Operations Management Research (2019) 12:129–145
https://doi.org/10.1007/s12063-019-00143-x

Modelling the barriers of Health 4.0–the fourth healthcare industrial revolution in India by TISM

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Received: 6 February 2019 / Revised: 16 July 2019 / Accepted: 17 July 2019 / Published online: 9 August 2019

Abstract

In healthcare industry, the phenomenon of Industry 4.0 is popular as Health 4.0 where the modern technologies are integrated with available data along with the use of artificial intelligence. The main objective of this paper is to explore the barriers of Health 4.0 application in healthcare sector in India. Fifteen barriers which can affect the adoption of Health 4.0 in the Indian healthcare sector have been identified through extensive literature review and opinions of healthcare industry and academic experts. A TISM (Total Interpretive Structural Modelling) model has been developed to extract the key barriers influencing Health 4.0 adoption which will guide the healthcare managers and decision makers to explore the effect of each barrier on other barriers as well as the degree of relationships among them. The result shows that lack of top management support, exclusive and skilled workforce requirement, inadequate maintenance support systems and political support are the major barriers as they have strong driving power. Timely action taken by the management to remove these hurdles will not only reduce the cost of medical procedures but also improve the quality of treatment so that the true potential of Health 4.0 can be utilized.

Keywords Industry 4.0 · Health 4.0 · Health 4.0 barriers · Healthcare industry · Healthcare industrial revolution · Total interpretive structural modelling · MICMAC analysis

1 Introduction

The Industrial Revolution is considered to be one of the most significant landmark in the history which impacted all the aspects of life in one way or the other. Technological advancements and industrialization led to the development of highly automated and motorized manufacturing processes giving rise to evolution of factory system Kamble et al. (2018). The first industrial revolution occurred with the invention of steam engine by Thomas Newcomen in the late eighteenth century which led to the use of steam to make machines causing the development of textile, coal and iron industry. This resulted in urbanization and increased communications and people moved to those cities where they could work as operators in factories. To provide accommodation to these people, houses of cheaper quality were built and community wells were the only source of drinking water. Facilities for sewage removal were hardly present. This led to the deterioration of health and spread of diseases like typhoid, cholera, tuberculosis, fever, smallpox and plague etc. Side by side many medical innovations were made due to advancement in science and technology and scientific causes of some diseases were explored. In 1796, Edward Jenner was successful in developing smallpox vaccination. Before this, there was no awareness about the causes of spread of diseases and remedies were dependent upon several superstitions and speculations. In the 1850s, Louis Pasteur discovered that the causes of disease were microorganisms. Healthcare industry in that era witnessed the inception of modular information system technologies and that period was known as Health 1.0 (Bodenheimer 1995; Thuemmler and Bai 2017). Second industrial revolution was another transition in technology focussing on the extensive use of electrical energy, petroleum and steel for creating mass production. Improved factories and contemporary technologies gave rise to the discovery of microscopes and other medical equipment. Simple networking was introduced in healthcare industry with the evolution of Electronic Health

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Records (EHR) which were integrated with medical imaging techniques providing better diagnosis of diseases. This was termed as Health 2.0 (Thuemmler and Bai 2017). During third industrial revolution, there was intensive computerization and digitalization. Digitalization was a major driver for healthcare industry with the capacity to restructure patient landscape. There was emergence of new business models in healthcare where healthcare managers used to collect data from various sources and relevant and significant information was extracted. This decade observed the use of genetic information and development of implants and wearables. The integration and networking of this data with EHR processes was marked as Health 3.0 (Bodenheimer 1995; Gray 2008; Thuemmler and Bai 2017). The fourth industrial revolution (identified as Industry 4.0) is characterized by amalgamation of technologies from physics, biology and information technology (Acemoglu 2002; Von Tunzelmann 2003). Industry 4.0 initially took place in Germany with a mission to create smart industries with the use of new advanced IT technologies such as big data analytics, cloud computing, virtual reality, internet of things, additive manufacturing and robotics etc. to create cyber-physical systems (CPS) in different sectors including healthcare. This is attained with the interaction and networking of various components of the processes and practically generate value reinforced by cyber physical technology, human-equipment interaction and novel business frameworks. In healthcare industry, this phenomenon of Industry 4.0 is also popular as Health 4.0 where all modern technologies described above are integrated with available data along with the use of artificial intelligence (Thuemmler and Bai 2017). Health 4.0 have made healthcare sector more collaborative, convergent and predictive. Now large amount of information is available to the doctors online which allows easy portability of data which can be accessed anywhere anytime by the healthcare professionals. Industry 4.0 is basically based upon nine pillars which are described in Table 1 (Qin et al. 2016; Rüßmann et al. 2015).

Industry 4.0 can point out the areas where there is scope for improvement thereby making decision process more informative and innovative. It has the ability to transform healthcare sector from a focussed and compassionate system to a value oriented system which can ensure proactive preventive measures. Department of Health has already started implementing Industry 4.0 concept in United States, where it has been declared that within a year 90% of Medicare would be converted into value based framework. Though the Indian healthcare sector is expanding rapidly and is expected to reach 280 billion US Dollars by the year 2020, yet it is highly fragmented (Raghupathi and Raghupathi 2014). A detailed comparison between Indian Healthcare industry today and by 2020 is depicted in the Fig. 1.

Industry 4.0 is the most advanced concept that has the capability to change the future of Indian healthcare sector if implemented judiciously and cautiously.

2 Review of literature

Literature review is divided into two sections. In the first section, literature on Industry 4.0 and its technologies in different industries are presented. In the second section, researches regarding the application of Industry 4.0 in healthcare industry are reviewed.

2.1 Industry 4.0 and its technologies

Industry 4.0 technologies are being widely used in manufacturing and automation sector. Kagermann et al. (2011) firstly explained the elementary concepts of Industry 4.0 and laid the basis of this emerging phenomenon. Authors identified Germany as a leading country in manufacturing sector where Industry 4.0 can be best implemented and physical world is blended with virtual world creating smart factories. In 2018, Kamble et al. identified twelve barriers which can hamper the manufacturing industries to implement Industry 4.0. Interpretive Structural Modelling approach was used to identify the interactive relationships among these barriers and a framework was developed so that Industry 4.0 can be implemented successfully (Kamble et al. 2018). Cao et al. in 2017 established the use of cloud computing in supply chain management (Cao et al. 2017). Holmstrom et al. indicated in their research that 3D printing offers a number of opportunities for innovations in products and processes and has revolutionized manufacturing industry along with their supply chains structures (Holmström et al. 2016). In 2016, Harrison et al. reviewed certain engineering techniques adopted for Industry 4.0. Authors conducted a case study on the applications of cyber physical system toolkit innovated at a university in United Kingdom that how it can support automation systems (Harrison et al. 2016). Also, Bahrin et al. reviewed the role of robotic and automation technologies in attaining Industry 4.0 (Bahrin et al. 2016). Bagheri et al. in their study constructed a model where CPS can be integrated in the manufacturing sector. It was stated that CPS are aimed to detect the information and explained "adaptive cluster" in detail for data analysis (Bagheri et al. 2015). Zhou et al. in their research introduced important technologies and several opportunities and challenges of Industry 4.0 in China. The study shows that for Industry 4.0 to be successful, China requires innovations in technology, knowledge and management with regard to manufacturing sector (Zhou et al. 2015). In 2015, Shafiq et al. defined cyber physical systems as "the conjunction of the physical and digital worlds by creating global networks for businesses that integrate their technology, warehousing systems, and production facilities". Digitization of physical systems is done to manage their operations (Shafiq et al. 2015). Deane et al. in 2009 discussed about management of supply chains risks and disruptions from IT security incidents (Deane et al. 2009). Besides this other industries have also started adopting Industry 4.0 technologies. In 2014 Lasi et al. discussed different key technologies and explored various driving forces for the Industry 4.0 concept (Lasi et al. 2014). Mueller et al. discussed the requirement and challenges of implementation of Industry 4.0 with special emphasis on cyber physical systems. The paper helps in understanding the theoretical concepts of Industry 4.0. Results of the study show that frameworks based on CPS help the industries to attain proper control over smart machineries. On the other hand, there are some challenges like data security, maintenance issues which need to be overcome (Mueller et al. 2017). In 2016, Harrison et al. reviewed certain engineering techniques adopted for Industry 4.0. Authors conducted a case study on the applications of cyber physical system toolkit innovated at a university in United Kingdom that how it can support automation systems (Harrison et al. 2016).

