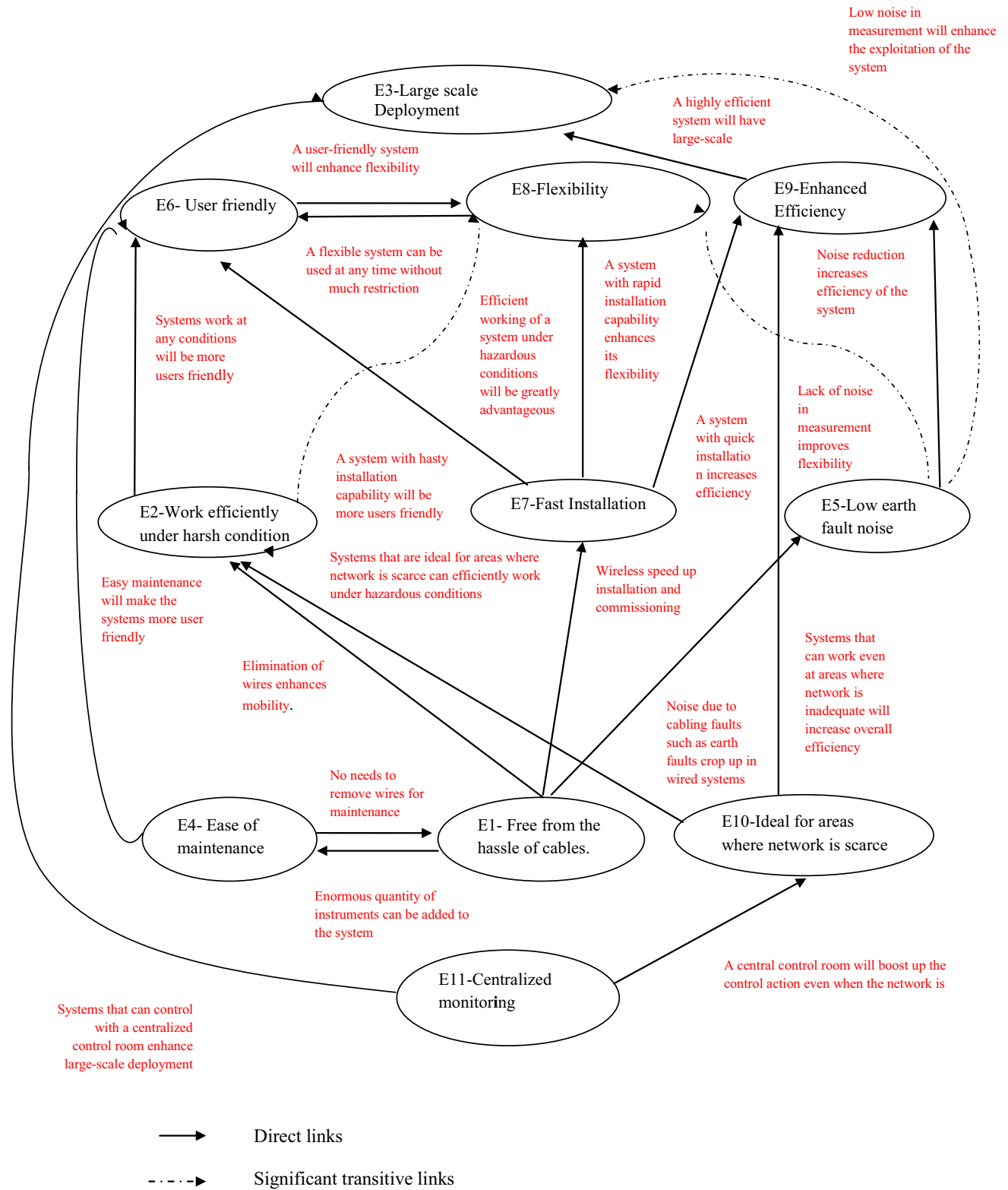


Fig. 4 TISM model

Table 5 Assessment of TISM model

	Ex 1	Ex 2	Ex 3	Ex 4	Ex 5	Ex 6	Ex 7	Ex 8	Average score for each link	Average score for the model
(1) Centralized monitoring affects/impacts ideal for areas where network is scarce	3	4	4	4	3	4	3	4	3.625	3.688
(2) Centralized monitoring affects/impacts large scale deployment	5	4	4	5	3	4	4	4	4.13	Accept the link
(3) Ideal for areas where network is scarce affects/impacts work efficiently under harsh conditions	4	3	3	2	3	4	3	3	3.13	Accept the link
(4) Ideal for areas where network is scarce affects/impacts enhanced efficiency	4	2	2	4	5	3	3	4	3.37	Accept the link
(5) Free from the hassle of cables affects/impacts work efficiently under harsh conditions	4	4	3	4	4	2	3	4	3.5	Accept the link
(6) Free from the hassle of cables affects/impacts ease of maintenance	4	4	3	4	3	3	4	4	3.63	Accept the link
(7) Free from the hassle of cables affects/impacts fast installation	5	5	4	4	5	4	4	4	4.38	Accept the link
(8) Free from the hassle of cables affects/impacts low earth fault noise	4	1	5	4	4	5	5	4	4	Accept the link
(9) Ease of maintenance affects/impacts user friendly	4	3	3	3	4	3	3	3	3.25	Accept the link
(10) Ease of maintenance affects/impacts free from the hassle of cables	2	4	2	3	3	4	4	3	3.125	Accept the link
(11) Low earth faults noise affects/impacts enhanced efficiency	4	5	4	3	5	4	4	4	4.125	Accept the link
(12) Low earth faults noise affects/impacts flexibility	3	4	4	2	3	4	4	3	3.375	Accept the link
