INTERPRETIVE STRUCTURAL MODELLING: HUMAN-MACHINE WORKSYSTEM COMPONENTS

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ABSTRACT

Worksystems are continuously evolving, with ongoing industrial development. Leamon's human-machine model is the base model to explain worksystem. It has nine essential components, namely 'Workspace', 'Environment', 'Organization, 'Sensory Mechanism', 'Processing', 'Effectors', 'Control', 'Control Process', and 'Display'. This study is an empirical study that draws a hierarchical structural model of worksystem components using interpretative structural modelling technique. It is based on contextual relationship and influence of these components on each other and worksystem as whole. With Fuzzy MICMAC analysis, their behavioural nature in system is identified and these components are further classified and grouped as 'driving', 'dependant', 'linkage' and 'autonomous' components. The outcome of the study will aid designers and operators to give more robustness and sustainability to worksystem, with better safety and analytical pathways. This will aid in apt decision making, necessary for performance, economics and safety of worksystem.

Keywords: Worksystem, Human machine model, Worksystem failure, Interpretive structure modelling, MICMAC analysis.

INTRODUCTION

Over the period, most industrial worksystems have transitioned, as a result of industrial infusion of newer technologies, increasing complexity and desired economic advantages (Karwowski, 2005). Despite the technological advances with improved design and safety aspect advances, history vouches, that failures in worksystem are inevitable (Perrow, 1984), ranging from normal accidents to catastrophic levels. Hence ongoing worksystems analysis are important, for optimising the performance and preventing worksystem failures (Onnasch et al., 2014; Park et al., 2013). Failure analysis and error management has become the most important part of worksystem analysis. It has been seen that in most worksystem failure cases, human is conveniently blamed (Dhillon & Liu, 2006; Hobbs & Williamson, 2003); and the second most common reason of failure is worksystem design (Day Ronal William, 2017). Occasionally, the other reasons of failures include life cycle of components, inadequate preventive maintenance, and extent of exploitation of components. This kind of knowledge marginally helps the designer and operators to improve-upon in their respective domain. Many investigation reports of classic worksystem failures have indicated that the reasons are more related to the complexity of worksystem, inter-relation of worksystem components, rather any independent component failure (Bainbridget, 1983). It is pertinent to note that the significance and contextual relationship of components, their nature and level of influence are important and essential to be known.

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Researcher have made attempts to develop various worksystem models and theories, but with limited lens of human error, design failures and component level failures, that may arise out of exploitation or maintenance lapses (Alter, 2013; Dix Alan, 2016; Shrivastava et al., 2009). However, the failure and functioning analysis lacks the needed knowledge of various worksystem component influence; be it on worksystem failure or among each other (Regazzoni and Rizzi, 2013). A systematic approach is needed to build the structural model of components in worksystem that will support the ongoing industrial revolution and mechanization. It will also help the designer and operator to better understand and design robust worksystem.

The increasing complexity of worksystem indicates, that the study of worksystem failure would not be fruitful without systematic approach. The components of automated and complex worksystem are inter-related. These components also influence the functioning of each other and as a whole (Zhang et al., 2019). The worksystem designer and operator require to know the relative significance of worksystem components. The components of higher influence are required to be given considerable emphasis (Singh and Kant, 2008), while designing safety parameter and drafting the standard operating procedure and manuals. The nature of components depends on their influence in the worksystem as driving, dependent, linkage or autonomous components. Any worksystem has 9 components (or elements), namely ‘Workspace’, ‘Environment’, ‘Organization, ‘Sensory Mechanism’, ‘Processing’, ‘Effectors’, ‘Control’, ‘Control Process’, and ‘Display’.

In this research, we have used Interpretive structure modelling (ISM) to study the worksystem, where its multiple components have direct and indirect interaction (Sushil, 2012). As the influence of each worksystem components is difficult to gauge in isolation, their contextual interrelationship becomes important (Onnasch, 2015). Based on the opinion of domain experts, the contextual relationship between components of worksystem are established. The scientific analysis of perception of domain experts is done; with software based computational techniques. Then the classification of components is done, based on driving and dependence power of the components in the worksystem. The driving and dependence power of the components have been calculated using fuzzy MICMAC analysis; which too is based on the inputs from experts. These inputs focus on intensity of inter-relation of components with each other.

This paper is organised in five sub parts: first parts includes the literature review of worksystem, ISM and MICMAC method of analysis, second part explains the methodology of ISM and MICMAC analysis. Results of analysis have been illustrated in the third section with classification of the components in four clusters. The discussion and conclusion explaining implication and contribution of the study is discussed in fourth and fifth section respectively.

LITERATURE REVIEW

Worksystem

Worksystem is defined as a system comprising one or more workers and work equipment acting together to perform the system function, in the workspace, in the work environment, and under the conditions imposed by the work tasks (ISO 6385:2016(E), 2016). Similar definition was given by Alter (2017) for IT related worksystem. It stated a worksystem as a system in which human participants and/or machines perform work (processes and activities) using information, technology, and other resources to produce specific product/services for specific internal and/or external customers (Alter, 2017). The Leamon’s Human-machine model described the components of the worksystem as Human,

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Machine, Workspace, Environment and Organization. Human and machines are placed at the core of the worksystem. Sensory mechanism, processing, effectors and control, control process, display are described as primary components of humans and machines respectively in the model (Leamon, 1980).