2.2 Literature review on health 4.0

In 2017 Thuemmler and Bai described in their book how advanced digital services and big data analytics are having a significant impact on healthcare industry and the fourth industrial revolution in healthcare is called as Health 4.0. The authors have narrated that the technological drivers of Industry 4.0 i.e. artificial intelligence, cloud computing, automated robots and cyber physical systems are bringing a major change in working style of industrial systems which is also affecting

Table 1 Pillars of Industry 4.0

S. No.	Pillars of Industry 4.0	Description
1	Horizontal and vertical system integration	Industry 4.0 concept creates maximum integration among different healthcare industries and their departments thereby enhancing their functionality and capabilities which become more cohesive due to evolution of universal clinical data integration.
2	The Internet of Things	It is a system of interlinked electronic and computing devices, digital machines, humans and objects so that data can be transferred within a network without any human to human or human to computer interaction to improve productivity and to make better decisions.
3	Cybersecurity	For Industry 4.0 concept to be successful, genuine and authentic communication and data security measures are required to deal with the cybersecurity issue. Secure, observant and vigilant strategies are required as cyber threats increase with increased networking and communication.
4	The Cloud	Industry 4.0 concept requires more data sharing across the industries. With improved cloud computing technologies, functionality of the machines will improve thereby minimizing the response time resulting in best service delivery.
5	Big Data Analytics	In Industry 4.0 huge data is collected from wide variety of sources to optimize production quality and minimize cost. With more number of sensors and processors integrated into the manufacturing system, it will be easier to improve the quality as well as quantity of data. Big data analytics help to achieve the maximum information from the huge data sets.
6	Simulation	Also referred as "Digital Twin" it is an exact digital mirror image of a production system which can simulate real time performance of a system. This helps to check the machines for the next product virtually before switching over physically so that quality of the product may be improved and best results can be achieved.
7	Additive manufacturing	3D printing is adopted by the companies for producing customized products in small batches which have many advantages like light weight products which are easier to be transported. Additive manufacturing will decrease transport and inventory costs.
8	Augmented reality	Augmented reality will have a significant role in Industry 4.0 as it helps in providing real and accurate information to the right people at right time and place. This will make systems more flexible and adaptive leading to less defects during operation facilitating better decision making.
9	Autonomous robots	Robots today have become more autonomous, cooperative and can handle complicated tasks easily. After a period of time robots will interact with each other and with humans and learn from them. They can be programmed to operate in remote areas in the similar environment as humans.

healthcare domain due to which even clinical care can be provided virtually outside the hospitals. Now patients can also keep a track of their health conditions with the help of smart devices based on data analytics (Thuemmler and Bai 2017). Manogaran et al. explored the role of sensor tailored wearable medical devices in providing information about our physical and psychological health. These sensors generate extensive data which is commonly called as Big data. A new and secure "Cloud-Redirection (MC-R) architecture" has been proposed to analyse the data generated by the sensors like heart rate, blood pressure, blood sugar level and pulse rate for healthcare processes. If any of these parameters exceeds its normal value, a warning message is sent to the physician with the help of wireless networks (Manogaran et al. 2017). Filipe et al. reviewed the contributions of "Wireless Body Area Networks (WBANs)" for various healthcare applications to monitor clinical parameters (Filipe et al. 2015). In 2014, Bates et al. analysed the role of big data analytics for the management of high cost and high risk patients. The authors discussed how different data analytical techniques like algorithms and monitoring systems can reduce costs and improve clinical outcomes (Bates et al. 2014). Chawla and Davis 2013 presented a framework with the help of which Big data can be utilized for patient oriented outcomes so that patient readmission rates can be reduced (Chawla and Davis 2013). Jee and Kim conducted a study to explore how big data applications can be used for reshaping the healthcare sector. Various opportunities and challenges brought about by big data are also discussed. The study concludes that data security is one of the major challenge which should be handled with utmost care and a structured approach is required for the management and integration of big data (Jee and Kim 2013). In 2011, Kumar and Lee conducted a survey to explore the critical issues like data security and confidentiality in healthcare programs using "Wireless Medical Sensor Networks (WSMNs)". They highlighted security issues in some well-known projects which were using WSMN technology. It was concluded that a well-designed security system is required for successful implementation of these wireless technologies and people will believe in a technology only if it is feasible, safe and practical (Kumar and Lee 2011). Lorincz et al. also explored the use of sensor networking technology in emergency clinical and disaster responses. The authors brought about certain challenges faced by the healthcare managers and concluded that a common digitized framework is required for integrating different devices so that better response can be provided for medical emergency and disaster management (Lorincz et al. 2004).

All the studies stated above show that though Industry 4.0 applications are being used in healthcare sector, still in India, only few large super speciality healthcare chains are trying to adopt Industry 4.0. Majority of healthcare organizations are still doubtful about its implementation because of excess investment in terms of infrastructure, training and policies (Kagermann 2015). Therefore, it is very important to explore the barriers of Industry 4.0 implementation in healthcare industry in India so that it can be implemented successfully and organizations can avail maximum benefit of this emerging phenomenon.

The objectives of this paper are as under:

1. To explore the barriers of Industry 4.0 application in healthcare sector in India and to identify mutual relationship among these barriers.
2. To compute the driving power and dependence power of these barriers using MICMAC i.e.