(13) Low earth faults noise affects/impacts large scale deployment	5	5	4	4	4	4	5	4	4.375	Accept the link
(14) Fast installation affects/impacts enhanced efficiency	4	3	4	2	3	3	3	3	3.13	Accept the link
(15) Fast installation affects/impacts flexibility	3	2	2	1	3	2	3	2	2.25 ^a	Reject the link
(16) Fast installation affects/impacts user friendly	5	0	5	4	3	4	4	4	3.62	Accept the link
(17) Flexibility affects/impacts user friendly	5	5	4	5	4	4	4	3	4.25	Accept the link
(18) User friendly affects/impacts flexibility	5	4	4	5	5	4	4	5	4.5	Accept the link
(19) Work efficiently under harsh conditions affects/impacts flexibility	4	4	4	3	4	3	4	4	3.75	Accept the link
(20) Work efficiently under harsh conditions affects/impacts user friendly	5	5	4	5	4	4	4	3	4.25	Accept the link

^a Reject the link

contextual relationship among each pair of variables but are also expected to provide logic behind each response. For example, while developing the TISM model for enablers of the flexible control system, an expert had to define and provide reason for 110 [i.e., $n(n - 1)$] pairs of relationships.

‘Scarcity of time’ being a general constraint for experts across all fields, it is not easy to find enough experts to volunteer for this stage. Nevertheless, after the model is developed, it is easier to find experts to evaluate the pictographic representation (TISM) of relationships, especially since the number of valid relationships reduces. In the present study of