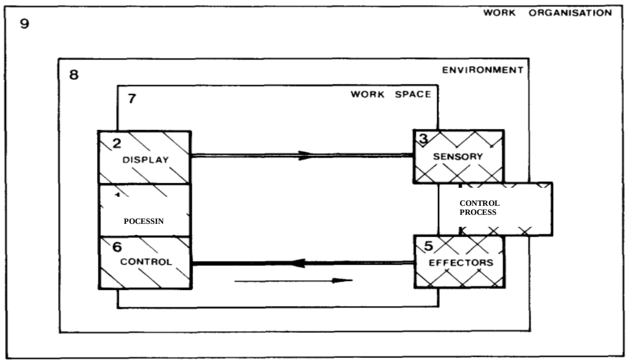

FIGURE 1
HUMAN MACHINE SYSTEM: A MODEL

(Adopted from Leamon, 1980).

This model illustrated the boundary of the components in worksystems and described that these components have interactions with each other.

Worksystem Evaluation Models

In literature, the worksystem failure evaluation is based on three approaches (i) Human as a Cause; where human error is mainly responsible for worksystem failures, (ii) System as a Cause; where systemic errors are responsible form failures and (iii) System – Person interaction as a cause; where the interactions of human components with other components are responsible for failures (Khanzode *et al.*, 2012). The interaction between the components of worksystem have been illustrated by various researchers (Bridger, 2003).

For many worksystem failures, the human errors was conveniently made responsible for most worksystem failure (Endsley and Robertson, 1996; Lind, 2008). But the recent advanced worksystem are automated, where human role is decreasing and role of machine component is increasing (Richards and Stedmon, 2015). These changed worksystems have largely improved machine components, to minimize the systemic errors. However, the worksystems are still failing. Therefore, it is important to examine the significance of each worksystem components and their contextual relationship and hierarchical importance in worksystem. This can further aid researchers and operators to reduce/ control failures.

Interpretative Structural Modelling (ISM)

ISM was first introduced by Warfield (1974), to address the complex issues; by interpretation of contextual relationship of components or factors involved. It is an interactive learning process, where various directly and indirectly related elements are structured into a comprehensive systematic model (Gupta et al., 2013). These elements are organised in the order of their relative significance, to facilitate the decision making at various level. The inputs for the ISM are sought from the group of domain experts. Based on the perception of domain experts, the contextual relationships of the components are coded in the form of matrix (Sonar et al., 2020). The direct and indirect inter-relationship of the components is computed for resolving the complex issue (Singh et al., 2007). Mostly evaluation of such problems may be biased to individual opinion, but the ISM methodology has an advantage of expert opinion being computed statistically, based on computer based programming to

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prevent any biases (Sushil, 2012). Therefore, the results of ISM can be utilized for strategic decision making of complex issues, in order to attain long term objectives (Mohammed et al., 2008). Then a hierarchical model is developed depending upon the contextual relationship of various components involved (Saxena et al., 1992). The ISM can be utilized to develop computer aided, well structured, systematic model with graphical representation. As compared to other techniques like Analytic Network Process (ANP), Analytic Hierarchical Process AHP and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), it does not require assessment of dominance level of component to establish the inter-relationship (Sonar et al., 2020).

MICMAC Analysis

MICMAC (Matrice d'Impacts croises-multiplication appliqúe an classment) is the abbreviation for cross-impact matrix multiplication applied to classification technique. It was demonstrated by Dupperrin & Godet (1973) and widely used by the researchers. It is based on multiplication properties of matrices and helps to analyse the drive power and dependence power of components. Components with high drive power are the one to drive the system. Based on their drive and dependence power, the components are categorised as autonomous, linkage, dependent and independent components (Goel et al. 2022).

1. Autonomous components: These have weak drive power and weak dependence power. They are relatively disconnected from the system. They have few links, which may be very strong.
2. Linkage components: These have strong drive as well as strong dependence power. In MICMAC analysis, they are considered unstable, meaning that any action on these will have an effect on others and also a feedback effect on themselves.
3. Dependent components: They are components with weak drive but strong dependence power.
4. Independent components: These have strong drive but weak dependence power. In MICMAC analysis, a component with a very strong drive power plays as 'key factor' and is identified as independent or linkage component.

ISM modelling illustrates the contextual relationship and hierarchical structure of component in the worksystem. But the components are variable in their inter-relationship and the intensity of relationship cannot be same between the two components. Therefore, the binary relationship of 0 and 1 as input from domain expert may not be absolute for analysis. To overcome this limitation, the Fuzzy MICMAC analysis would provide exact classification of components in the worksystem (Al-Zarooni and Bashir, 2020).

METHODOLOGY

The study was done in three steps:

1. Worksystem failure analysis using Leamon's worksystem model
2. ISM analysis
3. Fuzzy MICMAC analysis

Worksystem Failure analysis

The ISM and MICMAC analysis required inputs from domain experts. In order to explain the context of study, few classic cases of worksystem failures were assessed from last four decades. These were very complex, tightly coupled, and automated worksystem, as seen from Table 1. For the analysis, authenticated accident reports were used to prepare case illustrations. Based on the investigation reports, the systematic sequences of events responsible for failures were identified and analysed. Every event was further broken into

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elementary steps and corresponding interaction of the worksystem components was identified, which was based on Leamon's worksystem model.

Such brief reports of each of nine classic cases were prepared, that aided us in discussions and semi structure interview of domain experts.