Fig. 1 Indian Healthcare industry today and by 2020 Rudrappa et al. (2019)

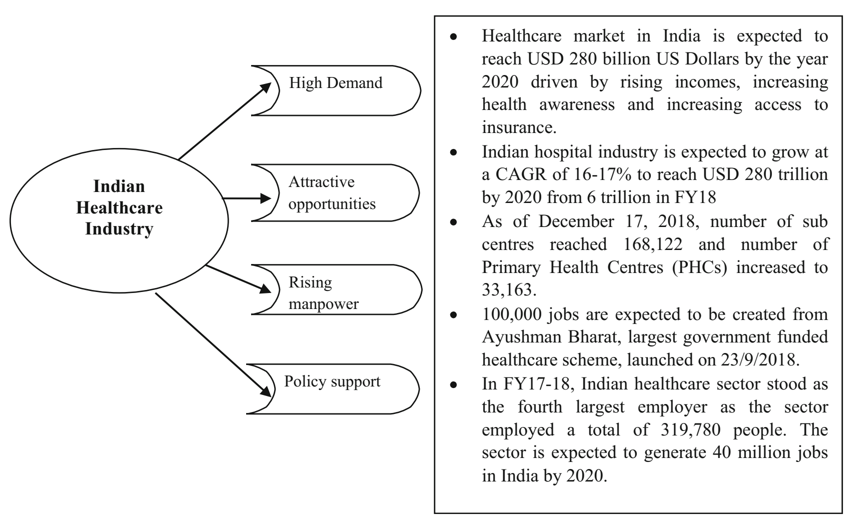

Table 2 Barriers to the adoption of Health 4.0 in India

S.No	Health 4.0 adoption barrier	Description	Reference
1	Job disruption risk (BH1)	Automated and robotic technologies play a major role in Health 4.0. But this leads to the replacement of employees with these automated technologies resulting in human job losses.	Qureshi and Syed (2014); Frey and Osborne (2017)
2	Extensive capital requirement (BH2)	Implementation of Health 4.0 requires excessive initial investment to develop appropriate infrastructure and advanced automated technologies in the healthcare organizations. Technologies like IoT require huge capital and there is always a fear of economic loss.	Kamble et al. (2018); Kamigaki et al. (2017)
3	Exclusive and skilled workforce requirement(BH3)	For successful implementation of Health 4.0, specialized training and skilled healthcare workforce is required to handle automated smart machines. Healthcare organizations have to lay emphasis on provision of special training sessions as digitization and use of Internet of Things requires good technical knowledge and enhanced skills. Clinical data is very sensitive and need to be handled very carefully which is possible only if workforce is specifically trained for this purpose to protect data theft.	Benešová and Tupa (2017); Gehrke et al. (2015)
4	Cybersecurity and privacy issues (BH4)	This is one of the biggest hurdle for successful implementation of Health 4.0. Large amount of confidential information is available online across cloud computing environment. This poses data security issues as important private data may be accessed by other parties which is a very sensitive issue in healthcare. Therefore it is obligation for the employees to be aware of cyber threat and data security. Cyber physical systems are more prone to cyber-attacks. So this issue needs to be addressed very carefully.	Kamble et al. (2018); Alaba et al. (2017); Babiceanu and Seker (2016)
5	Insufficient compendious IT infrastructure (BH5)	Advanced IT infrastructure is necessary to use Internet of Things for reinforcing Health 4.0 implementation. Absence of efficacious communication network and weak signal strength may hamper the entire process as continuous availability of data both horizontally and vertically is very important. This issue is a major concern for small healthcare organizations in India because of limited resources and insufficient data backup system.	Hecklau et al. (2016); Yan et al. (2014)
6	Intellectual property issues (BH 6)	The concept of intellectual property rights would be challenged in the era of Health 4.0. New innovations in medical field with the use of latest technologies may give rise to issues like patents, copyrights and licensing etc. which have to be handled with care.	Hecklau et al. (2016) (Bonczek et al. 2014; Lee, Kao, & Yang, 2014)
7	Non uniform regulations for clinical information exchange (BH7)	Health 4.0 is in a nascent stage in India. Lack of uniform standards for information exchange is making it hard for smaller hospitals to implement Health 4.0 and join the digital network chain as norms and standards are different for different organizations. Therefore, there is urgent requirement of standardized norms for implementing 4.0.	Christians and Liepin (2017)
8	Legal Implications regarding external data use (BH8)	Because of rising competition, digitalization is posing a challenge before law as proper knowledge about data security and artificial intelligence have to be followed before implementing a new digital phenomenon. Longstanding guidelines regarding the acceptance of clinical services must thus be revised before digital healthcare can really get going.	Christians and Liepin (2017); Shelbourn et al. (2005)
9	Inadequate maintenance support system (BH9)	Health 4.0 implementation requires extensive IT infrastructure that needs to be maintained and serviced regularly as any disruption in the integrated process will disrupt the entire system which is very dangerous for healthcare. Therefore smart maintenance systems should be there to avoid any breakdown. (Lee et al., 2014).	Lee et al. (2014)
10	Political support (BH 10)	There is huge requirement for certain vocational courses like big data analytics, data science, and specialized computer courses in this growing age of digitalization. Government should support by creating the basis of these fundamental requirements for Health 4.0 adoption. Also, Government can support by laying uniform standards at national and international levels which will help in free and secured information exchange (Bonczek et al. 2014).	Bonczek et al. (2014)
11	Lack of R & D clusters (BH11)	Continuous research and development is required in healthcare sector as doctors should be well versed with latest emerging diagnostic techniques and surgical interventions. There are inadequate R & D clusters and research facilities in hospitals in India.	Raghupathi and Raghupathi 2014
12	Lack of digital strategy and resource scarcity (BH12)	In a developing country like India, there is scarcity of resources and many diagnostic and therapeutic equipment are imported from other countries	Schröder (2016)

Table 2 (continued)

S.No	Health 4.0 adoption barrier	Description	Reference
		which sometimes lead to software compatibility issues. Sometimes hospitals don't have their own IT infrastructure due to which managers face difficulties in using IT technologies and finding the accurate solution.	
13	Lack of top management support (BH13)	Health 4.0 implementation initially requires extensive investment to develop and maintain appropriate infrastructure in the organizations. Additional cost is required for the training of the workforce. If top management is not supportive Health 4.0 adoption will not be successful.	Kamigaki et al. (2017)
14	Fragmented and non- standardized clinical data (BH14)	Healthcare industry in India is highly fragmented and rarely standardized. It is difficult for doctors, patients and managers to sustain a general overview of the different dimensions of care.	Raghupathi and Raghupathi 2014
15	Apprehension about IoT use (BH15)	IoT is one of the important pillars of Health 4.0 and if used judiciously can bring great economic gains for the healthcare organizations. But employees are still unclear about the potential benefits and proper use of IoT in terms of value and fast delivery of services. Several applications and technologies from IoT are still in the nascent stage and their outcomes are uncertain.	Ryan and Watson (2017); Li et al. (2015)

Matrice d'Impacts croises-multipication applique´ an classment (Impact Matrix Cross-Reference Multiplication Applied to Classification) analysis in order to rank them in order of priority so that they can be handled successfully.