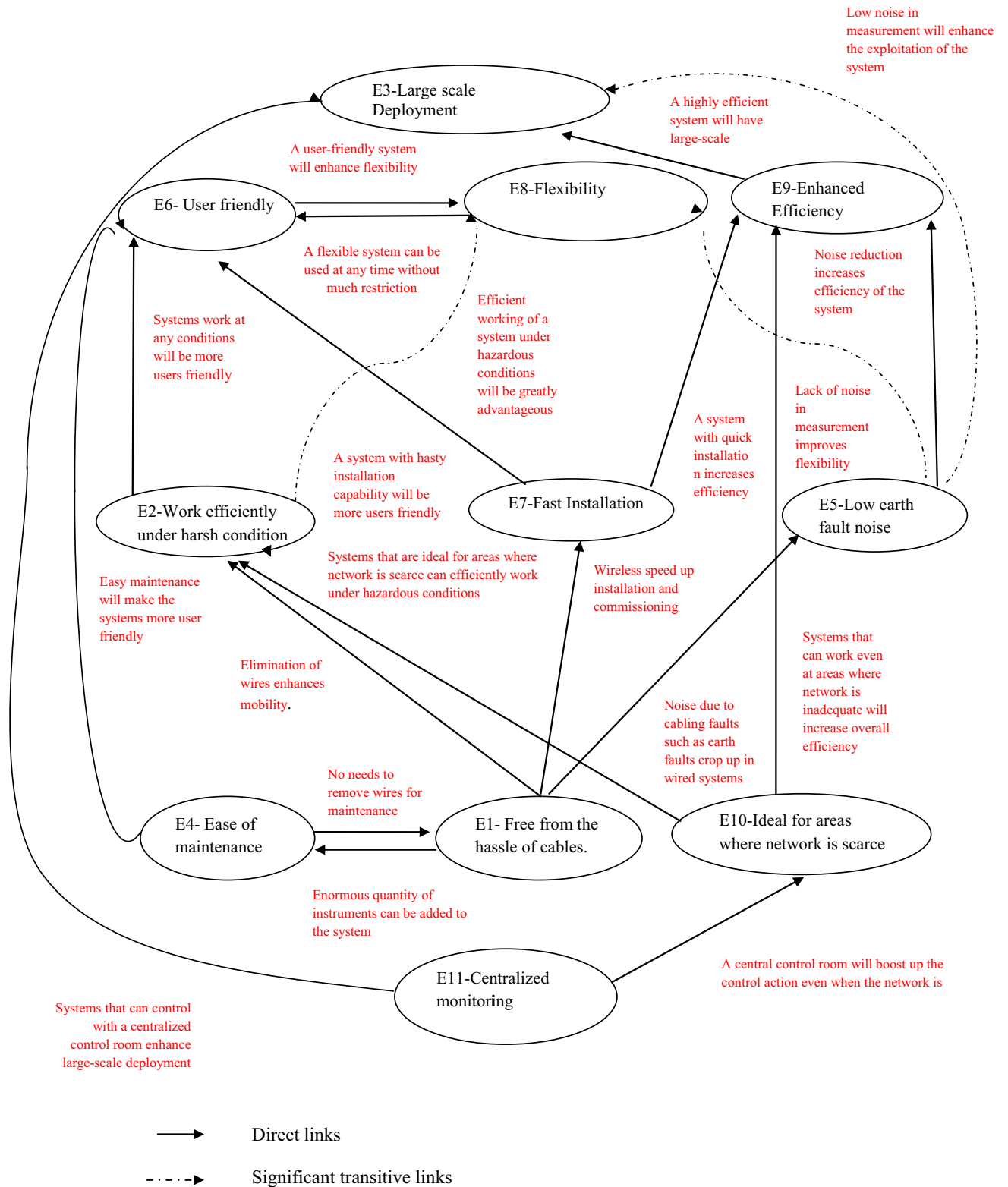


Fig. 5 Validated TISM model

enablers, the numbers of credible relationships have reduced from 110 to just 20. Thus, an evaluation of the developed TISM based model for the enablers is also introduced in this paper, as a possible solution to tackle this widespread limitation, facilitating validation of the model from a larger expert base.

Thus, for developing the initial TISM model for enablers, responses from five experts were taken. However, after the model was finally developed, feedbacks regarding the approval of the model, from eight other domain experts have been elicited using the appraisal stencil. Such an approach facilitated validation of the model from more number of domain experts, which comprised of top level officials of seven different process industries in Kerala. In this regard feedback from the eight domain experts were composed and the acceptability of the model was established on a five-point scale ranging from “strongly agree” to “strongly disagree” in relation to the linkages and reason(s) given by previous experts. Each link in the model is accepted if the average score for the model is above three and the entire model is assumed to be acceptable if the average of all the links beat the score of three (Table 5).

It is clear from the table that, all links, except link 15 were accepted and also the entire model is accepted. The rejected link is dropped from TISM model and the validated TISM model developed as shown in Fig. 5.