Table 1
CLASSIC CASES OF WORKSYSTEM FAILURE

Ser No	Year	Classic Case	Sector	Author /Reports	Nature of Accident
1	1977	Tenerife Airport Disaster)	Aviation	Digest and Circular, 1978	Catastrophic failure
2	1979	Three Mile Island – Nuclear Disaster	Nuclear Energy	President's Commission on The Accident at Three Mile Island, 1979	Catastrophic failure
3	1983	Gimli Glider	Aviation	Williams, 2003	Near Miss
4	1984	Bhopal Gas Tragedy	Process Industry	Eckerman, 2013	Catastrophic failure
5	1986	Challenger Disaster	Aerospace	Roger Commission, 1986	Catastrophic failure
6	2003	Columbia Spacecraft	Aerospace	Columbia Accident Investigation Board, 2003)	Catastrophic failure
7	2009	Air France	Aviation	BEA France, 2009	Catastrophic failure
8	2017	Air Canada Near Miss	Aviation	National Transportation Safety Board, 2018	Near Miss
9	2018	Lion Air Crash	Aviation		Catastrophic failure

(Author's Own compilation).

Interpretive Structural Modelling

For the development of interpretive structural modelling, eight domain experts from various industrial worksystem contributed voluntarily. They had rich experience (minimum 15 years) in their respective field, with core competency and had witnessed the technological transition in the worksystem. The heterogeneous sample size of 'eight' domain expert would have served to get better accuracy of data analysis, given the fact that 5 to 15 experts are recommended (Murry and Hammons, 1995; Novakowski and Wellar, 2008).

These experts being from various industrial worksystem would have helped to reduce the biases. The profiles of domain experts are illustrated in the Tables 2 & 3 and the flow chart of ISM process is presented in Figure 2.

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Table 2
PROFILE OF INDUSTRY EXPERTS

Industry	Designation	Exp (Years)	Roles / Responsibility	Strategic / Commercial
Defense Land System	Commanding Officer Armoured Regiment	17	Trained in Tank Technology Responsible for modification of battle Tank	Strategic (Tanks)
Railways	DGM (Operations)	15	Core team member of Metro Train coach manufacturing facilities	Commercial (Urban Transport)
Shipping	Captain of War Ship	21	Planning and execution of marine operations and rescues.	Strategic (War Ship)
Shipping	Chief Engineer (Merchant Ship)	19	Planning and maintenance of ships.	Commercial (Merchant Ships)
Aerospace	Deputy Controller (MSQAA)	26	Development, Manufacturing, Inspection and Maintenance of Missile system	Strategic (Missile System)
Aviation	Commanding Officer, UAV unit	17	Strategic deployment and operation of UAV units	Strategic (UAV)
Aviation	Captain (Private airlines)	23	Ex Air force pilot, Test pilot for IAF, Training of pilots and flying commercial aircraft	Commercial (Aircraft)
Aviation	GM (Operations)	18	Operation of Thermal power plant. State level Automatic Grid Management system	Commercial (Grid Management)

The selected domain experts were approached to establish the contextual relationship of components in worksystem, based on their experience and knowledge. Similar approaches were adopted by various researchers, to establish the contextual relationship of components of complex worksystem like information technology (Thakkar et al. 2008), automobile industry (Dwivedi et al., 2017) and implementation of Industry 4.0 (Goel et al. 2022).

The components of worksystem studied were based on Leamon's model of worksystem: (i) Organisation, (ii) Environment, (iii) workspace, (iv) senses/ sensors, (v) processing, (vi) effectors, (vii) controls, (viii) control process and (ix) display. The structural self-interaction matrix was prepared, based on the inputs, relating direct and indirect relationship of components of worksystem; which were provided by the domain experts.

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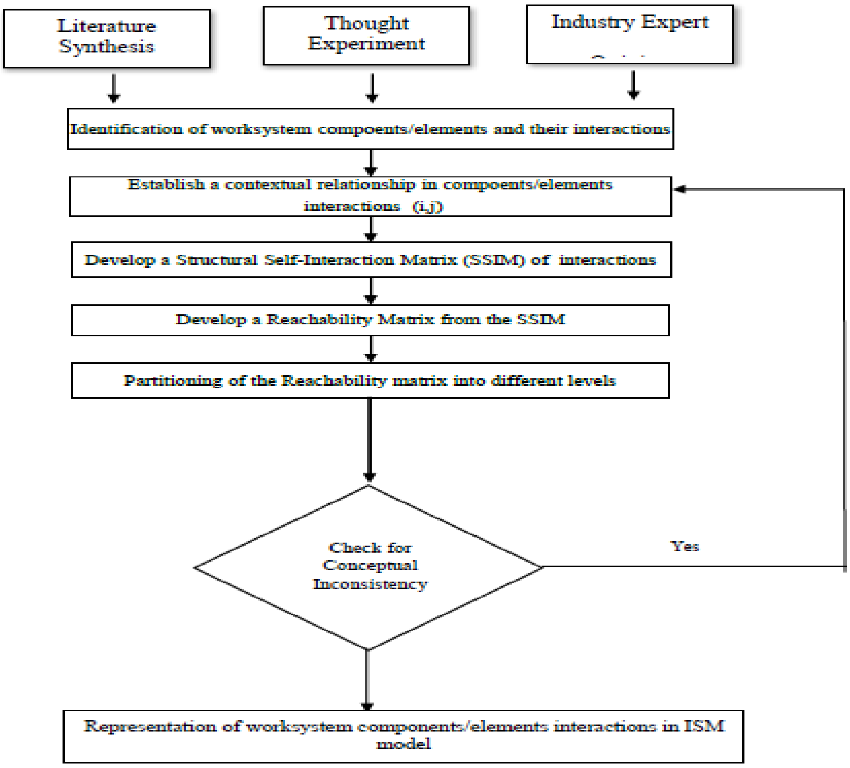

FIGURE 2 PROCESS FLOW OF DEVELOPMENT OF ISM

Source : (Mishra et al., 2017).