Fig. 2 Flow diagram of TISM Methodology

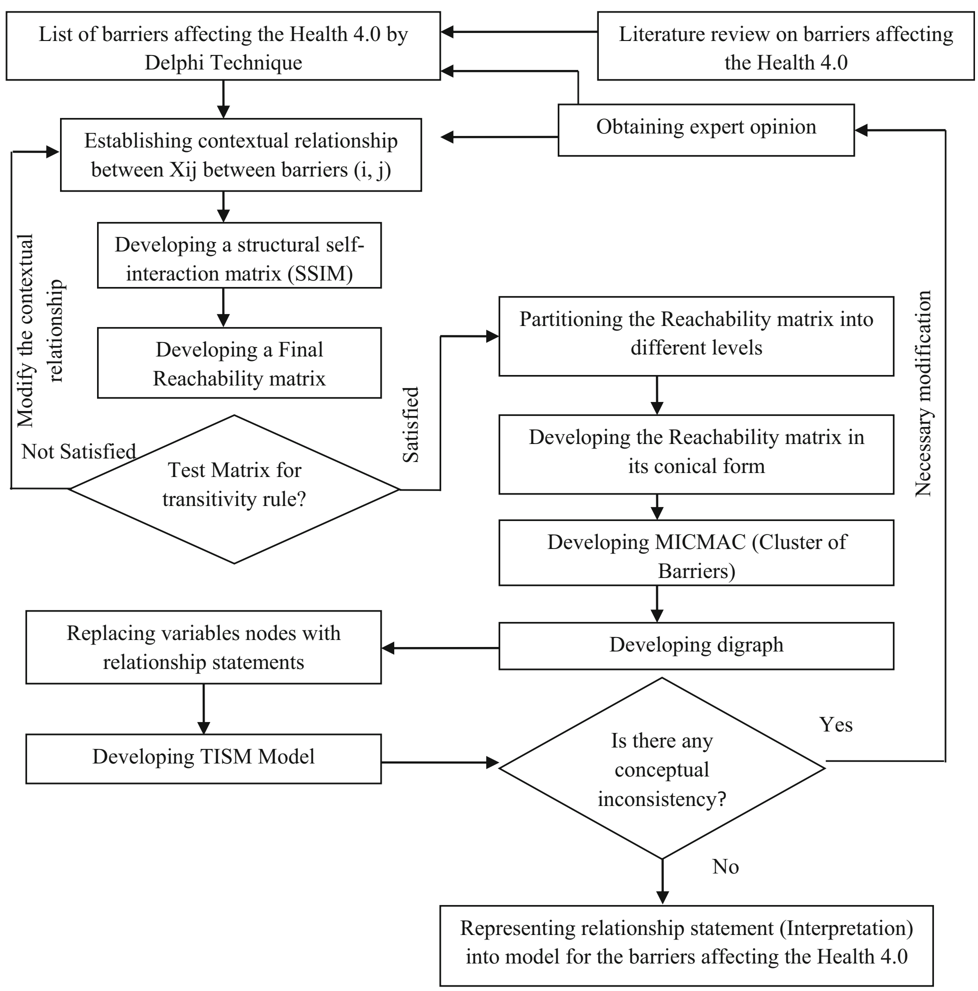

Table 3 Barriers, contextual relationship and interpretation

Barrier No.	Barrier	Contextual relation	Interpretation
	Health 4.0 adoption barrier	Barrier A will influence / enhance barrier B	How or in what way Barrier A will influence/enhance barrier B
BH1	Job disruption risk (BH1)		
BH2	Extensive capital requirement (BH2)		
BH3	Exclusive and skilled workforce requirement(BH3)		
BH4	Cybersecurity and privacy issues (BH4)		
BH5	Insufficient compendious IT infrastructure (BH5)		
BH6	Use Intellectual property issues (BH6)		
BH7	Non uniform regulations for clinical information exchange (BH7)		
BH8	Legal Implications regarding external data use (BH8)		
BH9	Inadequate maintenance support system (BH9)		
BH10	Political (BH10)		
BH11	Lack of R & D clusters (BH11)		
BH12	support Lack of digital strategy and resource scarcity (BH12)		
BH13	Lack of top management support (BH13)		
BH14	Fragmented and non- standardized clinical data (BH14)		
BH15	Apprehension about IoT (BH15)		

3. To develop a comprehensive structured model using TISM (Total Interpretive Structural Modelling) methodology to overcome these barriers.

3 Research methodology

3.1 Delphi technique to identify the barriers to adoption of health 4.0

Health 4.0 is an advanced concept where large number of elements incorporating industrial processes are amalgamated with internet networking technologies resulting in smart hospitals ahead. New innovations in healthcare industry and Industry 4.0 technologies promise to generate value added services. In a developing country like India, there is extensive digital divide between urban and rural areas and rural population is devoid of even basic healthcare facilities. Health 4.0 technologies like telemedicine, robotics can resolve this issue. But in India this revolution is still in its nascent stage. Health 4.0 has the potential to change the future of Indian healthcare industry. But there are certain barriers like cybersecurity, legal implications, non-standardized data which need to be addressed cautiously, otherwise real potential of Health 4.0 can never be attained. In order to identify the barriers which can affect the implementation of Health 4.0 in India we adopted an extensive review of existing literature and viewpoints of experts from healthcare and academic sector. Initially, articles published on Health 4.0, Industry 4.0 in healthcare and technologies of Industry 4.0 in peer reviewed journals, reports from the industry, newspaper and magazine articles were explored and 20 barriers were identified. After this, Delphi technique was performed in which a team of fifteen experts from the relevant areas were taken for validation of the barriers. Six doctors, five healthcare IT experts and four academicians having knowledge of Industry 4.0 applications were selected for this purpose from the hospitals of Delhi and NCR (Near Capital Regions). Previous researches show that ten to thirty experts are appropriate for carrying out Delphi technique in qualitative studies (Murry Jr and Hammons 1995). Finally after few rounds of Delphi, fifteen barriers appropriate for Indian healthcare sector were selected. These fifteen barriers are described in Table 2.

3.2 TISM methodology

TISM starts with establishing contextual relationships among different factors explored from the review of literature and expert's perspective (Jain and Raj 2016). TISM methodology was defined by Sushil (Sushil 2012a) and is derived from the concept of ISM methodology which was suggested by

Table 4 Contextual relationship

Symbol	Illustration
V	When barrier i influences or reaches to barrier j
A	When if barrier j reaches to barrier i
X	When both barriers i and j reach to each other
O	When there is no relationship between barriers i and j

Table 5 Structural self-interaction matrix (SSIM)

	BH15	BH14	BH13	BH12	BH11	BH10	BH9	BH8	BH7	BH6	BH5	BH4	BH3	BH2
BH1	A	O	A	A	O	A	A	O	O	O	A	O	A	X
BH2	A	A	A	A	O	A	A	O	X	A	O	A	A	
BH3	V	V	A	V	O	V	V	O	V	V	V	V		
BH4	A	O	A	A	O	O	A	A	V	X	O			
BH5	V	V	A	V	O	A	A	V	V	V				
BH6	A	X	A	A	O	A	O	O	O					
BH7	O	O	A	O	X	O	A	O						
BH8	A	O	A	X	V	A	O							
BH9	V	V	A	V	V	X								
BH10	V	V	A	V	V									
BH11	O	O	A	O										
BH12	O	O	A											
BH13	V	V												
BH14	A													

Warfield in 1973 (Warfield 1973). In TISM, complicated systems are interpreted and represented graphically (Sushil 2012b). ISM proposes the interrelationships among different factors which is further depicted in the form of a diagraph. TISM may also be referred as the advanced version of ISM and some studies have been conducted using this technology (Ajmera and Jain 2019a; Dubey and Ali 2014; Jain and Ajmera 2018; Jain and Raj 2014; Nasim 2011). TISM expresses direct and transitive relationships among different elements so that structured model can be interpreted also. TISM has been used in various areas like e-governance (Nasim 2011), Flexibility dimensions (Dubey and Ali 2014), education (Mahajan et al. 2016), performance management (Yadav 2014; Yadav et al. 2015), flexible manufacturing systems (Jain and Raj 2015; Jain and Soni 2019), organization excellence (Agarwal and Vrat 2015), quality of life in diabetic patients in India (Ajmera and Jain 2019b) and supply chain (Dubey et al. 2017). TISM has been used in higher private technical education (Prasad and Suri 2011) to analyze the relationships among different strategic performance management factors for exploring the best strategy (Kumar Srivastava and Sushil 2014). TISM has been used to identify various enablers in order to enhance sustainability of integrated logistics in an environment having uncertainty (Mohanty and Shankar 2017). Khatwani et al. also suggested TISM methodology for group decision making process (Khatwani et al. 2015).