Conclusion

The fields of management are swarming with innumerable models and elicitations of experts. ISM is well proven to utilize the experts’ knowledge and experience (Kumar

et al. 2013). An ISM interprets the associations in terms of the contextual relationship between each pair of elements, and the direction of their relationship (Sushil 2009). However, TISM uses the implementation of an interpretive matrix, which captures the causal thinking of the experts. In this paper, the enablers for the successful implementation of a flexible control system in the industry are identified and exemplified the use of a qualitative technique (TISM) to model these for greater understanding of the interplay of these enablers. As a possible innovative step to verify and enhance the validity of the model obtained, a model assessment has been added in addition to the demonstration of using the TISM technique. In general, this methodology of the modeling technique is expected to be worthy to the researchers; and for the domain practitioners the resultant model provided insights too. In this work, 11 enablers of ICT enabled wireless control system were identified and considered for analysis. This research illustrates that the developed TISM model is acceptable. From this, the importance of implementing the flexible control systems in industrial plant is evident. Implementation of the proposed flexible control system has become a necessity for industries to survive rapid changes and fierce competition that characterizes the current global business environments. The developed TISM model and its validation done herein for the enablers of the flexible control system encourage broad scale adoption of the technology in remote monitoring and control of plants.

Appendix I



Table 6 Interpretive logic-knowledgebase

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
E1: Free from the hassle of cables				
1	E1–E2	Free from the hassle of cables will influence or enhance work efficiently under harsh conditions	Y	Elimination of wires enhances mobility
2	E2–E1	Work efficiently under harsh conditions will influence or enhance free from the hassle of cables	N	
3	E1–E3	Free from the hassle of cables will influence or enhance large scale deployment	Y	Less space requirement enhances consumption
4	E3–E1	Large scale deployment will influence or enhance free from the hassle of cables	N	
5	E1–E4	Free from the hassle of cables will influence or enhance ease of maintenance	Y	No need to remove wires for maintenance
6	E4–E1	Ease of maintenance will influence or enhance free from the hassle of cables	Y	Enormous quantity of instruments can be added to the system
7	E1–E5	Free from the hassle of cables will influence or enhance low earth faults noise	Y	Noise due to cabling faults such as earth faults crop up in wired systems
8	E5–E1	Low earth faults noise will influence or enhance free from the hassle of cables	N	
9	E1–E6	Free from the hassle of cables will influence or enhance user friendly	Y	Eliminating intricacy due to cables will make user friendly
10	E6–E1	User friendly will influence or enhance free from the hassle of cables	Y	Transitive
11	E1–E7	Free from the hassle of cables will influence or enhance fast installation and commissioning	Y	Wireless speed up installation and commissioning
12	E7–E1	Fast installation and commissioning will influence or enhance free from the hassle of cables	Y	Transitive
13	E1–E8	Free from the hassle of cables will influence or enhance flexibility	Y	Wireless systems are more flexible
14	E8–E1	Flexibility will influence or enhance free from the hassle of cables	N	
15	E1–E9	Free from the hassle of cables will influence or enhance enhanced efficiency	Y	Instruments can be added to/ removed from the system at any time will increase the efficiency
16	E9–E1	Enhanced efficiency will influence or enhance free from the hassle of cables	N	
17	E1–E10	Free from the hassle of cables will influence or enhance ideal for areas where network is scarce	Y	Transitive

Table 6 continued

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
18	E10–E1	Ideal for areas where network is scarce will influence or enhance free from the hassle of cables	Y	Transitive
19	E1–E11	Free from the hassle of cables will influence or enhance centralized monitoring	N	
20	E11–E12	Centralized monitoring will influence or enhance free from the hassle of cables	N	
E2: Work efficiently under harsh conditions				
21	E2–E3	Work efficiently under hazardous conditions will influence or enhance large-scale deployment	Y	Working even at hazardous situation will provide large scale deployment
22	E3–E2	Large-scale deployment will influence or enhance work efficiently under hazardous conditions	N	
23	E2–E4	Work efficiently under hazardous conditions will influence or enhance ease of maintenance	N	
24	E4–E2	Ease of maintenance will influence or enhance work efficiently under hazardous conditions	N	
25	E2–E5	Work efficiently under hazardous conditions will influence or enhance low earth faults noise	N	
26	E5–E2	Low earth faults noise will influence or enhance work efficiently under hazardous conditions	N	
27	E2–E6	Work efficiently under hazardous conditions will influence or enhance user friendly	Y	Control systems that can work at any conditions will be more users friendly
28	E6–E2	User friendly will influence or enhance work efficiently under hazardous conditions	N	
29	E2–E7	Work efficiently under hazardous conditions will influence or enhance fast installation and commissioning	N	
30	E7–E2	Fast installation and commissioning will influence or enhance work efficiently under hazardous conditions	N	
31	E2–E8	<i>Work efficiently under hazardous conditions will influence or enhance flexibility</i>	Y	<i>Efficient working of a system under hazardous conditions will be greatly advantageous</i>
32	E8–E2	Flexibility will influence or enhance work efficiently under hazardous conditions	Y	Transitive
33	E2–E9	Work efficiently under hazardous conditions will influence or enhanced efficiency	Y	Working at hazardous conditions increases overall efficiency of the system