Computations and Results

Step 1: Structural Self –Interaction Matrix

Based on the semi-structure interview of domain experts, we documented their inputs about their respective worksystem. The domain experts provided their feedback in the following coded form, as per the instruction of the ISM technique. These feedbacks were compiled in the form of structural self-interaction matrix (SSIM).

V: Component i will affect the component j,
A: Component j will affect the component,
O: No relationship between component i and j, and
X: Components i and j will affect each other.

Where ‘i’ are component in row and; ‘j‘are components in column.

Inputs from all 8 domain experts were collected, regarding inter-relationship of components and their contextual relationship. Wherever, there was variation in the inputs, the consensus method was adopted to correlate the responses and establish the interrelationship of components (Dwivedi et al., 2017; Kavilal et al., 2018). The inputs were based on their experience of various industrial worksystem, domain knowledge and field expertise. The initial SSIM was developed with symbols of inputs V, A, X, and O, following which, the final SSIM was developed for further analysis.

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Table 3
STRUCTURAL SELF –INTERACTION MATRIX (SSIM)

	Components	09	08	07	06	05	04	03	02	01
01	Organization	O	A	O	V	O	O	O	A	-
02	Environment	X	X	O	V	V	O	V	-	
03	Workspace	X	V	X	A	X	V	-	-	-
04	Sensor	O	A	A	V	X	-	-	-	-
05	Effector	A	X	V	A	-	-	-	-	-
06	Processing	X	A	A	-	-	-	-	-	-
07	Display	X	V	-	-	-	-	-	-	-
08	Control Process	X	-	-	-	-	-	-	-	-
09	Control	-	-	-	-	-	-	-	-	-

These component relations are denoted with symbols, for examples if the 'Organisation' component affects the 'Control process' component, the relationship between the component 01 and component 08 is represented by 'A', similarly if component 03 'workspace' is affected by component 08 controlled process , then it is represented by 'V', similarly, if component 02 environment and 08 i.e. controlled process are interrelated and affects each other, then it is represented by symbol 'X' and Component 04 'sensor' and component 09 'control' have no relationship then it is represented by 'O'.

Step 2: Reachability Matrix

The structural self-interaction matrix is transformed to develop the initial reachability matrix (Table 4). This is transformed as the instruction of the ISM technique, by substituting the V, A, X, O with 0 and 1 as given below (Singh and Kant, 2008) .

(i) If the SSIM entry in the (i,j) is V , the initial reachability matrix entry for (i,j) convert to 1, and the (j,i) entry convert to 0.
(ii) If the SSIM entry in the (i,j) is A , the initial reachability matrix entry for (i,j) convert to 0, and the (j,i) entry convert to = 1.
(iii) If the SSIM entry in the (i,j) is X , then initial reachability matrix entry for (i,j) convert to 1, and the (j,i) entry convert to 1.
(iv) If the SSIM entry in the (i,j) is O , then initial reachability matrix entry for (i,j) convert to 0, and the (j,i) entry convert to 0.

Table 4
INITIAL REACHABILITY MATRIX

	Components	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
01	Organization	1	0	0	0	0	1	0	0	0
02	Environment	1	1	1	0	1	1	0	1	1
03	Workspace	0	0	1	1	1	0	1	1	1
04	Sensor	0	0	0	1	1	1	0	0	0
05	Effector	0	0	1	1	1	0	1	1	0
06	Processing	0	0	1	0	1	1	0	0	1
07	Display	0	0	1	1	0	1	1	1	1
08	Control Process	1	1	0	1	1	1	0	1	1
09	Control	0	1	1	0	1	1	1	1	1

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Step 3: Transitivity Matrix

The final reachability matrix also known as transitivity matrix. The transitivity is required to address the consistency in contextual relation of the components in the worksystem. The transitivity matrix is developed by using computer-based programming using MATLAB. It can be illustrated with an example, that if the component 'x' is related to 'y' and component 'y' is related to 'z' then a certain relationship exist between 'x' and 'z'(Singh *et al.*, 2007). The transitivity matrix is automatically developed by the programming, hence minimizing the rare chances of biases in the analysis Table 5.

Table 5
TRANSITIVITY MATRIX

	Components	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
01	Organization	1	0	0	0	0	1	0	0	0
02	Environment	1	1	1	1*	1	1	1*	1	1
03	Workspace	0	0	1	1	1	1*	1	1	1
04	Sensor	0	0	0	1	1	1	0	0	0
05	Effector	0	0	1	1	1	0	1	1	1*
06	Processing	1*	0	1	0	1	1	0	0	1
07	Display	0	0	1	1	1*	1	1	1	1
08	Control Process	1	1	1*	1	1	1	1*	1	1
09	Control	0	1	1	1*	1	1	1	1	1

Step 4: Level Partitioning

Hierarchical structure of worksystem components is then developed through the level partitioning. For the process of level partitioning, the antecedent sets and reachability sets are computed for each component of worksystem. The reachability set consists of the component itself and the other component that it may impact, whereas the antecedent set consists of the component itself and the other component that may impact it. Once the reachability and antecedent sets are made from the matrix and intersection points are identified from the sets. Depending upon the intersections point, the hierarchical structural model is developed. The level partitioning is illustrated in following tables.