Subsequent steps of TISM methodology are explained below: (Flow diagram is shown in Fig. 2)

Table 6 Initial reachability matrix

	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14	BH15
BH1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
BH2	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
BH3	0	1	1	1	1	1	1	0	1	1	0	1	0	1	1
BH4	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
BH5	1	0	0	0	1	1	1	1	0	0	0	1	0	1	1
BH6	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0
BH7	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0
BH8	0	0	0	1	0	0	0	1	0	0	1	1	0	0	0
BH9	1	1	0	1	1	0	1	0	1	1	1	1	0	1	1
BH10	1	1	0	0	1	1	0	1	1	1	1	1	0	1	1
BH11	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
BH12	1	1	0	1	0	1	0	1	0	0	0	1	0	0	0
BH13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BH14	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0
BH15	1	1	0	1	0	1	0	1	0	0	0	0	0	1	1

Table 7 Final reachability matrix

	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14	BH15
BH1	1	1	0	0	0	0	1*	0	0	0	0	0	0	0	0
BH2	1	1	0	0	0	0	1	0	0	0	1*	0	0	0	0
BH3	1*	1	1	1	1	1	1	1*	1	1	1*	1	0	1	1
BH4	1	1	0	1	0	1	1*	0	0	0	0	0	0	1*	0
BH5	1	1*	0	1*	1	1	1	1	0	0	1*	1	0	1	1
BH6	1*	1	0	1	0	1	1*	0	0	0	0	0	0	1	0
BH7	1*	1	0	0	0	0	1	0	0	0	1	0	0	0	0
BH8	1*	1*	0	1	0	1*	0	1	0	0	1	1	0	0	0
BH9	1	1	0	1	1	1*	1	1*	1	1	1	1	0	1	1
BH10	1	1	0	1*	1	1	1*	1	1	1	1	1	0	1	1
BH11	0	1*	0	0	0	0	1	0	0	0	1	0	0	0	0
BH12	1	1	0	1	0	1	1*	1	0	0	0	1	0	0	0
BH13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BH14	1*	1	0	1*	0	1	1*	0	0	0	0	0	0	1	0
BH15	1	1	0	1	0	1	1*	1	0	0	1*	0	0	1	1

1. Identify the barriers.
2. Interpret the interrelationships between the barriers. Apart from indicating whether 'element A will influence/ enhance element B' or not, it also explains 'how and in what way they will influence/ enhance each other'. It is depicted in Table 3.
3. Construction of Structural self-interaction (SSIM) matrix:

Taking into account the circumstantial relationships, the interaction between two elements (i and j) is determined by relevant experts. The symbols used to determine the interaction between any two factors are V, A, X, and O.

The use of symbols in SSIM has been explained in the Table 4.

4. Development of Reachability Matrix (RM):

This is established by converting information within SSIM into binary digits of 1 and 0 criteria which is also depicted in Table 4 above.

5. Transitivity Check

Transitivity is checked in the matrix rule and incorporated wherever required.

Table 8 Iterations

Sr.No.	Reachability set	Antecedent set	Intersection set	1eve1
BH1	1,2,7	1,2,3,4,5,6,7,8,9,10,12,13,14,15	1,2,7	I
BH2	1,2,7,11	1,2,3,4,5,6,7,8,9,10,11,12,14,15	1,2,7,11	I
BH7	1,2,7,11	1,2,3,4,5,6,7,9,10,11,12,13,14,15	1,2,7,11	I
BH11	2,7,11	2,3,5,7,8,9,10,11,13,15	2,7,11	I
BH4	4,6,14	3,4,5,6,8,9,10,12,13,14,15	4,6,14	II
BH6	4,6,14	3,4,5,6,8,9,10,12,13,14,15	4,6,14	II
BH14	4,6,14	3,4,5,6,9,10,13,14,15	4,6,14	II
BH8	8,12	3,5,8,9,10,12,13,15	8,12	III
BH12	8,12	3,5,8,9,10,12,13	8,12	III
BH15	15	3,5,9,10,13,15	15	IV
BH5	5	3,5,9,10,13	5	V
BH9	9,10	3, 9,10,13	9,10	VI
BH10	9,10	3,9,10,13	9,10	VI
BH3	3	3,13	3	VII
BH13	13	13	13	VIII

Table 9 Conical matrix

	BH1	BH2	BH7	BH11	BH4	BH6	BH14	BH8	BH12	BH15	BH5	BH9	BH10	BH3	BH13	Dr.P
BH1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
BH2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	4
BH7	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	4
BH11	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	3
BH4	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	6
BH6	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	6
BH14	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	6
BH8	1	1	0	1	1	1	0	1	1	0	0	0	0	0	0	7
BH12	1	1	1	0	1	1	0	1	1	0	0	0	0	0	0	7
BH15	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	9
BH5	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	11
BH9	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	13
BH10	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	13
BH3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
BH13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
DP	14	15	14	10	11	11	9	8	7	6	5	4	4	2	1	

6. Reachability Matrix Partition

The partitioning of reachability matrix is performed on different sets and subsets of the elements. A conical matrix is developed from final reachability matrix. The drive power of a barrier is derived by summing up the number of ones in the rows and its dependence power by summing up the number of ones in the columns. Clusters of barriers affecting the barriers of healthcare 4.0 is developed from the conical matrix.

7. Developing Digraph and TISM model

After checking for transitivity, digraph is created by identifying different levels of elements. This diagraph depicts hierarchy barriers. After this, final TISM model is constructed

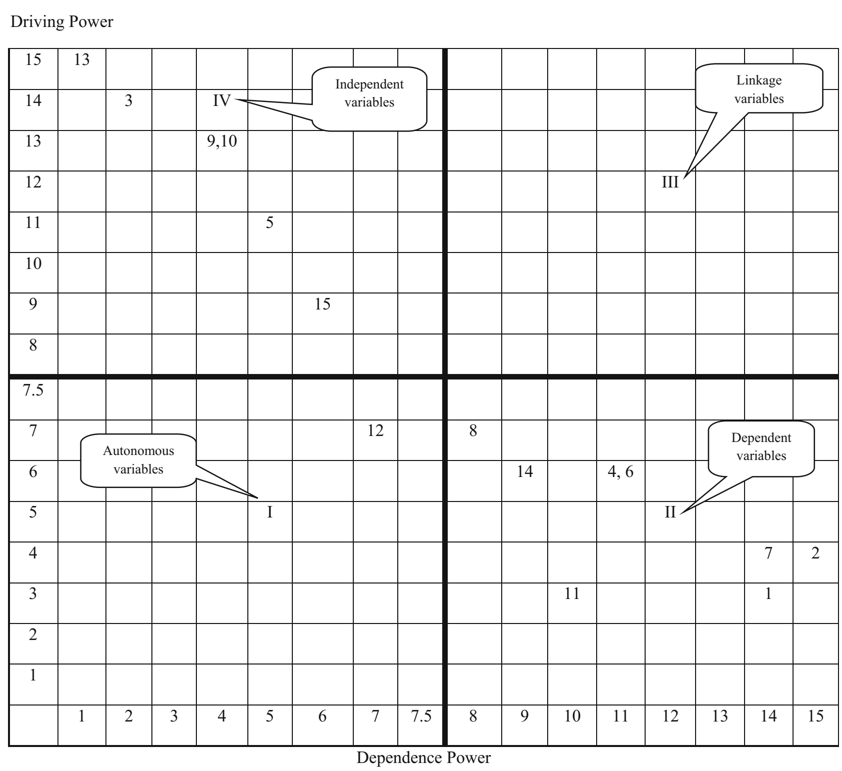

Fig. 3 Clusters of barriers affecting the barriers of healthcare 4.0

where all transitive and the direct influencing links are incorporated. Besides this, interpretation of relationships is also included to provide a proper explanation about the impact of one barrier on other.