Table 6 continued

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
34	E9–E2	Enhanced efficiency will influence or enhance work efficiently under hazardous conditions	N	
35	E2–E10	Work efficiently under hazardous conditions will influence or enhance ideal for areas where network is scarce	N	
36	E10–E2	Ideal for areas where network is scarce will influence or enhance work efficiently under hazardous conditions	Y	Systems that are ideal for areas where network is scarce can efficiently under hazardous conditions
37	E2–E11	Work efficiently under hazardous conditions will influence or enhance centralized monitoring	N	
38	E11–E2	Centralized monitoring will influence or enhance work efficiently under hazardous conditions	N	
E3: Large scale deployment				
39	E3–E4	Large scale deployment will influence or enhance ease of maintenance	N	
40	E4–E3	Ease of maintenance will influence or enhance large scale deployment	Y	Systems that can maintain easily will have large scale deployment
41	E3–E5	Large scale deployment will influence or enhance low earth faults noise	N	
42	E5–E3	<i>Low earth faults noise will influence or enhance large scale deployment</i>	Y	<i>Low noise in measurement will enhance the exploitation of the system</i>
43	E3–E6	Large scale deployment will influence or enhance user friendly	N	
44	E6–E3	User friendly will influence or enhance large scale deployment	Y	Transitive
45	E3–E7	Large-scale deployment will influence or enhance fast installation and commissioning	N	
46	E7–E3	Fast installation and commissioning will influence or enhance large scale deployment	Y	A system with quick installation increases large-scale deployment
47	E3–E8	Large scale deployment will influence or enhance flexibility	N	
48	E8–E3	Flexibility will influence or enhance large scale deployment	Y	A highly flexible system will have large-scale deployment
49	E3–E9	Large scale deployment will influence or enhance enhanced efficiency	N	
50	E9–E3	Enhanced efficiency will influence or enhance large scale deployment	Y	A highly efficient system will have large-scale deployment

Table 6 continued

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
51	E3–E10	Large scale deployment will influence or enhance ideal for areas where network is scarce	N	
52	E10–E3	Ideal for areas where network is scarce will influence or enhance large scale deployment	Y	Systems that can work where network is scarce enhance large-scale deployment
53	E3–E11	Large scale deployment will influence or enhance centralized monitoring	N	
54	E11–E3	Centralized monitoring will influence or enhance large scale deployment	Y	Systems that can control with a centralized control room enhance large-scale deployment
E4: Ease of maintenance				
55	E4–E5	Ease of maintenance will influence or enhance low earth faults noise	Y	Transitive
56	E5–E4	Low earth faults noise will influence or enhance ease of maintenance	N	
57	E4–E6	Ease of maintenance will influence or enhance user friendly	Y	Easy maintenance will make the systems more user friendly
58	E6–E4	User friendly will influence or enhance ease of maintenance	N	
59	E4–E7	Ease of maintenance will influence or enhance fast installation and commissioning	Y	Transitive
60	E7–E4	Fast installation and commissioning will influence or enhance ease of maintenance	N	
61	E4–E8	Ease of maintenance will influence or enhance flexibility	Y	Systems that can maintain easily will be more flexible
62	E8–E4	Flexibility will influence or enhance ease of maintenance	Y	Transitive
63	E4–E9	Ease of maintenance will influence or enhance enhanced efficiency	Y	Systems providing easy maintenance increases flexibility
64	E9–E4	Enhanced efficiency will influence or enhance ease of maintenance	N	
65	E4–E10	Ease of maintenance will influence or enhance ideal for areas where network is scarce	N	
66	E10–E4	Ideal for areas where network is scarce will influence or enhance ease of maintenance	N	
67	E4–E11	Ease of maintenance will influence or enhance centralized monitoring	N	
68	E11–E4	Centralized monitoring will influence or enhance ease of maintenance	N	