Table 6
LEVEL PARTITION – ITERATION 1

	Components	**Reachability set**	**Antecedent set**	**Intersection set**	**Level**
01	Organization	1 6	1 2 6 8	1 6	**1**
02	Environment	1 2 3 4 5 6 7 8 9	2 8 9	2 8 9	
03	Workspace	3 4 5 6 7 8 9	2 3 5 6 7 8 9	3 5 6 7 8 9	
04	Sensor	4 5 6	2 3 4 5 7 8 9	4 5	
05	Effector	3 4 5 7 8 9	1 2 3 4 5 6 7 8 9	3 4 5 7 8 9	
06	Processing	3 5 6 9	1 2 3 4 6 7 8 9	3 6 9	
07	Display	3 4 5 6 7 8 9	2 3 5 7 8 9	3 5 7 8 9	
08	Control Process	1 2 3 4 5 6 7 8 9	2 3 5 7 8 9	2 3 5 7 8 9	
09	Control	2 3 4 5 6 7 8 9	2 3 5 6 7 8 9	2 3 5 6 7 8 9	

In Table 6 the component 1 has matching reachability and intersection set, therefore the component is considered as level 1 for hierarchical model. As the level 1 component of worksystem is identified then it is separated from other component.

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These similar steps repeated for identification of level of other components. The final hierarchical ISM model is prepared based on the analysis in Figure 3. The higher the hierarchical level, more influential is the component in worksystem. Level-5 components: environment, control and control process have highest level of structural hierarchy and influence, whereas organisation component is at lowest level of hierarchy Tables 7-10.

Table 7
LEVEL PARTITION – ITERATION 2

	Components	Reachability set	Antecedent set	Intersection set	Level
02	Environment	2 3 4 5 7 8 9	2 8 9	2 8 9	
03	Workspace	3 4 5 7 8 9	2 3 5 7 8 9	3 5 7 8 9	
04	Sensor	4 5	2 3 4 5 7 8 9	4 5	**1I**
05	Effector	3 4 5 7 8 9	2 3 4 5 7 8 9	3 4 5 7 8 9	
06	Processing	3 5 9	2 3 4 7 8 9	3 9	
07	Display	3 4 5 7 8 9	2 3 5 7 8 9	3 5 7 8 9	
08	Control Process	2 3 4 5 7 8 9	2 3 5 7 8 9	2 3 5 7 8 9	
09	Control	2 3 4 5 7 8 9	2 3 5 7 8 9	2 3 5 7 8 9	

Table 8
LEVEL PARTITION – ITERATION 3

	Components	Reachability set	Antecedent set	Intersection set	Level
02	Environment	2 3 7 8 9	2 8 9	2 8 9	
03	Workspace	3 7 8 9	2 3 7 8 9	3 7 8 9	
05	Effector	3 7 8 9	2 3 7 8 9	3 7 8 9	
06	Processing	3 9	2 3 7 8 9	3 9	III
07	Display	3 7 8 9	2 3 7 8 9	3 7 8 9	
08	Control Process	2 3 7 8 9	2 3 7 8 9	2 3 7 8 9	
09	Control	2 3 7 8 9	2 3 7 8 9	2 3 7 8 9	

Table 9
LEVEL PARTITION – ITERATION 4

	Components	Reachability set	Antecedent set	Intersection set	Level
02	Environment	2 7 8	2 8	2 8	
03	Workspace	7 8	2 7 8	7 8	IV
05	Effector	7 8	2 7 8	7 8	IV
07	Display	7 8	2 7 8	7 8	IV
08	Control Process	2 7 8	2 7 8	2 7 8	
09	Control	2 7 8	2 7 8	2 7 8	

Table 10
LEVEL PARTITION – ITERATION 5

	Components	Reachability set	Antecedent set	Intersection set	Level
02	Environment	2	2	2	V
08	Control Process	2	2	2	V
09	Control	2	2	2	V

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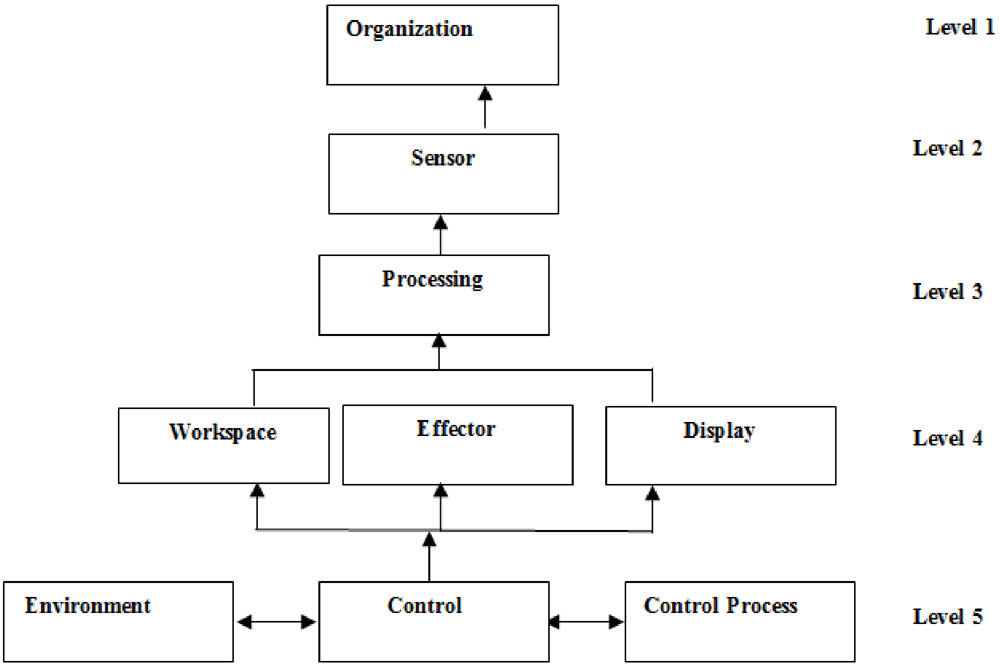