4 Modelling the barriers to the adoption of health 4.0 by TISM

Different steps to do the modelling of barriers to the adoption of Health 4.0 by TISM are given below:

1. Delphi technique - In the present research, the viewpoints of 15 professional experts (10 from healthcare industry and 5 from academia) were considered for analysis of relationship among criteria.
2. Selection of the barriers of Health 4.0 in the healthcare industry in India. Fifteen barriers were selected as described in the previous section.
3. Collection of responses and development of SSIM Matrix

In the present work, opinions of fifteen experts who have thorough understanding of the problem and have adequate experience in handling such problems were taken. Initial SSIM matrices were developed taking into account responses of all the experts based on the degree of interrelationship between the criteria.

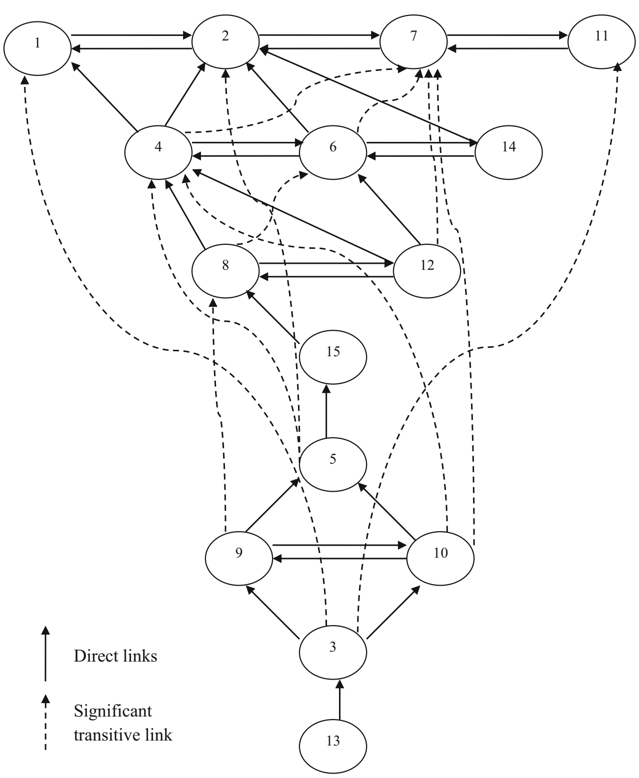

Fig. 4 Diagraph with significant transitive links

4. Computation of SSIM and Final Reachability Matrix

Table 5 Depicts the values of SSIM matrix. SSIM is converted into binary digits of 1 and 0 criteria as shown below

Symbol	Illustration	Binary digit in initial RM	
		(i,j) entry in matrix	(j,i) entry in the matrix
V	If factor i influences or reaches to factor j	1	0
A	If factor j influences or reaches to factor i	0	1
X	If both factors i and j influence each other	1	1
O	For no relation between two factors	0	0

Initial reachability matrix is shown in Table 6.

5. The matrix is reviewed for the transitivity links as depicted in Table 7 as final reachability matrix.

The matrix is then partitioned and the levels of different iterations are presented in Table 8.

A conical matrix is developed from final reachability matrix. It is shown in Table 9. Clusters of barriers affecting the barriers of healthcare 4.0 is developed from the conical matrix and shown in Fig. 3.

6. Graphical representation of the barriers in different levels is done and the directed links are introduced taking into account the interrelationships according to the reachability matrix. The significant transitive mutual relationships are shown in Fig. 4.
7. The final digraph is transformed into a binary interaction matrix and interpretive matrix and the interpretations of the barriers demonstrated in Tables 10 and 11.
8. TISM is derived from the connective and interpretive information demonstrated in the interpretive direct interaction matrix and digraph which is displayed in Fig. 5. Interpretations of the barriers are discussed in Table 11.

5 Data analysis and results

MICMAC analysis is conducted to explore and map the barriers of Health 4.0 in the Indian healthcare sector according to their drive and dependence powers shown in Table 8 as a conical matrix. These barriers are then classified into four groups i.e. autonomous, dependent, linkage and independent using MICMAC analysis.

(a) Group 1 barriers (Autonomous): These barriers are placed in the first quadrant and have weak drive and dependence powers. In the present work, "Lack of digital strategy and resource scarcity (BH 12)" lie in this quadrant.
(b) Group 2 barriers (Dependent): These barriers have strong dependence power but weak driving power. They lie in the second quadrant and are influenced by various other barriers. In this research, "Job disruption risk (BH1), Extensive capital requirement (BH2), Cybersecurity and privacy issues (BH4), Intellectual property issues (BH 6), Non uniform regulations for clinical information exchange (BH7), Legal Implications regarding external data use (BH8), Lack of R & D clusters (BH11) and Fragmented and non- standardized clinical data (BH14)" represent this quadrant.
(c) Group 3 barriers (Linkage): These barriers possess strong driving as well as dependence power. They are unsteady and very important and any activity with them will have a direct influence on others and also have feedback effect upon them. In this research no barrier lies in this quadrant.
(d) Group 4 Barriers (Independent): They lie in fourth quadrant and have strong driving power but weak dependence power. "Exclusive and skilled workforce requirement (BH3), Insufficient compendious IT infrastructure (BH5), Inadequate maintenance support system (BH9), Political support (BH 10), Lack of top management support (BH13), Apprehension about IoT use (BH15)" lie in this quadrant.

Results of the present work depict that "Lack of top management support" is the major barrier to the successful adoption of Health 4.0 in Indian healthcare industry as this barrier has very high driving power. Successful adoption of Health 4.0 in in India depends upon top management support to a large extent as this barrier has very high driving power. Health 4.0 requires extensive initial investment to develop and maintain appropriate infrastructure in the organizations. Also, additional cost is required for the training of the workforce and maintenance of support systems. All the major decisions are taken by top management. If top management is not supportive, Health 4.0 adoption will not be successful. Therefore it is essential for the top management to first understand the importance of technologies of Health 4.0 so that it can be implemented with high priority in the organizations. Another important barriers are exclusive and skilled workforce requirement, political support and inadequate maintenance support systems. Specialized technical and operational skills in handling the wide variety of clinical and non-clinical data in healthcare is the major requirement for Health 4.0. Digitization will change the specifications of the employees in all the phases of clinical chain i.e. from patient admission to discharge. All the medical processes will become more data driven requiring a completely new workforce expert in automation and software development. A similar study conducted by Koch et al. also concludes that Industry 4.0 requires employees who are expert in latest technologies of digitization (Koch et al. 2014). Health 4.0 requires substantial IT infrastructure that needs to be maintained and serviced regularly as any disturbance in the integrated process will disrupt the entire system. Therefore these issue need special attention and