Table 6 continued

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
E5: Low earth faults noise				
69	E5–E6	Low earth faults noise will influence or enhance user friendly	Y	Reduced noise in a system will be more users friendly
70	E6–E5	User friendly will influence or enhance low earth faults noise	Y	Transitive
71	E5–E7	Low earth faults noise will influence or enhance fast installation and commissioning	N	
72	E7–E5	Fast installation and commissioning will influence or enhance low earth faults noise	Y	Transitive
73	E5–E8	<i>Low earth faults noise will influence or enhance flexibility</i>	Y	<i>Lack of noise in measurement improves flexibility</i>
74	E8–E5	Flexibility will influence or enhance low earth faults noise	N	
75	E5–E9	Low earth faults noise will influence or enhance enhanced efficiency	Y	Noise reduction increases Efficiency of the system
76	E9–E5	Enhanced efficiency will influence or enhance low earth faults noise	N	
77	E5–E10	Low earth faults noise will influence or enhance ideal for areas where network is scarce	N	
78	E10–E5	Ideal for areas where network is scarce will influence or enhance low earth faults noise	Y	Transitive
79	E5–E11	Low earth faults noise will influence or enhance centralized monitoring	N	
80	E11–E5	Centralized monitoring will influence or enhance low earth faults noise	Y	Transitive
E6: User friendly				
81	E6–E7	User friendly will influence or enhance fast installation and commissioning	N	
82	E7–E6	Fast installation and commissioning will influence or enhance user friendly	Y	A system with hasty installation capability will be more users friendly
83	E6–E8	User friendly will influence or enhance flexibility	Y	A user-friendly system will enrich flexibility
84	E8–E6	Flexibility will influence or enhance user friendly	Y	A flexible system can be used at any time without much restriction
85	E6–E9	User friendly will influence or enhance enhanced efficiency	Y	A user friendly system increases overall efficiency
86	E9–E6	Enhanced efficiency will influence or enhance user friendly	Y	A highly efficient system is user friendly
87	E6–E10	User friendly will influence or enhance ideal for areas where network is scarce	N	

Table 6 continued

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
88	E10–E6	Ideal for areas where network is scarce will influence or enhance user friendly	Y	A system working in hazardous conditions is very much useful customers
89	E6–E11	User friendly will influence or enhance centralized monitoring	N	
90	E11–E6	Centralized monitoring will influence or enhance user friendly	Y	A centralized monitoring system is more useful to customers
E7: Fast installation and commissioning				
91	E7–E8	Fast installation and commissioning will influence or enhance flexibility	Y	A system with rapid installation capability enhances its flexibility
92	E8–E7	Flexibility will influence or enhance fast installation and commissioning	Y	Transitive
93	E7–E9	Fast installation and commissioning will influence or enhance enhanced efficiency	Y	A system with quick installation increases efficiency
94	E9–E7	Enhanced efficiency will influence or enhance fast installation and commissioning	N	
95	E7–E10	Fast installation and commissioning will influence or enhance ideal for areas where network is scarce	N	
96	E10–E7	Ideal for areas where network is scarce will influence or enhance fast installation and commissioning	Y	Transitive
97	E7–E11	Fast installation and commissioning will influence or enhance centralized monitoring	N	
98	E11–E7	Centralized monitoring will influence or enhance fast installation and commissioning	Y	Installation of centralized monitoring systems provides quick installation
E8: Flexibility				
99	E8–E9	Flexibility will influence or enhance enhanced efficiency	Y	Transitive
100	E9–E8	Enhanced efficiency will influence or enhance flexibility	Y	Transitive
101	E8–E10	Flexibility will influence or enhance ideal for areas where network is scarce	Y	Transitive
102	E10–E8	Ideal for areas where network is scarce will influence or enhance flexibility	Y	Systems that can work even at areas where network is insufficient will increase flexibility
103	E8–E11	Flexibility will influence or enhance centralized monitoring	N	
104	E11–E8	Centralized monitoring will influence or enhance flexibility	N	