FIGURE 3
LEVEL PARTITIONING OF WORKSYSTEM COMPONENTS

Fuzzy MICMAC Analysis

The MICMAC analysis is generally based on the input received form domain experts, which is binary in nature. The binary inputs regarding the inter-relationship of worksystem components may not give out the correct judgement of relationship and significance of components. The limitation of traditional MICMAC analysis can be overcome, by incorporating the fuzzy set theory. It uses the feedback of domain expert, where they assign different judgement values to contextual relationship. The fuzzy MICMAC analysis has been practiced by various researchers for classification of factors. The factors affecting additive manufacturing (Sonar *et al.*, 2020) and interdependencies of electrical power system (Al-Zarooni and Bashir, 2020) have been analysed using Fuzzy MICMAC analysis. The scale of quantification of interrelationship of worksystem components are spread from no relationship (0) to very high relationship (0.9) with inter-spread of 5 values. The value of interrelationship are captured as; 0.1 depicting very low, 0.3 depicting low, 0.5 depicting high, 0.7 as very high relationship between components (Gorane and Kant, 2013; Mishra *et al.*, 2017). The detailed technique of Fuzzy-MICMAC analysis Figure 3.

Binary Direct Relationship Matrix

The binary direct relationship matrix is prepared where the diagonal entries are made as zero. While developing the binary direct relationship, the transitivity of the Interrelationship is ignored, instead matrix based on initial reachability is used (Table 11).

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Table 11
BINARY DIRECT RELATIONSHIP MATRIX

	Components	01	02	03	04	05	06	07	08	09
01	Organization	**0**	0	0	0	1	0	0	0	0
02	Environment	1	**0**	1	0	1	1	0	1	1
03	Workspace	0	0	**0**	1	1	0	1	1	1
04	Sensor	0	0	0	**0**	1	1	0	0	0
05	Effector	0	0	1	1	**0**	0	1	1	0
06	Processing	0	0	1	0	1	**0**	0	0	1
07	Display	0	0	1	1	0	1	**0**	1	1
08	Control Process	1	1	0	1	1	1	0	**0**	1
09	Control	0	1	1	0	1	1	1	1	**0**

Development of Fuzzy Direct Relationship Matrix

The fuzzy direct relationship matrix is developed based on the inputs from domain experts, stating the interaction and inter-relationship of components of worksystem. The inputs from all domain experts were collected and placed in the form of matrix against respective component (Table 12).

Table 12
FUZZY DIRECT RELATIONSHIP MATRIX

	Components	01	02	03	04	05	06	07	08	09
01	Organization	**0**	0	0	0	0.7	0	0	0	0
02	Environment	0.1	**0**	0.5	0	0.7	0.5	0	0.7	0.3
03	Workspace	0	0	**0**	0.5	0.7	0	0.7	0.5	0.7
04	Sensor	0	0	0	**0**	0.3	0.7	0	0	0
05	Effector	0	0	0.1	0.7	**0**	0	0.7	0.7	0
06	Processing	0	0	0.3	0	0.5	**0**	0	0	0.7
07	Display	0	0	0.3	0.5	0	0.3	**0**	0.7	0.3
08	Control Process	0.3	0.7	0	0.7	0.7	0.7	0	**0**	0.5
09	Control	0	0.5	0.5	0	0.9	0.5	0.7	0.3	**0**

Fuzzy-MICMAC Stabilized Matrix

The fuzzy MICMAC stabilized matrix is achieved by matrix multiplication of fuzzy direct relationship matrix, using fuzzy matrix multiplication principles (Kandasamy et al., 2007). It is based on repetitive multiplication considering the fuzzy direct relationship matrix as base matrix (Table 13). Fuzzy matrix multiplication is carried out till the time the product matrix is also achieved as fuzzy matrix.

The fuzzy MICMAC analysis is based on the driving and dependence power of components of worksystem, which is achieved by summation of entries of row and column for driving and dependence power respectively.