Table 10 Interaction matrix

	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14	BH15
BH1	–	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
BH2	**1**	–	0	0	0	0	**1**	0	0	0	0	0	0	0	0
BH3	*1*	0	–	0	0	0	0	0	**1**	**1**	*1*	0	0	0	0
BH4	**1**	**1**	0	–	0	**1**	*1*	0	0	0	0	0	0	0	0
BH5	0	*1*	0	*1*	–	0	0	0	0	0	0	0	0	0	**1**
BH6	0	**1**	0	**1**	0	–	*1*	0	0	0	0	0	0	**1**	
BH7	0	**1**	0	0	0	0	–	0	0	0	**1**	0	0	0	0
BH8	0	0	0	**1**	0	*1*	0	–	0	0	0	**1**	0	0	0
BH9	0	0	0	0	**1**	0	0	*1*	–	**1**	0	0	0	0	0
BH10	0	0	0	*1*	**1**	0	*1*	0	**1**	–	0	0	0	0	0
BH11	0	0	0	0	0	0	**1**	0	0	0	–	0	0	0	0
BH12	0	0	0	**1**	0	**1**	*1*	**1**	0	0	0	–	0	0	0
BH13	0	0	**1**	0	0	0	0	0	0	0	0	0	–	0	0
BH14	0	**1**	0	0	0	**1**	0	0	0	0	0	0	0	–	0
BH15	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	–

Bold direct link

Italic Significant transitive link

Table 11 Barriers contextual relationship with interpretation

Barrier No.	Barrier	Contextual relation	Interpretation
	Health 4.0 adoption barrier	Barrier A will influence / enhance barrier B	How or in what way Barrier A will influence/ enhance barrier B
BH1	Job disruption risk	Barrier 1 influences barrier 2	To avoid the fear of job disruption among employees, special training is required to enhance their skills which requires extra financial burden on the management.
BH2	Extensive capital requirement	Barrier 2 influences barrier 1	Extra financial burden is borne by the management to provide training of advanced concepts of Health 4.0 to the employees so that the fear of jobs risk due to emerging technologies is avoided among them.
		Barrier 2 influences barrier 7	Extra capital investment is required to bring uniformity in regulations for clinical information exchange as processes have to be regularized at several platforms.
BH3	Exclusive and skilled workforce requirement(BH3)	Barrier 3 influences barrier 1	For successful implementation of Health 4.0, specialized training and skilled healthcare workforce is required to handle automated smart machines. This creates job risk among the existing employees.
		Barrier 3 influences barrier 9	Industry 4.0 implementation requires extensive IT infrastructure that needs to be maintained and serviced regularly as any disruption in the integrated process will disrupt the entire system. Skilled employees ensure regular maintenance of IT infrastructure.
		Barrier 3 influences barrier 10	Provision of specialized skills becomes easier with adequate political support.
		Barrier 3 influences barrier 11	Skilled workforce support research and development activities in the healthcare organizations as they have to keep themselves updated with recent trends and innovations in healthcare.
BH4	Cybersecurity and privacy issues (BH4)	Barrier 4 influences barrier 1	Cybersecurity issues increase the fear of job disruption among the employees.
		Barrier 4 influences barrier 2	To maintain data security in the organization appropriate infrastructure and advanced automated technologies are required which need excessive initial investment.
		Barrier 4 influences barrier 6	Data security issues also affect intellectual property rights like patents etc. as large amount of information is available online which if stolen can raise intellectual rights issues
		Barrier 4 influences barrier 7	Cybercrime issues are more prevalent in the absence of uniform standards for data transfer.
BH5	Insufficient compendious IT infrastructure	Barrier 5 influences barrier 2	To maintain sufficient IT infrastructure extra investment is required.
		Barrier 5 influences barrier 4	Absence of efficacious communication network affect security of data in the organizations.
		Barrier 5 influences barrier 15	In the absence of sufficient IT infrastructure employees are more apprehensive about IoT due to issues like confidentiality and cybercrime.
BH6	Intellectual property issues	Barrier 6 influences barrier 2	To resolve intellectual property issues sometimes excess capital is required.
		Barrier 6 influences barrier 4	Intellectual property rights like patents etc. also affect data security as large amount of information is available online which may be stolen.
		Barrier 6 influences barrier 7	Intellectual property rights issues arise because regulations and guidelines for information exchange are not laid down properly.
		Barrier 6 influences barrier 14	Intellectual property issues are more because of fragmented and non- standardized clinical data.
BH7	Non uniform regulations for clinical information exchange	Barrier 7 influences barrier 2	To bring uniformity in regulations for clinical information exchange various processes have to be regularized at several platforms which requires excess capital.
		Barrier 7 influences barrier 11	Continuous research and development is required in healthcare sector as doctors should be well versed with latest emerging diagnostic techniques and surgical interventions. But due to non-uniformity in the regulations research and development activities suffer.

Table 11 (continued)

Barrier No.	Barrier	Contextual relation	Interpretation
BH8	Legal Implications regarding external data use	Barrier 8 influences barrier 4	Organizations need to fortify that employees are familiar with the important processes and abide by the appropriate rules, regulations and laws especially in case of issues like cyber security, duty hours and safety measures.
		Barrier 8 influences barrier 6	Lack of legal implications regarding external data use give rise to intellectual property rights issues.
		Barrier 8 influences barrier 12	Absence of legal implications regarding external data use affect digital strategy of the organization as due to lack of legal knowledge digital strategy if difficult to be formed.
BH9	Inadequate maintenance support system	Barrier 9 influences barrier 5	If IT system is insufficient and also not maintained properly, it will disrupt the entire system thereby leading to more maintenance issues.
		Barrier 9 influences barrier 8	Neither there are legal guidelines regarding data use nor regarding maintenance of the support system due to which smaller organizations usually ignore servicing and maintenance issues.
		Barrier 9 influences barrier 10	Maintenance and support system for the equipment becomes better with political support.
BH10	Political support	Barrier 10 influences barrier 4	Political support plays an important role in addressing data security issues.
		Barrier 10 influences barrier 5	Government can support by creating the basic infrastructure and fundamental requirements for Industry 4.0 adoption.
		Barrier 10 influences barrier 7	Political support can bring uniformity in the regulations regarding clinical information exchange.
		Barrier 10 influences barrier 9	Government support helps in maintaining proper maintenance and support system in the organizations.
BH11	Lack of R & D clusters	Barrier 11 influences barrier 7	Continuous research and development is required in healthcare sector as doctors should be well versed with latest emerging diagnostic techniques and surgical interventions. Lack of R & D clusters affect these regulations also.
BH12	Lack of digital strategy and resource scarcity (BH12)	Barrier 12 influences barrier 6	Absence of digital strategy and resource scarcity affect compliance issues like appropriate rules, regulations and laws regarding data use.
		Barrier 12 influences barrier 7	Lack of digital strategy give rise to non-uniformity in the regulations and guidelines for clinical information exchange.
		Barrier 12 influences barrier 8	Digital strategy of the organization cannot be successful if employees are not well versed with digital rules and regulations.
BH13	Lack of top management support (BH13)	Barrier 13 influences barrier 3	Specialized training of the workforce requires excess investment which is possible only with top management support.
BH14	Fragmented and non-standardized clinical data (BH14)	Barrier 14 influences barrier 2	Excessive investment is required to create resources required for standardizing clinical data.
		Barrier 14 influences barrier 6	Because of fragmented and non-standardized clinical data intellectual property issues arise.
BH15	Apprehension about IoT (BH15)	Barrier 15 influences barrier 8	Employees are still unclear and apprehensive about certain issues which include legal obligations also.