Table 6 continued

Sl. nos.	Element nos.	Paired comparison of enablers	Y/N	In what way an enabler will influence/enhance other enabler? Give reason in brief
<i>E9: Enhances overall efficiency</i>				
105	E9–E10	Enhanced efficiency will influence or enhance ideal for areas where network is scarce	N	
106	E10–E9	Ideal for areas where network is scarce will influence or enhance enhanced efficiency	Y	Systems that can work even at areas where network is inadequate will increase overall efficiency
107	E9–E11	Enhanced efficiency will influence or enhance centralized monitoring	N	
108	E11–E9	Centralized monitoring will influence or enhance enhanced efficiency	Y	Diminution in the number of control rooms provides better efficiency
<i>E10: Ideal for areas where network is scarce</i>				
109	E10–E11	Ideal for areas where network is scarce will influence or enhance centralized monitoring	N	
110	E11–E10	Centralized monitoring will influence or enhance ideal for areas where network is scarce	Y	A central control room will boost up the control action even when the network is inadequate

Significant transitive links between the elements of enablers are given in italics

Appendix II

Table 7 Level I

Variables	Reachability set	Antecedent set	Intersection set	Level
E1	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10	E1, E4, E10, E11	E1, E4, E10	
E2	E2, E3, E6, E8, E9	E1, E2, E8, E10	E2, E8	
E3	E3	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11	E3	I
E4	E1, E3, E4, E5, E6, E8, E9, E10	E1, E4, E10	E1, E4, E10	
E5	E3, E5, E6, E8, E9,	E1, E4, E5, E10, E11	E5	
E6	E3, E6, E8, E9	E1, E2, E4, E5, E6, E7, E8, E10, E11, E9	E6, E8, E9	
E7	E3, E6, E7, E8, E9	E1, E5, E7, E10, E11	E7	
E8	E3, E6, E8, E9	E1, E2, E4, E5, E6, E7, E8, E9, E10, E11	E6, E8, E9	
E9	E3, E6, E8, E9,	E1, E2, E4, E5, E7, E8, E9, E10, E11, E6	E6, E8, E9	
E10	E1, E2, E3, E4, E5, E6, E7, E9, E10	E1, E4, E10	E1, E4, E10	
E11	E1, E3, E5, E6, E7, E8, E9, E10, E11	E11	E11	

Table 8 Level II

Variables	Reachability set	Antecedent set	Intersection set	Level
E1	E1, E2, E4, E5, E6, E7, E8, E9, E10	E1, E4, E10, E11	E1, E4, E10	
E2	E2, E6, E8, E9	E1, E2, E8, E10	E2, E8	
E4	E1, E4, E5, E6, E8, E9, E10	E1, E4, E10	E1, E4, E10	
E5	E5, E6, E8, E9	E1, E4, E5, E10, E11	E5	
E6	E6, E8, E9	E1, E2, E4, E5, E6, E7, E8, E9, E10, E11	E6, E8, E9	II
E7	E6, E7, E8, E9	E1, E5, E7, E8, E10, E11	E7, E8	
E8	E6, E8, E9	E1, E2, E4, E5, E6, E7, E8, E9, E10, E11	E6, E8, E9	II
E9	E6, E8, E9	E1, E2, E4, E5, E6, E7, E8, E9, E10, E11	E6, E8, E9	II
E10	E1, E2, E4, E5, E6, E7, E8, E9, E10	E1, E4, E10	E1, E4, E10	
E11	E1, E5, E6, E7, E8, E9, E10, E11	E11	E11	

Table 9 Level III

Variables	Reachability set	Antecedent set	Intersection set	Level
E1	E1, E2, E4, E5, E7, E10	E1, E4, E7, E10, E11	E1, E4, E7, E10	
E2	E2	E1, E2	E2	III
E4	E1, E4, E5, E10	E1, E4, E10	E1, E4, E10	
E5	E5	E1, E4, E5, E10, E11	E5	III
E7	E7	E1, E5, E7, E10, E11	E7	III
E10	E1, E2, E5, E7, E10	E1, E2, E10	E1, E2, E10	
E11	E1, E5, E7, E10, E11	E11	E11	

Table 10 Level IV

Variables	Reachability set	Antecedent set	Intersection set	Level
E1	E1, E4, E10	E1, E4, E10, E11	E1, E4, E10	IV
E4	E1, E4, E10	E1, E4, E10	E1, E4, E10	IV
E10	E1, E4, E10	E1, E4, E10	E1, E4, E10	IV
E11	E1, E10, E11	E11	E11	