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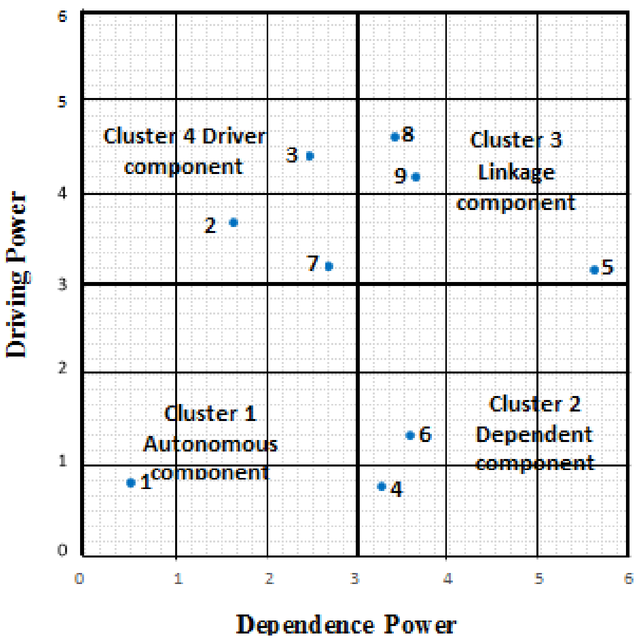
Table 13
FUZZY-MICMAC STABILIZED MATRIX

	Components	01	02	03	04	05	06	07	08	09	Driving Power
01	Organization	**0**	0	0	0	0.9	0	0	0	0	**0.9**
02	Environment	0.1	**0**	0.7	0	0.9	0.7	0	0.9	0.5	**3.8**
03	Workspace	0	0	**0**	0.7	0.9	0	0.9	0.7	0.9	**4.1**
04	Sensor	0	0	0	**0**	0.5	0.9	0	0	0	**1.4**
05	Effector	0	0	0.3	0.9	**0**	0	0.9	0.9	0	**3**
06	Processing	0	0	0.5	0	0.7	**0**	0	0	0.9	**2.1**
07	Display	0	0	0.5	0.7	0	0.5	**0**	0.9	0.5	**3.1**
08	Control Process	0.5	0.9	0	0.9	0.9	0.9	0	**0**	0.7	**4.8**
09	Control	0	0.7	0.7	0	0.9	0.7	0.9	0.5	**0**	**4.4**
	Dependence Power	**0.6**	**1.6**	**2.7**	**3.2**	**5.7**	**3.7**	**2.7**	**3.9**	**3.5**	

Classification of Work System Components

In addition to the ISM modelling of worksystem component, these are further grouped into four different clusters, using fuzzy MICMAC analysis. After the 'driving' and 'dependence' power of worksystem components is ascertained, the 'driving power' is plotted on 'y' axis and 'dependence power' on 'x' axis. As per the designated values, the components are classified into four clusters. – driver, linkage, dependent and autonomous clusters Figure 4.



S. No	Components
	Organization
	Environment
	Workspace
	Sensor
	Effector
	Processing
	Display
	Control Process
	Control

FIGURE 4
CLASSIFICATION OF WORKSYSTEM COMPONENTS

Autonomous Cluster

The worksystem components having weak driving and dependence power are categorized as autonomous component. Generally, these components do not have much influence in worksystem interaction. In this study the organisation is classified as autonomous component, which generally have less effect in the worksystem. Organisation plays role in recruiting, training of human and scheduling of task. The availability of

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infrastructure is vital responsibility of organisation. The procedure, safety rules and regulations are main function of organisation. Its function is generally not affected by other component malfunction.

Driver Cluster

The driver cluster encompasses the most important components of worksystem, which has strong driving and low dependence power. These components are important variable components, which influence the worksystem interactions. Environment, workspace and display are classified as driver components. Environments have major role in functioning of human and machine. The performance of sensors, actuators and control process is also largely affected by environment, as optimum environment is must for their functioning; failing which, sensors and actuators can malfunction. Display of control process has transformed from dial gauges to digital display and now with increasing complexity and coupling, as touch panels etc. In the example of touch panels, they serve as display, as well as control; hence any dysfunction in the touch panels will affect controls. The location of display, colour, and position of information on screen are also important for correct sensing the output/ information, relating worksystem function. Accessibility or reachability to display and control in worksystem is very essential for smooth and easy operations.

The complex worksystems can also have spacio-temporal distributed and fragmented workspace, where human and machine are operating in different workspace envelops

Linkage Cluster

The components with strong driving and dependence power lie in this cluster. These components act as facilitator for worksystem and are driven by driving components of worksystem. The linkage components also contribute towards interaction of dependent components. Effector, control, and control process have been placed as linkage components. Traditionally effectors were human limbs, but with automation in most cases, they are functioning as electronic actuators and at times also operating based on remote sensing operations. Controls in automatic worksystem are developed as gesture, sound, and biometric based control. The control process is largely operating, based on varying degree of machine learning and artificial intelligence applications. These are integrated with sensors and actuators in worksystem.

Dependent Cluster

The components having weak driving power and strong dependence power constitute the dependent cluster. These components are considered as indicator of worksystem components interactions. The processing and sensors are taken as components of dependent cluster. The environment and organization policies would impact the performance and functioning of processing. Similarly, environment, control process and display will also significantly affect the functioning of sensors in the worksystem.

DISCUSSION

In this study, we have used Leamon's Human-machine model to depict the components of worksystem. There are essential nine components of any worksystem: (1) Organisation, (2) Enviornment, (3) Workspace, (4) Control, (5) Control Process, (6) Display, (7) Effector, (8) Processing, and (9) Senses. This study is the first study to pronounce that there is some sort of interrelationship and interaction among the components of worksystem.

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This emerged via Interpretative structural modelling analysis. It gives a structural hierarchy to these components in the system, through level partitioning analysis. Further with Fuzzy MICMAC analysis, these components were analysed for their nature/ behaviour in the worksystem and were classified accordingly into four clusters: (i) Driver, (ii) Linkage, (iii) Dependant, and (iv) Autonomous components.