should be handled with utmost care. There is huge requirement for certain vocational courses like big data analytics, data science, and specialized computer courses in this growing age of digitalization. Government should support by creating the basis of these fundamental requirements for Health 4.0 adoption by laying down uniform standards at national and international levels which will help in free and secured information exchange (Bonczek et al. 2014). Large amount of sensitive and confidential clinical information is available online across the cloud computing environment. This poses data security issues as important private data may be accessed by other parties. Therefore this issue needs to be handled very diligently as digital systems are more prone to cyber-attacks. A study conducted by Pereira et al. also concludes that data security is the most serious and critical issue while implementing Industry 4.0 in the organizations (Pereira et al. 2017). Besides this, lack of uniform standards for information exchange is making it hard for smaller healthcare organizations to implement Health 4.0. It is very difficult to ensure liability and regulatory compliance as regulatory systems are not laid down properly. The important legal issues like liability, clinical data protection and security and intellectual property should be seriously taken care of (Alaba et al. 2017). In healthcare, data is huge, complicated and highly fragmented as it is evolved from diverse sources (Raghupathi and Raghupathi 2014). Clinical data includes notes written by clinicians and nurses, prescription slips, laboratory investigations, medical imaging reports, pharmacy, data generated from medical equipment like ventilator, ECGs and insurance reports etc. This huge variety of big data in healthcare industry is very difficult to be managed with available software systems.

6 Conclusion

Health 4.0 technologies have the ability to transform healthcare sector from a focussed and compassionate system to a value oriented system which can ensure proactive preventive measures. The barriers identified in this research will help the healthcare managers and policymakers to take concrete steps so that Health 4.0 can be implemented successfully in the healthcare sector in India. Also, barriers having high driving power can be identified easily so that management of healthcare organizations can develop strategies to deal with such barriers with high priority and execute Health 4.0 technologies meticulously in their organizations.

7 Implications of research, limitations and future prospects of research

Health 4.0 is a major breakaway in the healthcare industry and it has the potential to provide a new outlook to the industry by amalgamating the advanced technologies to attain utmost output with minimum usage of resources. But the review of existing literature shows that healthcare sector is facing certain barriers during the adoption of this remarkable phenomenon and despite maximum efforts fruitful results are not yet achieved in India. The results of this study presents many implications for the healthcare managers. Firstly, 15 such critical barriers with respect to Health 4.0 adoption in the Indian healthcare industry have been identified. The managers can thoroughly understand these barriers beforehand and focus towards reducing their effect so that Health 4.0 can be successfully implemented. Secondly, TISM methodology applied in the study will help to identify the interrelationships among these barriers so that the managers and decision makers can

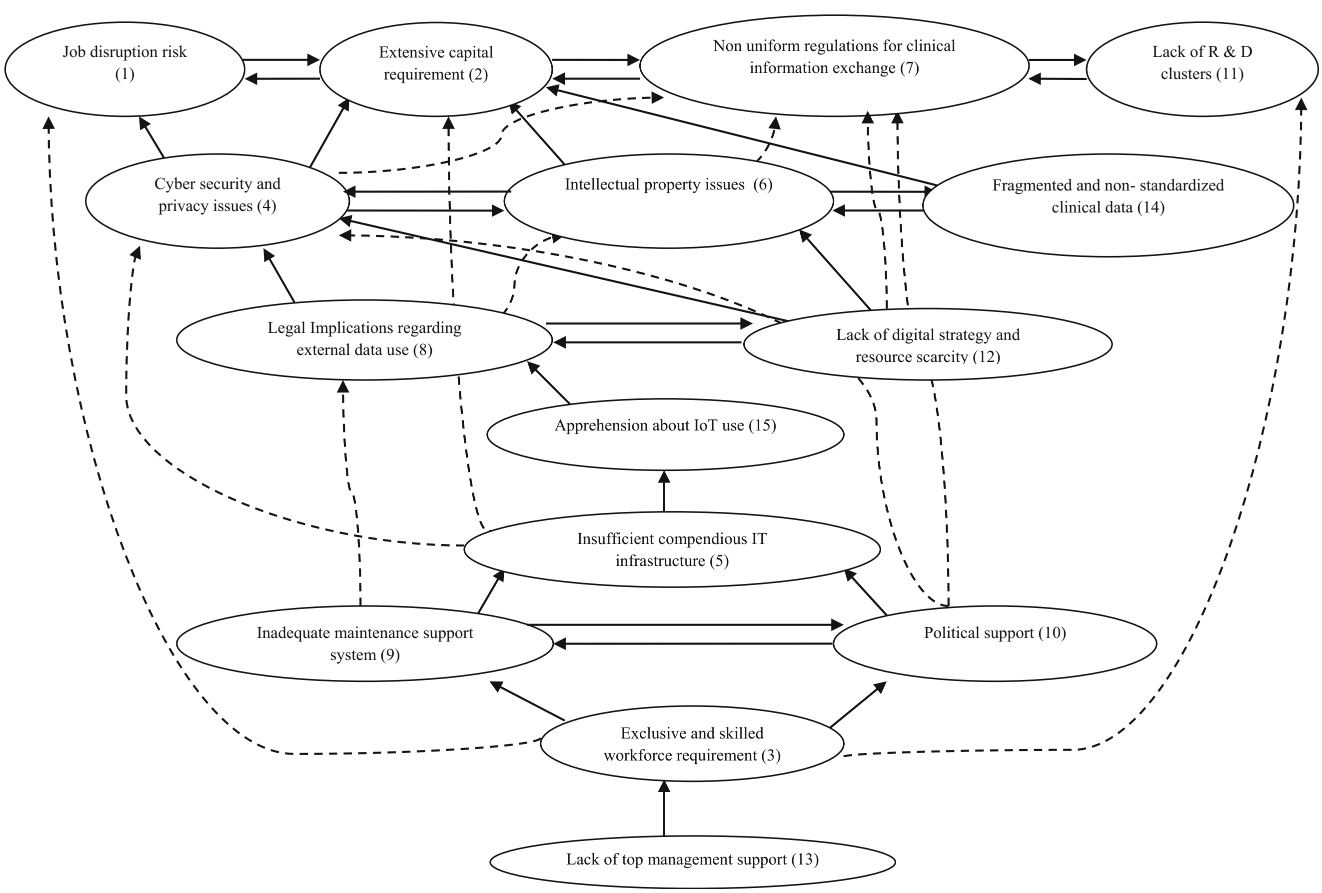

Fig. 5 Total interpretive structural model showing the levels of barriers

explore the effect of each barrier on other barriers as well as the degree of relationships among them. Thirdly, the model developed in the present research illustrates how various barriers affecting Health 4.0 adoption in healthcare organizations are interrelated and affect each other. Timely action taken by the management to remove these hurdles will not only reduce the cost but also improve quality of medical procedures so that true potential of Health 4.0 can be utilized.

In this research, 15 barriers affecting the Health 4.0 implementation in Indian healthcare industry have been identified. Some of the barriers were not considered which may affect Health 4.0 adoption in other countries. In future, similar researches may be carried out in many other countries as well to analyse the presence of several other barriers. Further, it is also suggested to do a comparative research regarding the existence of barriers to the adoption of Health 4.0 in the healthcare industries of other developing and developed countries to examine the significant variations if present. Also, quantification of TISM model can be done and the model can be further validated by using mathematical modeling and confirmatory factor analysis. SEM (Structural Equation Modeling) can be used to test the theoretical model.

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