Table 11 Level V

Variables	Reachability set	Antecedent set	Intersection set	Level
E11	E11	E11	E11	V

Appendix III



Table 12 Interaction matrix

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
(a) Binary matrix											
E1	-	1	0	1	1	0	1	0	0	0	0
E2	0	-	0	0	0	1	0	1	0	0	0
E3	0	0	-	0	0	0	0	0	0	0	0
E4	1	0	0	-	0	1	0	0	0	0	0
E5	0	0	1	0	-	0	0	1	1	0	0
E6	0	0	0	0	0	-	0	1	0	0	0
E7	0	0	0	0	0	1	-	1	1	0	0
E8	0	0	1	0	0	1	0	-	0	0	0
E9	0	0	1	0	0	0	0	0	-	0	0
E10	0	1	0	0	0	0	0	0	1	-	0
E11	0	0	1	0	0	0	0	0	0	1	-
(b) Interpretive matrix											
E1	-	Mobility enhanced by the elimination of wires	-	No need to remove wires for maintenance	Noise due to cabling faults such as earth faults crop up in wired systems	-	Wireless speed up installation and commissioning	-	-	-	-
E2	-	-	-	-	-	Control systems that can work at any conditions will be more users friendly	-	Efficient working of a system under hazardous conditions will be greatly advantageous	-	-	-
E3	-	-	-	-	-	-	-	-	-	-	-
E4	Enormous quantity of instruments can be added to the system	-	-	-	-	Easy maintenance will make the systems more user friendly	-	-	-	-	-
E5	-	-	Low noise in measurement will enhance the exploitation of the system	-	-	-	Reduced noise in a system will be greatly advantageous for its installation	Lack of noise in measurement improves flexibility of the system	Noise reduction increases Efficiency of the system	-	-

Table 12 continued

E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
E6	-	-	-	-	-	-	A user-friendly system will enrich flexibility	-	-	-
E7	-	-	-	-	A system with hasty installation capability will be more users friendly	-	A system with rapid installation enhances its flexibility	A system with quick installation increases efficiency	-	-
E8	-	A highly flexible system will have large-scale deployment	-	-	A flexible system can be used at any time without much restriction	-	-	-	-	-
E9	-	A highly efficient system will have large-scale deployment	-	-	-	-	-	-	-	-
E10	-	Systems that are ideal for areas where network is scarce can efficiently under hazardous conditions	-	-	-	-	-	Systems that can work even at areas where network is inadequate will increase overall efficiency	-	-
E11	-	Systems that can control with a centralized control room enhance large-scale deployment	-	-	-	-	-	-	A central control room will boost up the control action even when the network is inadequate	-

Element ‘1’ obtained in the interaction matrix due to transitivity is given in italics. However, bold is used to represent element ‘1’ obtained due to the answer “YES” for the paired comparison of enablers in table 2

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Key Questions

1. What is the relevance of TISM in information and communication technology (ICT), enabled wireless process control systems?
2. What is the added advantage of exploring TISM than traditional ISM in wireless?
3. Comment on the flexibility aspects of ICT enabled wireless process control systems?



B. Jayalakshmi is an Associate Professor in Instrumentation and control Engineering Department of NSS College of Engineering, Palakkad, India. She holds a bachelor's degree in Instrumentation and Control Engineering and a master's degree in Instrumentation and Control Systems. She has twenty-three years of teaching experience.

She has published six papers in international journals, one in a reputed national journal and 10 papers in the proceedings of the leading National and International Conferences. Her areas of research interest include wireless remote control of processes using information and communication technology, process control instrumentation and transducers.



V. R. Pramod is an Associate Professor in Mechanical Engineering Department of NSS College of Engineering, Palakkad, India. He holds a bachelor's degree in Mechanical Engineering, a master's degree in Maintenance Engineering and Management from IIT Madras and PhD in supply Chain management from IIT Delhi. He has seven years of industrial experience and fifteen years of

teaching experience. He has published over 25 papers in the proceedings of the leading National and International Conferences. He has published 30 papers in reputed international Journals. His current areas of research interest include supply chain management, telecom logistics and service management.