Level-5 (environment, control, control process) and level-4 (workspace, effector, display) components which have taken highest structural hierarchy, also have higher driving powers. Its means driving components have more influence in worksystem, which is similar to observations made Gupta et al. (2013). This can be explained by the fact that, control process and controls have transited big time, with increase automation and complexity in the worksystem. The control processes have upgraded from being automatic to autonomous, with application of artificial intelligence and machine learning. Advanced industries like aviation and aerospace have auto pilot, which takes over the controls. Even the decision making of human pilot, during emergencies are controlled and overridden by auto pilot actions. The controls have graduated from levers, handles and buttons to touch pads, gesture control and biometric based operations. These controls have enhanced the complexity and coupling in worksystem. The sophisticated control process, actuator, display, and sensors need optimum environmental condition for their functioning; failing which their functions are also affected. Traditionally, the workspace design was limited to anthropometric limits of human operator. But in contemporary worksystem, the workspace is fragmented; and not necessarily limited to anthropometric limits of human. This is mainly where remotely operated electronic actuator and advance controls are part of worksystem. The spacio-temporal and fragmented worksystem (e.g., Unmanned armed vehicle) have different workspace for human and machine. These different workspaces may experience different environment. The chance of adverse environment affecting other components is very high and some unpredicted performance of components can lead to worksystem failure.

Similarly, traditionally the display is located as needed by human senses and processing; but in artificial intelligence and machine learning based worksystem, we have inbuilt sensors. At times, the display and controls also have common interfaces, like in touch screen and interactive panels. Thus, worksystem design and panning has evolved beyond traditional design parameters and interactions.

The processing in the worksystem has the main function of decision making and action orders. It is very important in critical situations to take quick, right decisions in stipulated time frame. The algorithm-based machine learning, cyber physical system imbedded with artificial intelligence (AI) have proven to be game changer. The right level of automation and degree of powers given to AI must be correctly defined by the organization. Different rules and regulations, guided by digital ergonomics need to be used, while drafting the standard operating procedures and manuals. The training, scheduling, maintenance, and compensations too must be redefined.

The insight into hierarchy, importance, nature, and influence of various worksystem components will be useful to the designers and operators, to implement relevant design, redundancies, standard operating procedure and manuals, needed for successful worksystems, with minimum possibility of failure.

Where robust worksystems are concerned, it will also help market strategist to focus on the strength of design, strength and technological advancement of various component, modernisation and safety aspects while managing branding, finding appropriate end-users, and after sales services. Such knowledge will help marketing by guiding segmentation and messaging strategies that align with needs of different industries.

Additionally, where, worksystems are technologically advanced, robust and has appropriate incorporated components and redundancies, thereby reducing the chance of

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failure; such knowledge can help market experts to position the said worksystem as authority in the defined type of worksystem. For example, advanced sensing and processing components are crucial in healthcare equipment, needed for patient monitoring and diagnostics.

This study is the first of its kind, that has highlighted the structural hierarchical model of worksystem, expressed the contextual relationship among various components of worksystem and has classified them on basis of their nature and influence in the worksystem. The ISM and Fuzzy MICMAC analysis methods used computer aided analytical methods to avoid biases. The information was gathered from highly skilled and experienced domain experts of various high-tech and advanced worksystem. But this was limited to the worksystem expertise of India. Opinions across the globe, especially where exposure to technology is high, may have additional inputs for ISM.

We recommend future researcher to take lead from outputs of this study and explore the worksystem and its components.

CONCLUSION

This study ascertains the significance of various components of worksystem and determines its hierarchical structure in worksystem, which is first of its kind. The inputs for this study are taken from highly experienced and core competent domain experts of different industrial sectors (defense, aviation, aerospace, nuclear sector, shipping and railways), that have very complex, tightly coupled and high end automated worksystem. The modelling and analysis were carried out using ISM and Fuzzy MICMAC analysis methods, which were computer aided.

This reduces the risk of biases and effects of individual opinions. Up till now, worksystem failure analysis were mostly post-facto in nature, where either human error, or worksystem /component failure are generally the cause. Human error is either on the part of operator, who defaulted on operation part or designer for inappropriate/ inadequate design. Whereas component failure is attribute to life cycle of components, inadequate preventive maintenance, and extent of exploitation of components. Though these are known cause, we must not overlook the fact that there are inter component relationships and certain pattern of component influences on other components or entire system. The insight of such knowledge will surely aid the analytics to better understand the failure reasons and optimise performance of worksystem.

While formulating safety parameters and redundancies in the worksystem; and drafting the standard operating procedure and manuals. The preventive maintenance and after sales services for any worksystem should incorporate the knowledge of intercomponent relationship and nature of worksystem component.

Accordingly, a checklist can be formulated. The components with higher driving power will have greater influence on the worksystem; and linkage components will affect the dependent and autonomous components through driver components. The ISM based model developed in the study will also assist in strategic decision making, required for administrative and operational purpose.

A robustness and sustainable worksystem, in various industrial sectors is the need of hours. All the worksystems and industrial practices are subjected to process audits, safety ratings and ranking, on basis of various parameters for successful performance in their business domain.

The output of this study will assist all the stakeholders in apt decision making, and to maintain a fine balance between performance, economics and safety of worksystem.

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